

MINISTRY SCIENCES AND HIGHER EDUCATION RUSSIAN FEDERATION FEDERAL
STATE AUTONOMOUS EDUCATIONAL INSTITUTION OF HIGHER EDUCATION
"NORTH CAUCASIAN FEDERAL UNIVERSITY"

METHODOLOGICAL INSTRUCTIONS

By execution practical works
By discipline "Experimental Physics II/College Physics
Experiment II" for students in the training program
11.03.02 Infocommunication technologies And systems connections
Direction (profile)
"Intellectual processing data V infocommunication systems and networks"

TABLE OF CONTENTS

Introduction	3
Practical work No. 1	4
Practical Job No. 2	22
Practical Job No. 3	36
Practical Job No. 4	53
Practical Job No. 5	69
Practical Job No. 6	92
Practical Job No. 7	115
Practical work #8	133
Practical Job No. 9	142
Practical work #10	151
Practical work #11	157
Practical work #12	169
Practical work #13	181
Practical work #14	191
Practical work #15	198
Practical work #16	212

PRACTICAL JOB No. 1

TOPIC 1 INFORMATION AND TELECOMMUNICATION INFRASTRUCTURE HOW COMPLEX PHYSICAL SYSTEM

Class 1 MODELING AND STUDY SIMPLE ANALOG AND DIGITAL SIGNALS

TIME – 4 hours.

Educational questions:

- 1. Modeling And study simple analog signals.**
- 2. Modeling And study simple digital signals.**

TARGET PRACTICAL INSTALLATION WORKS:

Competencies, being formed discipline

OPK-1: Capable use provisions, laws And methods natural sciences and mathematics to solve engineering problems.

OPK-2: Capable on one's own conduct experimental research And use main techniques processing And performances received data.

Learning outcomes achieved as a result of completing practical work:

Be able to:

- apply physical laws and methods to formalize the representation of physical phenomena and processes that occur in telecommunications .
- conduct experimental research With help mathematical models according to the accepted methodology
- model And analyze main physical phenomena And processes in telecommunications using computer technology.

Own:

- skills use knowledge physicists at decision practical problems of engineering activities
- methods of processing and presenting data obtained as a result of experimental studies.
- skills in computer modeling of the main physical methods of receiving, transmitting and storing information.

EDUCATIONAL AND MATERIAL SECURITY:

- PC With simulator electronic schemes Electronics Workbench - 5.12" And system computer mathematicians Mathcad - 15";
- electronic methodological development By practical work.

STRUCTURE PRACTICAL WORK:

Class No. 1		90 min
Introductory Part		10 min
Examination readiness students To practical work		8 min
Introductory Part		2 min
Questions (tasks), subject research:		75 min
1. Modeling And study simple analog signals.		75 min
Final Part		5 min
Summing up results		3 min
Exercise students For independent work		2 min
Class No. 2		90 min
Introductory Part		10 min
Examination readiness students To practical work		8 min
Introductory Part		2 min
Questions (tasks), subject research:		50 min
2. Modeling And study simple digital signals.		50 min
Final Part		30 min
Protection reports By practical work		25 min
Summing up results		3 min
Exercise students For independent work		2 min

QUESTIONS, SUBJECTS RESEARCH

Brief theoretical or reference and information materials

Most signals are analog in nature, meaning they change continuously. in time And can accept any values on some interval. Analog signals are used V telephony, radio broadcasting, television .

Analog signals are described by some mathematical function of time. Examples of a simple analog signal:

- harmonic high-frequency signal;
- single-color signal V low-frequency sound range frequencies.

Harmonic signal - This harmonic hesitation, V which changes physical quantities are happening By law cosine or sinus (harmonic law), spreading over time in space, capable of carrying information (data) in one of its parameters is described by the equation:

$$y = A \cos(\omega t + \varphi_0), \quad (1)$$

Where A - amplitude signal; $\varphi = \omega t + \varphi_0$ - phase harmonic signal; t - time; ω - cyclical frequency signal; φ_0 - initial phase fluctuations.

The phase of oscillation is measured in radians and determines the value of the displacement (oscillating quantities) V given moment time. Amplitude oscillations depend only on the initial deviation (the initial energy imparted to the oscillatory system).

Using a harmonic signal, one can obtain an arbitrarily complex analog signal in the form of a sum of harmonics:

$$s(t) = \sum_{k=1}^N O h_{my.} \cdot \cos(k \omega t + \varphi_{ok}) . \quad (2)$$

It is impossible to input such a signal into a digital system for processing, since on any interval time He Maybe have infinite set values, and for an accurate (without error) representation of its value, numbers are required endless bit depth. That's why Very often necessary convert analog signal so that Can was introduce his a sequence of numbers of a given bit depth.

Discrete signal. Discretization of an analog signal consists in representing the signal as a sequence of values taken at discrete moments in time t_i (where i is the index). Usually, the time intervals between successive samples ($\Delta t_i = t_i - t_{i-1}$) are constant; in this case, Δt it's called **interval discretization**. Ourselves same values signal $x(t)$ V moments of measurement, that is, $x_i = x(t_i)$, are called **readings**.

Quantized signal. When quantized, the entire range of signal values is divided on levels, quantity which should be presented V numbers of a given bit depth. The distance between these levels is called the quantization step. Δ . Number these levels equals N (from 0 to $N-1$). To everyone level is assigned some number. Countdowns signal are compared With levels quantization and a number corresponding to a certain quantization level is selected as a signal. Each quantization level is encoded by a binary number with n digits. The number of quantization levels N and the number of digits n of the binary numbers encoding these levels are related by the relation $n \geq \log_2(N)$.

Digital signal. For Togo, to introduce analog signal a sequence of numbers of finite bit depth, it should first be converted into a discrete signal and then subjected to quantization. Quantization is a special case of discretization, when discretization occurs by the same value, called a quantum. As a result, the signal will be represented as follows in this way, What on each given interval time it is known an approximate (quantized) value of a signal that can be written as an integer. A sequence of such numbers will be a digital signal.

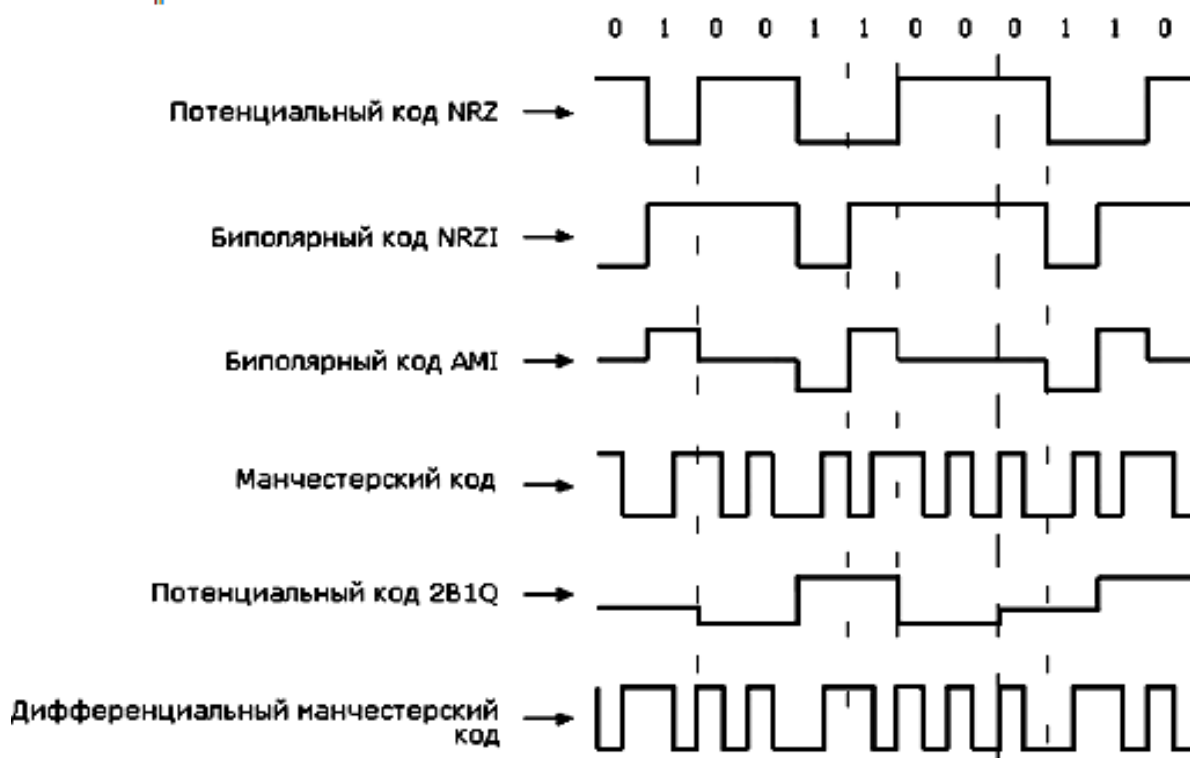
A digital signal is a discrete sequence of voltage pulses, every from which has stepped form. Every pulse – is a single signal. In general, data in binary form is encoded during transmission so that one bit of data can be mapped to several single ones. signals. IN the simplest case This correspondence has unambiguous character: one bit – one single signal. In the examples given in the previous sections, We How once met exactly this the simplest happening, When

binary 1 was presented high potential, A binary 0 - low. In this section We let's consider different schemes coding data on physical level.

If all single signals have the same polarity (i.e. all positive or all negative), then the signal is said to be unipolar. Otherwise case logical unit represent positive potential, and logical zero is negative. Data transfer rate is the number of bits per second that are transmitted using signals. This speed is also called the bit rate.

The bit duration (length) is the time interval required by the transmitter to emit a sequence of corresponding bits. At a data rate of R bits/sec, the bit length is equal to $1/R$.

Now let's look at what tasks the receiver must solve when transmitting. First in total, receiver must be exactly configured on length bat. He must be able to recognize start And end transmissions each bat, A Also level signal: short or high. On rice. 1 it is visible, What these tasks are being decided level measurement signal V in the middle lengths bat And comparison result measurements With threshold value. Due to noise on the line, errors may occur.



Rice. 1 - Examples codes

There are three important factors that influence the accuracy of transmission: noise level, data rate and channel bandwidth. more one factor, influential on transmission data: This way representations (encodings) data on physical level. Exists many such methods, we will consider only the most common ones. They are shown in Fig. 1 and in table 1.

Table 1. Properties codes

<p>Potential code NRZ (Non Return to Zero - "without returns To zero")</p> <p>1 - high potential</p> <p>0 - low potential</p>
<p>Bipolar code or unipolar NRZI (inverted NRZ code) is a potential code with inversion at unity, the code is formed by the inverse state at admission on entrance coding devices logical units, when a logical zero is received, the state of the potential does not change.</p> <p>0 - No difference level signal V beginning bit interval</p> <p>1 - difference level signal V beginning interval</p>
<p>Bipolar code AMI</p> <p>0 - no signal</p> <p>1 - positive or negative potential, back By relation To potential in the previous period</p>
<p>Mancunian code</p> <p>0 - transition With high potential on short V in the middle interval</p> <p>1 - transition With low potential on high V in the middle interval</p>
<p>Potential code 2B1Q</p> <p>Uses 4 level signals, meaning level is determined meaning couples bits of data.</p>

The main criteria for comparing different methods of data encoding at the physical level are :

1) **Signal bandwidth** . The fewer high-frequency components in the signal, the smaller the channel bandwidth required for transmission. The absence of a constant component, i.e., harmonics, is also important. With constant, Not changing parameters. Appearance such harmonics leads To availability permanent current between receiver And transmitter, which is highly undesirable. Finally, as we have already noted, the spectrum width affects the distortion of the signal shape. The wider the spectrum, the greater the distortion.

2) **Synchronization between receiver and transmitter** . We have already noted the need for the receiver to accurately determine the beginning and end of the bit interval. On small distances, For example, inside computer or An additional synchronization line is used for these purposes between the computer and its peripheral devices. A special clock circuit (clock) sends out synchronization pulses at strictly defined intervals along this line. The arrival of such a pulse signifies the beginning of a bit interval for the receiver. In networks over long distances, this solution is unsuitable for many reasons. Another solution to this problem is to create so-called self-synchronizing codes. For example, a change in signal level (edge) can serve good sign For receiver O beginning bitwise interval. Absence front between bitwise intervals significantly complicates solution to the synchronization problem when it is necessary to transmit bits with the same values in adjacent bit sequences.

3) **Error detection** . Although detection methods and Error corrections are located at the data link layer, which is located above the physical layer, those Not less, And on physical level very healthy have such possibilities .

4) **Noise sensitivity** . By using appropriate tricks in the data encoding scheme, high transmission performance can be achieved even in the presence of very high noise levels.

5) **Price And speed** . Despite on permanent reduction in price digital equipment general trend such is, What increase signal speed in order to increase the bit rate, this leads to an increase in the cost of equipment.

All schemes coding are divided on potential And impulse. U In potential codes, the bit value is transmitted by holding the signal potential at a certain level during the bit interval. In pulse codes, this value is transmitted by the transition (edge) of the signal level. The direction of the transition from low to high or from high to low determines the bit value.

1. MODELING AND STUDY SIMPLE ANALOG SIGNALS.

Content practical work, performed students on the first academic question

1.1. Description laboratory equipment:

– PC With simulator electronic schemes Electronics Workbench - 5.12" and the computer mathematics system "Mathcad - 14".

1.2. Initial data For modeling And research

Table 1.1 - Options tasks For research

<i>Option No.</i>	<i>A, IN</i>	<i>f, MHz</i>	<i>φ_0, grad</i>	<i>U, B</i>	<i>T, ms</i>	<i>τ, ms</i>
1	1.1	1.1	$\pi/20$	3	1	0,25
2	1,2	1,2	$\pi/18$	5	2	0,5
3	1,3	1,3	$\pi/16$	10	2,5	0,5
4	1,4	1,4	$\pi/14$	15	4	1
5	1,5	1,5	$\pi/12$	7	5	1
6	1,6	1,6	$\pi/10$	25	3	1
7	1,7	1,7	$\pi/8$	10	4,5	1,5
8	1,8	1,8	$\pi/6$	15	1	0,25
9	1,9	1,9	$\pi/4$	6	1	0,2
10	2,0	2,0	$\pi/5$	5,5	2	0,4
11	1,1	2,1	$\pi/7$	8	2	1
12	1,2	2,2	$\pi/9$	4	1	0,5
13	1,3	2,3	$\pi/11$	2	0,5	0,1
14	1,4	2,4	$\pi/13$	1	0,45	0.15
15	1.5	0.9	$\pi/15$	1.5	0.4	0.1
16	1.6	0.8	$\pi/17$	6	1	0.25
17	1.7	0.75	$\pi/19$	3	2	0.5
<i>Option No.</i>	<i>A, IN</i>	<i>f, MHz</i>	<i>φ_0, work</i>	<i>U, B</i>	<i>T, ms</i>	<i>τ, ms</i>
18	1.8	0.7	$\pi/21$	5	2.5	0.5
19	1.9	0.6	$\pi/3.5$	10	4	1

20	2.0	1.0	$\pi/3$	1.5	5	1
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1.3. Exercise For works:

Basic level:

1.1) Simulate a harmonic signal in the Mathcad program and conduct a study of its characteristics.

1.2) Conduct a study in the Mathcad program of the operations of transforming a harmonic signal that have the nature of differentiation and integration .

Increased level:

1.3) Simulate V program Mathcad multi-tone signal And to conduct a study of its characteristics and transformation operations.

1.4. Order execution work

Exercise 1.1. Simulate V program Mathcad harmonic signal and conduct a study of its characteristics.

A) Production tasks:

Produce mathematical modeling given harmonic signal in the Mathcad program, using the expression

$$s(t) = A \cdot \sin(\omega t + \varphi_0). \quad (3)$$

B) Initial data For modeling: A - amplitude harmonic

fluctuations, f - linear frequency oscillations, φ_0 - initial phase fluctuations - are presented by options in Table 1.1.

B) The modeling algorithm in the Mathcad system consists of the following sequence of actions (operations):

1) Enter V working window programs original data.

2) Enter formulas For calculation period T And cyclic frequency ω oscillations

3) Enter a formula that mathematically describes the given harmonic signal.

4) Build graphic image received harmonic signal $s(t)$. To do this, select “XY graph” on the “Graph” toolbar. To clearly display the signal, indicate the limiting time values from $-2T$ to $2T$ ***on the abscissa axis*** .

D) Conduct research on the harmonic signal by performing the following actions (operations):

1) Install shape dependencies signal from characterizing its parameters: amplitudes A , frequency f , period T and initial phase φ_0 .

2) Define energy characteristics signal V view his current values (That There is root mean square values for period) And constant component (That There is average values for period), which are calculated using the corresponding formulas:

$$S_d := \sqrt{\frac{1}{T} \cdot \int_0^T s(t)^2 dt} \quad \text{and} \quad S_o := \frac{1}{T} \cdot \int_0^T s(t) dt \quad (4).$$

5) Determine the first three moments time t when instant signal meaning will equals zero, those. find roots equations $s(t) = 0$. For this necessary **root** function. Enter this function using the keyboard in the following form: **root(s(q), q) =**, enter in advance variable q , For example, equal half period. This variable bu-
children use How initial approximation at search root.

6) Draw conclusions based on the results of the modeling and research.

Task 1.2. Conduct a study of the operations of transforming a harmonic signal, which have the nature of differentiation and integration, in the Mathcad program.

A) Production tasks:

In radio electronics, it is often necessary to perform signal transformation, which has the nature of differentiation or integration. At the input of a linear devices, implementing differentiation, is served signal $s(t)$ should receive a signal of the following type from the output:

$$S_{out}(t) = \tau_o \cdot \frac{ds(t)}{dt}. \quad (5)$$

In my queue, V integrating device connection between weekend $s(t)$
And input signals has next view:

$$S_{out}(t) = \frac{1}{\tau_o} \cdot \int_0^{\tau_o} s(t) dt. \quad (6)$$

In expressions (5) and (6) τ_o - a constant value with the dimension time and for the signal under study equal to its period.

B) Order research:

1) Enter the formula for calculating the differential transformation of a harmonic signal into the program's working window:

$$s1(t) := T \cdot \frac{d}{dt} s(t).$$

2) Build graphic image transformed harmonic signal $s1(t)$. To do this, select "X-Y graph" on the "Graph" toolbar. For visual displays signal indicate on axes abscissa marginal time values from $-2T$ to $2T$.

3) Conduct an analysis of the output signal obtained during the differential transformation (passing through a linear differentiating device). To do this, determine the phase shift between the signals at the input and output differential converter. For this enter V program the following expression:

$$\Delta\varphi := \frac{\text{root}(s(q), q) - \text{root}(s1(k), k)}{T} \cdot 360,$$

Where k - variable, used for initial approximations at search root of the equation $s1(t) = 0$.

4) Enter the formula for calculating the double differential transformation of a harmonic signal into the program's working window:

$$s2(t) := T^2 \cdot \frac{d^2}{dt^2} s(t)$$

5) Build graphic image transformed harmonic signal $s2(t)$. To do this, select "X-Y graph" on the "Graph" toolbar. For visual displays signal indicate on axes abscissa marginal time values from $-2T$ to $2T$.

6) Conduct analysis received V process double differential transformation (passage through a double linear differentiator) weekend signal. For this define phase shift between signals at the input and output of a double differential converter. To do this, enter the following expression into the program:

$$\Delta\varphi2 := \frac{\text{root}(s(q), q) - \text{root}(s2(p), p)}{T} \cdot 360,$$

Where p - variable, used for initial approximations at search root of the equation $s2(t) = 0$.

7) Enter the formula for calculating the integral transform of a harmonic signal into the program's working window:

$$S1(t) := \frac{1}{T} \cdot \int s(t) dt$$

8) Build graphic image transformed harmonic signal $S1(t)$. To do this, select "X-Y graph" on the "Graph" toolbar. For visual displays signal indicate on axes abscissa marginal time values from $-2T$ to $2T$.

9) Conduct analysis received V process integral transformation (passage through a linear integrator) of the output signal. To do this, determine the phase shift between the signals at the input and output of the integral converter. To do this, enter the following expression into the program :

$$\Delta\phi := \frac{\text{root}(S1(u), u) - \text{root}(s(q), q)}{T} \cdot 360,$$

where u is a variable used for the initial approximation when searching for the root of the equation $S1(t) = 0$.

10) Enter the formula for calculating the double integral transform of a harmonic signal into the program's working window:

$$S2(t) := \frac{1}{T^2} \cdot \int \int s(t) dt dt$$

11) Plot a graphical representation of the transformed harmonic signal $S2(t)$. To do this, select "graph" on the "Graph" toolbar. XY". For visual displays signal indicate on axes abscissa limiting time values from $-2T$ to $2T$.

12) Conduct analysis received V process double integral transformations (passage through double linear integrating device) of the output signal. To do this, determine the phase shift between the signals at the input and output of the dual integral converter. To do this, enter the following expression into the program:

$$\Delta\phi_2 := \frac{\text{root}(S2(g), g) - \text{root}(s(q), q)}{T} \cdot 360,$$

Where g - variable, used For initial approximations at search root of the equation $S2(t) = 0$.

13) Do conclusions By results conducted research.

Exercise 1.3. (increased level). Simulate V program "Mathcad" multi-tone signal and conduct a study of its characteristics and conversion operations.

A) Production tasks:

Independently carry out modeling and research of a three-tone signal of the audio frequency range in the Mathcad program, using expression (2). At this For odd options signal must consist of the first f , third $3f$ and fifth $5f$ harmonics, and for even variants – of the first f , second $2f$ and fourth $4f$ harmonics.

B) Initial data For modeling: A - amplitude harmonic fluctuations, f - linear frequency fluctuations, Φ_0 - initial phase fluctuations - at-
led By options V table 1.1.

Parameters harmonics:

- meaning frequencies f should be reduced V 1000 once.
- amplitudes harmonics - respectively equal A , $0.75A$ And $0.5A$;
- initial phases harmonics equal 0.

B) The modeling algorithm in the Mathcad system consists of the following sequence of actions (operations):

1) Enter V working window programs original data And necessary formulas for intermediate calculations.

2) Enter a formula that mathematically describes the given three-tone signal.

3) Build graphic image received signal $s(t)$.

D) Conduct research on the multi-tone signal by performing the following actions (operations):

1) Define energy characteristics signal V view his current values (That There is root mean square values for period) And constant component (That There is average values for period). Display on The graph shows the effective value of the harmonic signal.

2) Determine the period of a multi-tone signal, i.e. the time interval from 0 to the moment t when the signal begins to repeat.

3) Simulate procedure differential transformations signal and analyze the output signal.

4) Simulate the integral signal transformation procedure and analyze the output signal.

5) Draw conclusions based on the results of the modeling and research .

2. MODELING AND STUDY SIMPLE DIGITAL SIGNALS

Content practical work, performed students on the second academic question

1.1. Description laboratory equipment:

– PC With simulator electronic schemes Electronics Workbench - 5.12" and the computer mathematics system "Mathcad - 14".

1.2. Initial data For modeling And research

Table 2.1 - Options tasks For research

<i>Option No.</i>	<i>A, IN</i>	<i>f, MHz</i>	<i>φ_0, glad</i>	<i>U, B</i>	<i>T, ms</i>	<i>τ, ms</i>
1	1.1	1.1	$\pi/20$	3	1	0,25
2	1,2	1,2	$\pi/18$	5	2	0,5
3	1,3	1,3	$\pi/16$	10	2,5	0,5
4	1,4	1,4	$\pi/14$	15	4	1
5	1,5	1,5	$\pi/12$	7	5	1
6	1,6	1,6	$\pi/10$	25	3	1
7	1,7	1,7	$\pi/8$	10	4,5	1,5
8	1,8	1,8	$\pi/6$	15	1	0,25
9	1,9	1,9	$\pi/4$	6	1	0,2
10	2,0	2,0	$\pi/5$	5,5	2	0,4
11	1,1	2,1	$\pi/7$	8	2	1
12	1,2	2,2	$\pi/9$	4	1	0,5
13	1,3	2,3	$\pi/11$	2	0,5	0,1
14	1,4	2,4	$\pi/13$	1	0,45	0.15
15	1.5	0.9	$\pi/15$	1.5	0.4	0.1
16	1.6	0.8	$\pi/17$	6	1	0.25
17	1.7	0.75	$\pi/19$	3	2	0.5
<i>Option No.</i>	<i>A, IN</i>	<i>f, MHz</i>	<i>φ_0, work</i>	<i>U, B</i>	<i>T, ms</i>	<i>τ, ms</i>
18	1.8	0.7	$\pi/21$	5	2.5	0.5

19	1.9	0.6	$\pi / 3.5$	10	4	1
20	2.0	1.0	$\pi / 3$	1.5	5	1

1.3. Exercise For works:

Basic level:

2.1) Simulate a sequence of rectangular pulses from harmonic components in the Mathcad program.

2.2) Simulate in the Electronics Workbench program and conduct research sequences rectangular impulses, formed from harmonic components.

2.3) Conduct modeling and research in the Electronics Workbench program coding devices, representing data V digital NRZ code for transmission over a communication channel.

Increased level:

2.4) Conduct a study of the amplitude-frequency characteristics in the Electronics Workbench program And phase-frequency spectra sequences rectangular pulses.

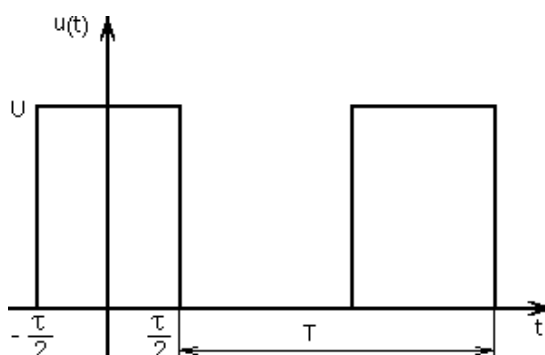
Task 2.1. Model a sequence of rectangular pulses from harmonic components in the Mathcad program.

A) Production tasks:

A sequence of digital data (bit sequence) can be simply represented as a sequence of rectangular pulses with a changing duty cycle, for example, as shown in Fig. 2.

The task is to use mathematical modeling to form a sequence of rectangular pulses with given parameters from a given number of harmonics.

B) Initial data For modeling: U - amplitude impulse, T - pulse repetition period, τ - pulse duration – given by options in Table 2.1.



Rice. 2 - Periodic subsequence rectangular impulses

B) The modeling algorithm in the Mathcad system consists of the following sequence of actions (operations):

1) Enter V working window programs original data according to assignment option: pulse amplitude U , duration τ , repetition period T .

2) Enter formula For calculation porosity impulses:

$$q = \frac{T}{\tau}.$$

3) Enter cycle, asking number harmonics: $n = 1 \dots 10$.

4) Enter formulas For calculation linear And cyclical frequencies harmoni-

Nick

:

$$f(n) = \frac{n}{T} \text{ And } \omega(n) = f(n) \cdot 2\pi.$$

5) Dial formulas For calculation coefficients Fourier:

$$a_0 = \frac{2}{T} \int_0^{\tau} U dt = \frac{2 \cdot U \cdot \tau}{T} = \frac{2U}{q},$$

$$a(n) = \frac{2}{T} \int_0^{\tau} U \cos(n\omega \cdot t) dt,$$

$$b(n) = \frac{2}{T} \int_0^{\tau} U \sin(n\omega \cdot t) dt.$$

6) Dial formulas For calculation amplitudes And initial phases harmonics:

$$U_0 = \frac{a_0}{2}, \quad U(n) = \sqrt{a(n)^2 + b(n)^2},$$

$$\psi(n) = \frac{\arctg(a(n)/b(n))}{2\pi} \cdot 360^\circ.$$

7) The results of calculations of the harmonic parameters that form a sequence of rectangular pulses are entered into Table 2.2.

Table 2.2 - Results calculations

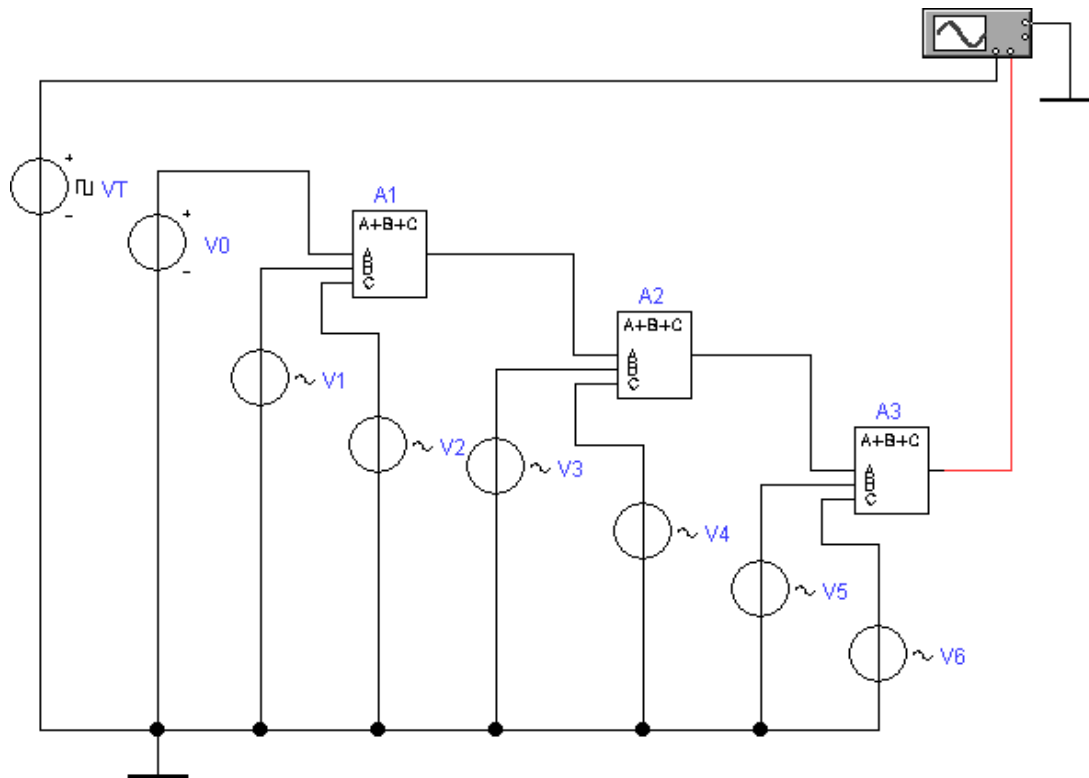
n	1	2	3	4	...	...	10
$a(n)$							
$b(n)$							
$f(n)$, Hz							
$U(n)$, IN							
$\psi(n)+360$, hail.							

7) Do conclusions By results conducted modeling.

Task 2.2. Conduct a study in the Electronics Workbench program subsequence rectangular pulses generated from harmonic components.

A) Production tasks:

In the Electronics Workbench program, assemble a circuit for simulating a sequence of rectangular pulses from a set of harmonic components. The circuit is shown in Fig. 3.



Rice. 3 - Scheme modeling sequences rectangular pulses from a set of harmonic components

B) Initial elements And parameters For modeling.

The initial elements for modeling are: constant voltage source $V0$, harmonic oscillation sources $V1-V6$, rectangular pulse source VT , analog adders $A1-A3$.

Initial parameters for modeling: linear frequencies $f(n)$ of harmonics, amplitudes $U(n)$ And initial phases $\psi(n) + 360^\circ$ harmonics, calculated V task 1.4.

Display exemplary And formed sequences is produced using an oscilloscope.

G) Order research:

1) Install parameters source permanent voltage $V0$ and sources harmonic fluctuations $V1 - V6$ V in accordance With calculated values recorded in Table 1.2.

2) In the rectangular pulse generator VT set the voltage equal to amplitude impulses U , meaning frequencies, equal basic frequency $f(1)$, the pulse duration in percent, equal to $100/q$ %.

3) Open oscilloscope, having set up his For displays By first channel of the pulse sequence from the reference generator VT , and through the second channel - sequences impulses, formed for check summation

harmonic components of the Fourier series. Enter the time diagrams of the pulse sequence in the practical work report. Compare and draw conclusions.

4) Display and measure the spectra of the sample and generated pulse sequences. To do this, perform the following operations:

- in the “Circuit” menu, select the “Schematic Options” submenu, and in the menu that opens, set the “Show nodes” option;

- in the “Analysis” menu, select the “Fourier Analysis” submenu, V opened menu install options: day off knot (Output node), fundamental frequency (Fundamental frequency) and number of harmonics (Number harmonics) – 20, install option displays phase-frequency spectrum (Display phase), then launch the spectrum analyzer emulator by clicking the Simulate button;

- measure the amplitude-frequency and phase-frequency spectra using special cursors by pressing the button to display them on the screen  Toggle cursors;

- display spectra V report;

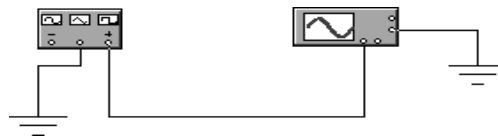
- compare both spectrum And do conclusions.

5) Draw conclusions based on the results of the modeling and research .

Task 2.3 (advanced). Conduct a study of the amplitude-frequency and phase-frequency spectra of a rectangular pulse train using the Electronics Workbench program.

A) Order research:

1) IN program Electronics Workbench collect diagram research, given on Fig. 4, which contains functional generator and oscilloscope.



Rice. 4 - Scheme research spectra

2) Functional generator install V mode generation rectangular pulses with a frequency of 1 kHz, a duty cycle of 2 (50%) and an amplitude of 1 V.

3) After running the EWB emulator, obtain a timing diagram of the pulse sequence using an oscilloscope. Measure the amplitude, period, and duration impulses. Results measurements And temporary diagram include in the report.

4) Run Fourier analysis of the pulse train and display the amplitude-frequency And phase-frequency spectra sequences rectangular impulses, containing 20 harmonics. Measure amplitude, phase And frequencies of the first 10 harmonics. The measurement results and spectra should be included in the report.

5) Analyze influence quantities period following impulses to the outside view spectra, For this at first increase period following impulses V 2 And 4 times, A then decrease - V 2 And 4 times. To depict received spectra in the report and draw conclusions.

6) Analyze the influence of the pulse duty cycle on the external view spectra, For this, sequentially installing porosity pulses equal to 3 (33%), 4 (25%) and 10 (10%), depict the obtained spectra in the report and draw conclusions.

7) Do conclusions By results conducted research.

Task 2.4. Use the Electronics Workbench program to simulate and study an encoding device that represents data in a digital NRZ code for transmission over a communication channel.

A) Production tasks:

In the Electronics Workbench program, create a schematic model of the coding devices (coder), transformative digital data (code words) V two-level digital signals V view unipolar code. At In this case, the high potential should correspond to a logical one, and the low potential to a logical 0.

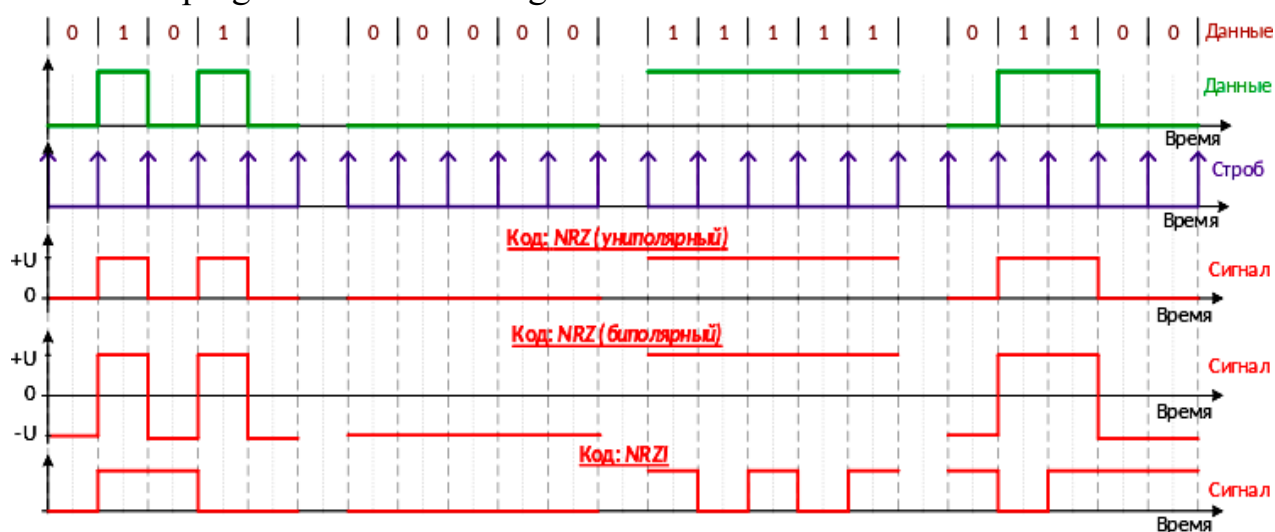
For coding use next formats codes:

1) Format without returns To zero (code **NRZ**). IN this format Not the level of a single bit transmitted within a clock cycle changes. A positive transition means a transition from 0 to 1 in the source code, a negative transition means a transition from 1 to 0. Absence differences shows, What values previous And subsequent bits are equal.

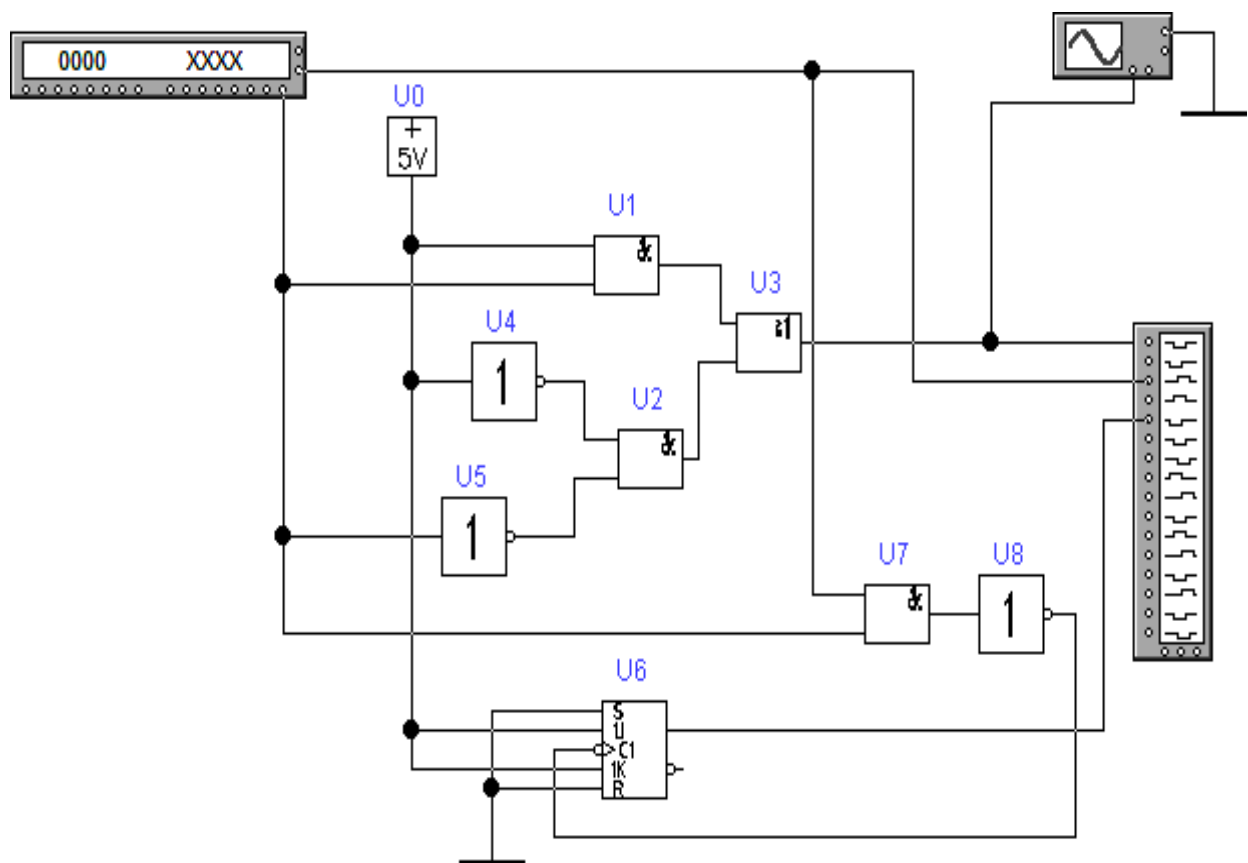
2) Format without returns To zero With difference at transfer 1 (code **NRZI**), is variety format BVN. IN this format changes in temperature signal are formed when transmitting 1, when transmitting 0 the signal level does not change.

Example coding data codes presented on rice. 5.

An example of a schematic model of a given encoding device in the Electronics Workbench program is shown in Fig. 6.



Rice. 5 - Coding codes NRZ



Rice. 6 - Schematic model coder **NRZ**

B) Initial elements And parameters For modeling And research. The initial elements for modeling are:

- generator words (Word Generator) - source digital data;
- high potential source – element U0, low potential source – “Earth”;
- to build an **NRZ encoder** - 2-input logical multipliers (elements U1, U2), 2-x entrance logical adder (element U3), inverters (elements U4, U5);
- to build an **NRZI encoder** - a JK trigger operating as a T trigger (element U6), 2-x entrance logical multiplier (element U7), inverter (element U8).

For displays digital data And digital signals use a logic analyzer and an oscilloscope.

Initial data for the study: code words for the options are given in Table 2.3.

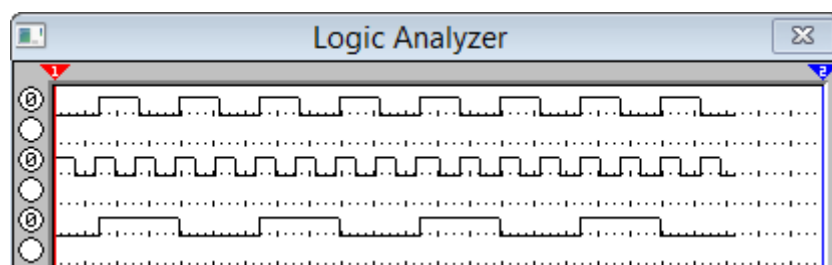
Table 2.3– Options tasks code words For research

Option No.	Code word	Option No.	Code word
1.	0101 1010 0110 0000	2.	0011 0110 0011 0111
3.	0100 1110 0101 1011	4.	0010 1011 0011 1111
5.	0101 1101 0110 0010	6.	0100 0001 0010 1100
7.	0101 1110 0101 0010	8.	0100 0011 0011 0101
9.	0101 1000 0101 1001	10.	0011 0100 0011 0011
11.	0100 1010 0101 1100	12.	0011 0001 0011 0000
13.	0100 1101 0100 1111	14.	0010 1111 0010 1101

15.	0101 0000 0101 0001	16.	0011 1100 0010 1010
17.	0101 0011 0101 0100	18.	0011 1001 0011 1000
19.	0101 0101 0110 0011	20.	0011 1110 0100 0010

IN) Order modeling.

- 1) Collect diagram research coder, depicted on rice. 6.
- 2) To convert a JK flip-flop into a counting T flip-flop, logical 1s must be applied to the J and K inputs. Verify this.
- 3) Tune generator words (Word Generator). For this program his first cells With address from 0000 By 000F like this in this way, to V The following code word was written in the least significant digits of the cells: 0101 0101 0101 0101. Set the frequency of the internal clock generator to 1 kHz. Set the word generator to step mode by pressing the Step button.
- 4) Make sure V volume, What sync pulses (Data ready), being formed generator words, are arriving on clock (countable) entrance trigger, A For display on the 3rd input of the logic analyzer. In this case, the output of the **NRZ encoder should be connected to the 1st input of the logic analyzer, and the output of the NRZI encoder to the 5th input** .
- 5) Check performance collected schemes. For this, turning on EWB simulator, by pressing the Step button of the word generator, obtain timing diagrams on the logic analyzer, shown in Fig. 7.
- 6) Draw conclusions based on the results of the simulation, including the complexity or simplicity of the simulated coding methods.



Rice. 7 - Example correct work coder **NRZ**

G) Order research.

- 1) Write the code word in the Word Generator according to the option.
- 2) Launched generator words V step by step mode, get on Using a logic analyzer, time diagrams of digital signals in **NRZ** and **NRZI** code format were generated and displayed in the practical work report.

3) Define duration τ single impulse (single bat) for the **NRZ code**, using the cursors (red and blue lines) of the logical analyzer, enter the result into the LR report.

4) Determine the values of the constant component of both digital signals when transmitting a code word in a communication channel. To do this, use the given formula for the **NRZ code**

$$S_0 = \frac{E_I \cdot \tau \cdot N_I}{T_{ks}} = \frac{E_I \cdot \tau \cdot N_I}{16} = \frac{E_I \cdot N_I}{16} = \frac{5}{16} N_I,$$

Where E_I - level logical units, IN; N_I - number logical units; T_{ks} - duration code words.

For code **NRZI** necessary With help cursors logical analyzer measure duration code words T_{ks} And total duration single-

impulses $\sum_{i=1}^n \tau I_i$, after what calculate level constant component according to the formula:

$$S_0 = \frac{\sum_{i=1}^n \tau I_i}{T_{ks}} E_I$$

5) Answer on question, What will With constant component V channel connections at increase lengths code words.

6) Write the code word 0000 0000 1111 1111 into the Word Generator.

7) Launched generator words V step by step mode, get on Using a logic analyzer, time diagrams of digital signals in **NRZ** and **NRZI** code format were generated and displayed in the practical work report.

8) Conduct analysis received temporary diagrams digital signals. To do this, you need to find answers to the following questions:

- at what point in time will the receiver of the communication channel determine the beginning of such a code word;
- What need to transmit For correct definitions beginning And end code word;
- how to determine the moment of receipt of the first eight zeros or any bit of the code word;
- what should be used to record the moments of arrival of these zeros or any bit of the code word;
- do conclusions, O volume, How researched codes protected from long sequences of logical zeros or ones.

8) Do conclusions By results conducted research.

1.5. Prepare a report on the work performed in accordance with the requirements set out in the job description.

IN report bring:

- original data,
- performed tasks,
- compiled listings programs mathematical models,
- developed or compiled circuit design models devices;
- research results in the form of formulas used and calculation results, obtained graphs, oscillograms, time diagrams, conclusions made and findings for each task;
- general conclusions O done work.

6. Protection practical work

For protection practical introduce fully decorated report, free of significant errors. Complete one of the tasks assigned by the teacher, explaining all the physical phenomena and processes occurring in the task being completed.

LIST LITERATURE:

- 1) Sagdeev K.M. Physical foundations of information security [Electronic resource]: educational allowance / TO. M. Sagdeev, IN. AND. Petrenko, A. F. Chipiga. — Electronic text data. - Stavropol: North Caucasus Federal University, 2015. - 394 p.
- 2) Evstifeev V.V. Physical foundations electricity and magnetism Electronic resource / Evstifeev V.V.: study guide. - Penza: PSU, 2019. - 416 p.
- 3) Bulatov V.N. Physical foundations of electronics Electronic resource / Bulatov V.N.: lecture notes for students in educational programs higher education in the following areas preparation 11.03.02 infocommunication technologies and communication systems. - Orenburg: OSU, 2018. - 178 p.
- 4) Goldstein A.E. Physical principles of obtaining information [Electronic resource]: textbook / A.E. Goldstein. — Electron. text data. — Tomsk: Tomsk Polytechnic University, 2010. — 292 p.

PRACTICAL JOB No. 2

TOPIC 2 PHYSICAL FIELDS AND WEDNESDAYS TRANSMISSIONS

Class 2 MODELING AND STUDY PROCESS OF PROPAGATION OF SIMPLE SIGNALS IN THE PHYSICAL ENVIRONMENT

TIME – 4 hours.

Educational questions:

1. Modeling And study process distribution pro- clear signals in the physical environment.

TARGET PRACTICAL INSTALLATION WORKS:

Competencies, being formed discipline

OPK-1: Capable use provisions, laws And methods natural sciences and mathematics to solve engineering problems.

OPK-2: Capable on one's own conduct experimental research And use main techniques processing And performances received data.

Learning outcomes achieved as a result of completing practical work:

Be able to:

– apply physical laws and methods to formalize the representation of physical phenomena and processes that occur in telecommunications .

– conduct experimental research With help mathematical models according to the accepted methodology

– model And analyze main physical phenomena And processes in telecommunications using computer technology.

Own:

– skills use knowledge physicists at decision practical tasks of engineering activities

– ways processing And performances data, received V as a result of experimental studies.

– skills computer modeling main physical methods of receiving, transmitting and storing information.

EDUCATIONAL AND MATERIAL SECURITY:

– PC With simulator electronic schemes Electronics Workbench - 5.12" And system computer mathematicians Mathcad - 15";

– electronic methodological development By practical work.

STRUCTURE PRACTICAL WORK:

Class No. 1		90 min
Introductory Part		10 min
Examination readiness students To practical work		8 min
Introductory Part		2 min
Questions (tasks), subject research:		75 min
1. Modeling and research of the process of propagation of simple signals in a physical environment.		75 min
Final Part		5 min
Summing up results		3 min
Exercise students For independent work		2 min
Class No. 2		90 min
Introductory Part		10 min
Examination readiness students To practical work		8 min
Introductory Part		2 min
Questions (tasks), subject research:		50 min
1. Modeling and research of the process of propagation of simple signals in a physical environment.		50 min
Final Part		30 min
Protection reports By practical work		25 min
Summing up results		3 min
Exercise students For independent work		2 min

QUESTIONS, SUBJECTS RESEARCH

1. MODELING AND RESEARCH OF THE PROPAGATION PROCESS SIMPLE SIGNALS IN PHYSICAL WEDNESDAY.

Brief theoretical or reference and information materials

For transmissions information (data) V view signals are used various physical environments (optical fiber, twisted pair, coaxial cable, radio channel, channel infrared radiation), implementing transfer information (data) due to various physical phenomena and processes.

To simplify the analysis of real physical environments, it is customary to abstract from physical processes, flowing V them. For this physical processes are approximately replaced by a certain circuit model (equivalent circuit), consisting of a set of idealized elements connected ideal conductors. System equations, describing properties of such models, is mathematical model electrical chains, possessing the properties and characteristics of the physical environment.

It is known from radio engineering that any physical environment can be represented by a simple scheme substitution, representing by yourself a passive linear simple electrical circuit of the first order, i.e. containing one reactive element. Such a simple circuit has no voltage or current sources, has the property of linear signal transformation, and contains, in addition to active resistance (resistor), either capacitance (capacitor) or inductance (inductor).

In addition, first-order electrical circuits have the property of inertia, i.e. a rapid change in the voltage applied to the circuit by an independent source leads to smooth changes in the voltage on the capacitor or current in inductance. Then how change current on capacitor and voltage on the inductance can occur abruptly.

Analysis of inertial properties of real physical systems allows to claim that any physical environment can be simplified and represented as an integrating circuit.

An integrating circuit is an electrical circuit in which the output voltage or current is proportional to the integral by time of the input voltage or current, for example:

$$U_{\text{вых}}(t) = K \int U_{\text{вх}}(t) dt. \quad (1.1)$$

On the basis of the integration of the charge on a capacitor with capacitance C under the action of an applied current (see Fig. 8, a) or the accumulation of magnetic flux in a coil with inductance L under the action of an applied voltage (see Fig. 8, b), i.e.:

$$U_c = \frac{1}{C} \int i_c dt \quad i_L = \frac{1}{L} \int U_L dt. \quad (1.2)$$

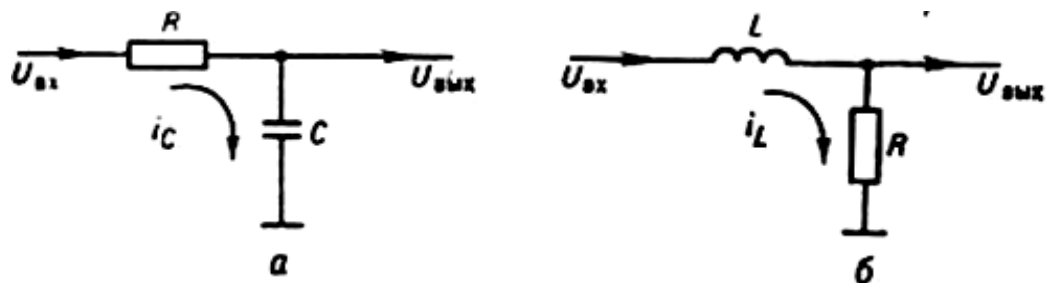


Рис. 1 - Интегрирующие цепи: а - RC цепь, б - RL цепь

Taking into account that the charging current of the capacitor in the RC circuit is equal to $i_c = U_{\text{вх}}/R$, and in the RL circuit the voltage on the coil and resistor is equal to $U_{\text{вх}}$, respectively, and $i_L R$, as a result we get

$$U_{\text{вых}}(t) = U_c(t) = \frac{1}{RC} \int U_{\text{вх}}(t) dt = \frac{1}{\tau} \int U_{\text{вх}}(t) dt, \quad (1.3)$$

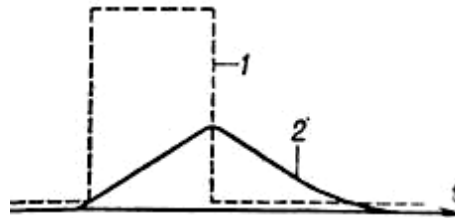
$$U_{\text{вых}}(t) = U_R(t) = \frac{R}{L} \int U_{\text{вх}}(t) dt = \frac{1}{\tau} \int U_{\text{вх}}(t) dt, \quad (1.4)$$

where $\tau = RC$ - work, characterizing speed charge capacitor,

called constant time RC chains, $\tau = L/R$ - attitude, characterize- which is the rate of change of current in the coil circuit due to the phenomenon of self-induction, called the time constant RL of the circuit.

IN integrating chains current charge capacitor or current in the coil is determined by the difference between the input and output voltages [$i = (U_{in} - U_{out})/R$] therefore, the integration of the input voltage is performed approximately and the more accurate the lower the output voltage compared to the input. The last condition is satisfied if the time constant τ much larger than the time interval over which integration occurs.

For correct integration of the pulse input signal it is necessary that τ was much longer than the pulse duration T (Fig. 2).



Rice. 2 - Weekend voltage integrating chains (2) at entrance impact in the form of a rectangular pulse (1)

Content practical work, performed students

1.1. Description laboratory equipment:

– PC With simulator electronic schemes Electronics Workbench - 5.12" and the computer mathematics system "Mathcad - 15".

1.1. Initial data For modeling And research

Table 1.1 - Options tasks For modeling And research

Option No.	E, IN	f, MHz	R, Ohm	$WITH, nF$	L, mcG
1	1.1	1.1	5	21	0,9
2	1,2	1,2	6	22	0,8
3	1,3	1,3	7	23	0,7
4	1,4	1,4	8	24	0,6
5	1,5	1,5	9	25	0,5
6	1,6	1,6	10	26	1
7	1,7	1,7	5	19	0,9
8	1,8	1,8	6	18	0,8
9	1,9	1,9	7	17	0,7
10	2,0	2,0	8	16	0,6
11	1,1	2,1	9	15	0,9
12	1,2	2,2	10	14	0,8
13	1,3	2,3	5	13	0,7
14	1,4	2,4	6	12	0,6
15	1,5	2,5	7	11	0,5

16	1.6	2.6	8	10	1
17	1.7	2.7	9	9	0.9
<i>Variant No.</i>	<i>Well, In</i>	<i>f, MHz</i>	<i>R, Ohm</i>	<i>WITH, nF</i>	<i>L, mcG</i>
18	1.8	2.8	10	8	0.8
19	1.9	2.9	5	7	0.7
20	2.0	3.0	6	6	0.6

1.3. Exercise For works:

Basic level:

1.1. Conduct a study in the programs "Mathcad" and "Electronics Workbench" of the process of propagation of simple signals through a physical medium modeled as an integrating RC circuit.

1.2. Conduct a study in the programs "Mathcad" and "Electronics Workbench" of the process of propagation of simple signals through a physical environment modeled as an integrating RL circuit.

1.4. Order execution work

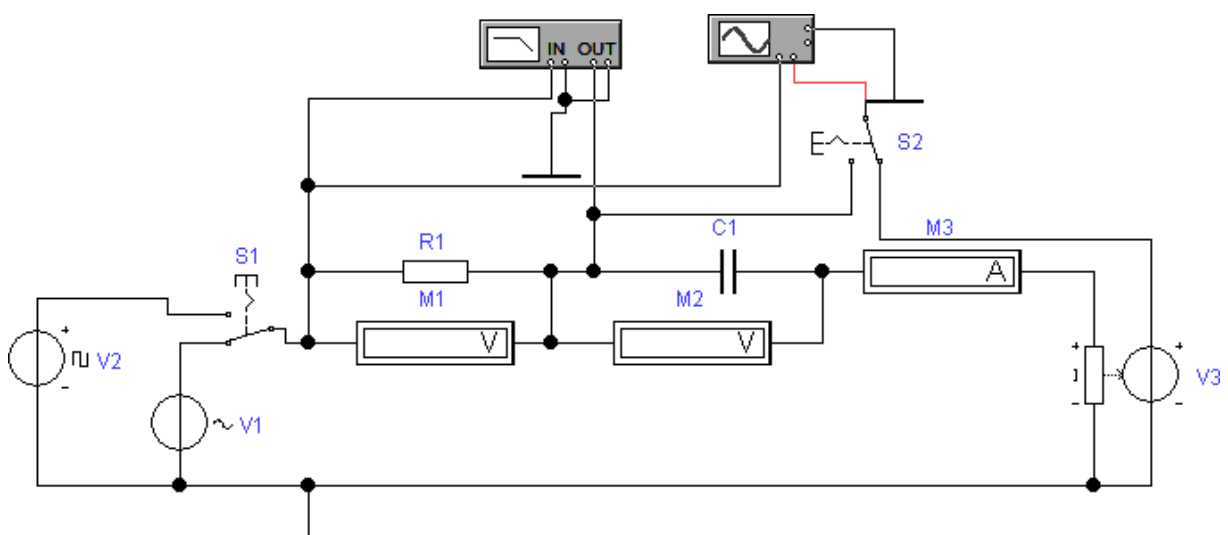
Exercise 1.1. Conduct study *V* programs *Mathcad* And *"Electronics Workbench"* of the process of propagating simple signals through a physical medium modeled as an integrating RC circuit .

A) Production tasks.

Develop a mathematical model of the physical environment in the Mathcad program transmissions information (data), representing by yourself integrating RC circuit and evaluate its transfer properties.

In the Electronics Workbench program, develop a circuit model of the physical environment for transmitting information (data) in the form of an integrating RC circuit, And evaluate her inertial And transmission properties at passage of harmonic and digital signals.

Example schemes integrating RC circuits presented on rice. 10. Source harmonic signal is - source variable voltage *V1* , and the digital signal is source *V2* , which forms a signal called a square wave, i.e. a sequence of pulses with a duty cycle of 2.



Rice. 3 - Integrating RC chain

Initial data For modeling are given By options (see table 1.1) parameter values:

- source signals – E – pulse amplitude for a digital signal or the effective value of voltage for a harmonic signal, f frequency,
- electrical chains - R And C .

For displays results modeling V circuit design models to use voltmeters $M1$ And $M2$, ammeter $M3$, oscilloscope And a graph plotter (Bode plotter) or otherwise a plotter of transfer characteristics in the form of an amplitude-frequency characteristic (AFC) and a phase-frequency characteristic (PFC). To measure electric current using an oscilloscope, a voltage source controlled by current $V3$ with a resistance of 1 is introduced into the circuit Ohm. B result value measurable oscilloscope The voltage will be equal to the current flowing through the circuit.

B) Order modeling And research.

1) For developments mathematical models V program Mathcad execute next actions (operations): enter original data - E , f , R And C ; enter formulas for calculating the following parameters and characteristics:

- constant time chains - $\tau := R \cdot C$;
- capacitive reactive resistance

$$X_c := \frac{1}{2\pi \cdot f \cdot C};$$

- module complete complex resistance chains Z

$$Z := \sqrt{R^2 + \left(\frac{1}{2\pi \cdot f \cdot C}\right)^2};$$

- current meaning forces current V chains

$$I := \frac{E}{Z};$$

- effective value of voltage drop across resistor U_R and capacitor U_C

$$U_r := I \cdot R \text{ And } U_c := I \cdot X_c;$$

- phase shift between input And weekend voltage -

$$\psi := 90 - \operatorname{atan}\left[\frac{\left(\frac{1}{2\pi \cdot f \cdot C}\right)}{R}\right] \cdot \frac{360}{2\pi};$$

- frequency cycle for constructing transient responses

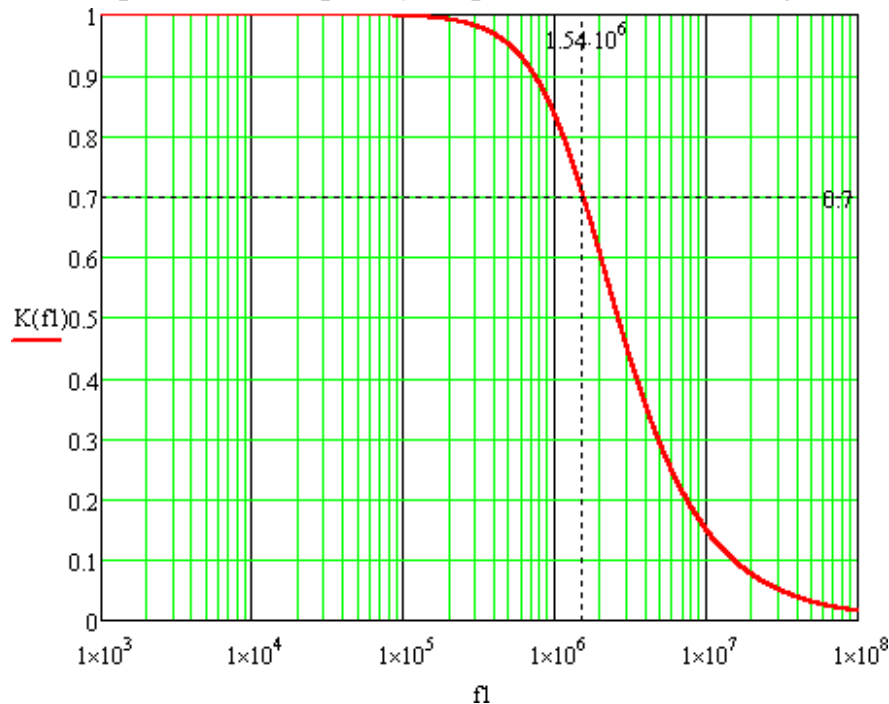
$$f1 := 0,1 \cdot 10^3 \dots 100 \cdot 10^6$$

;

- amplitude-frequency (frequency response) And phase-frequency (PFC) characteristics

$$K(f1) = \frac{1}{\sqrt{1 + (2\pi f1)^2 \tau^2}} \text{ And } \phi(f1) = \frac{\operatorname{arctg}(2\pi f1 \tau) \cdot 360^\circ}{2\pi}.$$

2) Display V report By practical work graphs frequency response And phase response integrating RC circuit, setting the abscissa axis (frequency) on a logarithmic scale. An example of the frequency response is shown in Fig. 11.



Rice. 4 - frequency response integrating RC circuits

3) Using the frequency response graph, determine the bandwidth of the simulated integrating RC circuit at a level of 0.707 and evaluate the selective properties of this circuit.

4) Determine the bandwidth of the simulated integrating RC circuit using the phase response graph. level 45° and evaluate selective properties of this chain.

5) For circuit design modeling launch program “Electronics Workbench EWB 5.12”. Assemble a circuit that simulates the integrating RC circuit shown in Fig. 10. Set the values of the parameters R , C , E and f ***specified according to the option***.

6) Conduct research process distribution harmonic signal through simulated physical Wednesday. For this submit on entrance harmonic effect of the integrating RC circuit by moving switch S1 to the lower position. Using a graph plotter, obtain the frequency response and phase response of the circuit when original values ***WITH***, display their report By practical work And compare With previously calculated characteristics. By received frequency response determine the bandwidth of the circuit (at the level of -3 dB) and its nature.

7) Determine the phase shift between the input and output voltage of the circuit. To do this, move the oscilloscope cursors to the instantaneous voltage values, With identical current phases, For example on highs (amplitude) of oscillations, then measure temporary delay $\Delta\tau$ between input And output signal in the window $T2 - T1$. Calculate the phase shift using the formula

$$\psi = 360 \cdot \Delta\tau \cdot f = 360 \cdot (T_2 - T_1) \cdot f, \text{ hail.}$$

8) Conduct research into the process of digital signal propagation through simulated physical Wednesday. For this submit on entrance integrating RC chains pulsed impact, having installed switch S1 translate into upper position. Measure values stresses on resistor U_R And capacitor U_C , as well as current I in the circuit, enter the results in table 2.2.

Table 2.2 - Experimental data For integrating RC chains

Impact	Initial parameters	Experimental data				
		I, mA	U_R, mV	U_C, mV		
pulsed	0.5 C					
	WITH					
	2 C					

9) WITH help oscilloscope take off temporary diagrams input voltage And voltage on capacitor, For this switch S2 must be V left position. Received temporary diagrams display V from- report. Analyze received oscillograms, having established, how the time representation of the output signal differs from the input signal, and what led to To distortion species signal. By oscillogram define the duration of transient processes and compare it with the pulse duration.

10) Using a Fourier analyzer, construct the spectra of the input and output signals. To do this, first set the node at the circuit's input in the Fourier analyzer, then set the node at the circuit's output, with the fundamental frequency equal to the specified frequency f and the number of harmonics equal to 20.

11) Analyze received spectra, having established, how spectrum weekend signal is different from the spectrum input signal, and Also what led To change in spectrum.

12) Using an oscilloscope, record the input voltage timing diagrams. And current V chains, For this switch S2 must be V right position. Display the resulting time diagrams in the report.

13) Repeat points 8) – 12) for other values of circuit capacitance, equal to 0.5C and 2C.

14) Do conclusions By results, done work, V conclusions reflect all physical processes occurring in the circuit, establish which processes lead to distortion of the shape of rectangular pulses in the circuit.

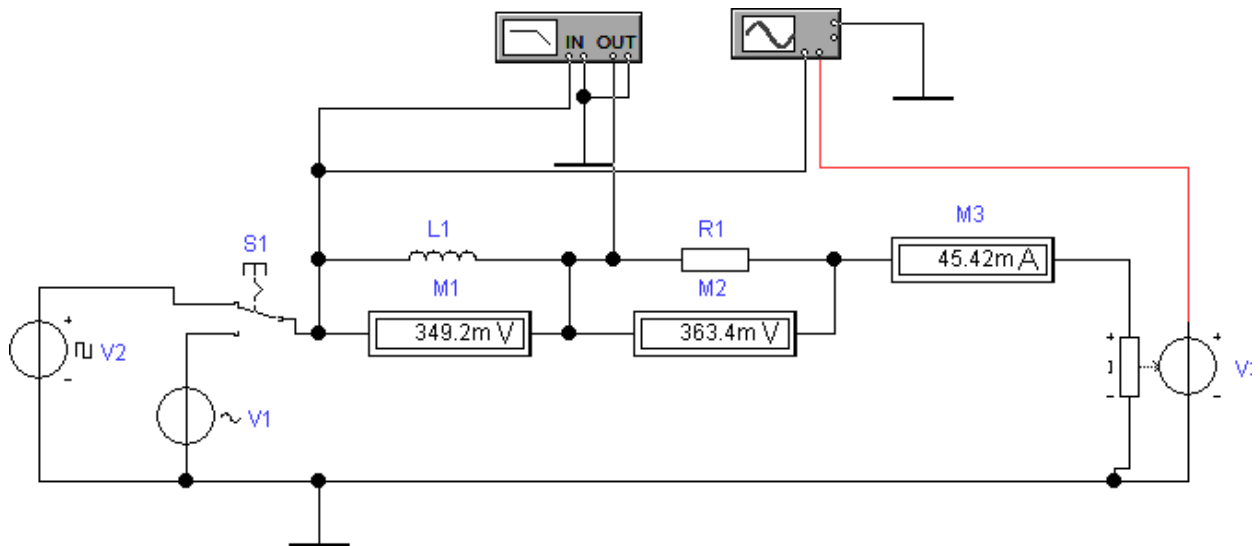
Exercise 1.2. Conduct study V programs Mathcad And "Electronics Workbench" of the process of propagating simple signals through a physical medium modeled as an integrating RL circuit .

A) Production tasks.

Develop a mathematical model of the physical environment in the Mathcad program transmissions information (data), representing by yourself integrating RL circuit and evaluate its transfer properties.

In the Electronics Workbench program, develop a circuit model of the physical environment for transmitting information (data) in the form of an integrating RC circuit, And evaluate her inertial And transmission properties at passage of harmonic and digital signals.

An example of an integrating RL circuit is shown in Fig. 5. Source harmonic signal is - source variable voltage $V1$, and the digital signal is source $V2$, which forms a signal called a square wave, i.e. a sequence of pulses with a duty cycle of 2.



Rice. 5 - Integrating RC chain

Initial data For modeling are given By options (see table 2.1) parameter values:

- source signals – E – pulse amplitude for a digital signal or the effective value of voltage for a harmonic signal, f frequency,
- electrical chains - R And L

For displays results modeling V circuit design models to use voltmeters $M1$ And $M2$, ammeter $M3$, oscilloscope And a graph plotter (Bode plotter) or otherwise a plotter of transfer characteristics in the form of an amplitude-frequency characteristic (AFC) and a phase-frequency characteristic (PFC). To measure electric current using an oscilloscope, a voltage source controlled by current $V3$ with a resistance of 1 is introduced into the circuit Ohm. B result value measurable oscilloscope The voltage will be equal to the current flowing through the circuit.

B) Order modeling And research.

1) For developments mathematical models V program Mathcad execute next actions (operations): enter original data - E , f , R And L ; enter formulas for calculating the following parameters and characteristics:

$$\tau := \frac{L}{R} ;$$

- constant time chains -
- capacitive reactive resistance

$$X_L := 2\pi \cdot f \cdot L ;$$

– module complete complex resistance chains Z

$$Z := \sqrt{R^2 + (2\pi \cdot f \cdot L)^2} ;$$

– current meaning forces current I chains

$$I := \frac{E}{Z} ;$$

– effective value of voltage drop across resistor U_R and capacitor U_C

$$U_R := I \cdot R \quad \text{And} \quad U_L := I \cdot X_L ;$$

– phase shift between input And weekend voltage -

$$\psi := \arctan \left[\frac{(2\pi \cdot f \cdot L)}{R} \right] \cdot \frac{360}{2\pi} ;$$

– frequency cycle for constructing transient responses

$$f1 := 0,1 \cdot 10^3 \dots 100 \cdot 10^6$$

;

– amplitude-frequency (frequency response) And phase-frequency (PFC)

$$\text{charact} K(f1) := \frac{1}{\sqrt{1 + (2\pi \cdot f1)^2 \cdot \tau^2}} \quad \phi(f1) := \frac{-\arctan(2\pi \cdot f1 \cdot \tau) \cdot 360}{2\pi}$$

And

2) Display V report By practical work graphs frequency response And phase response integrating RL circuit, setting the abscissa axis (frequency) on a logarithmic scale .

3) Using the frequency response graph, determine the bandwidth of the simulated integrating RL circuit at a level of 0.707 and evaluate the selective properties of this circuit.

4) Using the phase response graph, determine the passband of the simulated integrating RL circuit at a level of 45° and evaluate the selective properties of this circuit.

5) For circuit design modeling launch program "Electronics Workbench EWB 5.12". Assemble a circuit that simulates the integrating RL circuit shown in Fig. 10. Set the values of the parameters R , L , E and f **specified according to the option** .

6) Conduct research process distribution harmonic signal through simulated physical Wednesday. For this submit on entrance integrating RL circuit harmonic influence by moving switch S1 to the lower position. Using a graph plotter, obtain the frequency response and phase response of the circuit when original values **WITH** , display their report By practical work And compare With previously calculated characteristics. By received frequency response determine the bandwidth of the circuit (at the level of -3 dB) and its nature.

7) Determine the phase shift between the input and output voltage of the circuit. To do this, move the oscilloscope cursors to the instantaneous voltage values, With identical current phases, For example on highs (amplitude) of oscillations, then measure temporary delay $\Delta\tau$ between input And output signal in the window $T_2 - T_1$. Calculate the phase shift using the formula

$$\psi = 360 \cdot \Delta\tau \cdot f = 360 \cdot (T_2 - T_1) \cdot f, \text{ hail.}$$

8) Conduct research into the process of digital signal propagation through simulated physical Wednesday. For this submit on entrance integrating RL chains pulsed impact, having installed switch S1 translate into upper position. Measure values stresses on resistor U_R And capacitor U_L , as well as current I in the circuit, enter the results in table 1.3.

Table 1.3 - Experimental data For integrating RL chains

Impact	Initial parameters	Experimental data				
		I, mA	U_R, mV	U_L, mV		
pulsed	0.5 L					
	L					
	2 L					

9) WITH help oscilloscope take off temporary diagrams input voltage and output voltage on the resistor. Display the resulting timing diagrams in the report. Analyze the resulting oscillograms, establishing, how temporary performance weekend signal is different from entrance signal, A Also What led To distortion species signal. By determine the oscillogram duration transitional processes and compare her with pulse duration .

10) Using a Fourier analyzer, construct the spectra of the input and output signals. To do this, first set the node at the circuit's input in the Fourier analyzer, then set the node at the circuit's output, with the fundamental frequency equal to the specified frequency f and the number of harmonics equal to 20.

11) Analyze received spectra, having established, how spectrum weekend signal is different from the spectrum input signal, and Also what led To change in spectrum.

12) Using an oscilloscope, record timing diagrams of the input voltage and current in the circuit. Display the resulting timing diagrams in the report .

13) Repeat points 8) - 12) For others values capacity chains, equal 0.5L And 2L.

14) Do conclusions By results, done work, V conclusions reflect all physical processes occurring in the circuit, establish which processes lead to distortion of the shape of rectangular pulses in the circuit.

1.5. Compose report O done work By to the second question V in accordance with the requirements set out in the job description.

IN report bring:

- original data,
- performed tasks,
- researched fundamental electrical schemes,
- mathematical models (formulas) And results calculations,
- research results – measured parameters entered into tables, oscillograms, frequency response and spectra;
- conclusions O done work.

6. Protection practical work

For protection practical introduce fully decorated report, free of significant errors. Complete one of the tasks assigned by the teacher, explaining all the physical phenomena and processes occurring in the task being completed.

LIST LITERATURE:

- 1) Sagdeev K.M. Physical foundations of information security [Electronic resource]: study guide / K.M. Sagdeev, V.I. Petrenko, A.F. Chipiga. - Electronic text data. - Stavropol: North Caucasus Federal University, 2015. - 394 p.
- 2) Evstifeev V.V. Physical foundations electricity and magnetism Electronic resource / Evstifeev V.V.: study guide. - Penza: PSU, 2019. - 416 p.
- 3) Bulatov V.N. Physical foundations of electronics Electronic resource / Bulatov V.N.: lecture notes for students in educational programs higher education in the following areas preparation 11.03.02 infocommunication technologies and communication systems. - Orenburg: OSU, 2018. - 178 p.
- 4) Goldstein A.E. Physical principles of obtaining information [Electronic resource]: textbook / A.E. Goldstein. — Electron. text data. — Tomsk: Tomsk Polytechnic University, 2010. — 292 p.

PRACTICAL JOB No. 3

TOPIC 3

ELEMENTS THEORIES FIELDS

Class 3

MODELING AND RESEARCH OF CHARACTERISTICS PHYSICAL FIELDS, PROCESSES THEIR TRANSFORMATIONS.

TIME – 4 hours.

Educational questions:

- 1. Modeling And study characteristics scalar physical fields**
- 2. Modeling And study vector fields And their transform-**

niy.

TARGET PRACTICAL INSTALLATION WORKS:

Competencies, being formed discipline

OPK-1: Capable use provisions, laws And methods natural sciences and mathematics to solve engineering problems.

OPK-2: Capable on one's own conduct experimental research And use main techniques processing And performances received data.

Learning outcomes achieved as a result of completing practical work:

Be able to:

- apply physical laws and methods to formalize the representation of physical phenomena and processes that occur in telecommunications .
- conduct experimental research With help mathematical models according to the accepted methodology
- model And analyze main physical phenomena And processes in telecommunications using computer technology.

Own:

- skills use knowledge physicists at decision practical problems of engineering activities
- methods of processing and presenting data obtained as a result of experimental studies.
- skills in computer modeling of the main physical methods of receiving, transmitting and storing information.

EDUCATIONAL AND MATERIAL SECURITY:

- PC With simulator electronic schemes Electronics Workbench - 5.12" And system computer mathematicians Mathcad - 15";
- electronic methodological development By practical work.

STRUCTURE PRACTICAL WORKS:

Class No. 1		90 min
Introductory Part		10 min
Examination readiness students To practical work		8 min
Introductory Part		2 min
Questions (tasks), subject research:		75 min
1. Modeling And study characteristics scalar physicheskih fields		75 min
Final Part		5 min
Summing up results		3 min
Exercise students For independent work		2 min
Class No. 2		90 min
Introductory Part		10 min
Examination readiness students To practical work		8 min
Introductory Part		2 min
Questions (tasks), subject research:		50 min
1. Modeling and vector research fields and their transformcallings.		50 min
Final Part		30 min
Protection reports By practical work		25 min
Summing up results		3 min
Exercise students For independent work		2 min

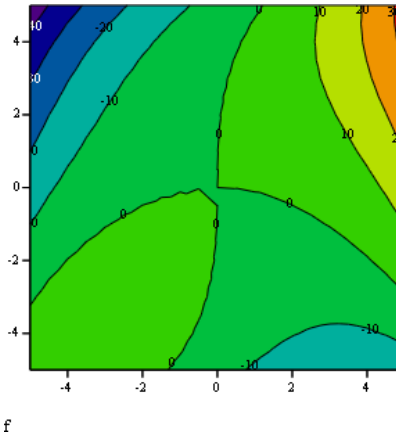
QUESTIONS, SUBJECTS RESEARCH

Brief theoretical or reference and information materials

To visualize the representation of a scalar field, its graphical representation is used – a level surface.

The locus of points M at which the field $f(M)$ has a given value C is called *the level surface* of the scalar field $f(M)$.

The equation of the level surface is $f(M)=C$. The level surfaces corresponding to various values C , fill out all region, V which the field is defined, and no two surfaces $f(M)=C_1$ and $f(M)=C_2$, where C_1 and C_2 are not equal, have no common points. The relative position of the level surfaces provides a visual performance of corresponding scalar field. Places the approach of surfaces indicates a rapid change in the function $f(M)$, a slow change functions $f(M)$ correspond places discharge surfaces (cm. Fig. 1).



Rice. 1 –Representations scalar fields V view surfaces levels

If scalar field defined V flat areas, That surfaces Level lines degenerate into **level lines** . Level lines are usually used to depict temperature distribution (isotherms), pressure distribution (isobars), terrain relief on topographic maps (horizontals), equipotential lines of electrostatic fields, etc.

Level surfaces allow us to judge the rate of change of a scalar field $f(\mathbf{M})$ By to that or to another direction only qualitatively. The quantitative characteristic of the rate of change of the field $f(\mathbf{M})$ is given by the derivative with respect to direction .

Let's assume, What V areas W defined scalar field $f(\mathbf{M})$. Let us consider a point $\mathbf{M}$ and some fixed direction determined by a unit vector $\mathbf{s}$. Through the point $\mathbf{M}$ we draw a line $\mathbf{S}$ parallel to the vector $\mathbf{s}$, let's take a point $\mathbf{M}_1$ on it and build a relationship

$$\frac{f(\mathbf{M}_1) - f(\mathbf{M}_2)}{MM_1} . \quad (1)$$

Existing limit relationship (1), When dot $\mathbf{M}_1$, moving By chosen direct $\mathbf{S}$, is approaching To $\mathbf{M}$, it's called derivative scalar fields $f(\mathbf{M})$ at the point $\mathbf{M}$ in direction $\mathbf{s}$ and is designated df/ds . Thus, the directional derivative is

$$\frac{df}{ds} = \lim_{M_1 \rightarrow M} \frac{f(\mathbf{M}_1) - f(\mathbf{M}_2)}{MM_1} . \quad (2)$$

Derivative (2) By direction vectors $\mathbf{s}$ at condition $\mathbf{M}_1 \rightarrow \mathbf{M}$ characterizes speed changes fields $f(\mathbf{M})$ V direction this vectors And Not is associated with the choice of a particular coordinate system.

IN Cartesian system coordinates derivative By direction $\mathbf{s}$ calculated by the formula

$$\frac{df}{ds} = \frac{df}{dx} \cos \alpha + \frac{df}{dy} \cos \beta + \frac{df}{dz} \cos \gamma . \quad (3)$$

Where α, β, γ - corners, formed vector $\mathbf{s}$ With axes coordinates.

An important characteristic of a scalar field is **the gradient** , which allows analytically describe This field V vector presentation. IN Cartesian

system coordinates gradient scalar fields $f(M)$ is determined By formula

$$\text{grad } f = \frac{df}{dx} \vec{i} + \frac{df}{dy} \vec{j} + \frac{df}{dz} \vec{k}. \quad (4)$$

At this They say, What V areas W defined vector field gradients. Let us note some **properties of the gradient**.

1) Derivative By to anyone direction equal scalar the product of the gradient and the unit vector of this direction

$$\frac{df}{ds} = \text{grad } f \cdot \vec{s} = |\text{grad } f| \cdot \cos \theta. \quad (5)$$

Here θ - corner between single vector directions s And gradient.

Using This property, Can give definition gradient, Not dependent on the coordinate system. The gradient of a scalar field $f(M)$ at a point M is a vector whose projection onto the direction of a given unit vector is equal to the derivative of the field $f(M)$ in this direction.

$$\vec{F} = \text{grad} f(M) = \frac{df}{ds}. \quad (6)$$

2) The directional derivative takes its greatest value in the direction of the gradient

$$\max \frac{df}{ds} = |\text{grad } f| = \sqrt{\left(\frac{df}{dx}\right)^2 + \left(\frac{df}{dy}\right)^2 + \left(\frac{df}{dz}\right)^2}. \quad (7)$$

3) Gradient vector directed By normals To surfaces level V upward direction functions $f(M)$. From here it follows directly that if $f(M)=C$ – level surface in a scalar field and $\vec{n}(M)$ is the unit normal to this level surface at point M , then

$$\vec{n} = \pm \frac{\text{grad} f}{|\text{grad} f|}, \quad (1.8)$$

Where sign + or - is selected V dependencies from orientation surfaces.

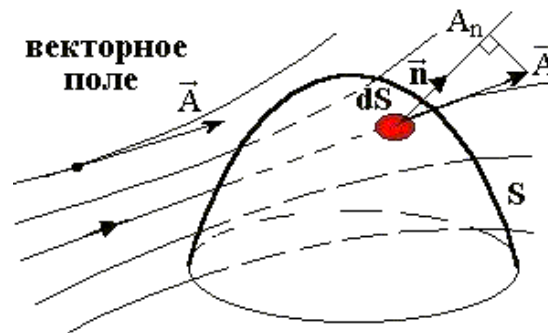
4) If in the region W the gradient is zero ($\text{grad } f=0$), then $f = \text{constant}$, i.e. the scalar field is constant in W .

When describing physical fields, in addition to scalar quantities, vectors are used. Let V some areas spaces W defined vector field, this is means, What V each point this areas spaces asked vector fields,

which we will designate A .

The structure of a vector field is made up of vector, or as they are called in physics, lines of force – curves in space, tangent at each point which matches By direction With certain V this point pro-

wanderings vector fields A (see rice. 2).



Rice. 2 – Example vector fields

It follows note, What V difference from scalar fields structure vector fields is much more complex. This is due to the nature of the behavior of vector lines at different points in space. Thus, there may be points in space at which vector lines can begin or end. If any point in space is the beginning of vector lines, then we say that at this point in space there is **a source of the vector field**. The point in space at which the vector lines end is called **a sink**. Obviously, for an electric field, sources and sinks are, respectively, positive and negative charges. Moreover, the greater vector lines it begins in this point spaces, the more powerful, the more abundant located V this point spaces source. For quantitative (mathematical) characteristics of vector field sources in mathematics theories fields introduce some scalar function, called divergence (from the Latin word *divergentia* – divergence, discrepancy).

Note that all the terminology comes from hydrodynamics, so for clarity, we can imagine the velocity field of fluid flow, for example, in a bathtub. The source would then be the faucet or shower, and the drain would be the hole in the bathtub.

Divergence of a vector field $\vec{A}$ at point M is called the limit to which the ratio of the vector flow tends $\vec{A}$ through the surface S to the volume ΔV , limited this surface, When last one is tightening To point M , $\Delta V \rightarrow 0$.

$$\text{div} \vec{A} = \lim_{\substack{\Delta V \rightarrow 0 \\ (S \rightarrow M)}} \frac{\oint_S (\vec{A}, \vec{n}) ds}{\Delta V} \quad (9)$$

How visible from definitions, divergence represents by yourself density flow of a vector field. It is known that the density of any quantity given in space (for example, charge density) is defined as the limit of the ratio this quantities, prisoner V volume ΔV To size this volume. So and in (9) the divergence is defined as the limit of the ratio of the flow of the vector field from within the volume ΔV to the value of this volume.

Clear, what if V point M located source fields, That $\text{div} \vec{A} > 0$, because flow $F > 0$, because scalar work vectors $(\vec{A}, \vec{n}) > 0$, if same $\text{div} \vec{A} < 0$, $F < 0$, because scalar work vectors $(\vec{A}, \vec{n}) < 0$. Except this How visible from expressions (9), how more flow vectors

$\vec{A}$ (numerator V (9)), those more $\text{div} \vec{A}$, those, respectively, more vector lines begin at a given point in space, and therefore the more powerful, the more abundant source. Let us note, between by the way, What use V quality It would be impossible to simply determine the characteristics of the power of the field sources by the flow of the vector field, since it tends to zero when the integration surface S **contracts** to the point M . Contraction of the surface S to the point M is necessary, since the field sources can be very close to each other, and we must separate them, determining the power of each source. When calculating same limit relationship V (9), we get some final expression. That is, the divergence of a vector field is a local concept – a function of a point in space.

Continuing the analogy with hydrodynamics, we can say that the flow of the vector field of velocities of a flowing liquid through a surface is the amount of liquid (volume), flowing through this one surface V unit time, A divergence - the amount of liquid that appears or disappears at a given point spaces V unit time, referred To unit volume (fluid flow density).

Based on from definitions divergences (9) V mathematical theories fields received next **formula, allowing calculate divergence V Cartesian coordinate systems** :

$$\text{div} \vec{A} = \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z} \quad (10)$$

To characterize the degree of vorticity of the field, **the concept of circulation density is introduced**, defining it as the limit to which the circulation ratio tends vectors $\vec{A}$ By contour L , To area ΔS , limited this contour, When given circuit is tightening To under consideration point space. At this respectively, $\Delta S \rightarrow 0$:

$$\lim_{\substack{\Delta S \rightarrow 0 \\ (L \rightarrow M)}} \frac{1}{\Delta S} \oint_L (\vec{A}, \vec{\tau}) dl \quad (11)$$

Calculating this limit, we will already have some finite value, different from zero number. However This meaning will depend from orientation contours L V field. This is means, What All manifold values density circulation vector field Maybe be, at all speaking, presented V view projections some vectors, on normal To site contours L . At this given vector By the absolute value will be equal to the maximum value of the circulation density of the vector

$\vec{A}$ at the point in space under consideration, and is directed in the direction corresponding to the direction of the normal to the contour L , at which the circulation density takes on this maximum value.

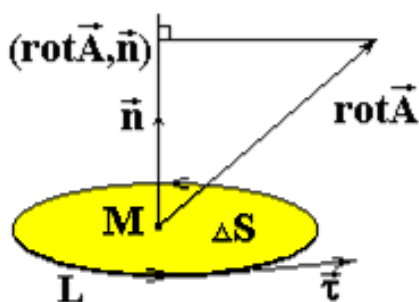
This vector it's called rotor or whirlwind vector fields $\vec{A}$ (from the French (or English) word *rotation*, or Latin *roto* – I rotate) and the projection of this vector onto any direction at each point in space is determined by the expression:

$$(\text{rot} \vec{A}, \vec{n}) = \lim_{\Delta S \rightarrow 0} \frac{1}{\Delta S} \oint_{\vec{L}} (\vec{A}, \vec{\tau}) dl, \quad (12)$$

Here $\vec{n}$ - normal To site ΔS , agreed upon With direction bypass contours L rule right screws (gimlet) - rice. 3.

Based on from definitions (12) Can get projections rotor $\text{rot} \vec{A}$ on one-nichnye vectors, And define those the most $\text{rot} \vec{A}$ V Cartesian coordinates:

$$\text{rot} \vec{A} = \left[\frac{\partial A_z}{\partial y} - \frac{\partial A_y}{\partial z} \right] \cdot \vec{i} + \left[\frac{\partial A_x}{\partial z} - \frac{\partial A_z}{\partial x} \right] \cdot \vec{j} + \left[\frac{\partial A_y}{\partial x} - \frac{\partial A_x}{\partial y} \right] \cdot \vec{k} \quad (13)$$



Rice. 3 - Vortex field

1. MODELING AND RESEARCH OF THE CHARACTERISTICS OF SCALAR PHYSICAL FIELDS

Content practical work, performed students on the first academic question

1. Description laboratory equipment:

– PC With established system computer algebra "Mathcad- 15".

2. Initial data For modeling And research

Table 1 - Options tasks For modeling And research

Optio n	No. sourc e	Charge q	X	Y	$f(x,y)$	Optio n	No. sourc e	Charge q	X	Y	$f(x,y)$
1	1	$20 \cdot 10^{-9}$	0.82	0.54	$x^2 + xy - y^4$	14	1	$-20 \cdot 10^{-9}$	0.54	0.82	$y^4 + x - x^3 y^2$
	2	$-15 \cdot 10^{-9}$	0.12	0.90			2	$15 \cdot 10^{-9}$	0.90	0.12	
	3	$30 \cdot 10^{-9}$	0.33	0.68			3	$-30 \cdot 10^{-9}$	0.68	0.33	
	4	$-25 \cdot 10^{-9}$	0.25	0.59			4	$25 \cdot 10^{-9}$	0.59	0.25	
2	1	$40 \cdot 10^{-9}$	0.16	0.71	$x^3 + xy - y^3$	15	1	$-40 \cdot 10^{-9}$	0.71	0.16	$y^3 - x^2 - x^2 y^2$

Varia nt	No. sourc e .	Charge q	X	Yes	$f(x,y)$	Varia nt	No. sourc e .	Charge q	X	Yes	$f(x,y)$
	2	$10 \cdot 10^{-9}$	0.20	0.57			2	$-10 \cdot 10^{-9}$	0.57	0.20	
	3	$-25 \cdot 10^{-9}$	0.38	0.83			3	$25 \cdot 10^{-9}$	0.83	0.38	
	4	$-30 \cdot 10^{-9}$	0.4	0.45			4	$30 \cdot 10^{-9}$	0.45	0.4	
3	1	$-10 \cdot 10^{-9}$	0.55	0.86	$x^3 + 3xy^2 - y^3$	16	1	$10 \cdot 10^{-9}$	0.86	0.55	$y^3 - x^2 - x^3$
	2	$15 \cdot 10^{-9}$	0.39	0.63			2	$15 \cdot 10^{-9}$	0.63	0.39	
	3	$10 \cdot 10^{-9}$	0.58	0.58			3	$-10 \cdot 10^{-9}$	0.58	0.58	
	4	$-25 \cdot 10^{-9}$	0.16	0.36			4	$25 \cdot 10^{-9}$	0.36	0.16	
4	1	$17 \cdot 10^{-9}$	0.13	0.48	$x^4 + 3xy^2 - y^3$	17	1	$17 \cdot 10^{-9}$	0.48	0.13	$y^2 - x^4 + x^3$
	2	$29 \cdot 10^{-9}$	0.22	0.35			2	$-29 \cdot 10^{-9}$	0.35	0.22	
	3	$-33 \cdot 10^{-9}$	0.30	0.51			3	$33 \cdot 10^{-9}$	0.51	0.30	
	4	$14 \cdot 10^{-9}$	0.73	0.25			4	$-14 \cdot 10^{-9}$	0.25	0.73	
5	1	$40 \cdot 10^{-9}$	0.44	0.58	$x^4 + 3xy^2 - y^5$	18	1	$40 \cdot 10^{-9}$	0.58	0.44	$x^4 + y^3 + x^2 + y$
	2	$-30 \cdot 10^{-9}$	0.31	0.62			2	$30 \cdot 10^{-9}$	0.62	0.31	
	3	$20 \cdot 10^{-9}$	0.25	0.69			3	$-20 \cdot 10^{-9}$	0.69	0.25	
	4	$-10 \cdot 10^{-9}$	0.73	0.18			4	$10 \cdot 10^{-9}$	0.18	0.73	
6	1	$-33 \cdot 10^{-9}$	0.64	0.12	$x^4 - x^2 y^2 - y^5$	19	1	$33 \cdot 10^{-9}$	0.12	0.64	$x^4 y^3 - x^3 y^4$
	2	$-27 \cdot 10^{-9}$	0.50	0.32			2	$-27 \cdot 10^{-9}$	0.32	0.50	
	3	$18 \cdot 10^{-9}$	0.46	0.28			3	$-18 \cdot 10^{-9}$	0.28	0.46	
	4	$45 \cdot 10^{-9}$	0.81	0.55			4	$45 \cdot 10^{-9}$	0.55	0.81	
7	1	$14 \cdot 10^{-9}$	0.43	0.60	$x^3 - x^2 y^2 - y$	20	1	$14 \cdot 10^{-9}$	0.60	0.43	$x^3 y - xy^3$
	2	$-12 \cdot 10^{-9}$	0.29	0.44			2	$12 \cdot 10^{-9}$	0.44	0.29	
	3	$45 \cdot 10^{-9}$	0.57	0.33			3	$-45 \cdot 10^{-9}$	0.33	0.57	
	4	$20 \cdot 10^{-9}$	0.65	0.70			4	$20 \cdot 10^{-9}$	0.70	0.65	
8	1	$-29 \cdot 10^{-9}$	0.24	0.44	$y^3 + x^4$	21	1	$29 \cdot 10^{-9}$	0.44	0.24	$x^4 y - xy^4$
	2	$19 \cdot 10^{-9}$	0.33	0.52			2	$19 \cdot 10^{-9}$	0.52	0.33	
	3	$22 \cdot 10^{-9}$	0.73	0.40			3	$-22 \cdot 10^{-9}$	0.40	0.73	
	4	$30 \cdot 10^{-9}$	0.59	0.20			4	$30 \cdot 10^{-9}$	0.20	0.59	
9	1	$-37 \cdot 10^{-9}$	0.63	0.70	$y^2 + x^2 - xy$	22	1	$37 \cdot 10^{-9}$	0.70	0.63	$x^4 - y^3 - x^2 - y$
	2	$-24 \cdot 10^{-9}$	0.49	0.86			2	$24 \cdot 10^{-9}$	0.86	0.49	
	3	$-16 \cdot 10^{-9}$	0.18	0.23			3	$-16 \cdot 10^{-9}$	0.23	0.18	
	4	$45 \cdot 10^{-9}$	0.54	0.11			4	$-45 \cdot 10^{-9}$	0.11	0.54	
10	1	$18 \cdot 10^{-9}$	0.76	0.35	$y^3 + x^2 - xy$	23	1	$-18 \cdot 10^{-9}$	0.35	0.76	$x^2 y^3 + y^2 + x$
	2	$-26 \cdot 10^{-9}$	0.68	0.49			2	$26 \cdot 10^{-9}$	0.49	0.68	
	3	$14 \cdot 10^{-9}$	0.32	0.31			3	$-14 \cdot 10^{-9}$	0.31	0.32	
	4	$30 \cdot 10^{-9}$	0.50	0.15			4	$30 \cdot 10^{-9}$	0.15	0.50	
11	1	$41 \cdot 10^{-9}$	0.87	0.63	$y^2 + x^2 - xy$	24	1	$-41 \cdot 10^{-9}$	0.63	0.87	$y^2 + x^2 + xy$
	2	$14 \cdot 10^{-9}$	0.49	0.26			2	$14 \cdot 10^{-9}$	0.26	0.49	
	3	$-14 \cdot 10^{-9}$	0.39	0.14			3	$-14 \cdot 10^{-9}$	0.14	0.39	

	4	-25·10 ⁻⁹	0.41	0.81			4	25·10 ⁻⁹	0.81	0.41	
12	1	22·10 ⁻⁹	0.54	0.60	$y^2 + x^2 - x^2y$	25	1	22 · 10 ⁻⁹	0.60	0.54	$x + y + x^2 - y^3$
	2	33 · 10 ⁻⁹	0.75	0.27			2	-33 · 10 ⁻⁹	0.27	0.75	
	3	-44·10 ⁻⁹	0.45	0.70			3	44·10 ⁻⁹	0.70	0.45	
	4	11·10 ⁻⁹	0.18	0.33			4	-11·10 ⁻⁹	0.33	0.18	
13	1	-23·10 ⁻⁹	0.46	0.68	$y^4 + x - x^2y^3$	26	1	23·10 ⁻⁹	0.68	0.46	$x^2y + y^2$
	2	32·10 ⁻⁹	0.77	0.14			2	-32·10 ⁻⁹	0.14	0.77	
	3	17 · 10 ⁻⁹	0.59	0.17			3	-17 · 10 ⁻⁹	0.17	0.59	
	4	-19 · 10 ⁻⁹	0.36	0.41			4	19 · 10 ⁻⁹	0.41	0.36	

3. Exercise For work

Basic level:

- 1) To model and explore static physical processes in the Mathcad system field, educated system independent sources, V scalar view.
- 2) To model and explore static physical processes in the Mathcad system field, educated system independent sources, V vector view.
- 3) Simulate V system Mathcad scalar physical field And transform it into a gradient vector field.

4. Order execution work

Task 1.1. Model and investigate static in the Mathcad system physical field, educated system independent sources, in scalar form.

1. The initial data for modeling is a physical field in a vacuum, created by the system from N independent sources, having quantities charges q_n and coordinates (X_n, Y_n) , $n = 1 - N$.

The task of modeling is to obtain the spatial distribution of the scalar value of the field in the form of its potential, determined by formula (14)

$$\varphi(x, y) = \sum_{n=1}^N \frac{k \cdot q}{\sqrt{(x - X_n)^2 + (y - Y_n)^2}}, \quad (14)$$

where (x, y) are the coordinates of the field point in space; k is the coefficient determined by the sphericity of space and the permeability of the medium, equal to

$$k = \frac{1}{4 \pi \varepsilon_o}, \quad (15)$$

Here ε_o - dielectric permeability vacuum.

2. Algorithm calculation fields V system "Mathcad".
 - 1) Enter V working window programs original data:
 - $\varepsilon_o = 8.85 \cdot 10^{-12}$;
 - $N = 4$.
 - 2) Enter formula (15) For calculation coefficient k .
 - 3) Enter the variable ORIGIN=1 to specify the number of the first element array (vector or matrix) equal to 1.
 - 4) Enter cycle numbers, asking vector (array) sources fields - $n=1...N$.
 - 5) Enter quantities charges q_1, q_2, q_3, q_4 How elements vectors, taking their values from table 1.1 with initial data.
 - 6) Enter coordinates charges $X_1, Y_1, X_2, Y_2, X_3, Y_3, X_4, Y_4$ as elements vectors, taking their values from Table 1.1 with the initial data.

7) Enter cycles $i=1...100$ And $j=1...100$, asking indices V matrix points in space at which the field potential is determined.

8) Enter the coordinates of the points in space (x , y) as matrix elements, in the form $x_i=0.01 \cdot i$ and $x_j=0.01 \cdot j$.

9) Enter formula (14) to calculate the field potential, transforming it to matrix form of the type:

$$\varphi_{i,j} = \sum_{n=1}^N \frac{k \cdot q_n}{\sqrt{(x_i - X_n)^2 + (y_j - Y_n)^2 + 0.001}} ,$$

Where magnitude 0.001 introduced V denominator formulas For elimination operations division by zero.

Example listing programs V system Mathcad given on rice. 4.

3. Debug file programs, having made sure What at calculation Not errors occur. Add the program listing to the report.

4. Plot a graph of the field potential distribution in 2D space in the form of equipotential lines (levels). To do this, click on the icons (pictograms) on the toolbar in sequence.  →  (or otherwise Insert → Schedule → Contour surface (Lines level)). IN opened template graphics V place input functions insert calculated potential matrix φ .

5. Construct a graph of the field potential distribution in 3-dimensional space. For this on panels tools sequentially press on icons (pictograms)  →  or  (or otherwise Insert → Schedule → Schedule surfaces or 3D graphics). IN opened template graphics V place input functions insert the calculated potential matrix φ .

```

ORIGIN := 1
~~~~~
N := 4
~~~~~

ε₀ := 8.85 · 10-12      k :=  $\frac{1}{4\pi \cdot \epsilon_0}$ 

n := 1..N

q₁ := 20 · 10-9      q₂ := 30 · 10-9      q₃ := -20 · 10-9      q₄ := -10 · 10-9

X₁ := 0.3      X₂ := 0.7      X₃ := 0.5      X₄ := 0.75
Y₁ := 0.3      Y₂ := 0.6      Y₃ := 0.5      Y₄ := 0.4

i := 1..100      j := 1..100

xᵢ := 0.01 · i      yⱼ := 0.01 · j

φi,j :=  $\sum_{n=1}^N \frac{k \cdot q_n}{\sqrt{(x_i - X_n)^2 + (y_j - Y_n)^2 + 0.001}}$ 

```

Rice. 4 - Listing programs modeling static physical field formed by a system of N independent sources, in scalar form

6. Conduct a study of the appearance of the spatial distribution of the field from the number of sources and their joint location. For this, changing meaning numbers sources N from 1 to 4 With taking into account their given coordinates, to build 3D potential distribution graphs space and in the form of equipotential lines. For ease of perception, 3-dimensional graphs are displayed V view color surfaces With wire frame, And at the need to rotate in space. Enter all obtained graphs into the report.

7. Draw conclusions based on the results of the work performed. In the conclusions, reflect how the field potential changes with distance, the number of sources, the magnitude of their charges, and their relative spatial arrangement.

Task 1.2. Model and investigate static in the Mathcad system physical field, educated system independent sources, in vector form.

1. The initial data for modeling is a physical field in a vacuum, which is created system from N independent sources, having quantities charges qn and coordinates (x_n, y_n) , $n = 1 - N$.

The task of modeling is to obtain the spatial distribution of the vector value of the field in the form of its intensity, determined by formula (16)

$$E_{x,y} = \frac{k \cdot qn \cdot R_x}{|R_{x,y}|^3} \quad (16)$$

Where $R_{x,y}$ - vector distances from source to points fields V space;

4.2.2. Algorithm calculation fields V system "Mathcad".

1) Enter V working window programs original data:

- imaginary unit $i = \sqrt{-1}$;
- $\epsilon_0 = 8.85 \cdot 10^{-12}$.

2) Enter formula (15) For calculation coefficient k .

3) Enter quantities charges $q1, q2, q3, q4$, taking their values from tables 1.1 With original data And multiplying their on 1000.

4) Enter the coordinates of charges $X1, Y1, X2, Y2, X3, Y3, X4, Y4$, taking their values from table 1 with the initial data and multiplying by 20.

5) Enter cycles $x=1...20$ And $y=1...20$, asking spatial coordinates of the field points at which the field strength is determined.

6) Set the distance vector fields for each field source using the complex variable function:

$$R_{nx, the} = Xn_x + i \cdot In_{the}, \quad n = 1 \dots N$$

7) Ask matrices tensions, created each source of the field by entering expression (1.16) into the program

8) Enter formula For calculation total fields tensions used

I'm zuyu principle superpositions, those. $ES = E1 + E2 + \dots + En$.

9) Enter function For calculation standardized fields tensions

$$E_{x,y} = \frac{ES_{x,y}}{|ES_{x,y}|}$$

Example listing programs V system Mathcad given on rice. 5.

3. Debug file programs, having made sure What at calculation Not errors occur. Add the program listing to the report.

4. Build schedule distribution vectors tension fields V vector-nom presentation.

For this on panels tools sequentially click on icons (pictograms)  →  (or otherwise Insert → Schedule → Vector field). IN opened template graphics V place input functions insert calculated matrix of intensity vectors **E**.

6. Conduct a study of the appearance of the vector field distribution depending on the number of sources and their joint location. To do this, change the number terms V formula total fields $ES = E1 + E2 + \dots + En$ from 1 to 4 With taking into account

their given coordinates and values of the charges of the field sources, construct graphs of vector surfaces tensions fields. Bring in V report All obtained graphs.

7. Draw conclusions based on the results of the work done. Reflect in the conclusions, How changes vector tension from distances, from quantities sources, the magnitude of their charges and their mutual spatial arrangement.

$$\begin{aligned}
 i &:= \sqrt{-1} \\
 \epsilon_0 &:= 8.85 \cdot 10^{-12} & k &:= \frac{1}{4\pi \cdot \epsilon_0} \\
 q1 &:= 10 \cdot 10^{-6} & q2 &:= -7 \cdot 10^{-6} & q3 &:= 8 \cdot 10^{-6} & q4 &:= -10 \cdot 10^{-6} \\
 x1 &:= 9 & y1 &:= 6 & x2 &:= 13 & y2 &:= 14 & x3 &:= 15 & y3 &:= 8 & x4 &:= 3 & y4 &:= 5 \\
 x &:= 0..20 & y &:= 0..20 \\
 X1_x &:= x - x1 & Y1_y &:= y - y1 & X2_x &:= x - x2 & Y2_y &:= y - y2 \\
 X3_x &:= x - x3 & Y3_y &:= y - y3 & X4_x &:= x - x4 & Y4_y &:= y - y4 \\
 R1_{x,y} &:= X1_x + i \cdot Y1_y & R2_{x,y} &:= X2_x + i \cdot Y2_y \\
 R3_{x,y} &:= X3_x + i \cdot Y3_y & R4_{x,y} &:= X4_x + i \cdot Y4_y \\
 E1_{x,y} &:= k \cdot \frac{q1 \cdot R1_{x,y}}{(|R1_{x,y}|)^3} & E2_{x,y} &:= k \cdot \frac{q2 \cdot R2_{x,y}}{(|R2_{x,y}|)^3} \\
 E3_{x,y} &:= k \cdot \frac{q3 \cdot R3_{x,y}}{(|R3_{x,y}|)^3} & E4_{x,y} &:= k \cdot \frac{q4 \cdot R4_{x,y}}{(|R4_{x,y}|)^3} \\
 ES &:= E1 + E2 + E3 + E4 & E_{x,y} &:= \frac{ES_{x,y}}{|ES_{x,y}|}
 \end{aligned}$$

Rice. 5 - Listing programs modeling static physical field formed by a system of 4 independent sources, in vector form

Exercise 1.3. Simulate V system Mathcad scalar physical field and transform it into a gradient vector field.

1. Construct a graphical representation of a scalar field in the Mathcad system, described function $f(x,y)$, given V table 1.1 original data according to the specified option. To do this, perform the following steps:

- enter V working window programs given function $f(x,y)$;
- build three-dimensional surface fields, opening sample 3D graphics And by introducing the function f there ;
- construct a graph of equipotential lines (levels) of the field by opening the contour surface graph template and entering the function f there .

2. Algorithm transformations fields.

1) Enter the formula for calculating the field gradient in vector form in the program's working window:

$$\text{grad}(x, y) = \begin{pmatrix} \frac{d}{dx} f(x, y) \\ \frac{d}{dy} f(x, y) \end{pmatrix}.$$

2) Calculate analytically gradient fields, by entering function $\text{grad}(x, y) \rightarrow$. Results calculations bring in V report.

3) Introduce cycles $i=1...10$ and $j=1...10$ that define indices in the matrix of points spaces in which the field gradient is defined.

4) Define matrix vector fields, by entering expression For her element-

co
mra
de

$$V_{i,j} = \text{grad}(i-5, j-5).$$

5) Calculate projections century (torus) gradient
 $X_{i,j} = V_{i,j} \begin{pmatrix} 0 \\ \text{Yes} \end{pmatrix}, j = V_{i,j} \begin{pmatrix} 1 \end{pmatrix}$

Example listing programs V system Mathcad given on rice. 6.

$$f(x,y) := x^3 - x^2 \cdot y^2 - y^1$$

$$\text{grad}(x,y) := \begin{pmatrix} \frac{d}{dx} f(x,y) \\ \frac{d}{dy} f(x,y) \end{pmatrix} \quad \text{grad}(x,y) \rightarrow \begin{pmatrix} 3 \cdot x^2 - 2 \cdot x \cdot y^2 \\ -2 \cdot y \cdot x^2 - 1 \end{pmatrix}$$

$$i := 0..10 \quad j := 0..10$$

$$V_{i,j} := \text{grad}(i-5, j-5)$$

$$X_{i,j} := (V_{i,j})_0$$

$$Y_{i,j} := (V_{i,j})_1$$

Rice. 1.6 - Listing programs transformations scalar physical fields into the gradient vector field

3. Plot a vector gradient field graph. To do this, click on the icons (pictograms) on the toolbar in sequence.  →  (or else Insert □ Graph □ Vector Field). In the graph template that opens, insert the calculated projections in the function entry area. vector in the form (X, Y) . Add the resulting vector field graph to the report.

4. Conduct study dependencies vector fields from original scalar field. To do this, successively replace the power of the variable x in one of the terms of the function $f(x, y)$, **and the power of the variable y** in the other term. For the changed values of the function, calculate the gradient of the field and plot the graphs of the vector field.

5. Do conclusions By results, done work.

2. MODELING AND RESEARCH OF THE CHARACTERISTICS OF SCALAR PHYSICAL FIELDS

Content practical work, performed students on the second academic question

1. Description laboratory equipment:

- PC With established system computer algebra "Mathcad- 14".

2. Initial data For modeling And research

Table 1.1 - Options tasks For modeling And research

3. Exercise For work

Basic level:

1) Model a vector physical field in the Mathcad system and transform it into a scalar divergence field.

2) Model a vector physical field in the Mathcad system and transform it into a rotor vector field.

Increased level:

3) On one's own simulate V system Mathcad scalar physical field and transform it into a scalar Laplacian field.

Task 2.1. Model a vector physical field in the Mathcad system and transform it into a scalar divergence field.

1. To model a vector field, use the program developed in the previous task 1.3.

2. To transform the resulting gradient vector field into a scalar divergence field, it is necessary to make a change to the algorithm of the previous program. To do this, perform the following operations:

1) Finish writing V working window programs, compiled For execution task 1.3, the formula for calculating the divergence of a vector field:

$$\text{div}(x, y) = \frac{d}{dx} \text{grad}(x, y) + \frac{d}{dy} \text{grad}(x, y)$$

2) Calculate analytically divergence vector fields, by entering function $\text{div}(x, y) \rightarrow$. Results calculations bring in V report.

3) Define matrix scalar fields divergences, by entering expression for its elements

$$D_{i,j} = \text{div}(i - 5, j - 5)$$

3. Plot a 3-D graph of the scalar divergence field. To do this, click the icons (pictograms) on the toolbar in sequence. 

→  or  (or otherwise Insert → Schedule → 3D graphics And schedule surface). In opened template graphics V place input functions insert calculated field matrix in the form D . Add the resulting scalar field graph to the report.

4. Build schedule equipotential lines scalar fields divergence. For this on panels tools sequentially press on badges (pictograms)  →  (or otherwise Insert → Schedule → Lines level). IN opened template graphics V place input functions insert calculated field matrix in the form D . Add the resulting scalar field graph to the report.

5. Conduct a study of the dependence of the obtained scalar divergence field from original scalar fields, asked function $f(x, y)$. For to consistently increase the degree of the variable in one of the terms of the function $f(x, y)$ x , A V friend term - degree variable y . For changed meanings functions calculate divergence vector fields And build graphs scalar divergence field.

6. Do conclusions By results, done work.

Task 2.2. Model a vector physical field in the Mathcad system and transform it into a vector field of a rotor.

1. To model a vector field, use the program created to complete task 1.3.

2. To transform the obtained gradient vector field into a vector field rotor necessary supplement V algorithm previous programs. To do this, perform the following operations:

1) Finish writing V working window programs, compiled For execution task 1.3, the formula for calculating the rotor of a vector field:

$$\text{rot}(x, y) = \begin{vmatrix} \frac{d}{dx} & \text{grad}(x, y) \\ \frac{d}{dy} & \text{grad}(x, y) \end{vmatrix}$$

2) Calculate analytically rotor vector fields, by entering function $\text{rot}(x, y) \rightarrow$. Calculation results bring in V report.

3) Determine the matrix of the rotor vector field by introducing an expression for its elements

$$R_{i,j} = \text{rot}(i-5, j-5)$$

Calculate projections century (torus) rotor

$$4) \quad XR_{i,j} = R_{i,j} \begin{pmatrix} 0 \\ YR \end{pmatrix}, j \quad R_{i,j} \begin{pmatrix} 0 \\ Y \end{pmatrix}$$

3. Plot a 3D graph of the rotor's vector field points. To do this, click the icons (pictograms) on the toolbar in sequence. 

→  (or Insert □ Graph □ 3D Graph). In the graph template that opens, insert the calculated field matrix in the form (XR , YR) in the function entry space. Add the resulting graph of vector field points to the report.

4. Build schedule vector fields rotor. For this on panels tools, click on the icons (pictograms) in sequence  →  (or otherwise Insert → Schedule → Vector field). IN opened template graphics V Insert the calculated field matrix in the form (XR , YR) into the function input field. Add the resulting vector field graph to the report.

5. Conduct a study of the dependence of the obtained rotor vector field on the original scalar field given by the function $f(x,y)$. For this purpose, sequentially increase V one from terms functions $f(x,y)$ degree variable x , and in the other term, the power of the variable y . For the changed values of the function, calculate the curl of the vector field and plot the graphs of the curl vector field.

6. Do conclusions By results, done work.

5. Prepare a report on the work completed on the first question in accordance with the requirements set out in the job description .

IN report bring:

- original data,
- performed tasks,
- compiled listings programs modeling,
- results modeling and research - calculated formulas describing the fields, obtained graphs;
- conclusions O done work.

6. Protection practical work

For protection practical introduce fully decorated report, free of significant errors. As instructed by the teacher, complete one of the tasks from each academic question, explaining everything physical phenomena And processes, happening V simulated physical field and equivalent circuit of the wave process.

LIST LITERATURE:

1) Sagdeev K.M. Physical foundations of information security [Electronic resource]: study guide / K.M. Sagdeev, V.I. Petrenko, A.F. Chipiga. - Electronic text data. - Stavropol: North Caucasus Federal University, 2015. - 394 p.

2) Evstifeev V.V. Physical foundations electricity and magnetism Electronic resource / Evstifeev V.V.: study guide. - Penza: PSU, 2019. - 416 p.

3) Bulatov V.N. Physical foundations of electronics Electronic resource / Bulatov V.N.: lecture notes for students in educational programs higher education in the following areas preparation 11.03.02 infocommunication technologies and communication systems. - Orenburg: OSU, 2018. - 178 p.

4) Goldstein A.E. Physical principles of obtaining information [Electronic resource]: textbook / A.E. Goldstein. — Electron. text data. — Tomsk: Tomsk Polytechnic University, 2010. — 292 p.

PRACTICAL JOB No. 4

TOPIC 4

WAVE PROCESSES

Class 4

MODELING AND STUDY PROPERTIES AND CHARACTERISTICS WAVE PROCESSES.

TIME – 4 hours.

Educational questions:

1. Modeling And study properties And characteristics wave processes.

TARGET PRACTICAL INSTALLATION WORKS:

Competencies, being formed discipline

OPK-1: Capable use provisions, laws And methods natural sciences and mathematics to solve engineering problems.

OPK-2: Capable on one's own conduct experimental research And use main techniques processing And performances received data.

Learning outcomes achieved as a result of completing practical work:

Be able to:

- apply physical laws and methods to formalize the representation of physical phenomena and processes that occur in telecommunications .

- conduct experimental research With help mathematical models according to the accepted methodology

- model And analyze main physical phenomena And processes in telecommunications using computer technology.

Own:

- skills use knowledge physicists at decision practical problems of engineering activities

- methods of processing and presenting data obtained as a result of experimental studies.

- skills in computer modeling of the main physical methods of receiving, transmitting and storing information.

EDUCATIONAL AND MATERIAL SECURITY:

- PC With simulator electronic schemes Electronics Workbench - 5.12" And system computer mathematicians Mathcad - 15";
- electronic methodological development By practical work.

STRUCTURE PRACTICAL WORKS:

Class No. 1		90 min
Introductory Part		10 min
Examination readiness students To practical work		8 min
Introductory Part		2 min
Questions (tasks), subject research:		75 min
1. Modeling And study properties And characteristics wave-out processes.		75 min
Final Part		5 min
Summing up results		3 min
Exercise students For independent work		2 min
Class No. 2		90 min
Introductory Part		10 min
Examination readiness students To practical work		8 min
Introductory Part		2 min
Questions (tasks), subject research:		50 min
1. Modeling And study properties And characteristics wave-out processes.		50 min
Final Part		30 min
Protection reports By practical work		25 min
Summing up results		3 min
Exercise students For independent work		2 min

QUESTIONS, SUBJECTS RESEARCH

1. MODELING AND RESEARCH OF THE PROPERTIES AND CHARACTERISTICS OF WAVE PROCESSES

Brief theoretical or reference and information materials

A *wave* is any excitation (change) of a medium that propagates in space and time, or otherwise in phase space, with energy transfer and without mass transfer. In other words, waves or a wave are called changing with time spatial alternation highs And minimums any physical quantities - For example, density substances, electric field strength, temperature.

Due to this The wave process can have a wide variety of physical natures: mechanical, electromagnetic, gravitational, etc.

A *harmonic wave* is a wave that changes in time in a harmonic manner. law. In a different way This spreading monochromatic oscillation or oscillation of one frequency.

A harmonically changing wave $A(t)$, propagating, for example, in the direction of the x -axis, can be mathematically described in the following form:

$$A(t) = A_o \sin(\omega t - kh + \varphi), \quad (1)$$

Where A_0 - amplitude or maximum deviation fluctuations relatively equal newweight states; $\omega = 2\pi \cdot f$ - circular frequency fluctuations; expression, one hundred the most important V brackets, it's called phase fluctuations And defines instant state of oscillation, i.e. at a given moment in time; φ – a constant called the initial phase fluctuations, her meaning usually is determined source oscillations .

Wave plastic bag - certain totality harmonic waves, possessing different frequencies, which describe possessing wave properties of a formation, generally limited in time and space. In another way under wave package or in a train waves understood row disturbances, between which there are some breaks.

Characteristics wave processes are:

1) **Geometric parameters** :

- wave crest – a set of points on a wave with maximum positive deviation from the equilibrium state;
- wave valley (trough) – a set of points on a wave with the greatest negative deviation from the state of equilibrium;
- A wave surface is a set of points that have the same oscillation phase at a given moment in time. Depending on the shape of the wave front, waves are classified as plane, spherical, elliptical, and other types.

For standing waves, the concept of an antinode (maximum oscillation amplitude) and a node (minimum oscillation amplitude) is used.

2) **Temporary And spatial periodicity** :

- period fluctuations (T , With) - time, for which is being carried out full oscillation cycle. Period fluctuations - There is magnitude reverse frequency waves (f , Hz), i.e. the rate of change of phase over time at some given point;
- length waves (λ , m) - the smallest distance between two maxima or minima of disturbance in space. Otherwise, it is the rate of phase change (lag process in time) V definite moment time With by changing the coordinate.

Temporal and spatial periodicities are interconnected by a parameter called **the phase velocity of wave propagation** (V , m/s) in the medium:

$$V = \frac{\omega}{k} = \frac{2\pi \cdot f}{2\pi/\lambda} = f \cdot \lambda = \frac{\lambda}{T}, \quad (2)$$

where ω – circular (cyclic) frequency of oscillation (rad/s); k – wave number (1/m), showing number length waves, stacked on distance 2π V meters. Phase velocity is a purely abstract mathematical concept showing speed movements any phase points waves, this speed is not associated with the movement of anything material in space.

3) **Intensity wave process** , which characterized by parametramie:

- amplitude wave process (A_0 , m) or maximum deviation ko-swings relatively equilibrium states;

– energy density of the wave W , for a harmonic wave this parameter is also a harmonic wave function equal to

$$W = \beta \cdot A_o^2 \sin^2(\omega t - kh), \quad (3)$$

where β is a proportionality coefficient depending on the properties of the medium and the type of wave;

– the energy flow of a wave process is the ratio of the wave energy dW **transmitted through an area dS** transverse to the beam in a small period of time dt to this period of time; the energy flow is equal to

$$dW = W(x,t) \cdot dS \cdot dt = W \cdot dS \cdot V \cdot dt, \quad (4)$$

the meaning of this formula is that it is this energy that fills the space during time dt cylinder section dS , length $l = Vdt$ where for time dt V case the same energy leaves the harmonic wave.

– energy flux density I (W/m^2) is the ratio of the energy flux through a transverse surface to its area, it is equal to

$$I = \int \frac{dW}{dS} dt = W \cdot V \quad (5)$$

In a lossy environment, a propagating wave gives up part of its energy substance Wednesday, at this **amplitude fields decreases** (weakening). This can be taken into account by introducing a dependency

$$A(X) = A_o(x) \cdot \exp^{-\alpha \cdot X}, \quad (6)$$

Where α - coefficient attenuation, m^{-1} .

Based on on in principle superpositions (fair V So called linear environments), any inharmonic wave Can replace equivalent system of sinusoidal waves, called **a wave packet** (otherwise - a wave group). Totality values frequencies harmonic waves, components plastic bag, they call spectrum. Spectrum Maybe be solid, discrete and mixed. For example, the spectrum of electromagnetic radiation of hot bodies (thermal radiation spectrum) is continuous. A discrete spectrum is observed V radiation many gas discharges. Example mixed spectrum gives radiation of stars.

If V some homogeneous And isotropic environment two point the source excites spherical waves,

IN arbitrary point spaces, representing by yourself homogeneous and isotropic Wednesday, Maybe happen overlay waves V in accordance With The principle of superposition (overlapping). **The phenomenon** that leads to a mutual increase or decrease in the resulting amplitude of two or more coherent waves when they are superimposed on each other **is called wave interference**. Interference is accompanied by alternating maxima (antinodes) and minima (nodes) of intensity in space. The result of interference (interference pattern) depends on the phase difference of the superimposed waves.

Let us consider two simultaneously propagating sinusoidal waves S_1 and S_2 , created by point sources B_1 and B_2 , at the point of overlap:

$$\begin{aligned} \text{With } S_1 &= A_1 \sin(\omega_1 t - k_1 x + \varphi_1) = A_1 \sin \Phi_1, \\ S_2 &= A_2 \sin(\omega_2 t - k_2 x + \varphi_2) = A_2 \sin \Phi_2 \end{aligned} \quad (7)$$

Where $\Phi_1 = \omega_1 t - k_1 x + \varphi_1$ And $\Phi_2 = \omega_2 t - k_2 x + \varphi_2$ — phases spreading waves; k_1 And k_2 - wave numbers, ω_1 And ω_2 - cyclical frequencies each waves; φ_1 And φ_2 - initial phases.

These waves will cause an oscillation at the point of superposition, which, according to the principle of superposition, is described formula $S = S_1 + S_2$. According to formula spherical wave:

IN resulting the wave is $S = S_1 + S_2 = A \sin \Phi$ amplitude A And phase Φ determined by the formulas:

$$\begin{aligned} A &= \sqrt{A_1^2 + A_2^2 + 2A_1A_2 \cos(\Phi_2 - \Phi_1)}, \\ \Phi &= \arctg \left(\frac{A_1 \sin \Phi_1 + A_2 \sin \Phi_2}{A_1 \cos \Phi_1 + A_2 \cos \Phi_2} \right) \end{aligned} \quad (8)$$

The simplest wave package is So called quasi-harmonic wave (otherwise - *wave zug*), resulting How result overlays two harmonic waves with identical amplitudes A and propagating along the same beam, but having slightly different frequencies. Using the product representation of the sum of sines, the wave function of the train can be easily represented as:

$$\Psi = 2A \cos \left(\frac{\Delta \omega \cdot t - \Delta k \cdot x}{2} \right) \sin(\omega \cdot t - kx) \quad (9)$$

Where through $\Delta \omega$ designated difference frequencies harmonic waves, A through ω their arithmetic mean frequency. The value of $B(t, x)$ changes slowly in time and space, i.e.

$$B(t, x) = 2A \cos \left(\frac{\Delta \omega \cdot t - \Delta k \cdot x}{2} \right) \quad (10)$$

This function (10) is called the envelope of the train. It is also like a running harmonic wave, modulating By amplitude running sine wave frequencies ω . Her length waves $\Delta \lambda = 2\pi / \Delta k$ much more lengths waves sinusoids With often that one ω , A *speed distribution*, called *group speed*, equal

$$u = \frac{\Delta \omega}{\Delta k} = \frac{\Delta f}{\Delta \lambda} \quad (11)$$

It has been established, what exactly is **group speed is the speed re-nose energy Tsuga** . She V in general case is different from phase speed $V = \omega / k$

So, the group velocity is associated with the movement of disturbances in space fixed amplitudes; because energy waves connected With her amplitude, the group velocity is the speed of propagation of energy in space .

Wednesday it's called dispersing , If V her waves different lengths are spreading With different speed. Addition phase speed waves from lengths waves (or, What That same the most, from $= F(\lambda) = F(\omega)$, called frequencies), i.e. V **etsya dispersion** .

For a dispersive medium, the relationship between group and phase velocities can be easily obtained by taking into account the dependence of frequency and wave number on wavelength:

$$u = V - \lambda \frac{\Delta V}{\Delta \lambda} \quad (12)$$

This formula (12) has Name formula Rayleigh.

At $\Delta V / \Delta \lambda = 0$ dispersion absent. IN this case group speed will coincide With phase speed, And equal speed Sveta **WITH** , therefore, in non-dispersing environments components complex waves will be move with the same speed, And herself complex wave Not will change his own forms (will not "blur").

At $\Delta V / \Delta \lambda > 0$ will be carried out condition $V < u$. At these conditions By-the refractive index of the medium decreases with increasing frequency, since the partial derivative of the phase velocity and the partial derivative of the refractive index n with respect to wavelength are related by the relation

$$\frac{\partial V}{\partial \lambda} \quad \text{WITH} \quad \frac{\partial n}{n^2 \partial \lambda} \quad (13)$$

This dependence is called normal dispersion . It manifests itself when light passes through glass and other transparent media. In this case, the maxima of the waves in the wave packet move faster than the envelope. As a result, new maxima arise at the tail of the packet due to the addition of waves, which move forward and disappear at the head.

At $\Delta V / \Delta \lambda < 0$ And $V > u$, indicator refraction is increasing. This depend- The dispersion characteristic of the anomalous dispersion appears in the spectral regions where intense absorption is observed. In this case, the wave maxima appear V head parts of the package, are moving back And disappear V his tail. At abnormal dispersion "If indicator refraction strongly change- etsya With frequency ($\partial n / \partial \lambda$ enough great), That Maybe turn out to be, What group speed V , formally calculated By existing formula Rayleigh, will

greater than the speed of light in a vacuum, which contradicts the special theory of relativity.” This feature manifests itself when ultra-short radio waves pass through the ionosphere.

In everyone cases non-zero dispersion wave plastic bag with time blurs.

Content practical work, performed students on the second academic question

1. Description laboratory equipment:

– PC With simulator electronic schemes Electronics Workbench - 5.12" and the computer mathematics system "MathCAD - 14".

2. Initial data For modeling And research

Table 1 - Options original data For research

<i>Option No.</i>	<i>R, kOhm</i>	<i>WITH, μF</i>	<i>φ about , city</i>	<i>K1</i>	<i>K2</i>	<i>f_{zad} , <i>MHz</i></i>	<i>$\Delta\phi$, kHz</i>
1	1.1	9.5	10	1.0	0.55	2.0	100
2	1.2	9.0	20	0.95	0.6	2.1	200
3	1.3	8.5	30	0.9	0,65	2,2	300
4	1,4	8,0	40	0,85	0,7	2,3	400
5	1,5	7,5	50	0,8	0,75	2,4	500
6	1,6	7,0	60	0,75	0,8	2,5	400
7	1,7	6,5	70	0,7	0,85	2,6	300
8	1,8	6,0	80	0,65	0,9	2,7	200
9	1,9	5,5	75	0,6	0,95	2,8	100
10	2,0	5,0	65	0,55	1,0	2,9	150
11	1,9	10	55	1	0,55	3,0	250
12	1,8	10,5	45	0,95	0,6	3,1	350
13	1,7	11,0	35	0,9	0,65	3,2	450
14	1,6	11,5	25	0,85	0,7	3,3	100
15	1,5	12,0	15	0,8	0,75	3,4	200
16	1,4	12,5	5	0,75	0,8	3,5	300
17	1,3	13,0	85	0,7	0,85	3,6	400
18	1,2	13,5	90	0,65	0,9	3,7	500
19	1,1	14,0	100	0,6	0,95	3,8	400
20	1,0	14,5	110	0,55	1,0	3,9	300
21	0,9	15,0	120	1	0,8	4,0	200
22	0,8	15,5	130	0,95	0,85	4,1	100
23	0,7	16,0	140	0,9	0,9	4,2	150
24	0,6	16,5	150	0,85	0,95	4,3	250
25	0.5	17.0	160	0.8	1.0	4.4	350

3. Exercise For work

Basic level:

1) Simulate V programs Electronics Workbench» And MathCAD harmonic wave And measure her characteristics.

2) Simulate V programs Electronics Workbench» And MathCAD

fading harmonic wave process And research his characteristics .

3) Simulate And research V programs Electronics Workbench» And MathCAD phenomenon interference two waves.

4) Simulate V program Electronics Workbench» wave plastic bag and determine its characteristics.

Increased level:

5) Simulate And research V program Electronics Workbench» process dispersion waves.

6) Simulate And research V program Electronics Workbench» running and standing waves in a long line.

4. Order execution work

Exercise 1.1. Simulate V programs Electronics Workbench» And MathCAD harmonic wave And measure her characteristics.

1) For circuit design modeling harmonic waves collect in the program "Electronics Workbench" the simplest circuit containing a harmonic source (sinusoidal) voltage And oscilloscope, speaker as a measuring instrument. In order to simulate in the program

“Electronics Workbench” spatial distribution of the wave we make the assumption that the phase velocity of wave propagation is 1000 m/s. With this assumption measured With help oscilloscope period fluctuations, equal 1 ms will correspond to a wavelength of 1 m.

2) Set the source to a harmonic (sinusoidal) voltage of 1 V and a frequency of

$$f = 1000 + N_{var} \cdot 100, \text{ Hz},$$

Where N_{var} . - number options according to number list V magazine.

3) Measure the oscillation period using an oscilloscope. Calculate the wavelength λ taking into account that the phase velocity V of wave propagation is equal to 1000 m/s. The results of the calculations and measurements are to be included in the practical work report.

4) of A_o using an oscilloscope wave process. Record the measurement results in the practical work report.

5) Perform mathematical modeling of the undamped wave process in the MathCAD program, using the following expressions:

$$A(x) = A_o \sin(\omega t) = A_o \sin\left(\frac{\omega}{V} x\right) = A_o \sin\left(\frac{2\pi}{\lambda} x\right),$$

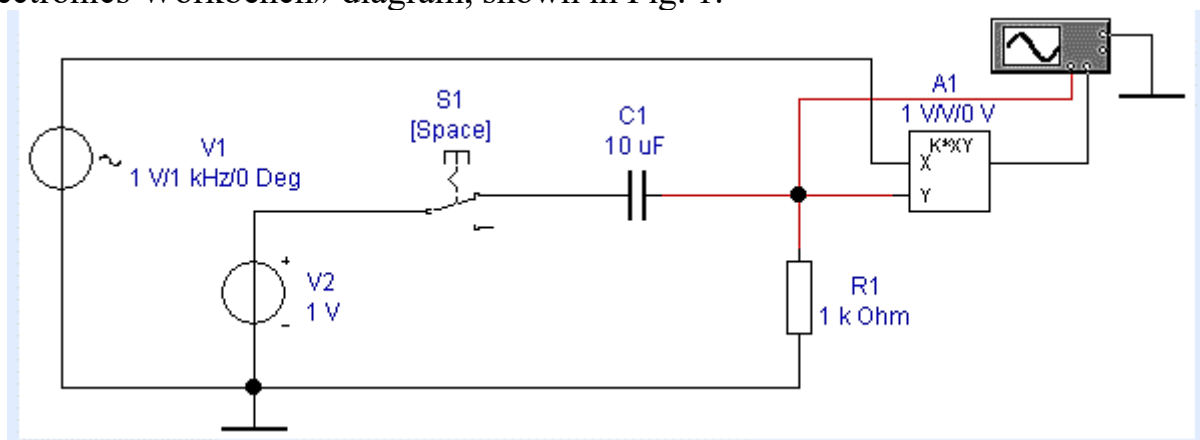
$$W(x) = \beta^2 A_o^2 \sin^2\left(\frac{2\pi}{\lambda} x\right).$$

6) In the computer mathematics system “MathCAD” perform the following operations:

- calculate the maximum energy density of the wave W , provided that the proportionality coefficient β , depending on the properties of the medium and the type of wave, is equal to 0.5;
 - build graphs wave harmonic process **Oh**) And distribution of the wave energy density $W(x)$ from the coordinate (distance) x ;
 - received graphs and calculation results should be included in the laboratory work report.
- 7) Do conclusions about under study wave process.

Exercise 1.2. Simulate V programs Electronics Workbench» And MathCAD fading harmonic wave process And research its characteristics.

1) For circuit simulation of damped harmonic wave process collect V program Electronics Workbench» diagram, shown in Fig. 1.



Rice. 1 - Scheme modeling fading harmonic wave process

This simulation is based on the circuit implementation of expression (6). The circuit in Fig. 1 contains:

- a sinusoidal voltage source $V2$ that creates a continuous harmonic wave,
- source permanent current $V1$ And RC circuit, modeling wave attenuation factor in the propagation medium;
- analog multiplier $A2$.

IN RC circuits, pluggable To source permanent current $V1$, arises a transient process that simulates the wave propagation medium, leading to its attenuation according to the exponential law. Multiplier $A2$ ensures the multiplication of the undamped wave process by the wave attenuation factor caused by its attenuation in the propagation medium.

2) Change parameters RC circuits, taking their values from tables 2.1 according to your option. Set the frequency in source $V1$ equal to

$$f = 1000 + N_{var} \cdot 100 \text{ Hz},$$

Where N_{var} . **No.** - number options according to number list V magazine.

3) Launch simulator EWB So, to key **SI** was open. Close the key **SI** , seeing on screen oscilloscope fading wave process, Stop the EWB simulator. Add an oscillogram of the decaying wave process to the practical work report.

4) Define With help oscilloscope By crooked attenuation (By first channel) distances x at which the wave attenuates by a factor of e and 10.

5) Conduct mathematical modeling of the decaying wave process in the MathCAD program, using the formula:

$$A(x) = A_0 \sin\left(\frac{2\pi}{\lambda} x\right) \cdot \exp^{-\frac{x}{VRC}}.$$

6) In the computer mathematics system “MathCAD” perform the following operations:

- build schedule dependencies amplitudes fading waves **Oh**) from the coordinate (distance) x ;
- construct a graph of the dependence of the attenuation multiplier on the coordinate (distance) x ;
- display V report By practical work received graphics;
- calculate and enter into the report the attenuation coefficient of the medium α using the ratio

$$\exp_X^{-\alpha \cdot} = \exp^{-\frac{x}{V \cdot R} \cdot C}.$$

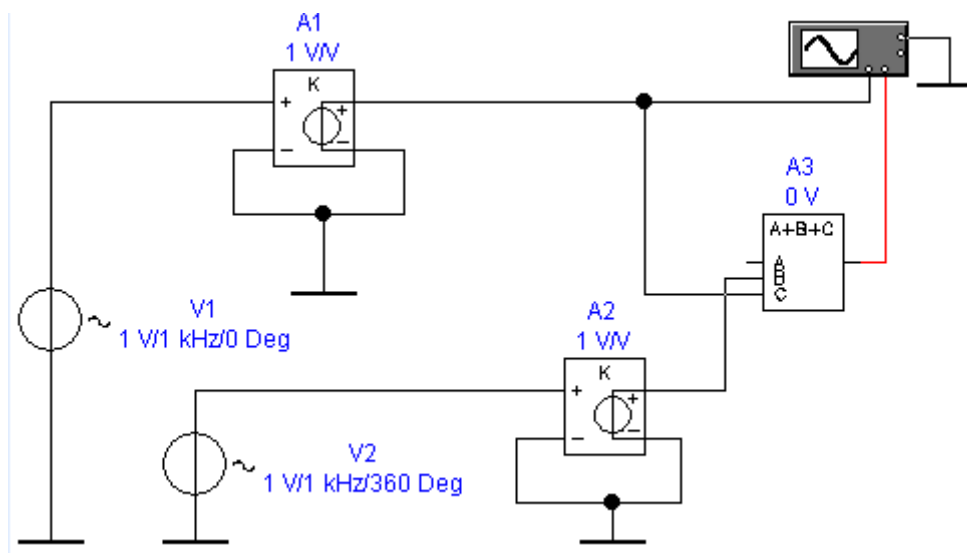
- define By graphics distances X , on which wave fades away $V e$ And 10 times, enter the results into the report.

7) Do conclusions about under study wave process.

Task 1.3. Model and investigate the phenomenon of interference of two waves in the programs “Electronics Workbench” and “MathCAD”.

1) 2 in the Electronics Workbench program.

The circuit contains two sources **V1** and **V2** , generating coherent waves of the same frequency, those. waves which phase difference not depends on time. The process attenuation amplitudes waves V environment distribution achieved for inclusion account V diagram scaling links **A1** And **A2** , analog adder **A3** forms a sum wave at the point of their superposition.



Rice. 2 - Scheme modeling phenomena interference two waves

2) Install given parameters schemes, taking their values from tables 1.1 according to to his own option. Frequency fluctuations remains former, How V previous tasks. The given initial phase φ_o set in source *V1* , and in source *V2* – $360 + \varphi_o$. Set the specified medium transfer coefficient ***K1*** in the **scaling link A1** , and the coefficient ***K2*** – in link **A2** .

3) Run the EWB simulator and obtain on the oscilloscope screen on the first channel the original wave oscillation and the resulting wave obtained as a result of the interference of two waves. Determine the amplitude of the resulting wave. Bring in V report By practical work received wave processes and results of calculations.

4) phase values in source *V2* **equal to** $450 + \varphi_o$, $540 + \varphi_o$, $630 + \varphi_o$, $720 + \varphi_o$, get With help oscilloscope graphs resulting waves, determining the oscillation amplitude. Record the results in the practical work report and conduct a comparative analysis.

5) Conduct mathematical modeling of the wave in the MathCAD program, received V result additions two coherent waves, using the formulas for this:

$$A1(x, \varphi) = A_o \sin\left(\frac{2\pi \cdot f}{V} x + \varphi\right),$$

$$A2(x, \varphi) = A_o \sin\left(\frac{2\pi \cdot f}{V} x + \varphi\right),$$

$$A(x, \varphi) = A1(x, \varphi) + A2(x, \varphi).$$

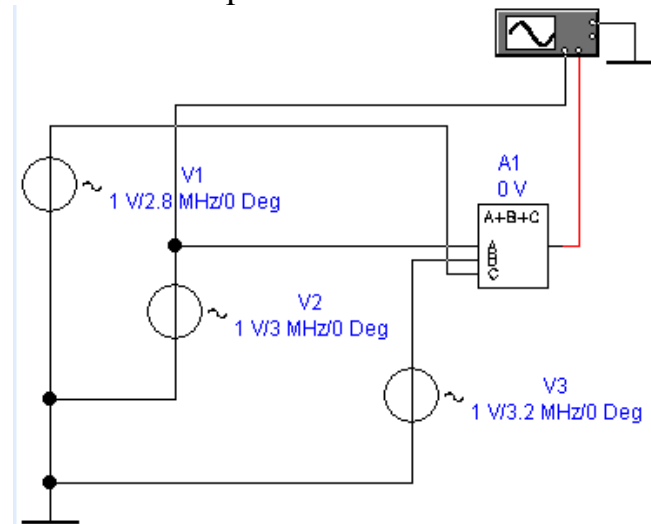
6) In the computer mathematics system “MathCAD” perform the following operations:

- construct a 3-dimensional graph of the interference pattern, setting the cycle of change of coordinate (distance) x from 0 to 4 with a step of 0.05; and the cycle of change of phase difference φ from 0 to 4π in increments of $\pi/36$;
- display a 3-dimensional interference pattern graph in the practical work report.

7) Do conclusions By results done work.

Task 1.4. Simulate a wave packet in the Electronics Workbench program and determine its characteristics.

1) For circuit design modeling wave package collect V program Electronics Workbench» diagram, given on rice. 2.3. Scheme contains three source *V1*, *V2* And *V3* , generating coherent radio waves on slightly different frequencies, as well as an analog adder *A1* that forms a wave packet.



Rice. 3 - Scheme modeling wave package

This scheme allows simulate wave plastic bag radio waves, propagating in the medium at a speed of $300 \cdot 10^6$ m/s. In this case, at a source frequency radiation, equal 3 MHz, period fluctuations 333.3 ns, measured V oscilloscope, will correspond to a wavelength of 100 m.

2) Install given parameters schemes, taking their values from tables 2.1 according to to his own option. At this V source *V2* - install given cha-

hundred
sources *V1* And *V3* - accordingly
 $f_3 = f_{ass} + \Delta f/2$.

$$f_2 = f_{back}, A V$$

$$f_1 = f_{back} - \Delta f/2 \text{ And}$$

3) Run the EWB simulator and get the second signal on the oscilloscope screen. channel wave plastic bag. Define With help oscilloscope amplitude and duration wave package, length his waves. Compare length waves package with long waves, created source *V2* . Bring in V report By In practical work, the obtained wave packet and measurement results.

4) Calculate the group velocity of the wave packet using expression (2.11) and include the calculation results in the report.

5) Disconnect source *V2* from analog adder *A1* , And again complete the tasks specified in points 3 and 4.

6) Do conclusions By results done work.

Exercise 1.5. Simulate And research V program "Electronics Workbench" wave dispersion process.

1) For circuit simulation of the wave dispersion process, assemble the circuit shown in Fig. 4 in the Electronics Workbench program.

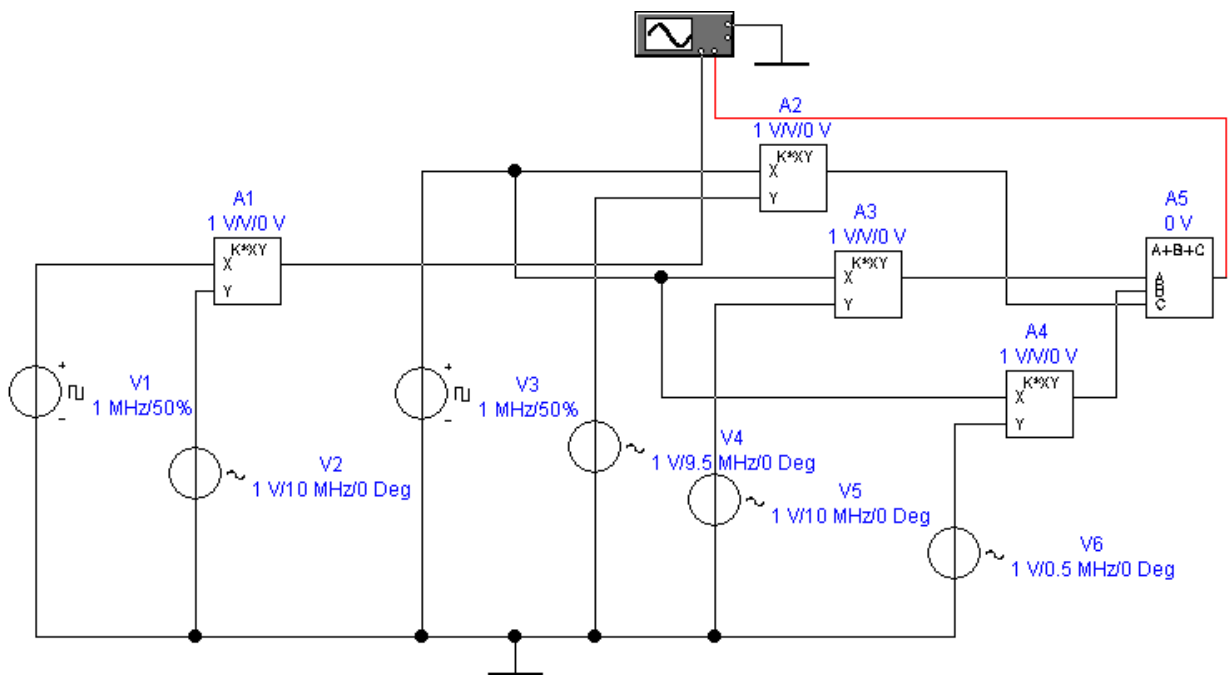


Fig. 4 - Scheme modeling process dispersion waves

IN this scheme With help generator rectangular impulses *V1* , a harmonic wave source *V2* and an analog multiplier *A1* simulated a sequence of radio pulses propagating in a conventional non-dispersive environment. Modeling dispersing Wednesday is produced With using sources *V4 – V6* , analog multipliers *A2 – A4* and analog adder *A5* . This model simulates an environment in which the carrier frequency of the radio pulse *V* different points spaces changes, forming some beams of radio pulses, which, when added together at the receiving point, lead to distortion of the shape of the original radio pulse.

Launch simulator EWB And make sure V correctness work schemes.

2) Install given parameters schemes, taking their values from tables 2.1 according to to his own option. At this V sources *V2* And *V5* - install frequency $f = 10 \cdot f_{back}$, A V sources *V4* And *V6* accordingly $f = 10 \cdot f_{back} - 2\Delta f$ And $f = 10 \cdot f_{ass} + 2\Delta f$.

3) Run the EWB simulator and obtain on the oscilloscope screen via the second channel a sequence of radio pulses that have passed through the dispersive Wednesday. Bring in V report By practical work received timing diagram. Determine what happened to the sequence of radio pulses .

4) Determine the amount by which the wavelength changed during the process of radio wave dispersion.

5) Change size parameter Δf (changes frequencies V Wednesday) V two times more And V two times less given. Repeat execution tasks By points 3 and 4.

6) Do conclusions By results done work.

Task 1.6. Model and investigate traveling and standing waves in a long line using the Electronics Workbench program.

1) For circuit simulation of traveling waves in a long line, assemble the circuit shown in Fig. 5 in the Electronics Workbench program.

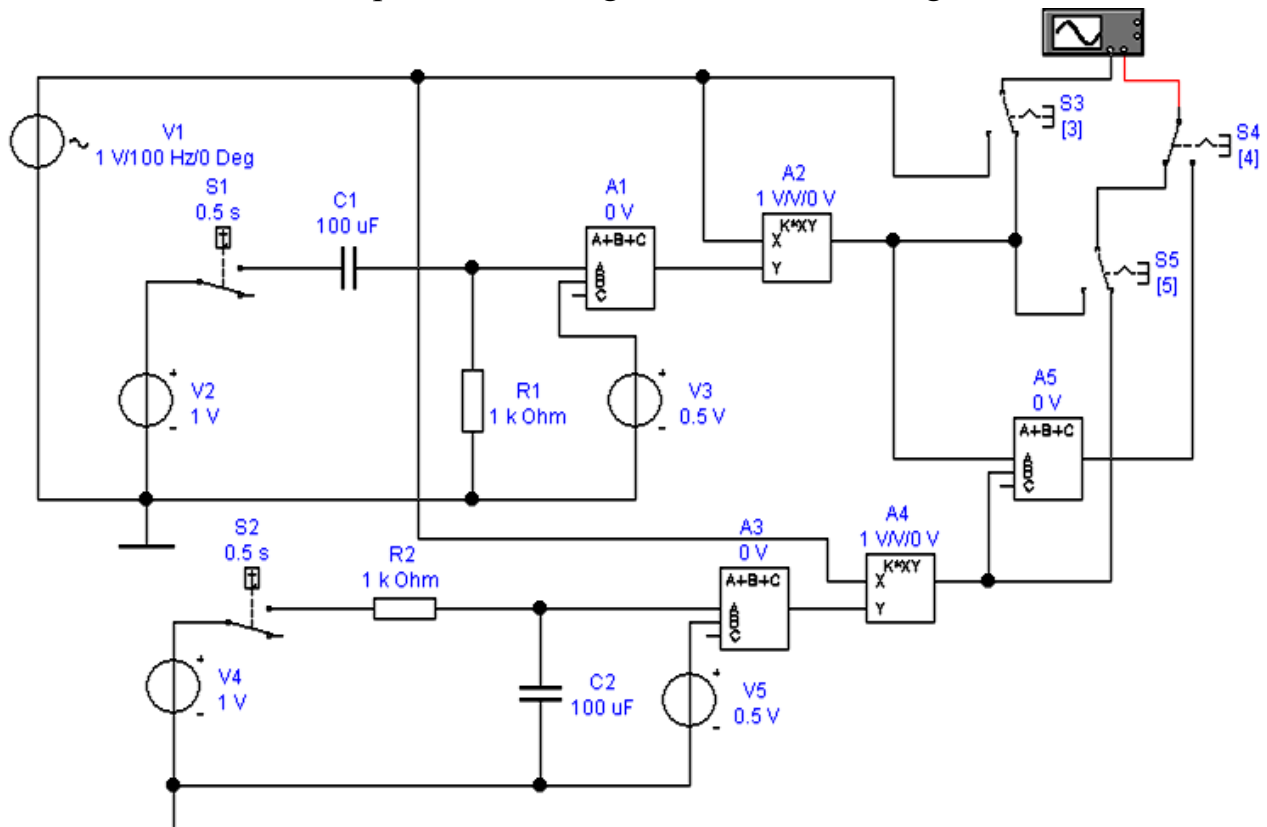
IN this scheme V quality source, exciting wave performs source of sinusoidal voltage $V1$. Direct traveling wave propagating from source To load, modeled on elements $V2$, $V3$, $S1$, $C1$, $R1$, $A1$ And $A2$. Reverse running wave, spreading from loads To source, modeled on elements $V4$, $V5$, $S2$, $C2$, $R2$, $A3$ And $A4$. Process attenuation the direct wave is modeled using a differentiating circuit on elements $C1$ and $R1$, A reverse waves - for check integrating chains on elements $R2$ And $C2$. The total traveling wave is created by adding the forward and reverse waves in the tax adder $A5$.

Assemble the specified circuit, run the EWB simulator, and make sure it works correctly.

2) Set the given parameters of the circuit, taking their values for C and R from Table 1.1 according to your version, and in the source $V1$, set the frequency equal to

$$f = \frac{1000 + N_{var} \cdot 100}{10} \text{ Hz},$$

Where $var.No.$ - number options according to number list V magazine.



Rice. 5 - Scheme modeling running waves V long lines

3) Conduct study direct running waves, For this having installed switches $S3$, $S4$ And $S5$ V left position, to carry out next operations:

- start the EWB simulator, and after switches ***S1*** and ***S2*** *are automatically turned on and then off* , turn off the simulator;
- first channel oscilloscope tune on display waves source, enter the received wave into the practical work report;
- Set the second channel of the oscilloscope to display a direct traveling wave, and enter the resulting wave into the practical work report;
- analyze received waves, having determined reasons changes in the direct traveling wave compared to the original source wave.

4) Conduct a study of forward and backward traveling waves by installing switches ***S3*** And ***S5*** V right position, A ***S4*** - V left position, perform the following operations:

- start the EWB simulator, and after switches ***S1*** and ***S2*** *are automatically turned on and then off* , turn off the simulator;
- first oscilloscope channel set up to display direct running wave, enter the resulting wave into the practical work report;
- set the second channel of the oscilloscope to display the reverse running wave, enter the resulting wave into the practical work report;
- compare received waves.

5) Conduct a study of the sum wave in a long line by installing switches ***S3*** And ***S4*** V right position, to carry out the following operations:

- start the EWB simulator, and after switches ***S1*** and ***S2*** *are automatically turned on and then off* , turn off the simulator;
- first oscilloscope channel set up to display direct running wave, enter the resulting wave into the practical work report;
- second channel oscilloscope tune on display the total wave, enter the resulting wave into the practical work report;
- analyze total hesitation, having determined Which wave it is.

6) Do conclusions By results done work.

5. Prepare a report on the work done on the second question in accordance with the requirements set out in the job description.

IN report bring:

- original data,
- performed tasks,
- simulated electrical schemes, With help which research is being conducted ,
- mathematical models (formulas) And results calculations,
- research results – measured parameters, graphs of wave processes;
- conclusions O done work.

6. Protection practical work

For protection practical introduce fully decorated report, free of significant errors. As instructed by the teacher, complete one of the tasks from each academic question, explaining everything physical phenomena And processes, happening V simulated physical field and equivalent circuit of the wave process.

LIST LITERATURE:

- 1) Sagdeev K.M. Physical foundations of information security [Electronic resource]: study guide / K.M. Sagdeev, V.I. Petrenko, A.F. Chipiga. - Electronic text data. - Stavropol: North Caucasus Federal University, 2015. - 394 p.
- 2) Evstifeev V.V. Physical foundations electricity and magnetism Electronic resource / Evstifeev V.V.: study guide. - Penza: PSU, 2019. - 416 p.
- 3) Bulatov V.N. Physical foundations of electronics Electronic resource / Bulatov V.N.: lecture notes for students in educational programs higher education in the following areas preparation 11.03.02 infocommunication technologies and communication systems. - Orenburg: OSU, 2018. - 178 p.
- 4) Goldstein A.E. Physical principles of obtaining information [Electronic resource]: textbook / A.E. Goldstein. — Electron. text data. — Tomsk: Tomsk Polytechnic University, 2010. — 292 p.

PRACTICAL JOB No. 5

TOPIC 5

ELECTRIC FIELDS

Class 5

MODELING AND STUDY OF ELECTRIC FIELDS

TIME – 4 hours.

Educational questions:

1. Modeling And study electrical fields.

TARGET INSTALLATION PRACTICAL WORKS: TARGET SETTING OF PRACTICAL WORK:

Competencies, being formed discipline

OPK-1: Capable use provisions, laws And methods natural sciences and mathematics to solve engineering problems.

OPK-2: Capable on one's own conduct experimental research And use main techniques processing And performances received data.

Learning outcomes achieved as a result of completing practical work:

Be able to:

- apply physical laws and methods to formalize the representation of physical phenomena and processes that occur in telecommunications .
- conduct experimental research With help mathematical models according to the accepted methodology
- model And analyze main physical phenomena And processes in telecommunications using computer technology.

Own:

- skills use knowledge physicists at decision practical problems of engineering activities
- methods of processing and presenting data obtained as a result of experimental studies.
- skills in computer modeling of the main physical methods of receiving, transmitting and storing information.

EDUCATIONAL AND MATERIAL SECURITY:

- PC With simulator electronic schemes Electronics Workbench - 5.12" And system computer mathematicians Mathcad - 15";
- electronic methodological development By practical work.

STRUCTURE PRACTICAL WORKS:

Class No. 1		90 min
Introductory Part		10 min
Examination readiness students To practical work		8 min
Introductory Part		2 min
Questions (tasks), subject research:		75 min
1. Modeling And study electrical fields.		75 min
Final Part		5 min
Summing up results		3 min
Exercise students For independent work		2 min
Class No. 2		90 min
Introductory Part		10 min
Examination readiness students To practical work		8 min
Introductory Part		2 min
Questions (tasks), subject research:		75 min
2. Modeling And study electrical fields.		75 min
Final Part		5 min
Summing up results		3 min
Exercise students For independent work		2 min

QUESTIONS, SUBJECTS RESEARCH

1. MODELING AND RESEARCH OF ELECTRIC FIELDS

Brief theoretical or reference and information materials

Calculation fields electrical charges.

Matter is structured in such a way that some elementary particles have a property called electric charge. This property manifests itself in the force interaction of elementary particles and material objects consisting of these elementary particles. There are two types of electric charges: positive and negative. The proton and positron have a positive charge. negative at electron. Same names charges repel, A opposites attract. The magnitude of the positive and negative charge

elementary particles the same $q_e = 1,602 \cdot 10^{-19}$ C. If in mothers-

nal object quantity positive And negative charges If they are identical, then it is quasi-neutral. There is no electrical force interaction between such objects.

Electrons are more mobile and the electric charge of a material body is more frequent total connected With disadvantage or excess electrons. Weight electron

$m_e = 9,11 \cdot 10^{-31}$ kilogram (kg). Positively And negatively charged

bodies interact So same, How And elementary particles. Strength interactions two tel, possessing charge, is calculated With help law Pendant

$$\vec{F}_e = \frac{q_{e1} \cdot q_{e2}}{4\pi\epsilon_0 r^2} \cdot \vec{e}_r. \quad (1.1)$$

IN denominator expressions enters coefficient proportionality $\epsilon_0 = 10^{-9}/36\pi$ (F/m) - electric constant or dielectric penetrating bridge vacuum.

Strength, defining interaction electrical charges, exists at any point in space, so we can talk about a vector field of electric forces. The force acting on a unit charge is called the electric field strength, or simply the electric field strength.

$$\vec{E} = \frac{\vec{F}_e}{q_{e2}} = \frac{q_{e1}}{4\pi\epsilon_0 r^2} \cdot \vec{e}_r \quad (\text{V/m}). \quad (1.2)$$

The electric field is sufficient to describe the force acting on a stationary electric charge in a vacuum.

The field strengths created by a set of individual charges are added together geometrically according to the principle of superposition, i.e. independent superposition of fields:

$$\vec{E} = \sum_{i=1}^n \vec{E}_i. \quad (1.3)$$

In a material environment, this force changes due to the properties of the environment. Therefore, they introduce V consideration vector field, named electrical induction or an electric displacement field. In homogeneous media, the vectors and are proportional Friend to a friend. Coefficient proportionality they call dielectric skoy permeability. Distinguish absolute ϵ_A And relative ϵ dielectric-tricheskaya permeability:

$$\epsilon_A = \epsilon \cdot \epsilon_0. \quad (1.4)$$

Electric induction is calculated next way:

$$\vec{D} = \epsilon_A \vec{E} = \frac{q_e}{4\pi \cdot r^2} \cdot \vec{e}_r \quad (\text{Kl/m}^2). \quad (1.5)$$

If electric charge distributed V some areas space, then we can introduce the electric charge density C/m³ as the derivative of the charge with respect to volume:

$$\rho = \frac{dq}{dV}. \quad (1.6)$$

The total charge will be determined by integrating over the volume in which its density differs from zero, i.e.

$$q = \int_V \rho \, dV. \quad (1.7)$$

A For fields from the charge distributed in some volume V, limited by surface S, use the integral form of the law:

$$\int_V \operatorname{div} \varepsilon_a E \, dV = \oint_S \varepsilon_o E \cdot dS = q, \quad (1.9)$$

Expression (1.9) has a slightly different meaning. The electric charge in some volume V , limited surface S defines total divergence electric fields V volume And flow electric fields through surface S , limiting this volume.

$$\int_V \operatorname{div} E \, dV = \int_S \underline{n} E \cdot dS = q, \quad (1.11)$$
$$\underline{\varepsilon}_n = \varepsilon_a + \frac{\sigma}{i\omega} = \varepsilon_a - i \frac{\sigma}{\omega}. \quad (1.12)$$

IN electric field With tension E on particle With mass m And charge-
house q is valid strength $F = q \cdot E$. If movement non-relativistic, A field one-
dear, That particle is moving With permanent acceleration

4

This movement is completely analogous to the movement of a particle in a uniform constant gravitational field. For relativistic movements weight particles m increases with velocity V , and acceleration decreases.

Let us assume that charged particles, initially moving along the X -axis (Fig. 1.1) with velocity V_o fly into the electric field of a flat capacitor in the middle between his plates. If gap between plates d is small compared to their length L , then edge effects can be neglected and the electric field between the plates can be considered uniform. Directing the Y -axis parallel to the field, we have: $E_x = E_z = 0$, $E_y = E$.

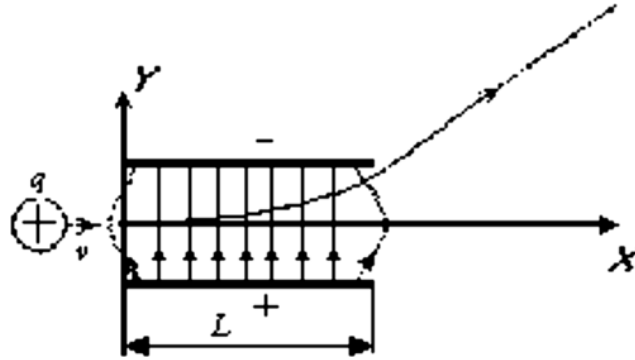


Fig. 1.1 – The movement of a charged particle in the field of a flat capacitor

Movement particles V this case is happening under action constant forces And like movement horizontally abandoned bodies V field gravity.

This means that the motion of the particle shown in Fig. 1.1, in the general case, is an equally variable curvilinear motion of the material points. Curvilinearity movements conditioned by those, What on particle is in effect With one sides initial pulse, vector whom equal $P = m \cdot V_o$, A With another sides strength electric fields $F = q \cdot E$, directed perpendicularly initial movement particles. IN this case besides tangen-

sebaceous component vectors complete acceleration a_t , directed By kasa-body To trajectories movements, arises normal (centripetal) component of the total acceleration vector a_n , directed along the normal to the trajectory towards the center of curvature.

Equation equally variable movements regardless from his trajectories for a material point has the form:

$$S = S_o + V_o \cdot t + \frac{a_t \cdot t^2}{2}, \quad (1.14)$$

Where S_o - distance points from the original provisions V moment beginning countdown or otherwise path, passed To moment $t=0$; V_o - initial speed; a_t - tangential acceleration; t is the current time.

Since the motion is uniformly variable, the numerical value of the velocity of a point at any moment in time is determined from the equation

$$V = V_o + a_t \cdot t, \quad (1.15)$$

Equations (1.14) And (1.15) are the main ones formulas of equal-variable movements, They contain six various quantities: three constants: S_o , V_o , a_t and three variables: S , V , t . Consequently, to solve the problem of the uniform motion of a point, at least four quantities must be given in its condition, since a system of two equations can only be solved if they contain two unknowns.

For definitions trajectories non-relativistic movements charged particles moving With constant speed $V = V_o$ V homogeneous electric- Czech field flat capacitor let's write it down equation of motion in view trajectories of the force vector:

$$\vec{F} = \frac{d\vec{P}}{dt} = \frac{d(m \cdot V)}{dt} \quad (1.16)$$

Since the motion of a particle is described in a three-dimensional Cartesian coordinate system and the coordinates of a point x , y , z change over time, we will represent the equation of motion in the form of a system of differential equations of the first order order V view projections vectors forces on axes coordinates And systems differential equations of the second order in the form of coordinates of a point, i.e.

$$\left\{ \begin{array}{l} \frac{dEx}{dt} = \frac{d(m \cdot \frac{\partial S}{\partial x})}{dt} = 0 \\ \frac{dF_y}{dt} = \frac{d(m \cdot \frac{\partial V}{\partial y})}{dt} = q \cdot E \\ \frac{dF_z}{dt} = \frac{d(m \cdot \frac{\partial V}{\partial z})}{dt} = 0 \end{array} \right. \quad \text{and} \quad \left\{ \begin{array}{l} \frac{\partial^2 S_x}{\partial x^2} = a \quad x = 0 \\ \frac{\partial^2 S}{\partial x^2} = \frac{q \cdot E}{m} \\ \frac{\partial^2 S}{\partial z^2} = a_z = 0 \end{array} \right. \quad (1.17)$$

If we consider the motion of a charged particle with relativistic speed in a homogeneous electric field, then mass this particles m will be relativistic, and therefore the momentum of the particle will also be relativistic:

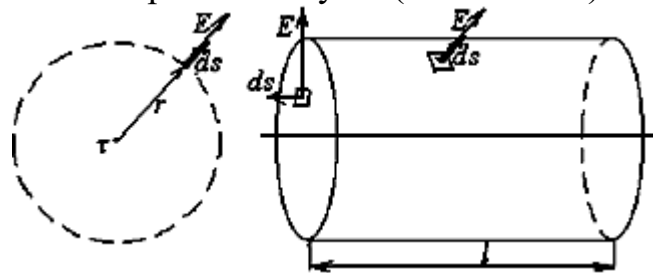
$$m = \frac{m_o}{\sqrt{1 - \left(\frac{V}{C}\right)^2}}, \quad \vec{P} = m \cdot \vec{V} = \frac{m_o V}{\sqrt{1 - \left(\frac{V}{C}\right)^2}} \quad (1.18)$$

Likewise considered higher occasion For non-relativistic particles, we write a system of second-order differential equations, the solution of which will describe the trajectory of a relativistic charged particle in a uniform electric field:

$$\begin{cases} \square x = \frac{\partial^2 S_x}{\partial x^2} = a_x = 0 \\ \square y = \frac{\partial^2 S_y}{\partial y^2} = a_y = 0 \\ \square z = \frac{\partial^2 S_z}{\partial z^2} = a_z = 0 \end{cases} \quad (1.19)$$

Electrostatic field charged axes

Charged axis it's called Very thin, theoretically endlessly long conductor, carrier on to myself charge. All charge axes indicate impossible (He equal infinity), therefore it is indicated linear charge $\tau = q \cdot l$, i.e. for- / row, coming on unit lengths axes. Let axis With positive charge τ located V environment With permeability ϵ_a (cm. rice. 1.2).



Rice. 1.2 - Charged axis

Using the integral form of Gauss's theorem, we will calculate the field strength at an arbitrary point located at a distance r from the axis. For this purpose, we draw a closed surface in the form of a cylinder of length l **through this point**. The flow of the vector E takes place only through the lateral surface this cylinder, because V points, located on his bottoms vectors E And ds perpendicular And their work equals zero. IN points same lateral surface vectors E and ds coincide in direction and their product is equal to the product of the modules, and the module E is the same at all these points due to symmetry. Taking into account the above, we have $\int E ds = \int E ds = E \int ds = E \cdot 2 \pi r l$.

Inside surfaces integration charge

$$q = \tau l. \text{ That's } E \cdot 2 \pi r l = \frac{\tau l}{\epsilon_a} \text{ why}$$

or

$$E = \frac{\tau}{2 \pi \epsilon_a r}, \quad (1.20)$$

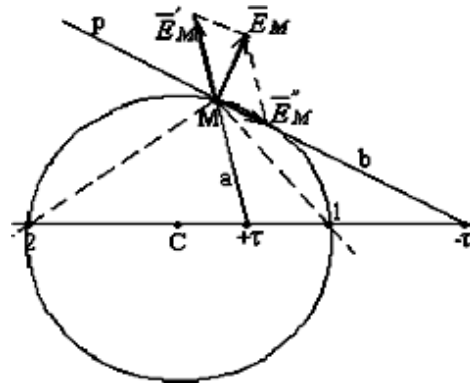
those. tension V this field changes back proportionally distance from the axis.

Potential fields V arbitrary point, remote on distance r from axes, equal

$$\varphi = -\int E dr = -\int \frac{\tau}{2\pi\epsilon_a r} \cdot \frac{dr}{r} = -\frac{\tau}{2\pi\epsilon} \ln r + A = \frac{\tau}{2\pi\epsilon_a} \ln \frac{1}{r} + A. \quad (1.21)$$

The integration constant A depends on the location of the point of zero potential. Consequently, in a given field, the potential varies logarithmically.

On practice more often total two charged axes carry on to myself equal By magnitude and charges τ and $-\tau$ of opposite sign . This is the case shown in Fig. 1.3.



Rice. 1.3 - Two charged axes

Let us take an arbitrary point M in the field, the position of which we will characterize distance A to positive axes And distance b to negative axes And V first queue let's calculate V her tension fields, using

method overlays: $\vec{E}_M = \vec{E}'_M + \vec{E}''_M$, Where $\vec{E}'_M$ и $\vec{E}''_M$ - components, created positively And negatively charged axis respectively. Quantities these components can be determined by the formulas:

$$E'_M = \frac{\tau}{2\pi\epsilon_a a}; \quad E''_M = \frac{\tau}{2\pi\epsilon_a b}. \quad (1.22)$$

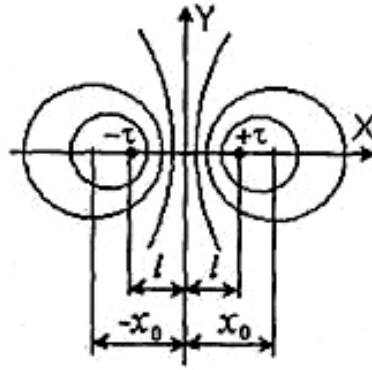
Likewise For potential $\varphi_M = \varphi'_M + \varphi''_M$, Where

$$\varphi'_M = \frac{\tau}{2\pi\epsilon_a} \ln \frac{1}{a} + A; \quad \varphi''_M = \frac{-\tau}{2\pi\epsilon_a} \ln \frac{1}{b} + A. \quad (1.23)$$

Тогда

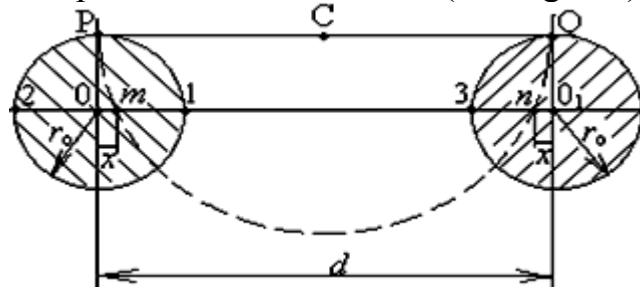
$$\varphi_M = \frac{\tau}{2\pi\epsilon_a} \left(\ln \frac{1}{a} - \ln \frac{1}{b} \right) + A = \frac{\tau}{2\pi\epsilon_{and a}} \ln \frac{b}{a} + A. \quad (1.24)$$

From expressions (1.24) follows, What totality points, For which correlatively-sheniye $b/a = const$, represents by yourself equipotential. From geometry it is known, that the geometric locus of points whose distances to two given points are a constant is a circle (Apollonius's theorem). Therefore, equipotentials in the field of two charged axes are circles (see Fig. 1.4).



Rice. 1.4 - Equipotential lines two charged axles

From a practical point of view, let us consider the electrostatic field and capacitance of a two-wire power transmission line (see Fig. 1.5).



Rice. 1.5 - Wires power lines

Let wires power lines have same radius r_o , located on distance d from each other and are located in a medium with permeability ϵ_a . If the left wire reported charge τ on unit lengths, right $-\tau$, That V space an electrostatic field will arise between the wires, which can be represented as part of the field of two charged axes. Indeed, since the wires are metallic, That inside them fields No ($E=0$), A potential everyone points each the wires are the same, i.e. the surface of each wire is equipotential. Therefore two charged axes, located V points m And n , will create such the same field picture as a two-wire power line, if points m and n are positioned so that surfaces wires were For them equipotentials. Points m And n are usually called electrical axes in contrast to geometric axes (points O and O_1). The displacement of the electrical and geometric axes (x) is the same in the left and right wires due to symmetry. To determine the value of x , we take points 1 and 2 and write down the expressions for the potentials of these points in the field of two charged

nykh axles, located V points m And n .:

$$\varphi_1 = \frac{\tau}{2\pi\epsilon_a} \ln \frac{b}{a} = \frac{\tau}{2\pi\epsilon_a} \ln \frac{d-r_o-x}{r_o-x}; \quad \varphi_2 = \frac{\tau}{2\pi\epsilon_a} \ln \frac{b}{a} = \frac{\tau}{2\pi\epsilon_a} \ln \frac{d+r_o-x}{r_o+x}. \quad (1.25)$$

So How points 1 And 2 located on surfaces one And Togo same pro-

water, That $\varphi_1 = \varphi_2$, therefore, $\frac{d - r_o - x}{r_o - x} = \frac{d + r_o - x}{r_o + x}$. Deciding This equality related-

$$x = \frac{d}{2} \pm \sqrt{\frac{d^2}{4} - r_o^2}.$$

 telno x, we will receive

In this expression, when measuring the displacement x from point O, plus determines the position of point n , and minus determines the position of point m . If $d \gg r_o$, then $x_1 = 0$, $x_2 = d$, i.e., the electrical and geometric axes coincide (there is no axial displacement). Once the axial displacement is determined, the problem is reduced to the previous one.

Let's move on To question O capacity two-wire lines. If two conductors are separated by a dielectric and carry charges of equal magnitude and opposite sign, then an electrostatic field is created in the space between them. Let the voltage between the conductors be equal to U. Then the capacitance between conductors it's called attitude absolute quantities charge on od-

nom from tel To voltage between them: $C = \frac{q}{U}$. Unit measurements capacity - F-

$F = \frac{Cl}{IN}$. So How voltage between bodies proportionally charge on them, That capacity no from charge, no from voltage Not depends, A depends she from configurations and geometric dimensions of bodies, their relative positions and properties dielectric, V which They are located. There are devices, designed to obtain a certain value of capacitance - these are capacitors, however, not only capacitors have capacitance, but any two bodies capable of carrying charges of equal magnitude and opposite sign.

Let's define capacity two-wire lines. Charge one from wires $q = \tau l$. Voltage between wires equals

$$U = \varphi_1 - \varphi_3 = \frac{\tau}{2\pi\epsilon_a} \ln \frac{d - r_o - x}{r_o - x} - \frac{\tau}{2\pi\epsilon_a} \ln \frac{r_o - x}{d - r_o - x} = \frac{\tau}{\pi\epsilon_a} \ln \frac{d - r_o - x}{r_o - x}. \quad (1.26)$$

Then capacity lines, With taking into account conditions $d \gg r_o$, those $x = 0$, equal

$$C = \frac{q}{U} = \frac{\pi \cdot \epsilon_a l}{\ln \left(\frac{d}{r} \right)}. \quad (1.27)$$

From the obtained formulas it is clear that the capacitance really depends on the dimensions of the line and the properties of the environment in which the wires are located; in particular, if the distance d between the wires increases, the capacitance will decrease.

Content practical work, performed students

1. Description laboratory equipment:

– PC With established system computer algebra "Mathcad- 14".

2. Initial data For modeling And research

Options tasks For modeling And research given V tables 1.1 – 1.3.

3. Exercise For work

Basic level:

1) To simulate and investigate in the Mathcad system the non-relativistic motion of charged particles in the electric field of a flat capacitor.

2) Simulate And research V system Mathcad electric field from a discrete set of electric charges.

Increased level:

3) Simulate And research V system Mathcad electric field of charged thin conductors.

Table 1.1 - Initial data For tasks 4.1.

<i>Option</i>	<i>L, m</i>	<i>d, m</i>	<i>m_o, kg</i>	<i>q, Cl</i>	<i>Or, V/m</i>	<i>V_o, m/s</i>
1.	1	0.05	$1.7 \cdot 10^{-27}$	$1.6 \cdot 10^{-19}$	$10 \cdot 10^{-14}$	100
2.	1.1	0.06	$1.8 \cdot 10^{-27}$	$3.2 \cdot 10^{-19}$	$12 \cdot 10^{-14}$	110
3.	1,2	0,07	$1.9 \cdot 10^{-27}$	$4.8 \cdot 10^{-19}$	$14 \cdot 10^{-14}$	120
4.	1,3	0,08	$2 \cdot 10^{-27}$	$-1.6 \cdot 10^{-19}$	$16 \cdot 10^{-14}$	130
5.	1,4	0,09	$2.2 \cdot 10^{-27}$	$-3.2 \cdot 10^{-19}$	$18 \cdot 10^{-14}$	140
6.	1,5	0,1	$2.5 \cdot 10^{-27}$	$-4.8 \cdot 10^{-19}$	$20 \cdot 10^{-14}$	150
7.	1	0,06	$2.3 \cdot 10^{-27}$	$-3.2 \cdot 10^{-19}$	$9 \cdot 10^{-14}$	140
8.	0,9	0,06	$2.1 \cdot 10^{-27}$	$-1.6 \cdot 10^{-19}$	$8 \cdot 10^{-14}$	120
9.	0,8	0,05	$1.6 \cdot 10^{-27}$	$1.6 \cdot 10^{-19}$	$7 \cdot 10^{-14}$	100
10.	0,7	0,04	$1.5 \cdot 10^{-27}$	$-1.6 \cdot 10^{-19}$	$6 \cdot 10^{-14}$	90
11.	0,6	0,04	$1.4 \cdot 10^{-27}$	$-1.6 \cdot 10^{-19}$	$5 \cdot 10^{-14}$	80
12.	0,5	0,03	$1.3 \cdot 10^{-27}$	$1.6 \cdot 10^{-19}$	$6 \cdot 10^{-14}$	70
13.	1	0,06	$1.6 \cdot 10^{-27}$	$-1.6 \cdot 10^{-19}$	$7 \cdot 10^{-14}$	110
14.	1,1	0,05	$1.8 \cdot 10^{-27}$	$-3.2 \cdot 10^{-19}$	$11 \cdot 10^{-14}$	120
15.	1,2	0,04	$1.9 \cdot 10^{-27}$	$-4.8 \cdot 10^{-19}$	$13 \cdot 10^{-14}$	130
16.	1,3	0,04	$2 \cdot 10^{-27}$	$1.6 \cdot 10^{-19}$	$15 \cdot 10^{-14}$	100
17.	1,4	0,03	$2.1 \cdot 10^{-27}$	$3.2 \cdot 10^{-19}$	$17 \cdot 10^{-14}$	90
18.	1,5	0,05	$2.2 \cdot 10^{-27}$	$4.8 \cdot 10^{-19}$	$19 \cdot 10^{-14}$	80
19.	1	0,06	$1.7 \cdot 10^{-27}$	$3.2 \cdot 10^{-19}$	$12 \cdot 10^{-14}$	70
20.	0,9	0,07	$1.5 \cdot 10^{-27}$	$-3.2 \cdot 10^{-19}$	$11 \cdot 10^{-14}$	60
21.	0,8	0,08	$1.4 \cdot 10^{-27}$	$1.6 \cdot 10^{-19}$	$10 \cdot 10^{-14}$	50
22.	0,7	0,09	$1.3 \cdot 10^{-27}$	$-1.6 \cdot 10^{-19}$	$9 \cdot 10^{-14}$	60
23.	0,6	0,1	$1.2 \cdot 10^{-27}$	$1.6 \cdot 10^{-19}$	$8 \cdot 10^{-14}$	70
24.	0,5	0,06	$1.8 \cdot 10^{-27}$	$-1.6 \cdot 10^{-19}$	$7 \cdot 10^{-14}$	80
25.	1,1	0,06	$1.9 \cdot 10^{-27}$	$-3.2 \cdot 10^{-19}$	$6 \cdot 10^{-14}$	90

relativistic in the Mathcad system movement charged particles V electric field flat

capacitor.

1. The initial data for the simulation is a flat capacitor of length L and gap (distance) between plates d creates electric field intensity E . A charged particle of mass m_o , possessing a charge q , initially moves with speed V_o . Initial data For each options given in table 1.1.

Initial conditions for solving the system of differential equations (1.17). At the initial moment of time $t=0$ the coordinates of the particles are equal to zero, i.e. $x_o=y_o=z_o=0$. Speed particles V elementary moment time directed along axes X , $x'_o=V_o$, $y'_o=z'_o=0$. those.

The task of the modeling is to obtain the trajectory of a charged particle in the electric field of a flat capacitor.

2. Algorithm calculation trajectories movements V system "Mathcad".

1) Enter the initial data for modeling in the working window of the program: L, d, E, m, q, V_o .

2) Solution systems differential equations (1.17) is carried out with help built-in functions **rkfixed**, using For search solutions Runge-Kutta method of the fourth order. To do this, set the boundary points of the interval $t1:=0, t2:=100$, on which the solution of the differential equations will be sought, and the number of points $N:=100$, at which an approximate solution is sought.

3) For applications functions **rkfixed** execute next operations:

– form vector initial conditions:

$$u := \begin{pmatrix} 0 \\ v_0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \begin{array}{l} \text{< } x(0) \text{ - координата частицы в начальный момент времени вдоль оси } X \\ \text{< } x'(0) \text{ - скорость частицы в начальный момент времени вдоль оси } X \\ \text{< } y(0) \text{ - координата частицы в начальный момент времени вдоль оси } Y \\ \text{< } y'(0) \text{ - скорость частицы в начальный момент времени вдоль оси } Y \\ \text{< } z(0) \text{ - координата частицы в начальный момент времени вдоль оси } Z \\ \text{< } z'(0) \text{ - скорость частицы в начальный момент времени вдоль оси } Z \end{array}$$

– form vector first And second derivatives:

$$D(t, u) := \begin{pmatrix} \frac{L}{N-t2} \cdot u_1 \\ 0 \\ u_3 \\ \frac{q \cdot E}{m_o} \\ u_5 \\ 0 \end{pmatrix} \begin{array}{l} \text{--- } x'(t) \text{ - первая производная } x \text{ по } t \\ \text{--- } x''(t) \text{ - вторая производная } x \text{ по } t \\ \text{--- } y'(t) \text{ - первая производная } y \text{ по } t \\ \text{--- } y''(t) \text{ - вторая производная } y \text{ по } t \\ \text{--- } z'(t) \text{ - первая производная } z \text{ по } t \\ \text{--- } z''(t) \text{ - вторая производная } z \text{ по } t \end{array}$$

4) Enter function **rkfixed**

$$Z := \text{rkfixed}(u, t1, t2, N, D).$$

This function returns a matrix in which the first column contains the points t at which solutions are to be found; the remaining columns contain the values of the solutions and their derivatives, i.e.

	t	x(t)	x'(t)	y(t)	y'(t)	z(t)
	0	1	2	3	4	5
0	0	0	100	0	0	0
1	1	100	100	$4.706 \cdot 10^8$	$9.412 \cdot 10^8$	0
2	2	200	100	$1.882 \cdot 10^9$	$1.882 \cdot 10^9$	0
3	3	300	100	$4.235 \cdot 10^9$	$2.824 \cdot 10^9$	0
4	4	400	100	$7.529 \cdot 10^9$	$3.765 \cdot 10^9$	0
5	5	500	100	$1.176 \cdot 10^{10}$	$4.706 \cdot 10^9$	0
6	6	600	100	$1.694 \cdot 10^{10}$	$5.647 \cdot 10^9$	0
7	7	700	100	$2.306 \cdot 10^{10}$	$6.588 \cdot 10^9$	0
8	8	800	100	$3.012 \cdot 10^{10}$	$7.529 \cdot 10^9$	0
9	9	900	100	$3.812 \cdot 10^{10}$	$8.471 \cdot 10^9$	0
10	10	$1 \cdot 10^3$	100	$4.706 \cdot 10^{10}$	$9.412 \cdot 10^9$	0

5) Build trajectories movements particles V electric field capacitor, i.e. the graph of **the y(x) dependence**, since the trajectory is in the XOY plane. To do this, introduce the operators:

$$x := Z^{(1)} \quad y := Z^{(3)}$$

Where operator $Z^{(n)}$ means selection n -th column matrices Z .

On the toolbar, click on the icons (pictograms) one after the other. 

→  (or alternatively Insert □ Graph □ X-Y Graph). In the graph template that opens, insert **y in the function entry space and x** in the variable entry spaces. Set the x-axis boundaries from 0 to L , and the ordinate axis parameters from $-d/2$ to $d/2$.

6) Plot a graph of the change in the velocity of the particle V_y along the coordinate y . To do this, enter the operator:

$$V_y := Z^{(4)}$$

On the toolbar, click on the icons (pictograms) one after the other. 

→  (or otherwise Insert □ Graph □ X-Y chart). In the chart template that opens V place input functions insert V_y , V places input variable X . Set parameters of only the abscissa axis from 0 to $d/2$ or $-d/2$.

7) Build schedule changes speed movements particles V_u from time-

menu. To do this, enter the operator $T := \frac{Z^{(0)}}{t \cdot N}$ and schedule by clicking on the icons in sequence. (pictograms)  →  (or otherwise Insert → Schedule → X-Y graph). In the graph template that opens, insert V_y or $-V_y$ **in the function entry space, and enter T in the x** variable entry space.

3. Conduct a study of the dependence of the particle's trajectory on the value tension fields E . For this at first decrease given tension fields V 5 once, A then increase V 5 once. For each meaning perform calculations and plot graphs of **the y(x) dependence**.

4. Conduct a study of the dependence of the trajectory of a particle on its initial speed movements V_o . For this at first decrease given

speed by 20%, and then increase by 20%. For each value, perform calculations and plot graphs of the $y(x)$ dependence .

5. Conduct a study of the dependence of the particle trajectory from its initial mass m_0 . To do this, first reduce the mass by half, and then increase it V two. For each meaning produce calculation And build graphs dependencies $y(x)$.

6. Conduct a study of the dependence of the particle trajectory from the size her charge q . For this at first decrease charge V two, A then increase V two. For each meaning produce calculation And build graphs dependencies $y(x)$.

7. Draw conclusions based on the results of the work performed. In the conclusions, reflect how the particle's trajectory changes due to changes in its parameters and the field parameters.

Exercise 1.2. Simulate And calculate electric field from discrete set of electric charges.

1. The initial data for the simulation is a set of point charges of up to 10 pieces, located in three-dimensional space, for which the dielectric constant is equal to $\epsilon = 1$.

The practical task is carried out according to the options. Tables 1.2 and 1.3 show original data. IN each option is being asked 4 charge. IN table

1.3 with the initial data for each charge, its position is indicated - coordinates in a rectangular coordinate system (x_1, y_1, z_1) - and the magnitude of the point charge q in coulombs, multiplied by 10^{-9} .

The task of modeling is to create a program for calculating the electric field V 10 points spaces, evenly distributed on given a straight line segment, the beginning and end of which are specified in Table 1.2, and calculate the modulus of the electric field strength vector and its projection onto the coordinate axes.

In the report, provide a graph of the change in the electric field and its projections onto coordinate axes. Calculation conduct V 11 points, evenly distributed in a straight line.

Table 1.2 - Coordinates segment direct

Вариант	Начало			Конец		
	x1	y1	z1	x2	y2	z2
1	12	14	30	16	18	40
2	8	14	30	12	18	40
3	4	14	30	8	18	40
4	0	14	30	4	18	40
5	-4	14	30	0	18	40
6	-8	14	30	-4	18	40
7	-12	14	30	-8	18	40
8	12	14	30	12	18	40
9	8	14	30	12	18	40
10	4	14	30	8	18	40
11	0	14	30	4	18	40
12	-4	14	30	0	18	40
13	-8	14	30	-4	18	40
14	-12	14	30	-8	18	40
15	12	14	30	16	18	40
16	8	14	30	12	18	40
17	4	14	30	8	18	40
18	0	14	30	4	18	40
19	-4	14	30	0	18	40
20	-8	14	30	-4	18	40
21	-12	14	30	-8	18	40
22	12	14	30	16	18	40
23	8	14	30	12	18	40
24	4	14	30	8	18	40
25	0	14	30	4	18	40
26	-4	14	30	0	18	40

Table 1.3 – Sources data for for. tasks 4.2

Vari- ant	No. is- accur ate.	Charge q	x1	y1	z1	Vari- ant	No. is- accur ate.	Charge q	x1	y1	z1
1	1	$20 \cdot 10^{-9}$	13	-13	22	14	1	$20 \cdot 10^{-9}$	11	-10	21
	2	$15 \cdot 10^{-9}$	13	-12	23		2	$15 \cdot 10^{-9}$	11	-11	22
	3	$30 \cdot 10^{-9}$	13	-11	24		3	$30 \cdot 10^{-9}$	11	-12	23
	4	$25 \cdot 10^{-9}$	13	-10	25		4	$25 \cdot 10^{-9}$	11	-13	24
2	1	$40 \cdot 10^{-9}$	13	-9	23	15	1	$40 \cdot 10^{-9}$	11	-13	22
	2	$10 \cdot 10^{-9}$	13	-8	24		2	$10 \cdot 10^{-9}$	11	-12	23
	3	$25 \cdot 10^{-9}$	13	-7	25		3	$25 \cdot 10^{-9}$	11	-11	24
	4	$30 \cdot 10^{-9}$	13	-6	26		4	$30 \cdot 10^{-9}$	11	-10	25
3	1	$10 \cdot 10^{-9}$	13	-5	24	16	1	$10 \cdot 10^{-9}$	11	-9	23
	2	$15 \cdot 10^{-9}$	13	-4	25		2	$15 \cdot 10^{-9}$	11	-8	24
	3	$10 \cdot 10^{-9}$	13	-3	26		3	$10 \cdot 10^{-9}$	11	-7	25
	4	$25 \cdot 10^{-9}$	13	-2	27		4	$25 \cdot 10^{-9}$	11	-6	26
4	1	$17 \cdot 10^{-9}$	13	-1	25	17	1	$17 \cdot 10^{-9}$	11	-5	24
	2	$29 \cdot 10^{-9}$	13	0	26		2	$29 \cdot 10^{-9}$	11	-4	25
	3	$33 \cdot 10^{-9}$	13	1	27		3	$33 \cdot 10^{-9}$	11	-3	26

	4	14·10 ⁻⁹	13	2	28		4	14 · 10 ⁻⁹	11	- 2	27
Variant	No. source.	Charge q	x1	y1	z1	Variant	No. source.	Charge q	x1	y1	z1
5	1	40·10 ⁻⁹	13	3	26	18	1	40·10 ⁻⁹	11	-1	25
	2	30·10 ⁻⁹	13	4	27		2	30·10 ⁻⁹	11	0	26
	3	20·10 ⁻⁹	13	5	28		3	20·10 ⁻⁹	11	1	27
	4	10·10 ⁻⁹	13	6	1		4	10·10 ⁻⁹	11	2	28
6	1	33·10 ⁻⁹	13	7	27	19	1	33·10 ⁻⁹	11	3	26
	2	27·10 ⁻⁹	13	8	28		2	27·10 ⁻⁹	11	4	27
	3	18·10 ⁻⁹	13	9	1		3	18·10 ⁻⁹	11	5	28
	4	45·10 ⁻⁹	13	10	2		4	45·10 ⁻⁹	11	6	1
7	1	14·10 ⁻⁹	13	11	28	20	1	14·10 ⁻⁹	11	7	27
	2	12·10 ⁻⁹	13	12	1		2	12·10 ⁻⁹	11	8	28
	3	45·10 ⁻⁹	13	13	2		3	45·10 ⁻⁹	11	9	1
	4	20·10 ⁻⁹	13	14	3		4	20·10 ⁻⁹	11	10	2
8	1	29·10 ⁻⁹	-12	14	15	21	1	29·10 ⁻⁹	-10	11	28
	2	19·10 ⁻⁹	-12	13	16		2	19·10 ⁻⁹	-10	12	1
	3	22·10 ⁻⁹	-12	12	17		3	22·10 ⁻⁹	-10	13	2
	4	30·10 ⁻⁹	-12	11	18		4	30·10 ⁻⁹	-10	14	3
9	1	37·10 ⁻⁹	-12	10	16	22	1	37·10 ⁻⁹	-10	14	1
	2	24·10 ⁻⁹	-12	9	17		2	24·10 ⁻⁹	-10	13	2
	3	16·10 ⁻⁹	-12	8	18		3	16·10 ⁻⁹	-10	12	3
	4	45·10 ⁻⁹	-12	7	19		4	45·10 ⁻⁹	-10	11	4
10	1	18·10 ⁻⁹	-12	6	17	23	1	18·10 ⁻⁹	-10	10	2
	2	26·10 ⁻⁹	-12	5	18		2	26·10 ⁻⁹	-10	9	3
	3	14·10 ⁻⁹	-12	4	19		3	14·10 ⁻⁹	-10	8	4
	4	30·10 ⁻⁹	-12	3	20		4	30·10 ⁻⁹	-10	7	5
11	1	41·10 ⁻⁹	-12	2	18	24	1	41·10 ⁻⁹	-10	6	3
	2	14·10 ⁻⁹	-12	1	19		2	14·10 ⁻⁹	-10	5	4
	3	14·10 ⁻⁹	-12	0	20		3	14·10 ⁻⁹	-10	4	5
	4	25·10 ⁻⁹	-12	-1	21		4	25·10 ⁻⁹	-10	3	6
12	1	22·10 ⁻⁹	-12	-2	19	25	1	22·10 ⁻⁹	-10	2	4
	2	33·10 ⁻⁹	-12	-3	20		2	33·10 ⁻⁹	-10	1	5
	3	44·10 ⁻⁹	-12	-4	21		3	44·10 ⁻⁹	-10	0	6
	4	11·10 ⁻⁹	-12	-5	22		4	11·10 ⁻⁹	-10	-1	7
13	1	23·10 ⁻⁹	-12	-6	20	26	1	23·10 ⁻⁹	-10	-2	5
	2	32·10 ⁻⁹	-12	-7	21		2	32·10 ⁻⁹	-10	-3	6
	3	17·10 ⁻⁹	-12	-8	22		3	17·10 ⁻⁹	-10	-4	7
	4	19 · 10 ⁻⁹	- 12	- 9	23		4	19 · 10 ⁻⁹	- 10	- 5	8

2. Algorithm calculation fields V system "Mathcad".

1) Enter V working window programs original data:

– dielectric permeability vacuum or electrical constant-

nuyy $\epsilon_0 = 10^{-9} / 36 \cdot \pi$;

– relative dielectric permeability Wednesday $\epsilon = 1$;

– absolute dielectric permeability Wednesday $\epsilon_a = \epsilon_0 \cdot \epsilon$;

- array points, V which are located charges, $i = 0 \dots 9$;

– array points on direct lines, V which necessary calculate electric field, $k = 0 \dots 10$;

– coordinates x_n, y_n, z_n And quantities charges q V view single-column ten elemental matrices, at this V first four element everyone columns values are entered in accordance with the given option, and the remaining elements are assigned the value 0, for example

$$x_n := \begin{pmatrix} -10 \\ -10 \\ -10 \\ -10 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \quad y_n := \begin{pmatrix} -13 \\ -12 \\ -11 \\ -10 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \quad z_n := \begin{pmatrix} 7 \\ 8 \\ 9 \\ 10 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \quad q := \begin{pmatrix} 11 \cdot 10^{-9} \\ 12 \cdot 10^{-9} \\ 13 \cdot 10^{-9} \\ 14 \cdot 10^{-9} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

– coordinates initial And final points direct, on which points for calculating the electric field $x_1 = , y_1 = , z_1 = , x_2 = , y_2 = , z_2 = ,$ are found, taking their values from Table 1.3.

2) Enter formulas For intermediate calculations:

– coordinates points, V which is calculated electric field:

$$x_{p1_k} := x_1 + \frac{x_2 - x_1}{10} k \quad y_{p1_k} := y_1 + \frac{y_2 - y_1}{10} k \quad z_{p1_k} := z_1 + \frac{z_2 - z_1}{10} k ;$$

– projections onto the coordinate axes of the distances between the points at which the charges are located and the points for which the electric field is calculated

$$dx_{k,i} := x_{p1_k} - x_{n_i} \quad dy_{k,i} := y_{p1_k} - y_{n_i} \quad dz_{k,i} := z_{p1_k} - z_{n_i} ;$$

– distances between dots, V which are located charges And dots, for which the electric field is calculated

$$r_{k,i} := \sqrt{\{dx_{k,i}\}^2 + \{dy_{k,i}\}^2 + \{dz_{k,i}\}^2} ;$$

– corners, which makes up radius vector r c axes coordinates x, y, z

$$fix_{k,i} := \arccos\left(\frac{dx_{k,i}}{r_{k,i}}\right) \quad fiy_{k,i} := \arccos\left(\frac{dy_{k,i}}{r_{k,i}}\right) \quad fiz_{k,i} := \arccos\left(\frac{dz_{k,i}}{r_{k,i}}\right)$$

Indexes k, i V given formulas mean, What is calculated the value at the k -th point of the field from *the* i -th point of charge placement.

3) Enter formulas for calculating the two-dimensional array of the electric field E at observation points from individual sources and arrays of its projections onto the coordinate axes EX, EY, EZ :

$$E_{k,i} := \frac{q_i}{4 \cdot \pi \cdot \epsilon \cdot a \cdot \{r_{k,i}\}^2}$$

$$EX_{k,i} := E_{k,i} \cdot \sin\{fix_{k,i}\} \quad EY_{k,i} := E_{k,i} \cdot \sin\{fiy_{k,i}\} \quad EZ_{k,i} := E_{k,i} \cdot \sin\{fiz_{k,i}\}$$

4) Enter formulas For calculation vectors total fields **EP** from everyone charges V each point observations, For this is calculated module fields , **EPP** its projections **EPX** , **EPY** , **EPZ** on coordinate axes and distance **sp** between points at which the measurement is carried out in the **xoy plane** , i.e.

$$EP_k := \begin{pmatrix} \sum_i EX_{k,i} \\ \sum_i EY_{k,i} \\ \sum_i EZ_{k,i} \end{pmatrix} \quad sp_k := \sqrt{\{xp1_k\}^2 + \{yp1_k\}^2}$$

$$EPX_k := \{EP_k\}_0 \quad EPY_k := \{EP_k\}_1 \quad EPZ_k := \{EP_k\}_2$$

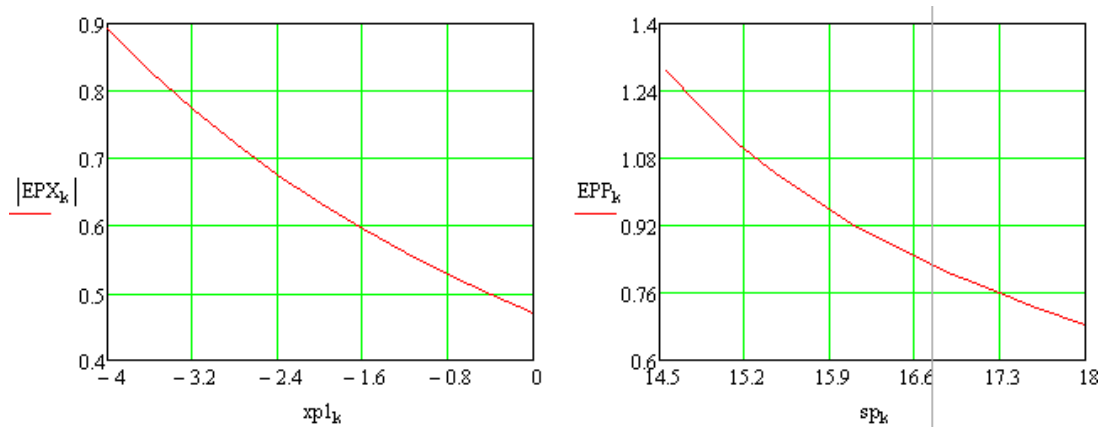
$$EPP_k := \sqrt{\{EPX_k\}^2 + \{EPY_k\}^2 + \{EPZ_k\}^2}$$

5) Debug file, created V program MathCAD, on test example (option 26). In order to check if there are any errors in the created program, take original data test options 26. Results calculations By This option is presented below.

Results some calculations:

$xp1_k =$	$yp1_k =$	$zp1_k =$	$r_{k,0} =$	$r_{k,1} =$	$r_{k,2} =$
-4	14	30	30.282	30.017	29.816
-3.6	14.4	31	31.399	31.124	30.911
-3.2	14.8	32	32.519	32.235	32.011
-2.8	15.2	33	33.64	33.348	33.113
-2.4	15.6	34	34.764	34.463	34.219
-2	16	35	35.889	35.581	35.327
-1.6	16.4	36	37.015	36.7	36.438
-1.2	16.8	37	38.143	37.822	37.551
-0.8	17.2	38	39.272	38.945	38.666
-0.4	17.6	39	40.402	40.069	39.783
0	18	40	41.533	41.195	40.902

6) Plot the graphs of the dependence of the modulus of the total field **EPP** on the distance **sp** and the modulus of its projections **EPX** on the coordinate axis X on the coordinates of the points on this axis. An example of the graphs is shown in Fig. 1.2.



Rice. 1.2

4.2.3. Carry out calculations of the electric field using the program in the Mathcad system according to your specified option.

- 1) Enter given original data.
- 2) Produce calculations.
- 3) Construct graphs of the dependence of the modulus of the total field **EPP** on the distance **sp** and the modulus of its projections **EPX**, **EPY**, **EPZ** on the coordinate axes.
4. Conduct a study of the dependence of the total field on the magnitude of charges and their number. To do this, perform the following operations:
 - 1) Change size one from given charges on negatively value. Carry out calculations and construct a new graph of the dependence of the modulus of the total field **EPP** on the distance **sp**.
 - 2) Take the initial data of any other option and enter the **xn coordinates**, **yn**, **zn** And quantities charges **q** V single-column matrices instead of noughties elements. Carry out calculations and construct a new graph of the dependence of the modulus of the total field **EPP** on the distance **sp**.
5. Do conclusions By results done work.

4.3. Simulate And research V system Mathcad electric field of charged thin conductors.

1. Initial data for modeling: a straight thread-like conductor of length $l = 10$ m at a fixed point in time has a linear charge, magnitude τl . He is located V three-dimensional space with Wednesday, having relative permittivity $\varepsilon = 1$. The conductor is located parallel to the **z axis**. Another similar conductor is located in the electric field of this conductor. conductor parallel first on distance **d**, significantly pre-superior diameter conductors, hence, electrical And the geometric axes of the conductors coincide (there is no displacement of the axes). Under the influence of electric fields V result phenomenon electrostatic induction in second conductor is being induced electric charge, A between conductors arises electrical capacity.

The practical task is carried out according to the options. Table 1.4 provides specific initial data, namely: the magnitude of the linear charge of the conductor τl V picocoulombs on meter; coordinates placements conductor (**XI**, **UI**)

V planes **HOW** spaces; coordinates displacements (ΔX , ΔU) second conductor relative to the first.

The task of modeling is to create a modeling program in the Mathcad system electric fields two charged thin conductors, allowing to calculate and display equipotential lines of the field, calculate modules tension electric fields And vectors electrical induction between conductors, as well as the electrical capacitance of conductors.

Table 1.4 - Initial data For tasks 4.3.

Option	$\tau I, pC/m$	XI, m	UI, m	$\Delta X, m$	$\Delta U, m$
1.	$300 \cdot 10^{-12}$	49	59	5	-1
2.	$280 \cdot 10^{-12}$	47	57	4	0
3.	$260 \cdot 10^{-12}$	45	55	3	-2
4.	$240 \cdot 10^{-12}$	43	53	2	3
5.	$220 \cdot 10^{-12}$	41	51	1	-4
6.	$200 \cdot 10^{-12}$	40	50	2	3
7.	$210 \cdot 10^{-12}$	42	48	3	-2
8.	$230 \cdot 10^{-12}$	44	46	4	1
9.	$250 \cdot 10^{-12}$	46	44	5	0
10.	$270 \cdot 10^{-12}$	48	42	-1	4
11.	$290 \cdot 10^{-12}$	50	40	-2	4
12.	$310 \cdot 10^{-12}$	51	41	-3	2
13.	$330 \cdot 10^{-12}$	53	43	-4	1
14.	$350 \cdot 10^{-12}$	55	45	-5	0
15.	$370 \cdot 10^{-12}$	57	47	-5	-1
16.	$390 \cdot 10^{-12}$	59	49	-4	1
17.	$400 \cdot 10^{-12}$	60	50	-3	2
18.	$380 \cdot 10^{-12}$	58	52	-2	2
19.	$360 \cdot 10^{-12}$	56	54	-1	4
20.	$340 \cdot 10^{-12}$	54	56	-2	-2
21.	$320 \cdot 10^{-12}$	52	58	-3	1
22.	$180 \cdot 10^{-12}$	49	60	3	-3
23.	$190 \cdot 10^{-12}$	47	53	2	2
24.	$410 \cdot 10^{-12}$	45	51	3	2
25.	$420 \cdot 10^{-12}$	40	55	5	-1

2. Algorithm modeling electric fields V system Mathcad:

1) Enter V working window programs original data:

– function ORIGIN=1 For Togo, to elements matrices And arrays were numbered starting from one;

- dielectric permeability vacuum or electrical constant-
 $\epsilon_0 = 10^{-9} / 36 \cdot \pi$;
- relative dielectric permeability Wednesday $\epsilon = 1$;
- absolute dielectric permeability Wednesday $\epsilon_a = \epsilon_0 \cdot \epsilon$;
- length conductors $l = 10$ m;
- size linear charge first conductor τ_1 ;
- the magnitude of the linear charge of the second conductor τ_2 initially equal to zero;
- array points spaces V planes **HOW**, V which are located conductors, $x = 1 \dots 100$ And $y = 1 \dots 100$;
- coordinates first conductor **$X1$** , **$Y1$** And coordinates displacements ΔX , ΔY second conductor relatively first.

2) Enter formulas For calculations:

- coordinates placements second conductor

$$X2 := X1 + \Delta X \quad Y2 := Y1 + \Delta Y ;$$

- distances between axes conductors:

$$d := \sqrt{\Delta X^2 + \Delta Y^2} ;$$

- distances from conductors to points spaces, V which the electric field is determined

$$r1_{x,y} := \sqrt{(X1 - x)^2 + (Y1 - y)^2} \quad r2_{x,y} := \sqrt{(X2 - x)^2 + (Y2 - y)^2} ;$$

- potentials V points fields, created each conductor

$$U1_{x,y} := \frac{-\tau_1 \cdot \log(r1_{x,y} + 1, e^1)}{2\pi \cdot \epsilon_a} \quad U2_{x,y} := \frac{-\tau_2 \cdot \log(r2_{x,y} + 1, e^1)}{2\pi \cdot \epsilon_a} ;$$

- total potentials V points fields - $U := U1 + U2$;
- differences potentials between conductors

$$\Delta U := U_{X1, Y1} - U_{X2, Y2} ;$$

- modules of the electric field strength and the electric induction vector between conductors

$$E := \frac{\Delta U}{d} \quad D := \epsilon_a \cdot E ;$$

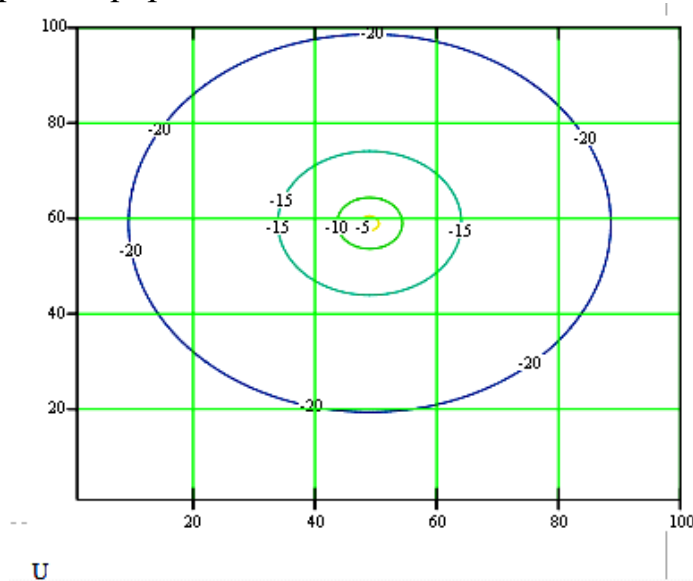
- electrical capacity conductors

$$C := \frac{\tau_1 \cdot l}{\Delta U} .$$

3) Debug the file created in MathCAD. To check the correctness of the work, plot a graph of the equipotential lines of the electric field, created first conductor. For this on panels tools consequently press on badges (pictograms)  →  (or otherwise Insert →

Schedule → Lines level). IN opened template graphics V place input functions insert U .

Example graphics equipotential lines:



3. Conduct a simulated electric field study. To do this, follow these steps:

1) Consistently installing size linear charge second conductor $\tau 2$, equal to $-0.5 \tau 1$; $-0.6 \tau 1$; $-0.7 \tau 1$; $-0.8 \tau 1$; $-0.9 \tau 1$ - $\tau 1$, conduct research :

- dependencies species displays fields from ratios quantities linear charges $\tau 1 / \tau 2$ conductors, by constructing graphs of equipotential lines of the electric field created by two thin charged conductors;

- dependencies module tension fields E between conductors from relations values of linear charges $\tau 1 / \tau 2$ conductors, having built corresponding schedule;

- dependence of the modulus of the vector of electric induction of the field D between conductors on the ratio of the magnitudes of the linear charges $\tau 1 / \tau 2$ of the conductors, by constructing the corresponding graph;

- dependencies quantities capacity electric conductors C from the ratio of the values of their linear charges $\tau 1 / \tau 2$, by constructing the corresponding graph .

2) Conduct a study of the dependence of the electrical capacity of charged conductors on their geometric measurements and the properties of the environment.

- For this install next original data: $\tau 2 = -\tau 1$, $\Delta Y=0$;

- changing distance ΔX from 1 to 10, build schedule dependence of electrical capacitance C on the distance between conductors d ;

- set $\Delta X=1$, changing the length of the conductors from 1 to 10 m, plot a graph of the dependence of the electrical capacitance C on the length of the conductors l ;

– install $l = 10$, changing size relative permittivity ϵ Wednesday between conductors from 1 to 10, build schedule for dependencies electrical capacity C from absolute dielectric permeability of the environment ϵ_a .

5. Prepare a report on the work completed on the first question in accordance with the requirements set out in the job description.

IN report bring:

- original data,
- performed tasks,
- compiled listings programs modeling,
- results of modeling and research – formulas describing the electric field, obtained results and graphs;
- conclusions O done work, with explanation physical meaning results obtained.

6. Protection practical work

For protection practical introduce fully decorated report, Free of significant errors. As directed by the teacher, complete one of the tasks from each question, explaining all the physical phenomena and processes occurring in the developed model.

LIST LITERATURE:

- 1) Sagdeev K.M. Physical foundations of information security [Electronic resource]: study guide / K.M. Sagdeev, V.I. Petrenko, A.F. Chipiga. - Electronic text data. - Stavropol: North Caucasus Federal University, 2015. - 394 p.
- 2) Evstifeev V.V. Physical foundations electricity and magnetism Electronic resource / Evstifeev V.V.: study guide. - Penza: PSU, 2019. - 416 p.
- 3) Bulatov V.N. Physical foundations of electronics Electronic resource / Bulatov V.N.: lecture notes for students in educational programs higher education in the following areas preparation 11.03.02 infocommunication technologies and communication systems. - Orenburg: OSU, 2018. - 178 p.
- 4) Goldstein A.E. Physical principles of obtaining information [Electronic resource]: textbook / A.E. Goldstein. — Electron. text data. — Tomsk: Tomsk Polytechnic University, 2010. — 292 p.

PRACTICAL JOB No. 6

TOPIC 6 MAGNETIC FIELDS AND MAGNETIC INFORMATION MEDIA

Class 6 MODELING AND STUDY MAGNETIC FIELDS AND PHENOMENA ELECTROMAGNETIC INDUCTION.

TIME - 4 hours.

Educational questions:

- 1. Modeling And study magnetic fields.**
- 2. Modeling And study phenomena electromagnetic induction**

s.

TARGET PRACTICAL INSTALLATION WORKS:

Competencies, being formed discipline

OPK-1: Capable use provisions, laws And methods natural sciences and mathematics to solve engineering problems.

OPK-2: Capable on one's own conduct experimental research And use main techniques processing And performances received data.

Learning outcomes achieved as a result of completing practical work:

Be able to:

- apply physical laws and methods to formalize the representation of physical phenomena and processes that occur in telecommunications .
- conduct experimental research With help mathematical models according to the accepted methodology
- model And analyze main physical phenomena And processes in telecommunications using computer technology.

Own:

- skills use knowledge physicists at decision practical problems of engineering activities
- methods of processing and presenting data obtained as a result of experimental studies.
- skills in computer modeling of the main physical methods of receiving, transmitting and storing information.

EDUCATIONAL AND MATERIAL SECURITY:

- PC With system computer mathematicians Mathcad - 15";
- electronic methodological development By practical work.

STRUCTURE PRACTICAL WORKS:

Class No. 1		90 min
Introductory Part		10 min
Examination readiness students To practical work		8 min
Introductory Part		2 min
Questions (tasks), subject research:		75 min
1. Modeling And study magnetic fields.		75 min
Final Part		5 min
Summing up results		3 min
Exercise students For independent work		2 min
Class No. 2		90 min
Introductory Part		10 min
Examination readiness students To practical work		8 min
Introductory Part		2 min
Questions (tasks), subject research:		75 min
2. Modeling And study phenomena electromagnetic inductions.		75 min
Final Part		5 min
Summing up results		3 min
Exercise students For independent work		2 min

QUESTIONS, SUBJECTS RESEARCH

1. MODELING AND STUDY MAGNETIC FIELDS AND PHENOMENA ELECTROMAGNETIC INDUCTION

Brief theoretical or reference and information materials Movement of charged particles in a magnetic field.

IN constant magnetic field on charged particle is valid strength Lo-

Renz

a

$$\mathbf{F}_L = q[\vec{v} \cdot \mathbf{B}]. \quad (1)$$

This strength perpendicular To speed $\mathbf{v}$ movements particles, A That's why ra- does not produce bots. It only bends the trajectory, but does not change the magnitude of the particle's velocity. Consequently, the particle's mass ***m does not change either***

Let's consider happening homogeneous magnetic fields. If speed particles are directed along fields $\mathbf{B}$, That strength $\mathbf{F}_L$ will contact V zero And particle will move in a straight line at a constant speed. This is due to the fact that the vector product of codirectional vectors is equal to zero.

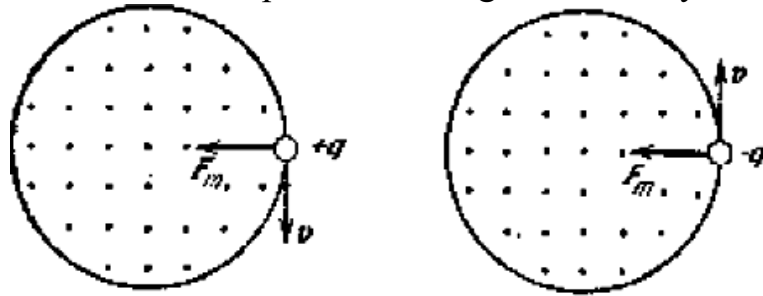
If same particle is moving perpendicularly To magnetic field, That her sko- growth, remaining constant By size, is changing By direction.. Strength Lo- Renza $\mathbf{F} = |\vec{v} \cdot \mathbf{B}| = q \cdot v \cdot B$ V this case maximum And constant By size

$$F = q[\vec{v} \cdot \mathbf{B}]$$

and is normal to the particle's trajectory. According to Newton's second law, the Lorentz force creates centripetal acceleration, directed To center circles.

From here follows, What trajectory particles will circle, plane which is perpendicular To magnetic field. Direction rotation particles V dependencies from sign charge By circles shown on rice. 2.1. On drawing If the magnetic field is directed toward the reader, then the positively charged particle will rotate counterclockwise, while the negatively charged particle will rotate clockwise. Or, using the right-hand rule, if the charge q is positive, then the directions of the vector $\mathbf{B}$ and the angular velocity ω are opposite. If the charge q is negative, then these directions coincide.

Rice. 1 - Movement particles V magnetic field By circles



Radius circles r , called cyclotron radius, located according to Newton's second law, which describes the motion of a material particle, from the condition - strength Lorentz, attached To particle, equal work masses particle on its centripetal acceleration, i.e.

$$q \cdot v \cdot B = \frac{m \cdot v^2}{r} \quad (2)$$

Hence, radius circles proportional speed movements cha- stiches

$$r = \frac{m \cdot v}{q \cdot B} \quad (3)$$

attitude q/m - they call specific charge particles.

At a speed v much less than the speed of light, the circular frequency ω does not depend on v , i.e.

$$\omega = \frac{|q| \cdot B}{m} \quad (4)$$

The period of rotation of a particle, i.e. the time T during which it completes one a full revolution is equal to

$$T = \frac{2\pi \cdot r}{v} = \frac{2\pi \cdot m}{|q| \cdot B} \quad (5)$$

those. period rotation Not depends from speed particles And radius trajectories.

IN in general view, speed charged particles V directed under angle α , Not equal 90° , To vector magnetic induction $\mathbf{B}$ (cm. rice. 2.2).

IN this case movement particles Can introduce V view superpositions:

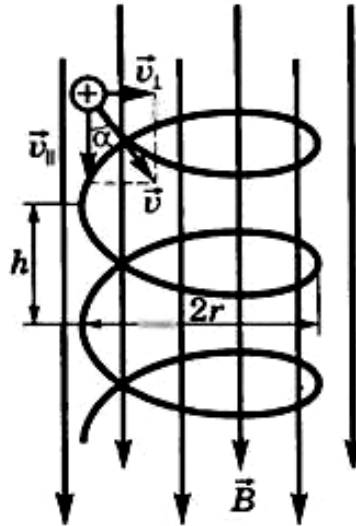
1) rectilinear uniform movements along power lines fields with speed, equal her parallel projections, i.e

$$V_{||} = V \cos \alpha ;$$

2) uniform movements By circles V planes, perpendicular

field, with a speed equal to its perpendicular projection, i.e. the radius of the circle is determined by the formula

$$r = \frac{m \cdot v \cdot \sin \alpha}{q \cdot B}, \quad (6)$$



Rice. 2 - Movement charged particles V magnetic field By spirals

IN result additions two data movements arises movement By spirals, axis which parallel magnetic field (cm. rice. 2). Step screw (spiral) line is equal to

$$h = v \cos \alpha \cdot T = \frac{2\pi \cdot m \cdot v \cdot \cos \alpha}{q \cdot B}. \quad (7)$$

The direction in which the spiral twists depends on the sign of the particle's charge.

If speed charged particles makes up corner α With direction vectors B heterogeneous magnetic fields, induction whom is increasing V direction movements particles, that radius r And step spirals h are decreasing With growth B . This is the basis for focusing charged particles in a magnetic field.

If on moving charged particle besides magnetic fields With in- If the duction B is simultaneously affected by an electrostatic field with a strength of E , then the resultant force applied to the particle is equal to the vector sum electrical forces And forces Lorenz: $\vec{F}_e = \vec{F}_L$. Character movements And The type of trajectory depends in this case on the ratio of these forces and on the direction of the electrostatic and magnetic fields.

Let us assume that a charged particle in a magnetic field initially moves along axes X with speed V_0 , A vector IN directed along axes Y (those.

$V_{ox}=V_o$, $V_{oy}=V_{oz}=0$, $B_x=B_z=0$, $B_y=B$). Then equation movements particles in the form of a trajectory of the force vector will have the form

$$\vec{F}_m = q[\vec{v}, \vec{B}] = q \begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ \dot{x} & \dot{y} & \dot{z} \\ 0 & B & 0 \end{vmatrix} = -\vec{i} B \dot{z} q + \vec{k} B \dot{x} q \quad (8)$$

By expanding this equation, we obtain a system of differential equations first And second order, solutions which will be describe trajectory of the particle:

$$\begin{cases} \frac{d(m_0 \cdot \dot{x})}{dt} = -B \dot{z} q \\ \frac{d(m_0 \cdot \dot{y})}{dt} = 0 \\ \frac{d(m_0 \cdot \dot{z})}{dt} = B \dot{x} q \end{cases} \Rightarrow \begin{cases} \ddot{x} = -\frac{qB}{m_0} \dot{z} \\ \ddot{y} = 0 \\ \ddot{z} = \frac{qB}{m_0} \dot{x} \end{cases} \quad (9)$$

Calculating the magnetic field created by an electric current (Maxwell's third equation)

From experiments was established, What two conductor With electric shock, located close to each other are attracted or repelled in the same way as electric charges are attracted or repelled. So, if there are infinitely many nearby long conductor With electric shock I_1 on distance r parallel to him place a conductor of length ℓ_2 with a current I_2 , then the force will act on it:

$$F = \frac{\mu_a I_1}{2\pi r} I_2 \ell_2 \quad (10)$$

Conductors will be attracted to each other if the currents flow in different directions, or push off, if currents they are coming V one direction. IN expression enters coefficient proportionality, μ_a henry/meter (GN/m). This magnetic constant or magnetic permeability. A distinction is made between absolute μ_a , relative μ magnetic permeability and magnetic permeability of vacuum $\mu_o = 4 \cdot 10^{-7} = 1.26 \cdot 10^{-6}$ H/m.,

$$\mu_a = \mu \mu_o \quad (11)$$

Strength, current on segment wires long 1m With electric shock 1A is called magnetic induction. Endlessly long wire With electric shock I_1 creates on distance r magnetic induction

$$\vec{B} = \frac{\mu_a I_1}{2\pi r} [\vec{e}_{\ell 1} \times \vec{e}_r] \text{ тесла (Тл)}. \quad (12)$$

Together With magnetic induction introduce tension magnetic fields H . Magnetic field strength is related to magnetic induction through magnetic permeability

$$\bar{H} = \bar{B} / \mu_a \text{ (A/M)} \quad (13)$$

If the electric current is distributed over the cross-section of the conductor, then to calculate the fields we need to move on to the current density

$$\bar{j}_e = dI/dS \cdot \bar{e}_s \quad (14)$$

Vector $\bar{e}_s$ - unit vector, directed perpendicularly transverse- obtain a vector quantity for the current density $\bar{j}_e$ from the scalar quantity of current I . In this case, the magnetic field is calculated using the total current law, which is also called Maxwell's third equation. For a point, the differential form of the law is used:

For fields from current, distributed over a limited curve L use the integral form of the law:

$$\text{rot } \bar{H} = \bar{j}_e + \epsilon_a \frac{\partial \bar{E}}{\partial t} \quad (15)$$

$$\int_S \text{rot } \bar{H} d\bar{S} = \oint_L \bar{H} d\bar{l} = I_e + \epsilon_a \int_S \frac{\partial \bar{E}}{\partial t} d\bar{S} \quad (16)$$

An analysis of relations (15) and (16) shows that they appear somewhat more complex than the expressions for calculating the electric field. This is due to two reasons. Firstly, on the left side of equation (15) there is an operation for finding the rotor, a this operation more difficult operations calculation divergences (cm. 1.8). Magnetic field directed perpendicularly to current And direction from points, V which the calculation is carried out. The current density is not the source of the divergence from this points magnetic fields, A defines rotational his component. This operation is closer to a vector product than a scalar one. Indeed, if we introduce a fictitious vector with projections in a rectangular coordinate system

$$\left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z} \right)$$

That left Part equations (8) Can introduce V view scalar produced

niya $\epsilon_a \bar{\nabla} \bar{E}$, A left Part equations (15) V view vector works $\bar{\nabla} \times \bar{H}$

Secondly, V equation (16) V right parts except density current there is one more term:

$$\bar{j}_{e_{cm}} = \epsilon_a \frac{\partial \bar{E}}{\partial t} \quad (17)$$

From structures expressions (16) follows count this one size more one view current. Her is called the displacement current. Like this, thus, magnetic field created by conduction current or displacement current.

The process of the emergence of a magnetic field from the second term on the right side of the expression (15) can be considered in a different way. Magnetic field arises then, when there is current or changing electric field. A changing electric field creates a changing magnetic field. This process can be called induction. However, electromagnetic induction is usually used to refer to the reverse process - emergence of electric fields at change magnetic.

Expressions for calculating the magnetic field (15) and (16) can be written for alternating currents changing with a certain circular frequency, using the method of complex amplitudes.

$$\text{rot} \vec{H} = \vec{j} + i\omega \epsilon_n \vec{E} \quad (18)$$

$$\oint_L \vec{H} d\vec{l} = \vec{I}_s + i\omega \int_S \epsilon_n \vec{E} d\vec{S} \quad (19)$$

So, received equation Maxwell, allowing calculate magnetic field created by electric conduction and displacement currents.

Let us apply the principle of permutation duality to Maxwell's third equation and write the law of electromagnetic induction sequentially in differential (20), integral (21) form and for the complex amplitude of the field strength (22), (23).

$$\text{rot} \vec{E} = -\vec{j}_m - \mu_0 \frac{\partial \vec{H}}{\partial t} \quad (20)$$

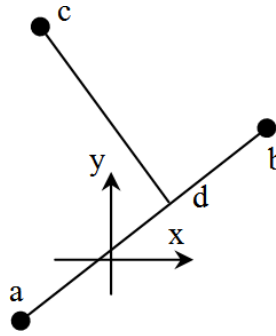
$$\oint_L \vec{E} d\vec{l} = -I_m - \mu_0 \int_S \frac{\partial \vec{H}}{\partial t} d\vec{S} \quad (21)$$

$$\text{rot} \vec{E} = -\vec{j}_m - i\omega \mu_n \vec{H} \quad (22)$$

$$\oint_L \vec{E} d\vec{l} = -\vec{I}_m - i\omega \int_S \mu_n \vec{H} d\vec{S} \quad (23)$$

Methodological recommendations By decision practical tasks

Let's consider methodology calculation magnetic fields, created a set of current-carrying conductors in a region of space described by coordinates x, y . Let us imagine what through point A, described coordinates x_n and y_n , and period $b(x_k, y_k)$ passes conductor with electric shock I_1 (cm. rice. 3). Necessary calculated
thief magnetic field V point With.



Rice. 3.

The magnetic induction for an infinite current-carrying conductor is calculated from the ratio

$$\vec{B} := \frac{\mu_0 I_1}{2\pi r} [\vec{e}_1 \times \vec{e}_r] \quad (24).$$

The magnetic induction vector B is a vector product And directed perpendicularly two straight ab And cd (cm. rice. 3). One from them (ab) - conductor, By to whom passes current. Second (cd) - perpendicular, lowered from points, V which is calculated magnetic induction on this one straight line. Let's arrange these both straight V planes drawing (cm. drawing). Then the magnetic induction at point c will always be directed perpendicular to the plane of the drawing .

By on the move calculations need to find distance between point, V which is calculated induction (**With**) And direct By which passes current (ab). For this we will perform two operations:

- 1) let's make up equation direct - conductor With electric shock;
- 2) let's define distance from selected points to this direct.

The equation of a straight line on a plane in general has the form: $Ax + By + C = 0$, where A , B , C - constant coefficients. If straight passes through two points with coordinates of the starting point (x_n, y_n) and the ending point (x_k, y_k), then its equation can be written as follows:

$$x(y_k - y_n) + y(x_n - x_k) + (x_k \cdot y_n - x_n \cdot y_k) = 0, \quad (25)$$

t.e. $A = (y_k - y_n)$; $B = (x_n - x_k)$; $C = (x_k \cdot y_n - x_n \cdot y_k)$.

The distance from the point for which the calculation is carried out, with coordinates (x_p, y_p), to the straight line – the current-carrying conductor, is found using the formula

$$r(x_p, y_p) := \pm \frac{Ax_p + By_p + C}{\sqrt{A^2 + B^2} \cdot (-\text{sign}C)}. \quad (26)$$

Thus, all the quantities in expression (24) for calculating the magnetic field are determined. If the magnetic field at the calculation point is created by currents flowing through several conductors, then the magnitude of the magnetic induction at the point is determined according to the principle of superposition, as the sum of the magnetic inductions from each field source, i.e.

$$BS(x_p, y_p) := \sum_i BI(x_p, y_p)_i \quad (27)$$

If a conducting circuit is placed in an alternating magnetic field, an EMF will arise in it. Let's consider a method for calculating the electromotive force created by an alternating magnetic field in a circuit.

Let's take advantage of its expression (2.21), on basis of which let's write it down

$$\oint_L \vec{E} d\vec{l} = -\dot{I}_M - i\omega \int_S \mu_n \vec{H} d\vec{S} = -\dot{I}_M - i\omega \int_S \vec{B} d\vec{S} \quad (28)$$

On the left side of the equation is an expression that determines the electromotive force. First term $\dot{I}_M$ right parts - magnetic current. If $\dot{I}_M$ conditions tasks are absent, that is equal to zero. Second term should be used for calculation. For calculation integral necessary define magnetic values induction B each point surfaces, limited contour. If the space is limited by a rectangular contour in which the magnetic induction is calculated in $(i_{xm} \times i_{ym})$ number of points, then the integral can be replaced by the sum over the surface of a rectangle with an area of $x_l \times y_l$, i.e.

$$\frac{1}{-i\omega} \oint_L \vec{E} d\vec{l} = \int_S \vec{B} d\vec{S} \approx \sum_k B_k \Delta S_k = \Delta S \sum_k B_k = \frac{x_l y_l}{i_{xm} i_{ym}} \sum_k B_k \quad (29)$$

Then for calculation EMF need to enter expression:

$$E = -i\omega \frac{x_l * y_l}{i_{xm} * i_{ym}} \sum_{ix} \sum_{iy} B_{S_{ix,iy}} \quad (30)$$

Content practical work, performed students on the first academic question

1. Description laboratory equipment:

– PC With established system computer algebra "Mathcad- 14".

2. Initial data For modeling And research

Options tasks For modeling And research given V tables 1.1 – 1.3.

Table 1.1 - Coordinates segment direct

Вариант	Начало			Конец		
	x1	y1	z1	x2	y2	z2
1	12	14	30	16	18	40
2	8	14	30	12	18	40
3	4	14	30	8	18	40
4	0	14	30	4	18	40
5	-4	14	30	0	18	40
6	-8	14	30	-4	18	40
7	-12	14	30	-8	18	40
8	12	14	30	12	18	40
9	8	14	30	12	18	40
10	4	14	30	8	18	40
11	0	14	30	4	18	40
12	-4	14	30	0	18	40
13	-8	14	30	-4	18	40
14	-12	14	30	-8	18	40
15	12	14	30	16	18	40
16	8	14	30	12	18	40
17	4	14	30	8	18	40
18	0	14	30	4	18	40
19	-4	14	30	0	18	40
20	-8	14	30	-4	18	40
21	-12	14	30	-8	18	40
22	12	14	30	16	18	40
23	8	14	30	12	18	40
24	4	14	30	8	18	40
25	0	14	30	4	18	40
26	-4	14	30	0	18	40

3. Exercise For work

Basic level:

- 1) To simulate and investigate in the Mathcad system the non-relativistic motion of charged particles in a magnetic field.
- 2) To simulate and investigate in the Mathcad system the magnetic field from a discrete set of constant electric currents.

Increased level:

- 3) Simulate And research V system Mathcad variable magnetic field and the phenomenon of electromagnetic induction.

Task 1.1. Model and investigate in the Mathcad system the non-relativistic motion of charged particles in a magnetic field.

1. **Initial data For modeling** - V three-dimensional space exists homogeneous magnetic field, at whom vector magnetic induction **In** direction V along axes **Y** . IN space fields hits charged particle mass **m_o** , possessing charge **q** , moving With non-relativistic speed **V_o** at an angle α to the magnetic field. At the initial moment of time, the coordinates of the particle were equal to zero.

The task of modeling is to obtain the trajectory of a charged particle in a uniform magnetic field in the Mathcad system, calculate the Lorentz force, the radius of the circle and the pitch of the helical trajectory of the charge.

The initial data for modeling for each option are given in Table 1.2.

Table 1.2 - Initial data For modeling.

<i>Option</i>	<i>m_o, kg</i>	<i>q, Cl</i>	<i>IN, Intramuscularly</i>	<i>V_o, m/s</i>	<i>α, hail</i>
1.	$1,7 \cdot 10^{-27}$	$1,6 \cdot 10^{-19}$	$10 \cdot 10^{-8}$	1000	40
2.	$1,8 \cdot 10^{-27}$	$3,2 \cdot 10^{-19}$	$9 \cdot 10^{-8}$	1100	50
3.	$1,9 \cdot 10^{-27}$	$4,8 \cdot 10^{-19}$	$8 \cdot 10^{-8}$	1200	30
4.	$2 \cdot 10^{-27}$	$-1,6 \cdot 10^{-19}$	$7 \cdot 10^{-8}$	1300	40
5.	$2,2 \cdot 10^{-27}$	$-3,2 \cdot 10^{-19}$	$6 \cdot 10^{-8}$	1400	50
6.	$2,5 \cdot 10^{-27}$	$-4,8 \cdot 10^{-19}$	$5 \cdot 10^{-8}$	1500	60
7.	$2,3 \cdot 10^{-27}$	$-3,2 \cdot 10^{-19}$	$4 \cdot 10^{-8}$	1400	70
8.	$2,1 \cdot 10^{-27}$	$-1,6 \cdot 10^{-19}$	$3 \cdot 10^{-8}$	1200	80
9.	$1,6 \cdot 10^{-27}$	$1,6 \cdot 10^{-19}$	$2 \cdot 10^{-8}$	1000	70
10.	$1,5 \cdot 10^{-27}$	$-1,6 \cdot 10^{-19}$	$1 \cdot 10^{-8}$	900	60
11.	$1,4 \cdot 10^{-27}$	$-1,6 \cdot 10^{-19}$	$1,5 \cdot 10^{-8}$	800	50
12.	$1,3 \cdot 10^{-27}$	$1,6 \cdot 10^{-19}$	$2,5 \cdot 10^{-8}$	700	40
13.	$1,6 \cdot 10^{-27}$	$-1,6 \cdot 10^{-19}$	$3,5 \cdot 10^{-8}$	1100	50
14.	$1,8 \cdot 10^{-27}$	$-3,2 \cdot 10^{-19}$	$4,5 \cdot 10^{-8}$	1200	65
15.	$1,9 \cdot 10^{-27}$	$-4,8 \cdot 10^{-19}$	$5,5 \cdot 10^{-8}$	1300	85
16.	$2 \cdot 10^{-27}$	$1,6 \cdot 10^{-19}$	$6,5 \cdot 10^{-8}$	1000	45
17.	$2,1 \cdot 10^{-27}$	$3,2 \cdot 10^{-19}$	$7,5 \cdot 10^{-8}$	900	55
18.	$2,2 \cdot 10^{-27}$	$4,8 \cdot 10^{-19}$	$8,5 \cdot 10^{-8}$	800	35
19.	$1,7 \cdot 10^{-27}$	$3,2 \cdot 10^{-19}$	$9,5 \cdot 10^{-8}$	700	45
20.	$1,5 \cdot 10^{-27}$	$-3,2 \cdot 10^{-19}$	$5,7 \cdot 10^{-8}$	600	55
21.	$1,4 \cdot 10^{-27}$	$1,6 \cdot 10^{-19}$	$8,7 \cdot 10^{-8}$	500	65
22.	$1,3 \cdot 10^{-27}$	$-1,6 \cdot 10^{-19}$	$6,6 \cdot 10^{-8}$	600	75
23.	$1,2 \cdot 10^{-27}$	$1,6 \cdot 10^{-19}$	$4,3 \cdot 10^{-8}$	700	85
24.	$1,8 \cdot 10^{-27}$	$-1,6 \cdot 10^{-19}$	$3,8 \cdot 10^{-8}$	800	75
25.	$1,9 \cdot 10^{-27}$	$-3,2 \cdot 10^{-19}$	$7,2 \cdot 10^{-8}$	900	65

2. Algorithm modeling V system "Mathcad".

1) Enter the initial data in the working window of the program according to your option: **B**, **m_o**, **q**, **V_o**, **α**.

2) Set the boundary points of the interval **t1:= 0**, **t2:= 10**, on which the solution of differential equations (9) will be sought to determine the trajectory of movement charge, A Also number points **N:= 1000**, V which approximately this solution is being sought.

3) Enter operators for calculating the projections of the velocity vector onto the coordinate axes :

$$V_x = V_0 \cdot \sin\left(\frac{\alpha \cdot \pi}{180}\right) \quad V_y = V_0 \cdot \cos\left(\frac{\alpha \cdot \pi}{180}\right) \quad V_z = 0.$$

Enter vector speed V view

$$V = \begin{pmatrix} V_x \\ V_y \\ V_z \end{pmatrix}.$$

4) Enter operator For calculation vectors forces Lorenz:

$$F = |q| \cdot V \cdot B.$$

5) Form vector initial conditions For solutions systems differential equations

(9):

$$u = \begin{pmatrix} 0 \\ V_x \\ 0 \\ |V_y| \\ 0 \\ |V_z| \end{pmatrix} \begin{array}{l} \leftarrow \text{coordinates particles V elementary moment time By axes X,} \\ \leftarrow \text{speed particles V elementary moment time along axes X,} \\ \leftarrow \text{coordinates particles V elementary moment time By axes Y,} \\ \leftarrow \text{speed particles V elementary moment time along axes Y,} \\ \leftarrow \text{coordinates particles V elementary moment time By axes Z,} \\ \leftarrow \text{speed particles V elementary moment time along axes Z.} \end{array}$$

6) Form a vector of first and second derivatives to solve the system of differential equations (2.9):

$$D(t, u) = \begin{pmatrix} u_1 \\ -B \cdot q \\ \frac{mo}{u_3} \cdot at^5 \\ u_3 \\ 0 \\ \frac{B \cdot q}{mo} \cdot u \\ 1 \end{pmatrix} \begin{array}{l} \leftarrow x'(t) - \text{first derivative } x \text{ By } t, \\ \leftarrow x''(t) - \text{second derivative } x \text{ By } t, \\ \leftarrow y'(t) - \text{first derivative } y \text{ By } t, \\ \leftarrow y''(t) - \text{second derivative } y \text{ By } t, \\ \leftarrow z'(t) - \text{first derivative } z \text{ By } t, \\ \leftarrow z''(t) - \text{second derivative } z \text{ By } t. \end{array}$$

7) For solutions systems differential equations (9) method Runge-Kutta fourth order introduce the function **rkfixed**. It calculates a matrix whose first column contains the points at which solutions must be found, A rest columns contain values decisions (coordinates) And their first derivatives:

$$Z = rkfixed(u, t_1, t_2, N, D).$$

8) Introduce operators to calculate the radius **R** of the circle of the charge's trajectory and pitch **h** of the helical (spiral) line of the trajectory of motion, as well as the cyclic frequency ω rotations:

$$R = \frac{mo \cdot V_x}{|q| \cdot B}, \quad h = \frac{2 \square \cdot mo \cdot V_y}{|q| \cdot B}, \quad .$$

9) For constructions trajectories movements particles enter operators, defining coordinates:

$$x = Z^{\langle 1 \rangle}, y = Z^{\langle 3 \rangle}, z = Z^{\langle 5 \rangle},$$

Where operator $Z^{\langle n \rangle}$ means selection n -th column matrices Z .

10) To construct the trajectory of the particle, introduce 2-dimensional graphs of the dependence $z(x)$ and $z(y)$, as well as a 3-dimensional graph of the dependence $z(x, y)$.

To enter 2-dimensional graphs, click on the toolbar in sequence. on badges (pictograms)  $\rightarrow$  or otherwise (Insert $\rightarrow$ Schedule $\rightarrow$ X-Y graph). In the graph template that opens, insert z in the function entry field, and x or y in the variable entry field.

For input 3-dimensional graphics trajectories movements particles on panels tools, click on the icons (pictograms) in sequence  $\rightarrow$  or otherwise (Insert $\rightarrow$ Schedule $\rightarrow$ 3-x measured schedule), at this V opened In the graph template, in the place where the function is entered, insert the coordinates of the function in brackets, i.e. (x, y, z) .

3. **Conduct a compliance check of the developed model with the real physical system**. In this case, it is necessary to establish whether the obtained model matches trajectory movements charged particles V homogeneous magnetic field with known theoretical results. To do this, use a 3-dimensional graph to plot the particle's trajectory and compare it with the trajectory shown in Figure 2.

4. **Conduct a study of the dependence of the trajectory of a particle on the magnitude of magnetic induction B and its directions**. For this, first decrease given magnetic field induction by 2 times, A then increase the initial value by 2 times, then set the initial value B with a negative sign, which means changing the direction of the induction vector to the opposite.

For each values magnetic induction B produce:

- calculation vectors forces Lorenz F , radius circles R , step screw motion h and rotation frequency ω ;
- get trajectory movements charged particles V view 3-x dimensional graph and 2-dimensional graphs of the dependence $z(x)$ and $z(y)$;
- define direction rotation.

Analyze received results And install, How depend listed characteristics trajectories movements from quantities magnetic induction.

5. **Conduct a study of the dependence of the particle trajectory from her initial speed movements V_o** . For this at first reduce the set speed by 2 times, and then increase the original speed by 2 times.

For each values speed V_o produce:

- calculation vectors forces Lorenz F , radius circles R , step screw motion h ;

- get trajectory movements charged particles V view 3-x dimensional graph and 2-dimensional graphs of the dependence $z(x)$ and $z(y)$;
- define direction vectors forces Lorenz.

Analyze received results And install, How depend the listed characteristics of the trajectory of movement from the initial speed.

6. ***Conduct a study of the dependence of the trajectory of a particle on its initial mass m_0*** . For this first reduces the mass by half, and then increases it by two.

For each values masses particles m_0 produce:

- calculation vectors forces Lorenz F , radius circles R , step screw motion h and rotation frequency ω ;

- get trajectory movements charged particles V view 3-x dimensional graph and 2-dimensional graphs of the dependence $z(x)$ and $z(y)$.

Analyze received results And install, How depend the listed characteristics of the trajectory of motion depend on the magnitude of the particle mass.

7. ***Conduct a study of the dependence of the particle trajectory from quantities her charge q And his sign*** . For this at first decrease charge in two, A then increase V two, at this For each quantities charge change the sign to the opposite.

For each values charge particles $\pm q$ produce:

- calculation vectors forces Lorenz F , radius circles R , step screw motion h and rotation frequency ω ;

- get trajectory movements charged particles V view 3-x dimensional graph and 2-dimensional graphs of the dependence $z(x)$ and $z(y)$;

- define direction rotation.

Analyze received results And install, How depend listed characteristics trajectories movements from quantities And sign charge particles .

8. ***Conduct a study of the dependence of the particle trajectory from the magnitude of the angle α between the velocity vectors of magnetic motion induction*** . For this at first decrease corner V two times, A then set it equal 90° , i.e. to conduct a simulation special case, when the velocity vector directed along axes X , those. perpendicularly vector magnetic induction B .

For each values angle α produce:

- calculation vectors forces Lorenz F , radius circles R , step screw motion h ;
- get trajectory movements charged particles V view 3-x dimensional graph and 2-dimensional graphs of the dependence $z(x)$ and $z(y)$.

Analyze received results And install, How depend the listed characteristics of the trajectory of movement from the value of the angle α .

9. Draw conclusions based on the results of the work done. In the conclusions, reflect how the trajectory of the charged particle and its parameters (R ,

h , ω) from the change in the particle parameters (q , mo , Vo) and the magnetic field parameters (B , F).

Task 1.2. Model and investigate in the Mathcad system the magnetic field from a discrete set of constant electric currents.

1. Initial data For modeling - V three-dimensional space, for which dielectric And magnetic permeability equal respectively

$\varepsilon = 1$ and $\mu = 1$, 4 infinitely long conductors with constant currents are placed in the XOY plane. The first conductor passes through the points with coordinates (xn_1 , yn_1) and (xk_1 , yk_1); the second conductor – with coordinates (xn_2 , yn_2) and (xk_2 , yk_2); the third conductor – with coordinates (xn_3 , yn_3) and (xk_3 , yk_3). Variants with the initial data of the coordinates through which the conductors pass and the magnitudes of the electric currents in the conductors are given in Table 1.3.

The task of the modeling is to create a program for calculating the magnetic induction at 100 points in space, uniformly distributed in a given rectangle, the coordinates of which are (x1, y1), (x1, y2), (x2, y2), (x2, y1). Based on the calculated data, construct a three-dimensional graph of the field distribution within the given rectangle.

Options coordinates rectangular areas spaces, V which The magnetic field is calculated and is given in Table 1.1.

Table 1.3 - Initial data For modeling magnetic fields

Optio n	No. wire .	Current, ma	xn1	yn1	xk1	yk1	Optio n	No. wire .	Current, ma	xn1	yn1	xk1	yk1
1	1	$(20+13j) \cdot 10^{-3}$	- 2	- 3	- 2	- 6	14	1	$(14+7j) \cdot 10^{-3}$	2	1	0	6
	2	$(15-17y) \cdot 10^{-3}$	- 2	- 6	- 8	- 6		2	$(12-6j) \cdot 10^{-3}$	0	6	7	6
	3	$(30+10j) \cdot 10^{-3}$	- 8	- 6	- 8	- 3		3	$(45+23j) \cdot 10^{-3}$	7	6	5	1
	4	$(25-25j) \cdot 10^{-3}$	- 8	- 3	- 2	- 3		4	$(20-11j) \cdot 10^{-3}$	5	1	2	1
2	1	$(40+9j) \cdot 10^{-3}$	- 2	- 1	0	- 6	15	1	$(29-13j) \cdot 10^{-3}$	- 8	- 4	- 3	- 5
	2	$(10-15j) \cdot 10^{-3}$	0	- 6	- 9	- 6		2	$(19+9j) \cdot 10^{-3}$	- 3	- 5	- 3	- 8
	3	$(25+11j) \cdot 10^{-3}$	- 9	- 6	- 7	- 1		3	$(22+12d) \cdot 10^{-3}$	- 3	- 8	- 8	- 10
	4	$(30-23d) \cdot 10^{-3}$	- 7	- 1	- 2	- 1		4	$(30-15d) \cdot 10^{-3}$	- 8	- 10	- 8	- 4
3	1	$(10+13j) \cdot 10^{-3}$	- 2	- 1	0	- 6	16	1	$(37+19j) \cdot 10^{-3}$	- 8	- 4	- 3	- 5
	2	$(10-13j) \cdot 10^{-3}$	0	- 6	- 7	- 3		2	$(24 + 14j) \cdot 10^{-3}$	- 3	- 5	- 3	- 8
	3	$(10 + 8j) \cdot 10^{-3}$	- 7	- 3	- 2	- 2		3	$(16-8j) \cdot 10^{-3}$	- 3	- 8	- 8	- 10

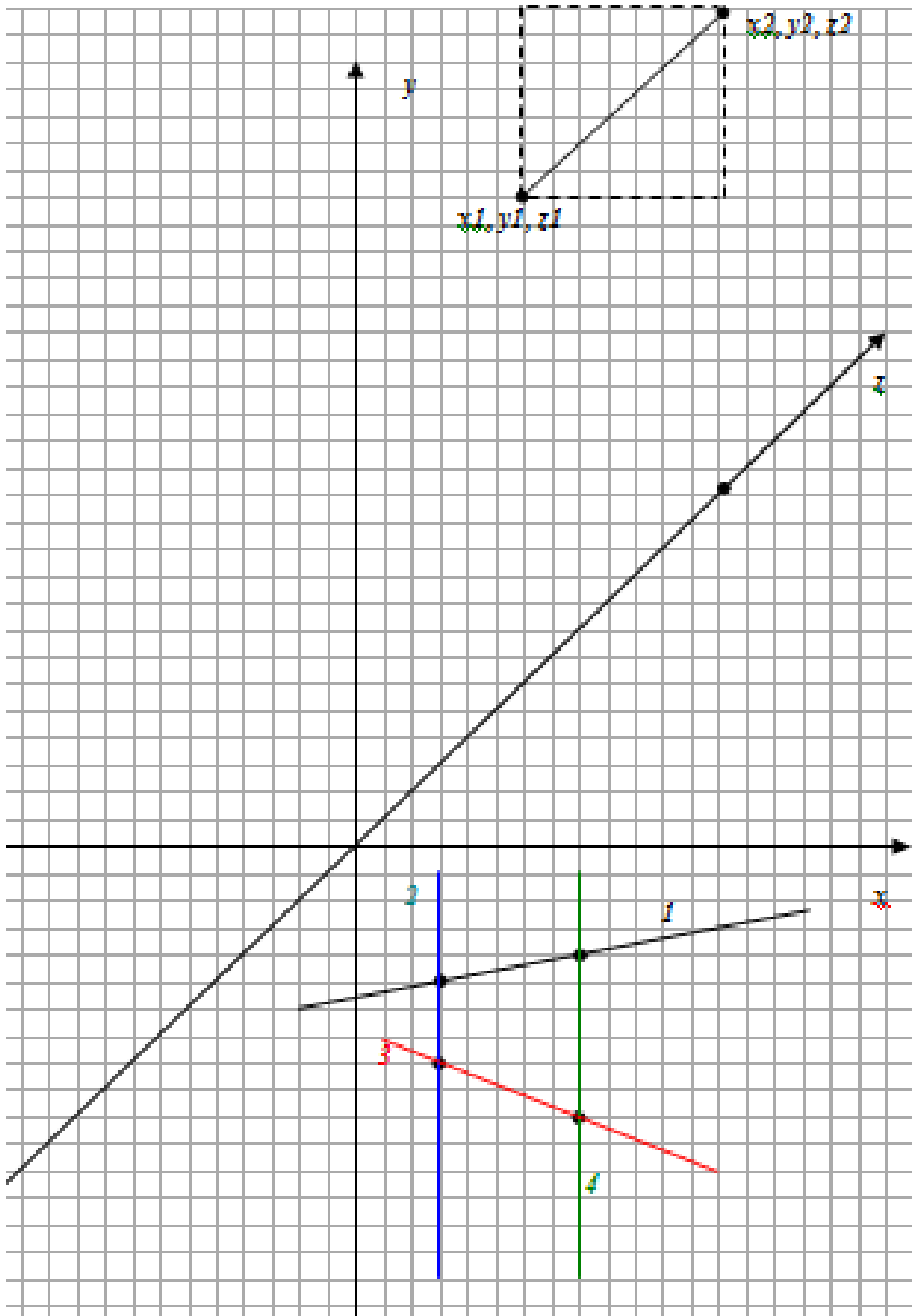
	4	$(25+19d) \cdot 10^{-3}$	- 7	- 3	- 1	- 4		4	$(45+21d) \cdot 10^{-3}$	- 8	- 10	- 8	- 4
4	1	$(17-11d) \cdot 10^{-3}$	- 8	-4	-3	-5	17	1	$(18+10j) \cdot 10^{-3}$	2	-1	0	-6
	2	$(29+13j) \cdot 10^{-3}$	-3	-5	-3	-8		2	$(26+13j) \cdot 10^{-3}$	0	- 6	7	- 3
	3	$(33+18j) \cdot 10^{-3}$	- 3	- 8	- 8	- 10		3	$(14-7j) \cdot 10^{-3}$	7	- 3	2	- 2
	4	$(14-6j) \cdot 10^{-3}$	- 8	- 10	-8	-4		4	$(30+17j) \cdot 10^{-3}$	7	-3	1	-4
5	1	$(40-23j) \cdot 10^{-3}$	2	-3	2	-6	18	1	$(41+14j) \cdot 10^{-3}$	-8	-4	-3	-5
	2	$(30+14j) \cdot 10^{-3}$	2	-6	8	-6		2	$(14+41j) \cdot 10^{-3}$	-3	-5	-3	-8
	3	$(20-17j) \cdot 10^{-3}$	8	-6	8	- 3		3	$(14-13j) \cdot 10^{-3}$	- 3	- 8	- 8	- 10
Optio n	No. wire .	Current, ma	xn1	yn1	xk1	yk1	Optio n	No. wire .	Current, ma	xn1	yn1	xk1	yk1
	4	$(10+10j) \cdot 10^{-3}$	8	-3	2	-3		4	$(25+6j) \cdot 10^{-3}$	-8	-10	-8	-4
6	1	$(33+3j) \cdot 10^{-3}$	2	-1	0	- 6	19	1	$(22+11j) \cdot 10^{-3}$	2	- 3	2	- 6
	2	$(27+7j) \cdot 10^{-3}$	0	- 6	9	- 6		2	$(33+23j) \cdot 10^{-3}$	2	- 6	8	- 6
	3	$(18-8) \cdot 10^{-3}$	9	- 6	7	- 1		3	$(44+14j) \cdot 10^{-3}$	8	- 6	8	- 3
	4	$(45+23j) \cdot 10^{-3}$	7	- 1	2	- 1		4	$(11-2) \cdot 10^{-3}$	8	- 3	2	- 3
7	1	$(14+7j) \cdot 10^{-3}$	2	- 1	0	- 6	20	1	$(23-10j) \cdot 10^{-3}$	2	- 3	2	- 6
	2	$(12-6j) \cdot 10^{-3}$	0	- 6	7	- 3		2	$(32+16j) \cdot 10^{-3}$	2	- 6	8	- 6
	3	$(45+23j) \cdot 10^{-3}$	7	- 3	2	- 2		3	$(17+7j) \cdot 10^{-3}$	8	- 6	8	- 3
	4	$(20-11j) \cdot 10^{-3}$	7	- 3	1	- 4		4	$(19-9j) \cdot 10^{-3}$	8	- 3	2	- 3
8	1	$(29-13j) \cdot 10^{-3}$	- 8	4	- 3	5	21	1	$(20+13j) \cdot 10^{-3}$	2	- 3	2	3
	2	$(19+9j) \cdot 10^{-3}$	- 3	5	- 3	8		2	$(15-17j) \cdot 10^{-3}$	2	3	8	3
	3	$(22+12j) \cdot 10^{-3}$	-3	8	-8	10		3	$(30+10j) \cdot 10^{-3}$	8	3	8	-3
	4	$(30-15j) \cdot 10^{-3}$	-8	10	- 8	4		4	$(25-25j) \cdot 10^{-3}$	8	- 3	2	- 3
9	1	$(37+19j) \cdot 10^{-3}$	2	- 3	2	- 6	22	1	$(40+9j) \cdot 10^{-3}$	- 2	1	0	6
	2	$(24 + 14j) \cdot 10^{-3}$	2	- 6	8	- 6		2	$(10-15j) \cdot 10^{-3}$	0	6	- 7	3
	3	$(16-8j) \cdot 10^{-3}$	8	- 6	8	- 3		3	$(25+11j) \cdot 10^{-3}$	7	3	2	2
	4	$(45+21j) \cdot 10^{-3}$	8	- 3	2	- 3		4	$(30-23j) \cdot 10^{-3}$	7	3	1	4
10	1	$(18+10j) \cdot 10^{-3}$	- 2	3	- 2	6	23	1	$(10+13j) \cdot 10^{-3}$	- 2	1	0	6
	2	$(26+13j) \cdot 10^{-3}$	- 2	6	- 8	6		2	$(10-13j) \cdot 10^{-3}$	0	6	- 7	3
	3	$(14-7j) \cdot 10^{-3}$	- 8	6	- 8	3		3	$(10+8j) \cdot 10^{-3}$	7	3	2	2
	4	$(30+17j) \cdot 10^{-3}$	- 8	3	- 2	3		4	$(25+19j) \cdot 10^{-3}$	7	3	1	4

11	1	$(41+14j) \cdot 10^{-3}$	-8	-4	-3	-5	24	1	$(17-11j) \cdot 10^{-3}$	-2	-3	-2	-6
	2	$(14+41j) \cdot 10^{-3}$	-3	-5	-3	-8		2	$(29+13j) \cdot 10^{-3}$	-2	-6	-8	-6
	3	$(14-13j) \cdot 10^{-3}$	-3	-8	-8	-10		3	$(33+18j) \cdot 10^{-3}$	-8	-6	-8	-3
	4	$(25+6j) \cdot 10^{-3}$	-8	-10	-8	-4		4	$(14-6j) \cdot 10^{-3}$	-8	-3	-2	-3
12	1	$(22+11j) \cdot 10^{-3}$	2	3	2	6	25	1	$(40-23j) \cdot 10^{-3}$	8	-4	3	-5
	2	$(33+23j) \cdot 10^{-3}$	2	6	8	6		2	$(30+14j) \cdot 10^{-3}$	3	-5	3	-8
	3	$(44+14j) \cdot 10^{-3}$	8	6	8	3		3	$(20-17j) \cdot 10^{-3}$	3	-8	8	-10
	4	$(11-2) \cdot 10^{-3}$	8	3	2	3		4	$(10+10j) \cdot 10^{-3}$	8	-10	8	-4
13	1	$(23-10j) \cdot 10^{-3}$	2	1	0	-4	26	1	$(33+3j) \cdot 10^{-3}$	8	-4	3	-5
	2	$(32+16j) \cdot 10^{-3}$	0	-4	9	-4		2	$(27+7j) \cdot 10^{-3}$	3	-5	3	-8
	3	$(17+7j) \cdot 10^{-3}$	9	-4	7	1		3	$(18-8) \cdot 10^{-3}$	3	-8	8	-10
	4	$(19-9j) \cdot 10^{-3}$	7	1	2	1		4	$(45+23j) \cdot 10^{-3}$	8	-10	8	-4

2. Construct on one drawing a geometric model of conductors and a rectangular area in which the magnetic field is calculated.

An example of a geometric model is shown in Fig. 4. In this figure, the black line indicates the 1st conductor with current, which creates a magnetic field, the blue line indicates the 2nd conductor, the red line indicates the 3rd conductor, and the green line indicates the 4th conductor. Infinitely long conductors pass through points With given coordinates given in Table 1.3.

The dotted line in Fig. 4 shows a rectangular region of space, V which is determined magnetic field, created conductors with currents. This region spaces is being built on base segment, passing through the points (x_1, y_1, z_1) and (x_2, y_2, z_2).



Rice. 4 - Example geometric models For tasks 1.2

Geometric model allows a priori define, which conductors with electric shock contribute more or less contribution V created magnetic field V from the studied area of space.

3. Algorithm calculation fields V system "Mathcad".

1) Enter V working window programs original data:

– dielectric permeability vacuum or electrical constant-

$$\epsilon_0 = 10^{-9} / 36 \cdot \pi ;$$

– relative dielectric permeability Wednesday $\epsilon = 1$;

– magnetic permeability of vacuum or magnetic constant

$$\mu_0 = 4 \pi \cdot 10^{-7} ;$$

– relative magnetic permeability Wednesday $\mu = 1$;

– number conductor With electric shock, $i = 0 \dots 3$;

– coordinates of the initial points x_n , y_n and the final points x_k , y_k , through which the conductors pass, as well as the values of their currents, taking from Table 1.3 only the real part, in the form of single-column four-element matrices, for example

$$x_n := \begin{pmatrix} 2 \\ 2 \\ 8 \\ 8 \end{pmatrix} \quad y_n := \begin{pmatrix} 3 \\ 6 \\ 6 \\ 3 \end{pmatrix} \quad x_k := \begin{pmatrix} 2 \\ 8 \\ 8 \\ 2 \end{pmatrix} \quad y_k := \begin{pmatrix} 6 \\ 6 \\ 3 \\ 3 \end{pmatrix} \quad I := \begin{pmatrix} 11 \cdot 10^{-3} \\ 12 \cdot 10^{-3} \\ 13 \cdot 10^{-3} \\ 14 \cdot 10^{-3} \end{pmatrix} .$$

– coordinates of the diagonal of the rectangular area (x_1 , y_1), (x_2 , y_2) from Table 1.1, at the points of which the magnetic field is calculated, for example:

$$x_1 := -12 \quad y_1 := 14 \quad x_2 := -4 \quad y_2 := 18 ;$$

– $M=10$ – the number of elements in the matrix coordinates of the point, in which the magnetic field is calculated,

– i_x , i_y – the current number of the column and row of the matrix of coordinates of the point, in which the magnetic field is calculated -

$$i_x := 0..M \quad i_y := 0..M .$$

2) Enter formulas For intermediate calculations:

– absolute dielectric permeability Wednesday $\epsilon_a = \epsilon_0 \cdot \epsilon$;

– absolute magnetic permeability Wednesday $\mu_a = \mu_0 \cdot \mu$;

– current coordinates By axes X And at for points, in which will magnetic field is calculated:

$$x_{p_{i_x}} := x_1 + \frac{i_x \cdot (x_2 - x_1)}{M} \quad y_{p_{i_y}} := y_1 + \frac{i_y \cdot (y_2 - y_1)}{M} ;$$

– matrices of coefficients of the equation of the i -th line describing the conductor through which the current passes:

$$\begin{aligned} \underline{\underline{A}}_i &:= y_{k_i} - y_{n_i} & B_i &:= x_{n_i} - x_{k_i} & \underline{\underline{C}}_i &:= x_{k_i} \cdot y_{n_i} - x_{n_i} \cdot y_{k_i} \\ & & \text{and} & & & \end{aligned}$$

3) Enter formulas For calculations:

– the shortest distance from the point for which the calculation is carried out to all straight lines on which current-carrying conductors are located

$$\begin{aligned} R0_{ix, iy} &:= \frac{A_0 \cdot xp_{ix} + B_0 \cdot yp_{iy} + C_0}{\left| \sqrt{(A_0)^2 + (B_0)^2} \cdot (-\text{sign}(C_0)) \right|} & R1_{ix, iy} &:= \frac{A_1 \cdot xp_{ix} + B_1 \cdot yp_{iy} + C_1}{\left| \sqrt{(A_1)^2 + (B_1)^2} \cdot (-\text{sign}(C_1)) \right|} \\ R2_{ix, iy} &:= \frac{A_2 \cdot xp_{ix} + B_2 \cdot yp_{iy} + C_2}{\left| \sqrt{(A_2)^2 + (B_2)^2} \cdot (-\text{sign}(C_2)) \right|} & R3_{ix, iy} &:= \frac{A_3 \cdot xp_{ix} + B_3 \cdot yp_{iy} + C_3}{\left| \sqrt{(A_3)^2 + (B_3)^2} \cdot (-\text{sign}(C_3)) \right|} ; \end{aligned}$$

– calculate values distances, by entering operators R0=, R1=, R2= And R3=, If distances will turn out to be negative, What physically Not acceptable, That to receive positive result enter sign minus V denominator corresponding expression, for example:

$$R0_{ix, iy} := \frac{A_0 \cdot xp_{ix} + B_0 \cdot yp_{iy} + C_0}{-\left| \sqrt{(A_0)^2 + (B_0)^2} \cdot (-\text{sign}(C_0)) \right|} ;$$

– magnetic induction V current point fields from each conductor

$$BI0_{ix, iy} := \frac{\mu a \cdot I_0}{2\pi \cdot R0_{ix, iy}} \quad BI1_{ix, iy} := \frac{\mu a \cdot I_1}{2\pi \cdot R1_{ix, iy}} \quad BI2_{ix, iy} := \frac{\mu a \cdot I_2}{2\pi \cdot R2_{ix, iy}} \quad BI3_{ix, iy} := \frac{\mu a \cdot I_3}{2\pi \cdot R3_{ix, iy}}$$

– size total magnetic induction fields V under consideration points in space:

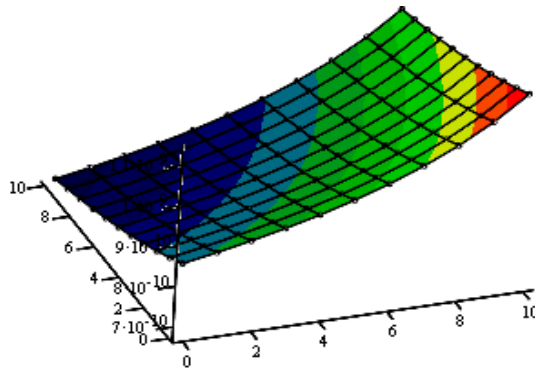
$$BS := BI0 + BI1 + BI2 + BI3 ;$$

– the magnitude of the magnetic field strength at the points in space under consideration:

$$\underline{\underline{H}} := \frac{BS}{\mu a}$$

4) Sharpen graphs distribution of magnetic induction And tension magnetic fields V given points space. For visualizations magnetic field in a given space, display a three-dimensional graph in the program, in which coordinates **x** And **y** indicate points fields, A coordinate **z** - meaning magnetic induction V these points fields. For constructions graphics on panels tools, click on the icons (pictograms) in sequence  →  (or otherwise Insert □ Graph □ 3-dimensional graph), while in the graph template that opens, in the place where you enter the function, insert the **BS** or **H function**.

5) Debug file, created V program MathCAD. Example The results of the simulation are shown in Figure 5.



BS

Rice. 5

4.2.4. Perform magnetic calculation fields With help programs in the system Mathcad By to his own given option:

- 1) Enter given original data.
- 2) Produce calculations.
- 3) Plot a graph of the distribution of magnetic induction and magnetic field strength at given points in space.
- 4) Determine the maximum and minimum values of the magnetic field strength at the points of the field. To do this, introduce the operators ***max(H)*** and ***min(H)*** and by clicking on key equals calculate from values, then V matrices ***BS*** And ***H*** find these values And define coordinates these points fields. Apply these coordinates on the drawing with the geometric model.

5. Conduct a study of the dependence of magnetic induction and magnetic field strength on the number of current-carrying conductors. To do this, perform the following operations:

- V matrix currents leave one by one one from currents, A to others assign values 0 (zero);
- perform calculations and plot a graph of the distribution of magnetic induction at given points in space;
- repeat calculation For others conductors And construction graphs;

6. Conduct a study of the dependence of magnetic induction and magnetic field strength on the magnitude of currents in conductors. To do this, perform the following operations:

- V matrix currents install given original data;
- arbitrarily change on order V big side size one of the currents;
- conduct calculations characteristics fields And build graphics;
- arbitrarily change signs two currents;
- conduct calculations characteristics fields And build graphics.

7. Do conclusions By results done work.

Task 1.3. Model and investigate in the Mathcad system an alternating magnetic field and the phenomenon of electromagnetic induction.

1. Initial data For modeling - V three-dimensional space, for which dielectric And magnetic permeability equal respectively

$\varepsilon = 1$ and $\mu = 1$, in the XOY plane there are 4 infinitely long conductors with alternating currents represented in complex form. The first conductor passes through points with coordinates (x_{n1}, y_{n1}) and (x_{k1}, y_{k1}) ; the second conductor – with coordinates (x_{n2}, y_{n2}) and (x_{k2}, y_{k2}) ; the third conductor – with coordinates (x_{n2}, y_{n2}) And (x_{k2}, y_{k2}) ; fourth conductor passes through points With coordinates (x_{n3}, y_{n3}) And (x_{k3}, y_{k3}) . Options With original data coordinates, through which the conductors pass, and the values of the complex electric currents in the conductors are given in Table 1.3. **The frequency of the alternating current is specified by the variant number N , multiplied by 10^6 Hz .**

The task of modeling is to create a program for calculating the magnitude of the electromotive force created by an alternating magnetic field in a conducting circuit, limiting rectangular region With coordinates $(x1, y1)$, $(x1, y2)$, $(x2, y2)$, $(x2, y1)$. Based on the calculated data, plot the dependence of the EMF in the circuit on time over several periods.

The variants of the coordinates of the circuit in which the EMF created by an alternating magnetic field is calculated are given in Table 1.1.

To solve this problem, it is necessary to modernize the program for calculating magnetic induction, created in the previous practical work, so that it would be possible to calculate the EMF of induction in a circuit (frame) from a set of alternating currents.

2. Load the file with the program developed during the previous task into the Mathcad system and save it under a new name.

3. Algorithm calculation EMF induction V system "Mathcad".

1) Enter V working window programs additional original data:

- imaginary unit $j := \sqrt{-1}$;
- linear frequency variable current $f = N \cdot 10^6$, Hz .
- quantities complex currents V view matrices

$$I := \begin{bmatrix} (11 + 3j) \cdot 10^{-3} \\ (12 + 6j) \cdot 10^{-3} \\ (13 + 4j) \cdot 10^{-3} \\ (14 + 3j) \cdot 10^{-3} \end{bmatrix} ;$$

- enter formula For calculation circular frequencies variable current

$$\omega := 2\pi \cdot f$$

2) Remove the operator for calculating the field strength and graphics in the previously developed program.

3) Enter formula For calculation EMF, being created V contour

$$E := -j \cdot \omega \cdot \frac{x1 \cdot x2}{M \cdot M} \cdot \left[\sum_{ix} \left(\sum_{iy} BS_{ix, iy} \right) \right]$$

4) Enter operators For calculation module And phase EMF

$$EM := |E| \quad \phi := \arg(E) \cdot \frac{180}{\pi}$$

5) Ask temporal cycle

$$t := 0, \frac{6\pi}{100 \cdot \omega} .. \frac{120\pi}{\omega}$$

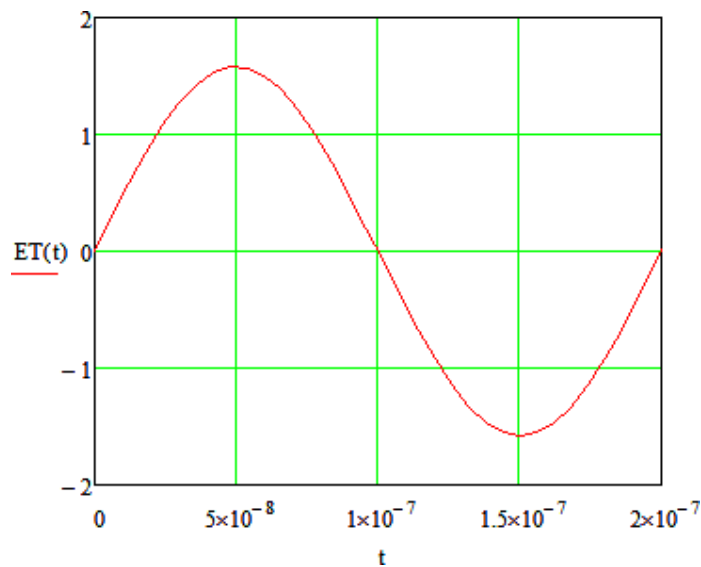
6) Enter operators For calculation EMF in temporal areas:

$$ET(t) := |E| \cdot \cos(\omega \cdot t + \arg(E))$$

7) Plot a graph of the EMF versus time. To do this, click the icons (pictograms) on the toolbar in sequence.  →  (or Insert □ Graph □ X-Y Graph). In the graph template that opens, in the input area functions insert t , V places input variable $ET(t)$. Ask maximum

meaning $t = 10^{-6} / N$.

On rice. 6 given example received EMF.



Rice. 6

4. Conduct a study of the dependence of the induced EMF in the circuit on the frequency of the alternating current. To do this, change the frequency values from f to $11f$ in increments of $2f$ calculate values module EMF induction. Build addition E from frequencies f . IN report bring graphs dependencies EMF from time For frequencies alternating current f and $11f$.

5. Conduct a study of the dependence of the induced EMF on the number of sources (conductors) variable current. For this to do next operations:

– in the current matrix, leave one of the currents in turn, multiplying the values of the other currents by 0 (zero);

- calculate the modulus and phase of the induced EMF; plot a graph of the time dependence of the induced EMF;
- repeat calculation For others conductors And construction graphs;
- define, Which conductor With electric shock creates the greatest EMF induction in the circuit.

6. Do conclusions By results done work.

5. Prepare a report on the work done on the second question in accordance with the requirements set out in the job description.

IN report bring:

- original data,
- performed tasks,
- compiled listings programs modeling,
- results of modeling and research – formulas describing the magnetic field and electromagnetic induction, obtained results and graphs ;
- conclusions O done work, with explanation physical meaning results obtained.

6. Protection practical work

For protection practical introduce fully decorated report, Free of significant errors. As directed by the teacher, complete one of the tasks from each question, explaining all the physical phenomena and processes occurring in the developed model.

LIST LITERATURE:

- 1) Sagdeev K.M. Physical foundations of information security [Electronic resource]: study guide / K.M. Sagdeev, V.I. Petrenko, A.F. Chipiga. - Electronic text data. - Stavropol: North Caucasus Federal University, 2015. - 394 p.
- 2) Evstifeev V.V. Physical foundations electricity and magnetism Electronic resource / Evstifeev V.V.: study guide. - Penza: PSU, 2019. - 416 p.
- 3) Bulatov V.N. Physical foundations of electronics Electronic resource / Bulatov V.N.: lecture notes for students in educational programs higher education in the following areas preparation 11.03.02 infocommunication technologies and communication systems. - Orenburg: OSU, 2018. - 178 p.
- 4) Goldstein A.E. Physical principles of obtaining information [Electronic resource]: textbook / A.E. Goldstein. — Electron. text data. — Tomsk: Tomsk Polytechnic University, 2010. — 292 p.

PRACTICAL JOB No. 7

TOPIC 7 PHENOMENON ELECTROMAGNETIC INDUCTION, ELECTROMAGNETIC FIELDS AND WAVES

Class 7 MODELING AND RESEARCH OF ELECTROMAGNETIC WAVES

TIME – 4 hours.

Educational questions:

1. Modeling And study electromagnetic waves.

TARGET PRACTICAL INSTALLATION WORKS:

Competencies, being formed discipline

OPK-1: Capable use provisions, laws And methods natural sciences and mathematics to solve engineering problems.

OPK-2: Capable on one's own conduct experimental research And use main techniques processing And performances received data.

Learning outcomes achieved as a result of completing practical work:

Be able to:

- apply physical laws and methods to formalize the representation of physical phenomena and processes that occur in telecommunications .
- conduct experimental research With help mathematical models according to the accepted methodology
- model And analyze main physical phenomena And processes in telecommunications using computer technology.

Own:

- skills use knowledge physicists at decision practical problems of engineering activities
- methods of processing and presenting data obtained as a result of experimental studies.
- skills in computer modeling of the main physical methods of receiving, transmitting and storing information.

EDUCATIONAL AND MATERIAL SECURITY:

- PC With system computer mathematicians Mathcad - 15";
- electronic methodological development By practical work.

STRUCTURE PRACTICAL WORKS:

Class No. 1		90 min
Introductory Part		10 min
Examination readiness students To practical work		8 min
Introductory Part		2 min
Questions (tasks), subject research:		75 min
1. Modeling And study electromagnetic waves.		75 min
Final Part		5 min
Summing up results		3 min
Exercise students For independent work		2 min
Class No. 2		90 min
Introductory Part		10 min
Examination readiness students To practical work		8 min
Introductory Part		2 min
Questions (tasks), subject research:		75 min
2. Modeling And study electromagnetic waves.		75 min
Final Part		5 min
Summing up results		3 min
Exercise students For independent work		2 min

1. MODELING AND STUDY ELECTROMAGNETIC WAVES

Brief theoretical or reference and information materials

The mathematical description of electromagnetic waves is obtained as a result solutions homogeneous equations Helmholtz, which directly follow from Maxwell's equations.

Equations Helmholtz

The second pair of Maxwell's equations is not always convenient to use because both vectors E and H are included in both the first and second equations of the pair. Usually these equations transform So, to vectors split up. This transformation Can to do in temporal areas And For complex amplitudes. In the first case, the equations are called wave equations, and in the second, Helmholtz equations. When analyzing electromagnetic processes in technical environments, Helmholtz equations are used.

$$\Delta \vec{H} + \gamma^2 \vec{H} = -\text{rot } \vec{j}_3 + i\omega \epsilon_a \vec{j}_M + \text{grad } \frac{\rho_M}{\mu_n}; \quad (1)$$

$$\Delta \vec{E} + \gamma^2 \vec{E} = \text{rot } \vec{j}_M + i\omega \mu_a \vec{j}_3 + \text{grad } \frac{\rho_3}{\epsilon_n}, \quad (2)$$

Where $\gamma = \omega \sqrt{\epsilon_n \mu_n}$ - constant distribution electromagnetic fields.

This differential equations second order With non-zero right partly. In this form, the Helmholtz equations are rarely used. More often, homogeneous equations are used that describe electromagnetic waves far from the source, i.e.

$$\Delta \vec{H} + \gamma^2 \vec{H} = 0; \quad (3)$$

$$\Delta \vec{E} + \gamma^2 \vec{E} = 0. \quad (4)$$

Electromagnetic field power flux density. Poynting vector

The electromagnetic field is capable of accumulating and transferring energy. The laws of change, conservation, and propagation of energy can be derived from Maxwell's equations.

For final volume V it's not difficult get such ratio:

$$\begin{aligned} \oint_V \text{div}[\vec{E} \times \vec{H}] \cdot d\vec{V} &= \oint_S [\vec{E} \times \vec{H}] d\vec{S} = \oint_S \vec{\Pi} d\vec{S} = \\ &= - \oint_V (\vec{J}_M \vec{H} + \vec{J}_E \vec{E}) \cdot d\vec{V} - \oint_V \frac{\partial}{\partial t} \left(\frac{\mu_a H^2}{2} + \frac{\epsilon_a E^2}{2} \right) \cdot d\vec{V}, \end{aligned} \quad (5)$$

which is called Poynting's theorem in a lossless medium. Poynting's theorem is a form of the law of conservation of energy for the electromagnetic field.

Let's first consider the bottom line of the expression. The first integral is the power of the electromagnetic field associated with the flow of electric and magnetic current. The second integral is the power accumulated in the electric and magnetic fields. So, the bottom line describes the total power accumulated V electromagnetic field With taking into account capacities electric And magnetic current. If this value changes, then a vector flux appears

$$\vec{\Pi} = \vec{E} \times \vec{H} \quad (6)$$

through the surface S , which bounds the volume V . The source of the Poynting vector (see the first integral in the top line of expression (5)) is the change in the power of the currents, flowing V field (first integral V lower parts expressions (5)) or the change in the energy of the field itself in the volume V (the second integral there).

The power stored in an electromagnetic field changes due to the power flow through the surface bounding the volume. The Poynting vector can also be introduced for complex amplitudes. In this case

$$\vec{\Pi} = \vec{E} \times \vec{H}^* \quad P = \frac{1}{2} \text{Re}(\vec{\Pi}) \quad Q = \frac{1}{2} \text{Im}(\vec{\Pi}) \quad S = \frac{1}{2} \sqrt{P^2 + Q^2} \quad (7)$$

Vector contains valid Part - active power P And imaginary part Q - reactive power. If between vectors E And H No shift phases, then the power will be purely active, with a phase shift of $\pi/2$ – purely reactive.

Flat electromagnetic waves

Electromagnetic wave they call flat, If And electrical, And magnetic field Not changes V planes perpendicular direction her dis-

propagation. A plane wave is the most commonly used model of the electromagnetic wave process in open space. It is convenient to search for an expression for a plane wave in a rectangular coordinate system (x, y, z).

Let a plane wave propagate along the z -axis, that is, the Poynting vector has a unique projection Π_z , which can be found by projecting expression (3.6) onto the z -axis.

$$\bar{\Pi}_z = \bar{e}_z (E_x H_y - E_y H_x). \quad (8)$$

From here follows, What V flat wave excellent from zero only transverse components of the electromagnetic field. The electromagnetic field is transverse.

IN planes perpendicular direction distribution (XOY plane) coordinate axes Bye Can arrange arbitrarily. We will direct axis x by electrical field, Then $H_y = 0$. Now, V expression (3.8) will remain one term,

$$\bar{\Pi}_z = \bar{e}_z E_x H_y. \quad (9)$$

Like this in this way, flat wave Can introduce V view electromagnetic field containing one projection of the electric field E_x and one projection of the magnetic field H_y .

Change these projections in time And space Can get, solving the Helmholtz equation for the electric field in a rectangular coordinate system And counting on magnetic field With help equations electromagnetic induction. For complex amplitudes fields, at condition, What on paths distribution radio waves No none obstacles And That's why reflected there is no wave, we get:

$$\bar{E}_x = A \exp(-i \gamma z), \quad (10)$$

$$\bar{H}_y = \frac{A}{Z_c} \exp(-i \gamma z), \quad (11)$$

$$\gamma = \omega \sqrt{\epsilon_n \mu_n}, \quad Z_c = \frac{\gamma}{\omega \mu_n} = \sqrt{\frac{\mu_n}{\epsilon_n}} \quad (12)$$

Size Z_c they call wave resistance environment. Wave so-resistance allows us to calculate the magnetic field in a plane wave if we know electrical. IN in general case wave resistance - magnitude complex. Its imaginary part is determined by the electrical and magnetic conductivity environment. IN environment without losses imaginary Part wave resistance is equal to zero and the electric and magnetic fields in space are mutually perpendicular.

IN expressions (10, 11) enters complex constant distribution γ . Her valid And imaginary Part differently influence on properties electromagnetic field. It is usually written in this form:

$$\gamma = \beta - i\alpha. \quad (13)$$

The real part of the propagation constant is called the wave number. or phase constant, A imaginary - constant attenuation. Taking advantage of new form constant distribution, let's rewrite expressions for complex amplitudes of the electric and magnetic fields in a plane wave

$$\vec{E}_x = A \exp(-\alpha z) \exp(-i\beta z), \quad (14)$$

$$\vec{H}_y = \frac{A}{Z_c} \exp(-\alpha z) \exp(-i\beta z). \quad (15)$$

The resulting expressions for the images of the E and H fields can be transformed into a function of coordinates and time, describing the actual fields rather than their images. To do this, each image must be multiplied by the instantaneous complex $\exp(i\omega \cdot t)$ and the real part of the resulting product must be taken. We do this and obtain:

$$E_x(t) = A \exp(-\alpha z) \cos(\omega t - \beta z); \quad (16)$$

$$H_y(t) = \frac{A}{Z_c} \exp(-\alpha z) \cos(\omega t - \beta z - \phi_z) \quad (17)$$

Here Z_c module complex wave resistance Z_c , $A \phi_z$ - his phase.

Thus, expressions for the complex image of the electric and magnetic field in a plane wave (14) and (15) and expressions for calculating the value of the electric and magnetic field itself (16) and (17) are obtained.

In view of big significance these expressions, let's discuss received result. Let's begin With expressions (16) For electric fields. Expression contains periodic function - cosine. Argument cosine continuously changes in space and time. It is called the phase of the electric field of a plane wave Φ ,

$$\Phi_E = \omega t - \beta z. \quad (18)$$

Phase magnetic fields is different on phase corner wave resistance-
nia,

$$\Phi_H = \omega t - \beta z - \phi_z.$$

Cosine periodic function, That's why through 2π radian values fields are repeated. If fix coordinate And change time, That field values are repeated through

$$T = 2\pi/\omega. \quad (19)$$

This meaning they call period By time, or Just period.

If you take an instant photograph, that is, record the time and watch how the fields change with the change in coordinates, then it is easy to establish that the field values are repeated through

$$\lambda = 2\pi/\beta. \quad (20)$$

This meaning they call period By coordinate, or length waves.

From (3.18) it is clear that the phase of a plane wave in a plane perpendicular to the z -axis is constant. This is the fundamental property of a plane wave.

The equation of the constant phase surface is a plane perpendicular to the z -axis. This plane moves with a velocity

$$v_{\phi} = \omega/\beta, \quad (21)$$

which it's called phase speed.

Each value included in the expression for phase (18) has its own name. Except variables coordinates z and time t in expression enters circular frequency ω and the wave number β .

The expression that stands in front of the cosine function in (16) is called the amplitude of the electric field in a plane wave, the same value in (17) is the amplitude of the magnetic field of a plane wave.

Attitude amplitudes electric fields To amplitude magnetic field - wave resistance. Wave resistance is determined only by the parameters Wednesday And Not depends from quantities electric And magnetic fields (We are not considering nonlinear media for now). Both amplitudes decrease with increasing coordinate z with attenuation constant α .

A plane monochromatic wave is an idealization of a real electromagnetic process. It is known that information is transmitted by modulated oscillation, which, How rule, has narrow spectrum, located near some central frequencies. Such signal Can replace monochromatic plane wave, the amplitude of which changes according to a certain law. The speed of movement of the maximum amplitude of this wave is called the group velocity.

Let's take narrowband non-monochromatic signal $E(t)$. Using Fourier transform, it can be represented as a finite or infinite number of harmonics with amplitude $G(\omega)$, that is, as a Fourier series or integral. Let's write the Fourier integral.

$$\bar{E}(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \bar{G}(\omega) \exp(i\omega t - i\beta z) d\omega \quad (22)$$

Signal we count narrowband, That There is $\Delta\omega_{\max}/\omega_0 \ll 1$, Where $\Delta\omega_{\max}$ - maximum deviation in circular frequency from the central frequency ω_0 . Let's use this property signal For Togo, to introduce his V view harmonic fluctuations With load-bearing circular frequency ω_0 . For this wave number We expand β into a power series near the carrier.

Considering that the deviation of the frequency from the central one is small, we will keep only the first two terms in the series

$$\beta \approx \beta_0 + (\omega - \omega_0) \left. \frac{d\beta}{d\omega} \right|_{\omega \rightarrow \omega_0} = \frac{\omega_0}{v_{\phi}} + \frac{\omega - \omega_0}{v_{\Gamma P}} \quad (23)$$

The wave number of a narrowband non-monochromatic signal is presented V view two terms. First term - wave number monochromatic-

carrier. The second term arises because there are spectral components with a frequency different from the carrier. Their propagation is described using the concept of group velocity.

$$v_{\text{rp}} = \frac{1}{\left. \frac{d\beta}{d\omega} \right|_{\omega \rightarrow \omega_0}} \quad (24)$$

Let us rewrite the exponent in expression (22) taking into account the introduced notations, i.e.

$$\exp i\omega t - i\beta z = \exp i\omega_0 t - i\beta_0 z \exp \left(i \frac{\omega - \omega_0}{v_{\text{rp}}} v_{\text{rp}} t - z \right)$$

Itself expression (3.22), Now will be recorded So:

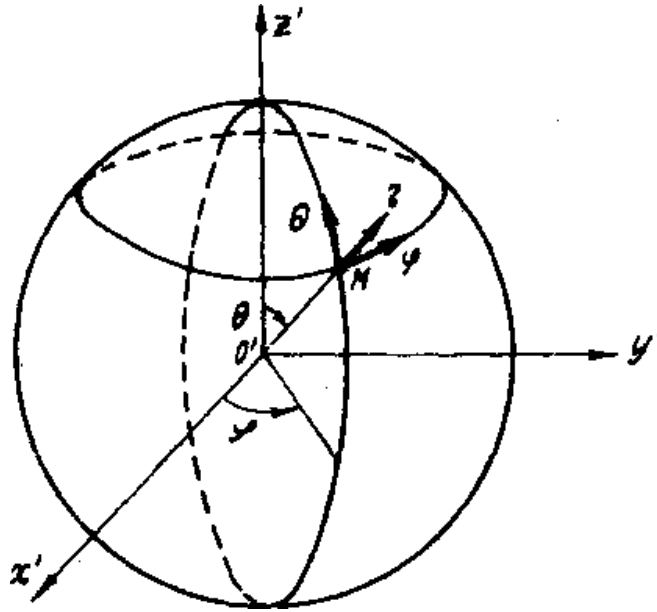
$$\bar{E}(t) = \left\{ \frac{1}{2\pi} \int_{-\infty}^{\infty} \bar{G}(\omega) \exp(i \frac{\omega - \omega_0}{v_{\text{rp}}} (v_{\text{rp}} t - z)) d\omega \right\} \exp(i\omega_0 t - \beta_0 z) \quad (25)$$

Narrowband non-monochromatic signal (22) replaced equivalent to monochromatic (cm. expression 25) With circular frequency ω_0 And wave number β_0 - appropriate central frequency non-monochromatic signal and amplitude, determined expression (25) before imaginary exponent. This signal moves in time at a speed of V_{GR} .

Spherical waves

Spherical wave Can get from - point source. If the medium is homogeneous in all directions, then the wave phase is constant on the surface of the sphere. This is a spherical wave. The problem of calculating the electromagnetic field in this case has spherical symmetry. It should be solved in a spherical coordinate system.

On drawing 1 given spherical system coordinates. This system is formed by three coordinate surfaces passing through the point ***M of interest to us*** and the polar axis ***0 Z*** passing through the origin. One surface is a sphere with its center at the origin, the second is a plane containing the polar axis and the point ***M***, and the third is a plane perpendicular to the polar axis.



Rice. 1 - Spherical wave

Each one pair coordinate surfaces, forms V intersection coordinate line. The coordinate line can be straight or curved. The coordinate system is called rectilinear if all coordinate lines are straight. If Although would one coordinate line Not straight, system coordinates is called curvilinear. The spherical coordinate system is curvilinear.

A coordinate system is called orthogonal if, at any point M , the tangents to the coordinate lines form a right-angled trihedron. A spherical coordinate system is orthogonal.

If at point M (Fig. 1) the electric field vector E is given. It is usually denoted direct with arrow, taking start V point M . Not follows forget that this vector describes the electric field at point M , and the line with the arrow is just a convenient way to graphically display the characteristics of the vector field at this point. To determine its projections in a nonlinear coordinate system necessary find direction coordinate axes V this point. The coordinate axes are always straight lines. They are defined as tangents to the coordinate lines. In Fig. 1, these are the lines r , φ and θ .

We will consider a homogeneous symmetrical spherical wave, which has electric And magnetic field Not depend from corner coordinates φ And θ . The only coordinate along which the field changes is the radius r . We choose a coordinate system so that the electric field is directed along the $\varphi \propto \xi_1 \sigma$. Calculations show that if there are no obstacles in the path of the electromagnetic wave and, therefore, no reflections occur, then

$$\dot{E}_\varphi = \frac{A}{r} \exp(-i\beta r), \quad (26)$$

Where A - amplitud electric fields V beginning coordinates Her meaning depends on the excitation conditions.

If V flat wave without losses By measure distribution amplitude the field does not change, then in a spherical wave it decreases inversely proportionally distance from points, V which wave was excited (from beginning coordinates). This can be explained quite simply. The surface occupied by a plane wave does not change as the wave propagates, which cannot be said about a spherical wave. By measure distribution square surfaces, which covers the front of the spherical wave, increases. Therefore, per unit area there is All less energy And tension fields should decrease, which follows from (26).

Using the law of electromagnetic induction, we find the magnetic field

$$\dot{H}_\theta = -\frac{\beta}{\omega\mu_0} \dot{E}_\varphi = -\frac{\dot{E}_\varphi}{Z_c}. \quad (27)$$

U spherical waves connection between electric And magnetic field is the same as for plane waves. They are related through the wave impedance of the medium. The magnetic field is perpendicular to the electric field and to the direction of propagation. The Poynting vector is directed along the radius, i.e.

$$\dot{\vec{\Pi}} = \dot{\vec{E}} \times \dot{\vec{H}}^* = \dot{E}_\varphi \dot{H}_\theta \vec{e}_r. \quad (28)$$

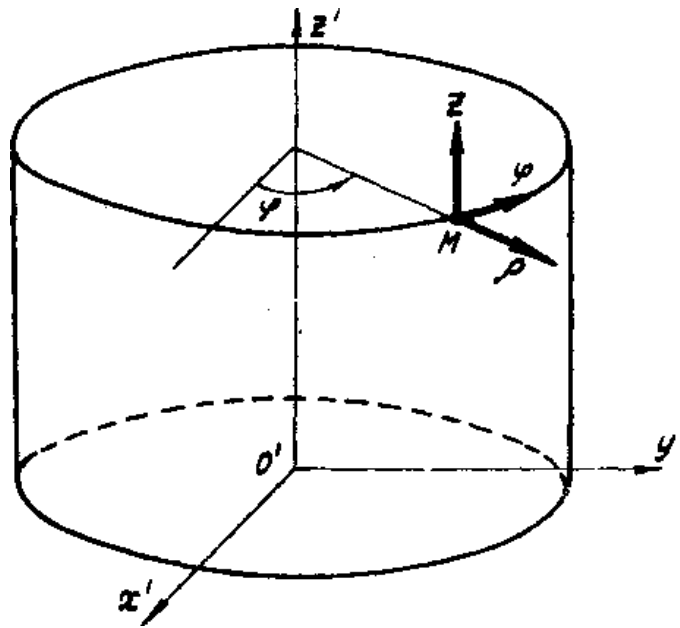
Expressions (26), (27) describe the complex image of the electric and magnetic fields in a spherical wave. Let us write the expressions for the fields as a function of coordinates and time, describing real fields, and Not their images.

$$E_\varphi(t) = \frac{A}{r} \exp(-\alpha r) \cos(\omega t - \beta r); \quad (29)$$

$$H_\theta(t) = \frac{A}{r Z_c} \exp(-\alpha r) \cos(\omega t - \beta r - \phi_z). \quad (30)$$

Cylindrical waves

Cylindrical waves radiate from a certain axis in space on which a current-carrying conductor is located. The structure of cylindrical waves is significantly more complex than the structure of plane and spherical waves. It requires the introduction of a cylindrical coordinate system (Fig. 2).



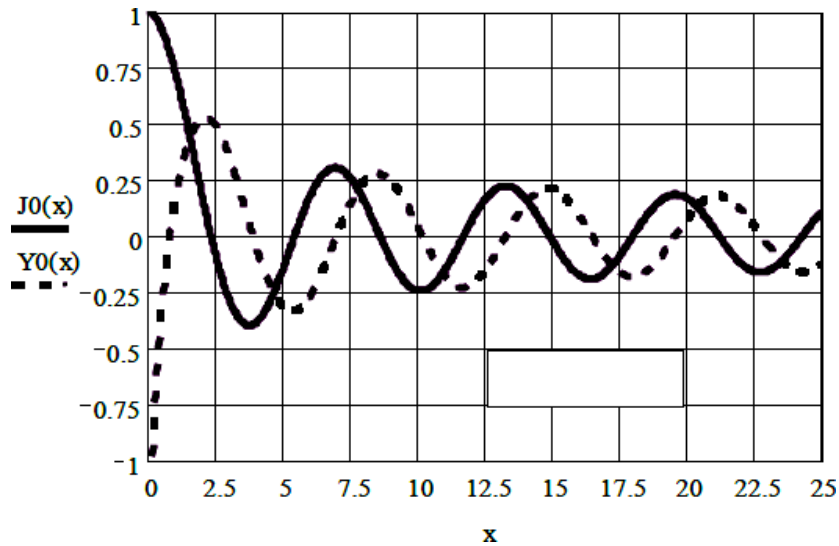
Rice. 2 - Cylindrical wave

The coordinate system is formed by three coordinate surfaces passing through the point M of interest to us, and the polar axis $0 \ Z$ passing through the origin. Let us describe these surfaces. One surface is a cylinder, axis which coincides with the polar axis $0 \ Z$; the second - plane, perpendicular to the polar axis; and the third is a plane tangent to the cylinder and passing through point M.

Each one pair coordinate surfaces, forms V intersection coordinate line. Cylindrical system coordinates ρ , φ , z (see Fig. 2) is orthogonal and curvilinear. The coordinate axes are the straight lines ρ , φ , z (see Fig. 2).

The simplest monochromatic symmetric cylindrical wave with a source V center satisfies two-dimensional equation Helmholtz And is described using the first Hankel function of zero order $H_0(x)$, which in turn is formed from cylindrical functions of the first $J_0(x)$ and second $Y_0(x)$ kind of zero order.

Cylindrical functions of the first ($J_0(x)$ is the Bessel function) and second kind ($Y_0(x)$ - function Neumann) - This Fine studied non-elementary functions of a real argument, for which tables of values exist and which, along with others, are introduced into basic mathematical programs, for example, MathCAD. Figure 3 shows the graphs of these functions.



Rice. 3 - Charts functions Bessel $J_0(x)$ And Neumann $Y_0(x)$

IN beginning coordinates function Bessel $J_0(x)$ equal unit, A function Neumann $Y_0(x)$ tends to $-\infty$. Then, as the argument increases, both functions change And By size And By sign nearby zero And All more are approaching to a sine wave. IN cylindrical system coordinates these functions perform that the same role as the sine and cosine functions in a rectangular coordinate system.

In a rectangular coordinate system, the sine and cosine functions are used to record a complex number in trigonometric form, i.e.

$$z = a + bi = c(\cos + i \sin) .$$

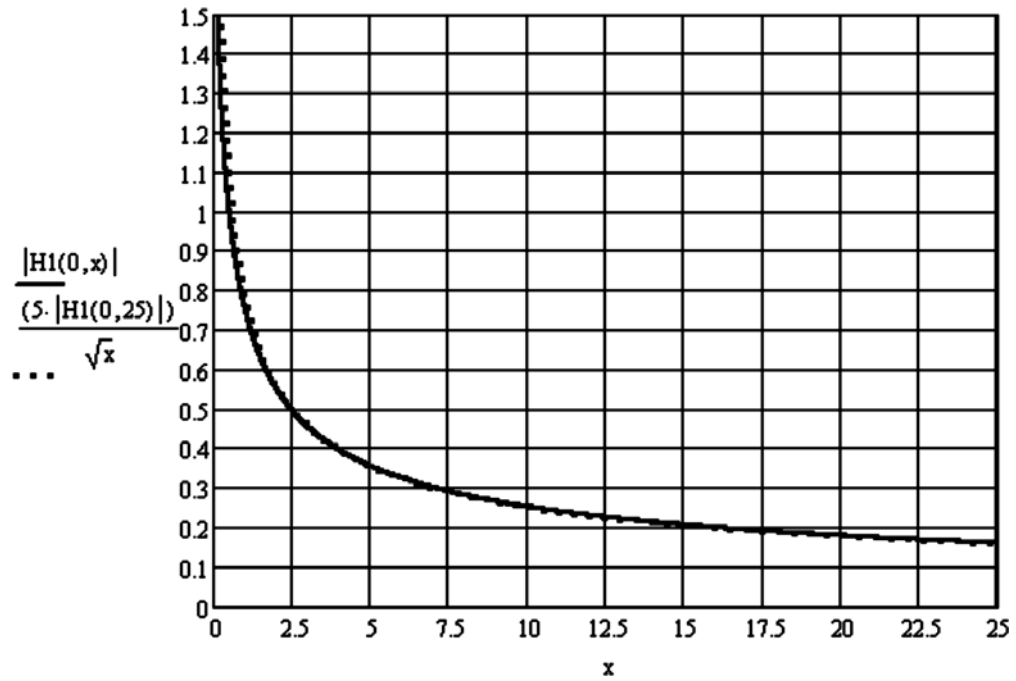
Likewise cylindrical functions first And second genus Same can be used For records complex numbers V cylindrical system coordinates, i.e.

$$H_0(x) = J_0(x) + i N_0(x).$$

This is the zeroth order Hankel function that is used to describe cylindrical waves. On rice. 3.4 is given schedule module Hankel functions. The modulus of the function determines the amplitude of the cylindrical wave and decreases as increase in its argument. Consequently, as it propagates, the amplitude of the cylindrical wave will decrease.

On rice. 3.4 solid line built schedule module functions Hankel,

and the dotted line is the function $A_1/\sqrt{x}$, Where A_1 selected So, to at $x = 25$ The value of the function coincided with the Hankel function. The graphs almost completely repeat each other and only diverge slightly for small values of the argument.



Rice. 4 - Schedule module functions Hankel

Thus, in practical applications for calculating the electric field cylindrical wave can be used simplified expression, is-

using instead of functions Hankel function $\sqrt{x}$.

Electric field V cylindrical wave With help functions Hankel is written as follows:

$$E(\rho, t) = \text{Re}\{H_0(\beta\rho) e^{i\omega t}\}, \quad (31)$$

Where ω - circular frequency, A β - wave number. On large distances from the axis ($\beta\rho \gg 1$) wave field acquires view:

$$E(\rho, t) = \frac{A}{\sqrt{\rho}} \cos(\omega t - \beta\sqrt{\rho}) \quad (32)$$

Only in this asymptotic representation can the amplitude and phase of a cylindrical wave be unambiguously distinguished. In this approximation, the phase velocity cylindrical waves matches With phase speed flat waves. As the distance from the axis increases, the square of the amplitude modulus decreases as $1/\sqrt{\rho}$, and the surface area of the cylinder enclosing the source increases proportionally ρ , so that, in accordance with the law of conservation of energy, the total value of the energy flux carried away from the source on the axis remains constant. An electromagnetic wave can be approximately considered as a plane wave with a slowly varying amplitude. Then the magnetic field in the wave can be found using the wave impedance of the medium, as was done for a plane wave.

Content practical work, performed students

1. Description laboratory equipment:

– PC With established system computer algebra "Mathcad- 14".

2. Initial data For modeling And research

Options tasks For modeling And research given V point

4.1.

3. Exercise For work

Basic level:

1) Simulate And research V system Mathcad parameters flat electromagnetic waves.

2) To model and investigate in the Mathcad system the spatio-temporal distribution of the intensity vectors of a plane electromagnetic wave.

Increased level:

3) To model and explore in the Mathcad system the features of the spatio-temporal distribution vectors tensions spherical and cylindrical electromagnetic waves.

4. Order execution work

Task 1.1. Model and investigate the parameters of a plane electromagnetic wave in the Mathcad system.

1. Initial data for modeling - a plane monochromatic electromagnetic wave propagates in a non-magnetic dielectric medium with the following parameters: relative permittivity - $\varepsilon = 81$, dielectric conductivity - σ_e equal number options multiplied by 10^{-2} Siemens, the relative magnetic permeability $\mu = 1$ and magnetic conductivity $\sigma_m = 0$. Before entering this medium, the amplitude of the electric field E_0 is equal to the variant number multiplied by 10^{-3} V/m, and the frequency f is the variant number multiplied by 10^7 Hz.

The modeling task is to create a program in the Mathcad system for calculating and studying the parameters of a plane electromagnetic wave propagating in a given medium. The program must calculate the following parameters: propagation constant (coefficient), wave number, attenuation constant (coefficient), wave impedance, refractive index of the medium, and phase velocity of the plane wave.

2. Algorithm developments programs V system "Mathcad".

1) Enter V working window programs original data:

– imaginary unit,

– parameters Wednesday ε , σ_e , μ , σ_m ;

– initial parameters waves E_0 And f ;

– constant quantities. $\varepsilon_0 = 10^{-9} / 36 \pi$ $\mu_0 = 4 \pi \cdot 10^{-7}$.

,

2) Enter formulas For calculation parameters Wednesday:

- circular (cyclic) frequencies waves - $\omega := 2\pi \cdot f$;
- complex permittivity and magnetic permeability

$$\epsilon n := \epsilon \cdot \epsilon_0 - i \frac{\sigma_e}{\omega} \quad \mu n := \mu \cdot \mu_0 - i \frac{\sigma_m}{\omega} ;$$

- speed Sveta - $c_{\omega\omega} := \frac{1}{\sqrt{\mu_0 \cdot \epsilon_0}}$;
- indicator refraction - $n := \sqrt{\mu \cdot \epsilon}$;

$$Z_{co} := \sqrt{\frac{\mu_0}{\epsilon_0}} \quad Z_c := \sqrt{\frac{\mu n}{\epsilon n}}$$

- wave resistances vacuum And Wednesday –

3) Enter formulas For calculation parameters flat electromagnetic wave:

- constant (coefficient) distribution waves - $\gamma := \omega \cdot \sqrt{\mu n \cdot \epsilon n}$;
- wave numbers or phase constant - $\beta := \text{Re}(\gamma)$;
- constant (coefficient) attenuation waves - $\alpha := \text{Im}(\gamma)$;

- length waves - $\lambda := \frac{2\pi}{\beta}$;

- phase speed flat waves - $vf := \frac{\omega}{\beta}$.

3. Calculate the parameters of a plane electromagnetic wave in air. To do this, perform the following operations:

1) Enter the initial data into the compiled program – parameters for air: $\epsilon = 1$, $\sigma_e = 0$, $\mu = 1$, $\sigma_m = 0$.

2) Calculate the parameters of the medium: refractive index n , wave impedance Z_c , compare the value of the latter with the wave impedance of vacuum.

3) Calculate the parameters of a plane electromagnetic wave: wave propagation coefficient γ , wave number β , wave attenuation coefficient α , wavelength λ , phase velocity of a plane wave vf .

4) Rate calculated quantities, do conclusions.

4. Calculate the parameters of a plane electromagnetic wave in a non-magnetic dielectric medium. To do this, perform the following steps:

1) IN news V compiled program given original data - ϵ , σ_e , μ , σ_m .

2) Calculate parameters Wednesday: indicator refraction n , wave so-resistance Z_c , compare their values with values For air.

3) Calculate the parameters of a plane electromagnetic wave: wave propagation coefficient γ , wave number β , wave attenuation coefficient α , wavelength λ , phase velocity of a plane wave vf .

5. Evaluate the calculated values, draw conclusions about the influence of the real environment on the parameters of a plane electromagnetic wave, and determine how many times the values of the wavelength and phase velocity have changed.

Task 1.2. To model and explore in the Mathcad system the spatio-temporal distribution vectors tensions plane electromagnetic wave.

1. Refine the program compiled in the previous paragraph and construct graphs of spatial and temporal dependencies of electrical intensities And magnetic fields flat waves. For this execute next steps.

1) Enter the range and step of change of time and spatial coordinates

$$t := 0, \frac{0.01}{\omega} .. \frac{20}{\omega} \quad u := 0, \frac{0.01}{\beta} .. \frac{100}{\beta} .$$

2) Enter formulas For calculation:

– complex amplitudes electric fields flat waves V environment,
those. $EK(u) := E_0 \cdot \exp(-i \cdot \gamma \cdot u)$;

– complex amplitudes magnetic fields flat waves V environment

$$HK(u) := \frac{EK(u)}{Z_c} ;$$

– instant values electric fields flat waves V point With longitudinal coordinate u at time t

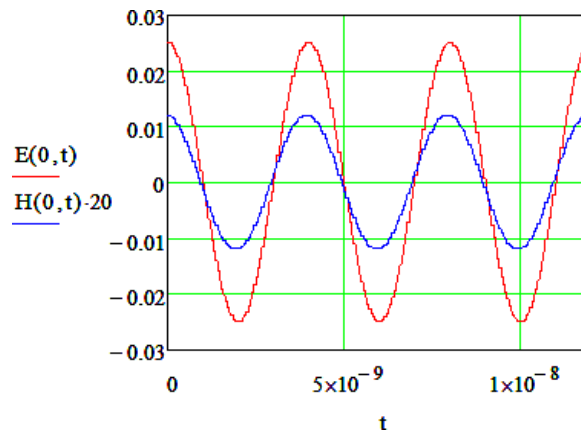
$$E(u, t) := \text{Re}(EK(u) \cdot \exp(-i \cdot \omega \cdot t)) ;$$

– instantaneous value of the magnetic field of a plane wave at a point with a fractional coordinate u at time t

$$H(u, t) := \text{Re}(HK(u) \cdot \exp(-i \cdot \omega \cdot t)) .$$

3) Build on one graphics two dependencies electric And magnetic fields V flat wave from time V point $u = 0$, those. distribution electromagnetic waves in time. IN connections With those, What amplitude electric fields are significantly greater than the magnetic field, then for the convenience of comparative analysis of the graphs necessary instant meaning magnetic fields multiply on coefficient, the value of which is approximately 2 times smaller than the modulus of wave resistance Z_c , for example, as shown in Fig. 5. In this case, 3–5 oscillation periods should be located on the graph. To do this, it is necessary to either change the upper limit of the time coordinate t on the graph, or change range of time changes in the program cycle.

Plot on two other graphs two dependences of the electric and magnetic fields in a plane wave on time at points in space with coordinates $u = 10/\beta$ and $20/\beta$. Draw conclusions about how the graphs differ and for what reason.



Rice. 5

4) Plot two dependences of the electric field in a plane wave on one graph from the longitudinal coordinate at the points $t = 0$ and $10/\omega$, i.e. the distribution of the electric field strength of a plane wave in space.

By longitudinal axes coordinates u put off so many fluctuations, to the signal was visible attenuating as it propagated.

Build on friend graphics two dependencies magnetic fields V plane wave from longitudinal coordinates V points $t = 0$ And $10/\omega$, those. distribution magnetic field strength of a plane wave in space.

Draw conclusions about the features of these graphs and determine which environmental parameters they depend on.

5) Enter formulas For calculation:

- complex conjugate of the amplitude of the magnetic field of a plane wave

$$HR1(u) := \text{Re}(HK(u)) - i \cdot \text{Im}(HK(u)) ;$$

- density flow active power along axes coordinates u

$$PSR(u) := \frac{1}{2} \cdot \text{Re}(EK(u) \cdot HR1(u)) ;$$

- density flow reactive power along axes coordinates u

$$QSR(u) := \frac{1}{2} \cdot \text{Im}(EK(u) \cdot HR1(u)) .$$

6) Build on one graphics two dependencies average active And reactive capacities from longitudinal coordinates u . Justify received results .

2. Do conclusions By results completed tasks.

Task 1.3. Model and investigate in the Mathcad system the features of the spatial propagation of spherical and cylindrical electromagnetic waves.

1. Refine and modify the program created in the previous section and plot graphs of the spatial dependences of electric field strengths in plane, cylindrical, and spherical waves. To do this, perform the following steps.

1) Delete V new program formulaic operators calculation capacities and all constructed graphs.

2) Change range And step spatial coordinates

$$u := \frac{1}{\beta}, \frac{1.01}{\beta} .. \frac{50}{\beta}.$$

3) Enter formulas For calculation:

– complex amplitudes electric fields spherical waves V

$$\text{environment, i.e. } EKS(u) := \frac{E_0 \cdot \exp(-i \cdot \gamma \cdot u)}{u} .;$$

– complex amplitudes electric fields cylindrical waves V

$$\text{environment, i.e. } EKC(u) := \frac{E_0 \cdot \exp(-i \cdot \gamma \cdot u)}{\sqrt{u}} .;$$

– instantaneous value of the electric field of a spherical wave at a point with longitudinal coordinate u at time t

$$ES(u, t) := \text{Re}(EKS(u) \cdot \exp(-i \cdot \omega \cdot t)) .$$

– instant values electric fields cylindrical waves at a point with longitudinal coordinate u at time t

$$EC(u, t) := \text{Re}(EKC(u) \cdot \exp(-i \cdot \omega \cdot t)) .$$

2. Conduct research features distribution spherical And cylindrical waves in space in relation to a plane wave in the real medium under study. To do this, perform the following operations.

1) Build on one graphics three dependencies tensions electric fields for plane, spherical and cylindrical waves from the longitudinal coordinate u at $t = 0$, i.e. the distribution of the amplitudes of electromagnetic waves in space.

2) Select the beginning of the graph along the coordinate axis u in such a way that the condition $\beta u \gg 1$ is satisfied for a cylindrical wave, i.e., the validity of expression (3.32) is ensured. For example, the graph can begin with the value of the longitudinal coordinate $u_0 = 5/\beta$, and end with $30/\beta$.

3) Draw conclusions about the reasons for such a distribution of the amplitudes of electric field strengths in spherical and cylindrical waves.

3. Consider peculiarities distribution spherical And cylindrical waves in space relative to a plane wave in a lossless medium. To do this, perform the following operations:

– V news V compiled program new original data For vacuum:

$$\varepsilon = 1, \sigma_e = 0, \mu = 1, \sigma_m = 0.$$

– get new graphs distribution waves V space;

– do conclusions.

4. Do conclusions By results completed tasks.

5. Compose report on done work By to the third question in accordance with the requirements set out in the job description.

IN report bring:

- original data,
- performed tasks,
- compiled listings programs modeling,
- results of modeling and research – formulas describing electromagnetic fields, obtained results and graphs;
- conclusions O done work, with explanation physical meaning results obtained.

6. Protection practical work

For protection practical introduce fully decorated report, Free of significant errors. As directed by the teacher, complete one of the tasks from each question, explaining all the physical phenomena and processes occurring in the developed model.

LIST LITERATURE:

1) Sagdeev K.M. Physical foundations of information security [Electronic resource]: study guide / K.M. Sagdeev, V.I. Petrenko, A.F. Chipiga. - Electronic text data. - Stavropol: North Caucasus Federal University, 2015. - 394 p.

2) Evstifeev V.V. Physical foundations electricity and magnetism Electronic resource / Evstifeev V.V.: study guide. - Penza: PSU, 2019. - 416 p.

3) Bulatov V.N. Physical foundations of electronics Electronic resource / Bulatov V.N.: lecture notes for students in educational programs higher education in the following areas preparation 11.03.02 infocommunication technologies and communication systems. - Orenburg: OSU, 2018. - 178 p.

4) Goldstein A.E. Physical principles of obtaining information [Electronic resource]: textbook / A.E. Goldstein. — Electron. text data. — Tomsk: Tomsk Polytechnic University, 2010. — 292 p.

PRACTICAL JOB No. 8

TOPIC 9 SCREENING FIELDS ELECTROMAGNETIC NATURE

Class 8 MODELING AND STUDY SCREENING PROCESS ELECTROMAGNETIC FIELDS

TIME - 2 hours.

Educational questions:

1. Study principles shielding fields And parasitic con-

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y

TARGET PRACTICAL INSTALLATION WORKS:

Competencies, being formed discipline

OPK-1: Capable use provisions, laws And methods natural sciences And mathematicians For solutions tasks engineering activities.

OPK-2: Capable on one's own conduct experimental research And use main techniques processing And performances received data.

Learning outcomes achieved as a result of completing practical work:

Be able to:

- apply physical laws and methods to formalize the representation of physical phenomena and processes that occur in telecommunications .
- conduct experimental research With help mathematical models according to the accepted methodology
- model And analyze main physical phenomena And processes in telecommunications using computer technology.

Own:

- skills use knowledge physicists at decision practical problems of engineering activities
- methods of processing and presenting data obtained as a result of experimental studies.
- skills in computer modeling of the main physical methods of receiving, transmitting and storing information.

EDUCATIONAL AND MATERIAL SECURITY:

- PC With simulator electronic schemes Electronics Workbench - 5.12"
- electronic methodological development By practical work.

STRUCTURE PRACTICAL WORK:

Class No. 1

	90 min
Introductory Part	10 min
Examination readiness students To practical work	8 min
Introductory Part	2 min
Questions (tasks), subject research:	75 min
1. Study principles shielding fields And parasitic connections	75 min
Final Part	5 min
Summing up results	3 min
Exercise students For independent work	2 min

1. STUDY OF THE PRINCIPLES OF FIELDS SHIELDING AND PARASITIC CONNECTIONS.

Brief theoretical or reference and information materials

Shielding is generally understood as protection of devices from impact external fields, So And localization radiation any means that prevent the manifestation of these emissions in the environment.

Efficiency shielding is determined degree weakening components of the field (electric or magnetic). It is defined as the ratio of the effective values of the field strength at a given point in space in the absence and presence of a screen. Since the ratio of these quantities reaches large values, it is more convenient to use a logarithmic representation of the shielding efficiency:

$$K_E = 20 \lg \frac{E_0}{E_1}, dB \quad K_H = 20 \lg \frac{H_0}{H_1}, dB \quad (1)$$

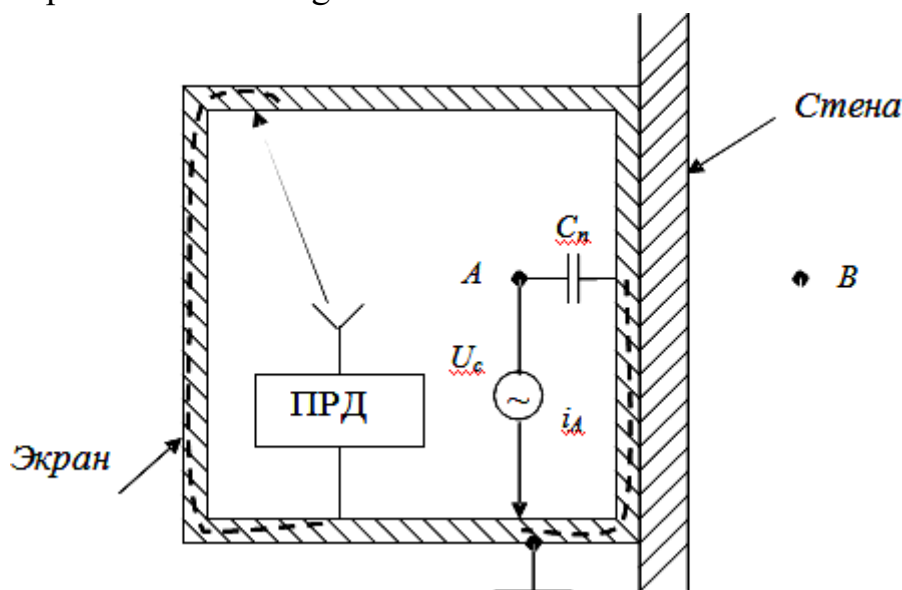
Where K_E - coefficient weakening (shielding) By electrical component, K_H – the attenuation (shielding) coefficient for the magnetic component, $E_0(H_0)$ – the strength of the electric (magnetic) component of the field in the absence of screen, $E_1(H_1)$ - tension electrical (magnetic) component of the field in the presence of a screen at the same point in space.

The theoretical solution to the shielding problem is extremely difficult, therefore, depending on the type of problem being solved, it seems convenient to consider *separate types of shielding* : electric, magnetostatic, and electromagnetic. The latter is the most general and frequently used, since in most cases of shielding one has to deal either with variable or fluctuating fields, and less often with truly static fields.

The main thing factor, defining quality screen, are radiophysical properties material And structural peculiarities. This allows for

calculation efficiency screen V real conditions to use most its simple representation: sphere, cylinder, plane-parallel sheet, etc.

Shielding With good contact is being done copper mesh or Foil is applied to all walls, ceilings, and floors, and the windows are covered with aluminum blinds. The shielding principle is shown in Fig. 1.



Rice. 1 - Principle actions shielding source AMY

Without a screen, information from point A from signal U_c was transmitted to point B through the parasitic capacitance C_p , and the signals from the transmitter were radiated into space. In the presence of a screen, the signal from point A through C_p is shorted to the screen, and the signal from the transmitter is also shorted to the screen. The effect of radiation outside the premises is reduced by 10 to 1000 times. Thus, information does not reach the agent's location.

At impossibility use shielding boxes most Important information signals are transmitted using shielded wires.

Suppression capacitive parasitic connections

Capacitive parasitic coupling between two electrical circuits occurs through a near electric field. ***To reduce parasitic capacitance, a conductive screen is introduced between the electrical circuits***, connected to the common wire and shorting most of the electrical power lines to the common wire.

By introducing a screen having a resistance equal to zero relative to the total wires, theoretically tip Can reduce to zero. Almost However, due to the presence of conductors and technological holes and the occurrence of edge effects, there is always a residual near electric field and, consequently, residual capacitance.

At shielding electric fields Very important create low resistance screen relatively corps (general wires). Appearance any resistance, especially inductive, V chains connections screen With common pro- dom creates the effect of parasitic coupling through an extraneous wire, that's why everyone

Metal elements of the structure must always be carefully connected to each other and to the common wire.

Suppression inductive parasitic connections

Parasitic inductive connection arises between two electrical chains through closer magnetic field. To reduce quantities magnetic Two types of shielding are used for fields : ***magnetostatic and dynamic*** .

Magnetostatic shielding or shunt shielding magnetic fields founded on application screens from ferromagnetic materials With big magnetic permeability. Efficiency Shielding effectiveness is reduced when the shield structure contains joints and seams that run across the magnetic field lines and reduce the effective magnetic permeability of the shield. The essence ***of dynamic shielding*** is that the alternating magnetic field weakens as it penetrates the metal, as the inner layers are shielded by eddy currents generated in the layers located closer to the surface.

Shielding wires And coils inductance

When shielding real components such as transformers, inductors, wires, etc., it is usually necessary to shield simultaneously from both electric and magnetic fields.

The best protection from both electric and magnetic fields is provided by information communication lines such as shielded bifilar, trifilar (three wires twisted together, one of which is used as an electrical screen), triaxial cable (insulated coaxial cable) cable, placed V electric screen), shielded flat cable (a flat multi-conductor cable covered with copper foil on one or both sides). To reduce the level of PEMI, it is necessary to make especially careful connections of the wire sheath (shield) to the equipment housing. Shielded wires and cables should be used mainly for connections separate blocks And nodes Friend With friend. Cable screens are being carried out V form cylinder from solid shells, V view spirally wound on a cable as a flat tape or in the form of a braid of thin wire. Single-layer screens And multilayered. Material: lead, steel, copper, aluminum or their combination.

To completely shield the wires from electric and magnetic fields, it is necessary to ensure that all the return current flows through the shield, i.e., that the currents flowing through the shielded wire and the shield are equal to each other (Fig. 2, a). To achieve this, it is necessary to connect the generator and load terminals To wire And screen directly without intermediate conductors, A compound With body produce V one point, better with sides signal receiver.

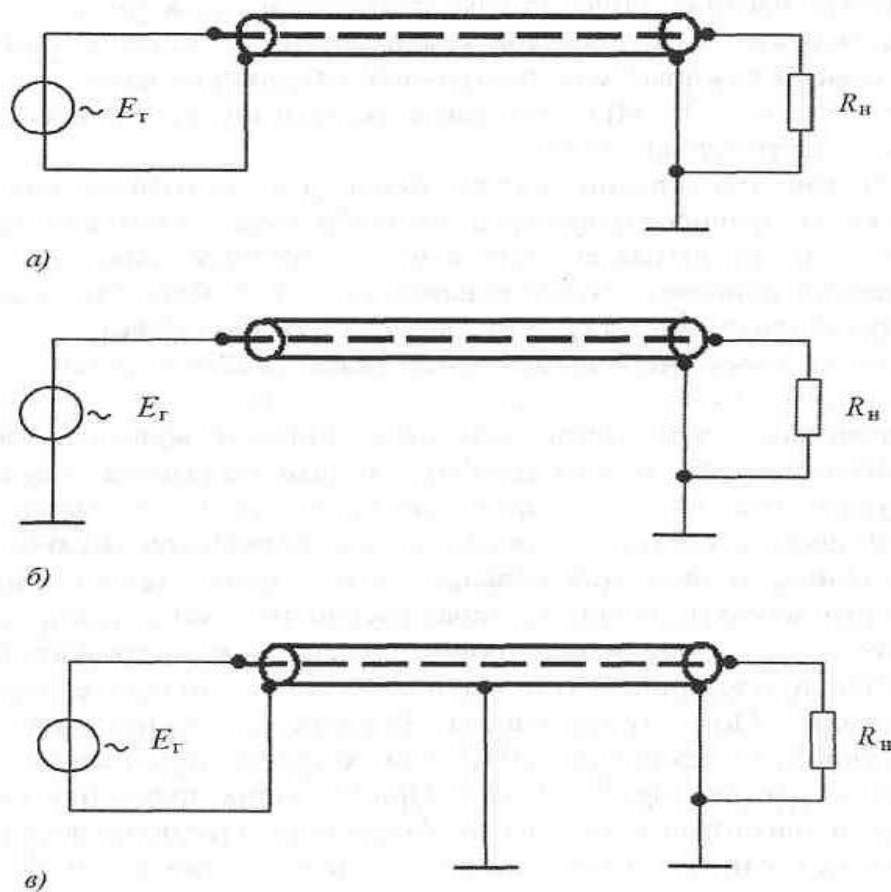


Fig. 2 – Complete shielding of the wire from electric and magnetic fields (A), shielding wires from electrical fields (b), shielding And for-mooing parts screen wires on frame (V)

When connecting the common wire of the generator to the body, and not to the screen (Fig. 2, b) it turns out shielding only from electric fields, at In the absence of a connection between the shield and the common wire, no shielding effect occurs. When the shield is shorted to the housing (Fig. 3.2, c), the magnetic shielding of the part of the wire located between the point where the shield is shorted to the housing and the load is disrupted. In this case, it is often observed that when disconnection connections screen near loads level tips decreases. If This phenomenon observed, necessary find And eliminate short circuit screen onto the case.

At high frequencies, due to the skin effect, the reverse current flows mainly along the inner surface of the screen, therefore at frequencies above 10 MHz short circuit screens on frame Not reduces efficiency shielding. To be shielded can Not only separate blocks equipment And their connecting lines, but also the premises as a whole.

Content practical work, performed students

1.1. Description laboratory equipment:

- PC With simulator electronic schemes Electronics Workbench - 5.12" and the computer mathematics system "Mathcad – 14";

1.2. Initial data For modeling And research

1.3. Exercise For works:

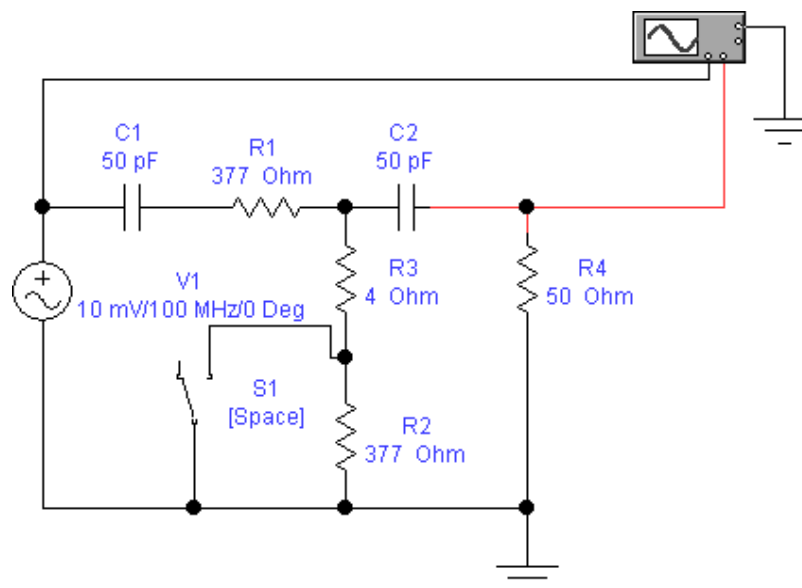
Basic level:

1. Simulate And research equivalent diagram substitutions the process of shielding a source of electromagnetic radiation.
2. Simulate And research equivalent diagram substitutions electrical process shielding coaxial cable.
3. Simulate And research equivalent diagram substitutions magnetic process shielding coaxial cable.

1.4. Order execution work

Exercise 1.1. Simulate And research equivalent diagram replacement of the process of shielding the source of electromagnetic radiation.

4.1.1. Collect And debug diagram substitutions, presented on rice. 3, With indicated on scheme parameters. This scheme is being modeled electromagnetic radiation, created source, placed V screen V in accordance With Fig. 1, shown in the theoretical part. In this equivalent circuit, the capacitance C1 represents by yourself parasitic capacity between point radiation And screen, A capacity C2 - parasitic capacity between screen And point reception. Because capacity equal, That Can count, What screen located in the middle between dots radiation and reception. Resistances R1 and R2 are the resistances of the medium. R3 is the resistance screen. R4 - input resistance measuring instrument (receiver) radiation.



Rice. 3 - Simulated equivalent scheme shielding source electromagnetic radiation

2. Conduct a study of the simulated equivalent circuit. To do this, perform the following steps:

1) At disconnected grounding screen produce measurement voltage of the EMI signal at point *A* on the 1st channel of the oscilloscope, and on the 2nd channel – the voltage of the EMI signal at point *B*. Display the voltage diagrams of the signals U_A *in the report* and U_B electromagnetic radiation.

2) Calculate the shielding effectiveness factor (attenuation coefficient) for the case of an ungrounded shield.

3) Simulate the screen transfer by changing the values of the parasitic capacitances, for example $C1 = 100$ pF, and $C2 = 10$ pF or vice versa. Repeat steps 1) and 2). Draw conclusions.

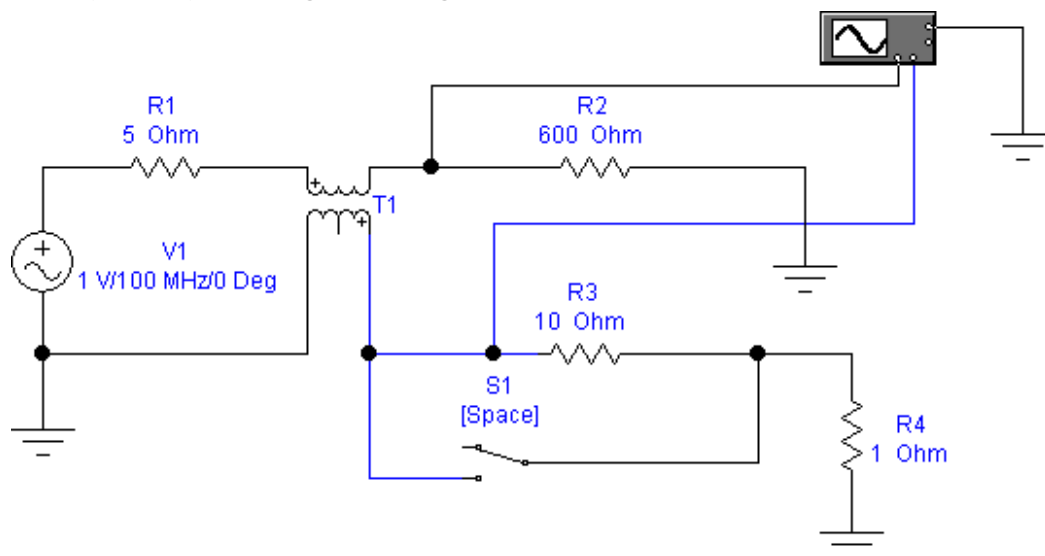
4) Ground screen, then produce measurement voltage signal EMI at point *A* on the oscilloscope channel 1, and the EMI signal voltage at point *B on the oscilloscope channel 2*. Display the signal voltage diagrams U_A *in the report*. and U_B electromagnetic radiation.

5). Calculate the shielding efficiency factor (attenuation coefficient) for the case of a grounded shield.

6) Do conclusions about efficiency electromagnetic shielding.

Exercise 1.2. Model And research equivalent circuit replacement of the process of electrical shielding of coaxial cable.

1. Assemble and debug the equivalent circuit shown in Fig. 4, with the specified on scheme parameters. This scheme is being modeled example screening cable, presented on rice. 2, b), That There is is being carried out shielding only electric fields. IN this case between wire And screen a parasitic phenomenon arises inductive coupling, which is modeled for transformer bill T1. B transformer T1 install coefficient transformations $n = 1$, leakage inductance $LE = 0.1$ μ H, and the primary winding inductance $LM = 5$ μ H. In the equivalent circuit, R1 models the internal resistance of the EMF source (signal), R2 - resistance central veins cable, R3 - resistance of the cable braid (screen), R4 – grounding resistance.



Rice. 4 - Simulated equivalent scheme electric screened-nia wires

2. Conduct a study of the simulated equivalent circuit. To do this, perform the following steps:

1) At disconnected grounding screen produce measurement voltage U_s electric current in the conductor via the 1st channel of the oscilloscope, and via the 2nd channel - voltage tips U_{NE} on screen wires. Display V report voltage diagrams of signals U_{with} and U_{NE} .

2) Calculate the shielding effectiveness factor (attenuation coefficient) for an ungrounded shield.

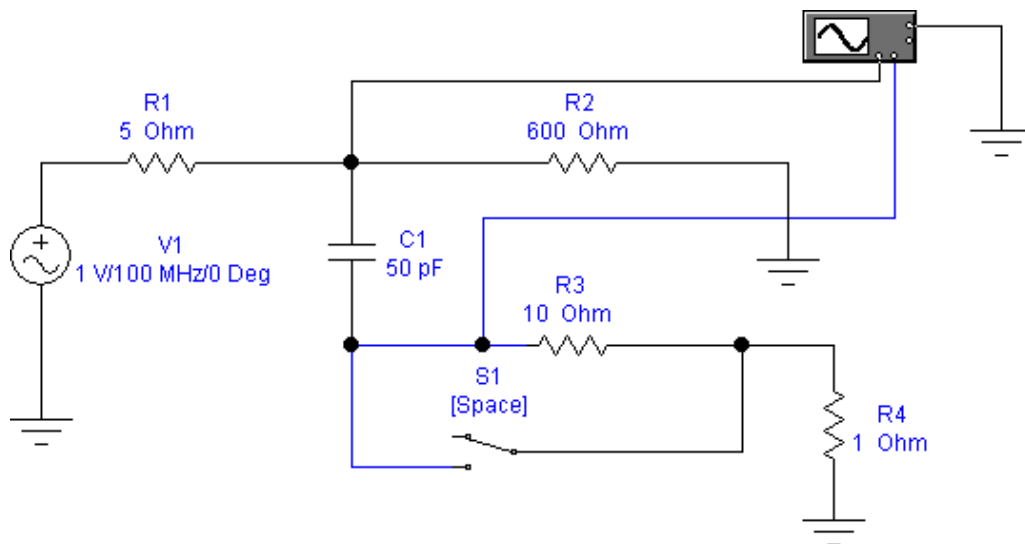
3) Ground the cable shield, then measure the voltage U_c electric current in the conductor via the 1st channel of the oscilloscope, and via the 2nd channel - voltage tips U_{NE} on screen wires. Display V report voltage diagrams of signals U_{with} and U_{NE} .

4) Calculate the shielding effectiveness factor (attenuation coefficient) when the shield is grounded.

5) Do conclusions about efficiency shielding.

Exercise 1.3. Model And research equivalent circuit replacement of the process of magnetic shielding of coaxial cable.

1. Assemble and debug the equivalent circuit shown in Fig. 5, with the specified on scheme parameters. This scheme is being modeled example screening cable, presented on rice. 2, V). IN this case between wire And screen Maybe arise parasitic capacitive connection, which modeled for capacity count C1. IN scheme substitutions R1 models internally resistance source EMF (signal), R2 - resistance central veins cable, R3 - resistance of the cable braid (screen), R4 – grounding resistance.



Rice. 5 - Simulated equivalent scheme magnetic shielding wires

2. Conduct a study of the simulated equivalent circuit. To do this, perform the following steps:

1) At disconnected grounding screen produce measurement voltage U_s electric current V conductor By 1st channel oscilloscope, A By 2nd

channel - voltage tips U_{NE} on screen wires. Display V report voltage diagrams of signals U_{with} and U_{NE} .

2) Calculate the shielding effectiveness factor (attenuation coefficient) for an ungrounded shield.

3) Ground the screen, then measure the voltage U_c electric current in the conductor via the 1st channel of the oscilloscope, and via the 2nd channel - voltage tips U_{NE} on screen wires. Display V report voltage diagrams of signals U_{with} and U_{NE} .

4) Calculate the shielding effectiveness factor (attenuation coefficient) when the shield is grounded.

5) Do conclusions about efficiency shielding.

5. Prepare a report on the work performed in accordance with the requirements set out in the job description.

IN report bring:

- original data,
- performed tasks,
- compiled listings programs mathematical models,
- developed or compiled circuit design models devices;
- research results in the form of formulas used and calculation results, obtained graphs, oscillograms, time diagrams, conclusions made and findings for each task;
- general conclusions O done work.

6. Protection practical work

For protection practical introduce fully decorated report, free of significant errors. Complete one of the tasks assigned by the teacher, explaining all the physical phenomena and processes occurring in the task being completed.

LIST LITERATURE:

1) Sagdeev K.M. Physical foundations of information security [Electronic resource]: study guide / K.M. Sagdeev, V.I. Petrenko, A.F. Chipiga. - Electronic text data. - Stavropol: North Caucasus Federal University, 2015. - 394 p.

2) Evstifeev V.V. Physical foundations electricity and magnetism Electronic resource / Evstifeev V.V.: study guide. - Penza: PSU, 2019. - 416 p.

3) Bulatov V.N. Physical foundations of electronics Electronic resource / Bulatov V.N.: lecture notes for students in educational programs higher education in the following areas preparation 11.03.02 infocommunication technologies and communication systems. - Orenburg: OSU, 2018. - 178 p.

4) Goldstein A.E. Physical principles of obtaining information [Electronic resource]: textbook / A.E. Goldstein. — Electron. text data. — Tomsk: Tomsk Polytechnic University, 2010. — 292 p.

PRACTICAL JOB No. 9

TOPIC 10

PHYSICAL PROCESSES IN THE SIMPLE ELECTRICAL CHAINS RADIOELECTRONIC EQUIPMENT

Class 9

MODELING AND RESEARCH OF ELECTRICAL CHAINS VARIABLE TOKA

TIME – 4 hours.

Educational questions:

- 1. Study distribution current And voltage V_{RL} - chains.**
- 2. Study distribution current And voltage V_{RC} - chains.**

TARGET PRACTICAL INSTALLATION WORKS:

Competencies, being formed discipline

OPK-1: Capable use provisions, laws And methods natural sciences and mathematics to solve engineering problems.

OPK-2: Capable on one's own conduct experimental research And use main techniques processing And performances received data.

Learning outcomes achieved as a result of completing practical work:

Be able to:

- apply physical laws and methods to formalize the representation of physical phenomena and processes that occur in telecommunications .
- conduct experimental research With help mathematical models according to the accepted methodology
- model And analyze main physical phenomena And processes in telecommunications using computer technology.

Own:

- skills use knowledge physicists at decision practical problems of engineering activities
- methods of processing and presenting data obtained as a result of experimental studies.
- skills in computer modeling of the main physical methods of receiving, transmitting and storing information.

EDUCATIONAL AND MATERIAL SECURITY:

- PC With simulator electronic schemes Electronics Workbench - 5.12"
- electronic methodological development By practical work.

STRUCTURE PRACTICAL WORK:

Class No. 1

90 min

Introductory Part

10 min

Examination readiness students To practical work

8 min

Introductory Part

2 min

Questions (tasks), subject research:

75 min

1. Study distribution current And voltage V RL - chains.

75 min

Final Part

5 min

Summing up results

3 min

Exercise students For independent work

2 min

Class No. 2

90 min

Introductory Part

10 min

Examination readiness students To practical work

8 min

Introductory Part

2 min

Questions (tasks), subject research:

50 min

1. Study distribution current And voltage V RC - chains.

50 min

Final Part

30 min

Protection reports By practical work

25 min

Summing up results

3 min

Exercise students For independent work

2 min

1. STUDY OF CURRENT AND VOLTAGE DISTRIBUTION IN RL CIRCUIT.

Content practical work, performed students on the first academic question

1.1. Description laboratory equipment:

- PC With simulator electronic schemes Electronics Workbench - 5.12"

1.2. Initial data For modeling And research

Table 1 - Options tasks For preliminary calculation And research-

niy

Option No.	E, B	R, Ohm	L, mGn	S, μ F	Variant No.	Well, B	R, Ohm	L, mGn	S, μ F
1	100	50	0.10	0.010	31	150	50	0.16	0.015
2	120	40	0.12	0.015	32	160	40	0.18	0.016
3	140	60	0.13	0.016	33	170	60	0.19	0.020
4	150	70	0.15	0.020	34	180	70	0.20	0.018
5	160	80	0.11	0.018	35	190	80	0.10	0.019
6	170	90	0.14	0.019	36	200	90	0.12	0.011
7	180	55	0.16	0.011	37	130	55	0.13	0.012
8	190	65	0.18	0.012	38	120	65	0.15	0.009
9	200	45	0.19	0.009	39	140	45	0.11	0.021
10	130	35	0.20	0.021	40	150	35	0.14	0.020
11	120	70	0.10	0.020	41	160	70	0.16	0.018
12	140	80	0.12	0.018	42	170	80	0.18	0.019

Option No.	E, B	R, Ohm	L, mH	WITH, μ F	Option No.	E, B	R, Ohm	L, mH	WITH, μ F
13	150	90	0.13	0.019	43	180	90	0.19	0.011
14	160	55	0.15	0.011	44	190	55	0.10	0.012
15	170	65	0.11	0.012	45	200	65	0.12	0.009
16	180	45	0.14	0.009	46	130	45	0.13	0.021
17	190	35	0.16	0.021	47	120	35	0.15	0.020
18	200	70	0.18	0.020	48	140	70	0.11	0.018
19	130	80	0.19	0.018	49	150	80	0.11	0.010
20	120	70	0.10	0.010	50	160	70	0.14	0.015
21	140	80	0.12	0.015	51	170	80	0.16	0.016
22	150	90	0.13	0.016	52	100	90	0.18	0.020
23	160	55	0.15	0.020	53	120	55	0.19	0.018
24	170	65	0.11	0.018	54	140	65	0.20	0.009
25	100	45	0.11	0.009	55	150	45	0.16	0.021
26	120	35	0.14	0.021	56	160	35	0.18	0.020
27	140	70	0.16	0.020	57	170	70	0.19	0.018
28	150	80	0.18	0.018	58	150	80	0.20	0.019
29	160	90	0.19	0.019	59	160	90	0.10	0.011
30	170	55	0.20	0.011	60	170	55	0.12	0.015

1.3. Exercise For works:

Basic level:

- 1.1) Study distribution voltage V unbranched RL - chains.
- 1.2) Study distribution current V branched RL - chains.

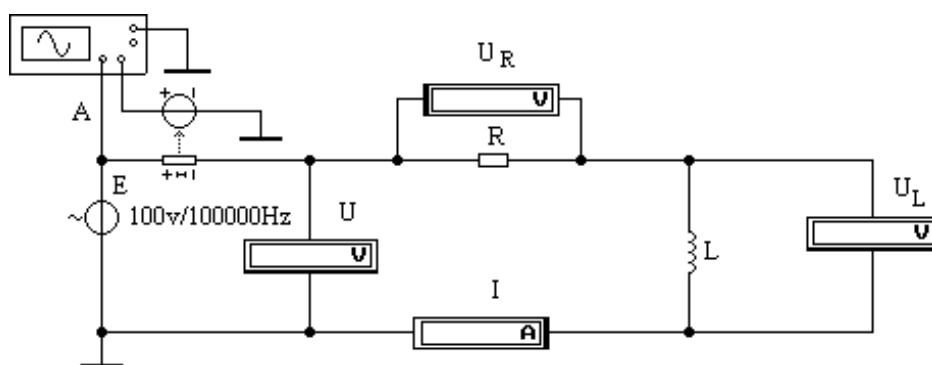
1.4. Order execution Description of

the research scheme

Research are being carried out on PC V environment Electronics Workbench. The research circuits contain an AC voltage source, a current-controlled voltage source, a resistor, an inductive coil, a capacitor, an oscilloscope, an ammeter, and voltmeters. The oscilloscope is used to determine the phase shifts between the current and voltage.

Task 1.1. Study of voltage distribution in an unbranched RL chains

- 1.1. Collect diagram electrical chains (cm. rice. 1).



Rice. 1 - Scheme research RL- chains

1.2. Set the values of resistance R and inductance L , EMF E and frequency $f = 10^5$ Hz of the source specified according to the option. To do this, move the cursor to the desired element and double-click the left button "mice" call window (With name element), V which install the required parameter value. Double-click the left mouse button on the channel line "IN" oscilloscope install desirable color oscillograms (for example, red).

1.3. After completion installations everyone parameters schemes button  - 0-1 translate V position 1-"On". By completion automatic calculations (a few seconds) button  Switch to position 0 - "Off". Enter the readings of the ammeter and voltmeters into Table 2 of the research results .

Table 2 – Research results unbranched sinusoidal current circuits

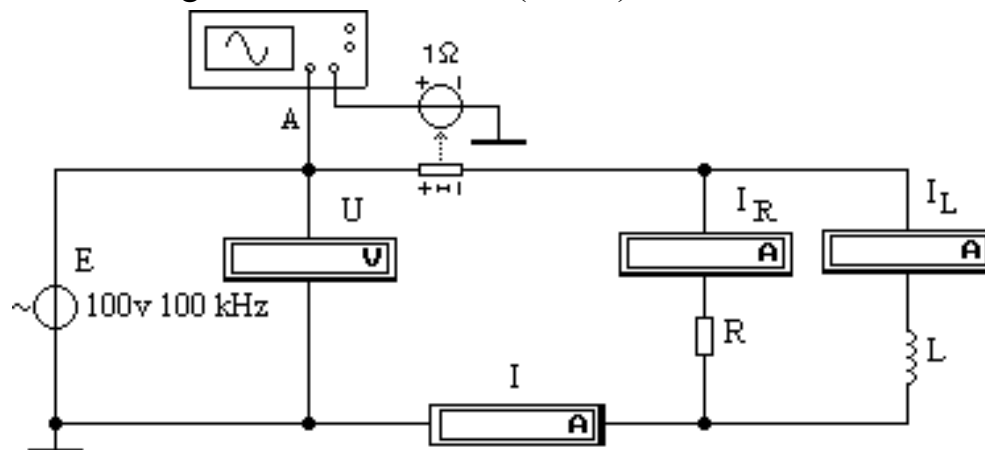
Type of chain	parameters	I, A	U, B	U_R, B	U_L, B	U_C, B	$T_2 - T_1, With$	$\varphi(t), degrees$
RL- цепь	$0.5L=$					-		
	$L=$					-		
	$2L=$					-		
RC- цепь	$0.5C=$				-			
	$C=$				-			
	$2C=$				-			

1.4. Double-click the left mouse button on the oscilloscope image to activate it and switch it to the "Zoom" mode. Set the sighting ruler 1 (red) to the point where the channel "A" oscillogram intersects the time axis when it transitions from a negative to a positive value (oscillogram voltage $u(t)$), A sighting ruler 2 - V point intersections time axis of the oscillogram of channel "B" when it transitions from a negative value to a positive one (oscillogram of current $i(t)$). The value of the time interval $T_2 - T_1$ is entered into Table 2.

- 1.5. Calculate shift phases between voltage $u(t)$ And electric shock $i(t)$ V degrees
By formula $\varphi(t) = 360^\circ \cdot (T_2 - T_1) \cdot f$ or $\varphi(t) = 360^\circ \frac{T_2 - T_1}{T}$. Here $T = 1/f$ - period
sinusoidal EMF source. Meaning shift phases bring in V table 2.
- 1.6. Install inductance coils $0.5L$, execute p.p. 1.3 - 1.5.
- 1.7. Install inductance coils $2L$, execute p.p. 1.3 - 1.5.
- 1.8. By setting the source frequency $0.2f$, $0.5f$, $2f$, $5f$, investigate the dependence voltage V RL- chains from frequencies, For this execute points 1.3 - 1.5.
- 1.9. By results research build vector diagrams current and stresses for all cases studied.
- 1.10. Do conclusions By results done work.

Exercise 1.2 Study distribution current V branched RL - chains.

- 1.1. Collect diagram electrical chains (rice. 1).



Rice. 1 - Scheme research RL chains

1.2. Set the values of resistance R and inductance L, EMF E and frequency $f = 10^5$ Hz of the source specified according to the option. To do this, move the cursor to the desired element and double-click the left button "mice" call window (With name element), V which install the required parameter value. Double-click the left mouse button on the channel line "A" oscilloscope install desirable color oscillograms (for example, red).

1.3. After completion installations everyone parameters schemes button  - 0-1 translate V position 1-"On". By completion automatic calculations (a few seconds) button  Switch to position 0 - "Off". Enter the ammeter and voltmeter readings into the research results table .

Table 3 – Results of studies of branched sinusoidal current circuits.

View chains	Parameters	U, B	I, A	I _R , A	I _L , A	I _C , A	T ₂ -T ₁ , With	φ (t), hail
RL chain	0.5L=					-		
	L=					-		
	2L=					-		
RC-цепь	0.5C=				-			
	C=				-			
	2C=				-			

1.4. Double-click the left mouse button on the oscilloscope image to activate it and switch it to the "Zoom" mode. Set the sighting ruler 1 (red) to the point where the channel "A" oscillogram intersects the time axis when it transitions from a negative to a positive value (oscillogram voltage $u(t)$), A sighting ruler 2 - V point intersections time axis of the oscillogram of channel "B" when it transitions from a negative value to a positive one (oscillogram of current $i(t)$). The value of the time interval **T₂-T₁** is entered into table 2.

1.5. Calculate shift phases between voltage $u(t)$ And electric shock $i(t)$ V degrees By formula $\varphi(t) = 360^\circ \cdot (T_2 - T_1) \cdot f$ or $\varphi(t) = 360^\circ \cdot \frac{T_2 - T_1}{T}$. Here $T = 1/f$ - period si-

nusoidal EMF source.

1.6. Install inductance coils 0.5L, execute p.p. 1.3 - 1.5.

1.7. Install inductance coils 2L, execute p.p. 1.3 - 1.5.

1.8. By setting the source frequency to 0.2f, 0.5f, 2f, 5f, investigate the dependence of the current in branched RL chains from the frequency, for to complete these points

1.3 - 1.5.

1.9. Based on the research results, construct vector diagrams of currents and voltages for all cases under study.

1.10. Results research compare With results Preliminary calculation. Draw conclusions.

2. STUDY OF CURRENT AND VOLTAGE DISTRIBUTION IN RC CIRCUIT.

Content practical work, performed students on the second academic question

1.1. Description laboratory equipment:

– PC With simulator electronic schemes Electronics Workbench - 5.12"

1.2. Initial data For modeling And research

Table 1.

1.3. Exercise For works:

Basic level:

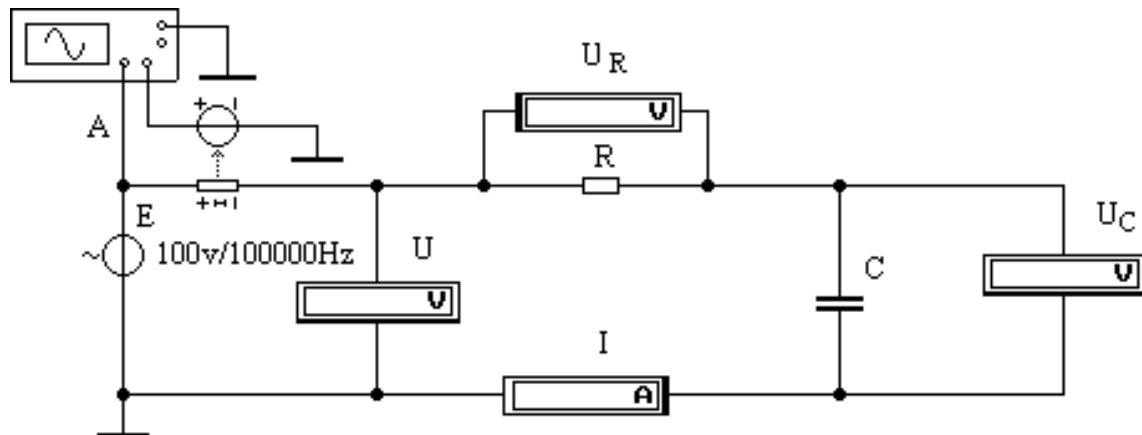
2.1) Study distribution voltage V unbranched RC - chains.

2.2) Study distribution current V branched RC - chains.

1.4. Order execution work

Task 2.1 Study of voltage distribution in an unbranched RC - chains.

2.1. Collect diagram electrical chains (cm. rice. 2).



Rice. 2 - Scheme research RC- chains

2.2. Set the values of the resistor R and the capacitor C capacitance specified according to the option, the value of the EMF of the source $E = 150\text{ V}$ and frequencies $f = 10^5\text{ Hz}$. Double by pressing left buttons "mice" on lines channel Set the desired value to "B" on the oscilloscope channel color (eg red).

2.3. After completion installations everyone parameters schemes button  - 0-1 translate V position 1-"On". By completion automatic calculations (a few seconds) button  Switch to position 0 - "Off". Enter the ammeter and voltmeter readings into Table 2 of the research results .

2.4. Using an oscilloscope, determine the value of the time interval $T_2 - T_1$ and enter it into table 2.

2.5. Calculate shift phases between voltage $u(t)$ i electric shock $i(t)$ V degrees By formula $\varphi(t) = 360^\circ \cdot (T_2 - T_1)$ or $\varphi(t) = 360^\circ \cdot \frac{T_2 - T_1}{T}$. Meaning shift phases for-) $\cdot f$

carry V table 2.

2.6. Install capacity capacitor $0.5C$, execute p.p. 2.3 - 2.5.

2.7. Install capacity capacitor $2C$, execute p.p. 2.3 - 2.5.

2.8. By setting the source frequency $0.2f$, $0.5f$, $2f$, $5f$, investigate the dependence voltage V RC- chains from frequencies, For this execute points 2.3 - 2.5.

2.9. By results research build vector diagrams current and stresses for all cases studied.

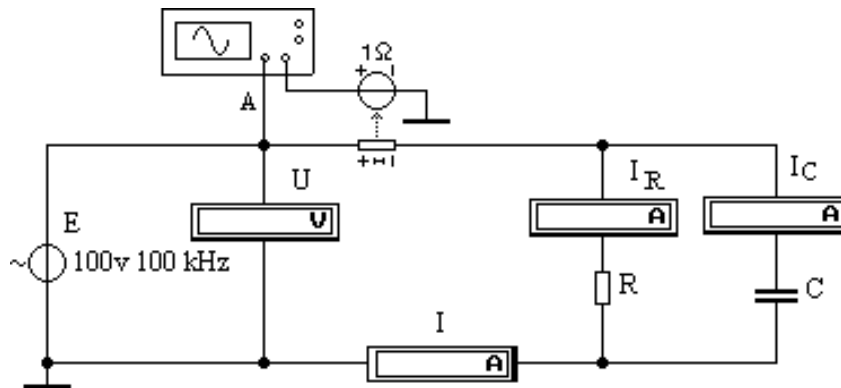
2.10. Do conclusions By results done work.

Exercise 2.2 Study distribution current V branched RC -

chai

ns 2.1. Collect diagram electrical chains (rice. 2).

2.2. Install given according to option quantities resistance re-
the thermistor R and the capacitance of the capacitor C , the value of the EMF of the
source $E = 150\text{ V}$ and frequencies $f = 10^5\text{ Hz}$. Double by pressing left buttons "mice"
on lines channel "A" of the oscilloscope set the desired channel color (eg red).



Rice. 2 - Scheme research RC chains

2.3. After completion installations everyone parameters schemes button -
“0-1” switch to position 1 - “On”. After completing the automatic calculations (a few
seconds), press the button switch to position 0 - "Off". Readings ammeters And
voltmeter bring in V table results research .

2.4. WITH help oscilloscope define meaning temporary interval (shift) T_2 -
 T_1 and enter into table 2.

2.5. Calculate shift phases between voltage $u(t)$ i electric shock $i(t)$ V degrees
by formulas $\varphi(t) = 360^\circ \cdot (T_2 - T_1) \cdot f$ or $\varphi(t) = 360^\circ \cdot \frac{T_2 - T_1}{T}$.
) $\cdot f$

2.6. Install capacity capacitor $0.5C$, execute p.p. 2.3 - 2.5.

2.7. Install capacity capacitor $2C$, execute p.p. 2.3 - 2.5.

2.8. By setting the source frequency $0.2f$, $0.5f$, $2f$, $5f$, investigate the
dependence current V branched RC chains from frequencies, For this execute points
2.3 – 2.5.

2.9. Based on the research results, construct vector diagrams of currents and
voltages for all cases under study.

2.10. Results research compare With results Preliminary calculation. Draw
conclusions.

**5. Prepare a report on the work performed in accordance with the
requirements set out in the job description.**

IN report bring:

- original data,
- performed tasks,

- compiled listings programs mathematical models,
- developed or compiled circuit design models devices;
- research results in the form of formulas used and calculation results, obtained graphs, oscillograms, time diagrams, conclusions made and findings for each task;
- general conclusions O done work.

6. Protection practical work

For protection practical introduce fully decorated report, free of significant errors. Complete one of the tasks assigned by the teacher, explaining all the physical phenomena and processes occurring in the task being completed.

LIST LITERATURE:

- 1) Sagdeev K.M. Physical foundations of information security [Electronic resource]: study guide / K.M. Sagdeev, V.I. Petrenko, A.F. Chipiga. - Electronic text data. - Stavropol: North Caucasus Federal University, 2015. - 394 p.
- 2) Evstifeev V.V. Physical foundations electricity and magnetism Electronic resource / Evstifeev V.V.: study guide. - Penza: PSU, 2019. - 416 p.
- 3) Bulatov V.N. Physical foundations of electronics Electronic resource / Bulatov V.N.: lecture notes for students in educational programs higher education in the following areas preparation 11.03.02 infocommunication technologies and communication systems. - Orenburg: OSU, 2018. - 178 p.
- 4) Goldstein A.E. Physical principles of obtaining information [Electronic resource]: textbook / A.E. Goldstein. — Electron. text data. — Tomsk: Tomsk Polytechnic University, 2010. — 292 p.

PRACTICAL JOB No. 10

TOPIC 11

PHYSICAL PROCESSES IN THE SIMPLE ELECTRICAL CHAINS RADIOELECTRONIC EQUIPMENT

Class 10

MODELING AND STUDY RESONANCE PHENOMENA IN ELECTRIC CIRCUITS

TIME - 2 hours.

Educational questions:

1. Study distribution current And voltage V oscillatory chains.

TARGET PRACTICAL INSTALLATION WORKS:

Competencies, being formed discipline

OPK-1: Capable use provisions, laws And methods natural sciences and mathematics to solve engineering problems.

OPK-2: Capable on one's own conduct experimental research And use main techniques processing And performances received data.

Learning outcomes achieved as a result of completing practical work:

Be able to:

- apply physical laws and methods to formalize the representation of physical phenomena and processes that occur in telecommunications .
- conduct experimental research With help mathematical models according to the accepted methodology
- model And analyze main physical phenomena And processes in telecommunications using computer technology.

Own:

- skills use knowledge physicists at decision practical problems of engineering activities
- methods of processing and presenting data obtained as a result of experimental studies.
- skills in computer modeling of the main physical methods of receiving, transmitting and storing information.

EDUCATIONAL AND MATERIAL SECURITY:

- PC With simulator electronic schemes Electronics Workbench - 5.12"
- electronic methodological development By practical work.

STRUCTURE PRACTICAL WORK:

Class No. 1

Introductory Part

Examination readiness students To practical work

Introductory Part

Questions (tasks), subject research:

1. Study distribution current And voltage V oscillator-
Noah chains.

Final Part

Protection reports By practical work

Summing up results

Exercise students For independent work

90 min

10 min

8 min

2 min

50 min

50 min

30 min

25 min

3 min

2 min

1. STUDY OF CURRENT AND VOLTAGE DISTRIBUTION IN A RESONANT CIRCUIT

Content practical work, performed students

1.1. Description laboratory equipment:

- PC With simulator electronic schemes Electronics Workbench - 5.12"

1.2. Initial data For modeling And research

Table 1 – Options assignment for for. of the preliminary calculation and Research-
niy

Option No.	Or, B	R, Om	L, mH	C, μ F	Option No.	Or, B	R, Ohm	L, mGn	S, μ F
1	100	50	0.10	0.010	31	150	50	0.16	0.015
2	120	40	0.12	0.015	32	160	40	0.18	0.016
3	140	60	0.13	0.016	33	170	60	0.19	0.020
4	150	70	0.15	0.020	34	180	70	0.20	0.018
5	160	80	0.11	0.018	35	190	80	0.10	0.019
6	170	90	0.14	0.019	36	200	90	0.12	0.011
7	180	55	0.16	0.011	37	130	55	0.13	0.012
8	190	65	0.18	0.012	38	120	65	0.15	0.009
9	200	45	0.19	0.009	39	140	45	0.11	0.021
10	130	35	0.20	0.021	40	150	35	0.14	0.020
11	120	70	0.10	0.020	41	160	70	0.16	0.018
12	140	80	0.12	0.018	42	170	80	0.18	0.019
13	150	90	0.13	0.019	43	180	90	0.19	0.011
14	160	55	0.15	0.011	44	190	55	0.10	0.012
15	170	65	0.11	0.012	45	200	65	0.12	0.009
16	180	45	0.14	0.009	46	130	45	0.13	0.021
17	190	35	0.16	0.021	47	120	35	0.15	0.020
18	200	70	0.18	0.020	48	140	70	0.11	0.018
19	130	80	0.19	0.018	49	150	80	0.11	0.010
20	120	70	0.10	0.010	50	160	70	0.14	0.015
21	140	80	0.12	0.015	51	170	80	0.16	0.016
22	150	90	0.13	0.016	52	100	90	0.18	0.020

Option No.	E, B	R, Ohm	L, mH	WITH, μF	Variant No.	Well, B	R, Ohm	L, mGr	With, μF
23	160	55	0.15	0.020	53	120	55	0.19	0.018
24	170	65	0.11	0.018	54	140	65	0.20	0.009
25	100	45	0.11	0.009	55	150	45	0.16	0.021
26	120	35	0.14	0.021	56	160	35	0.18	0.020
27	140	70	0.16	0.020	57	170	70	0.19	0.018
28	150	80	0.18	0.018	58	150	80	0.20	0.019
29	160	90	0.19	0.019	59	160	90	0.10	0.011
30	170	55	0.20	0.011	60	170	55	0.12	0.015

1.3. Exercise For works:

Basic level:

- 1.1) Study voltage distribution V sequential oscillatory circuit
- 1.2) Study of voltage distribution in a parallel oscillatory circuit

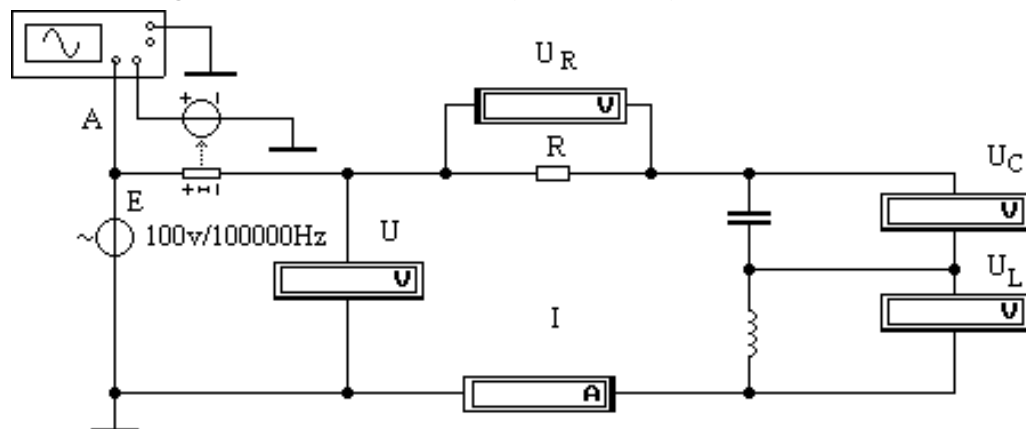
1.4. Order execution Description of

the research scheme

Research are being carried out on PC V environment Electronics Workbench. The research circuits contain an AC voltage source, a current-controlled voltage source, a resistor, an inductive coil, a capacitor, an oscilloscope, an ammeter, and voltmeters. The oscilloscope is used to determine the phase shifts between the current and voltage.

Task 1.1. Study of stress distribution in series oscillatory circuit

1. Collect diagram electrical chains (cm. rice. 1).



Rice. 1 - Scheme research RLC- chains

2. Install given according to option quantities resistance rubber

stor R, inductance L And capacity capacitor **WITH** $\text{cut} = \frac{1}{4 \pi^2 \cdot 10^5 \cdot L}$, meaning-
nie EMF And frequencies $f = 10^5 \text{ Hz}$ source E.

3. After completion of installation of all parameters of the scheme button  - "0- 1" translate V position 1-"On". By completion automatic calculations (a few seconds) button  Switch to position 0 - "Off". Enter the ammeter and voltmeter readings into Table 2 of the research results .

4. WITH help oscilloscope define meaning temporary interval T2-T1 and enter into table 2.

Table 2– Results research RLC chains

Type of chain	parameters	I, A	U, B	U_R, B	U_L, B	U_C, B	T2- T1, With	$\varphi(t)$, degrees
RLC-chain	C<Crease							
	Cut=							
	C>Cut							

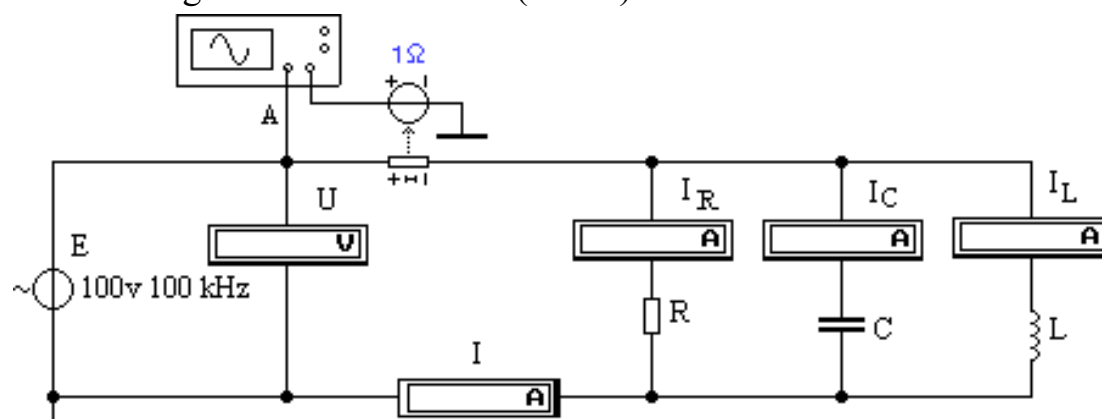
5. Calculate shift phases between voltage **$u(t)$** And electric shock **$i(t)$** V degrees By formula $\varphi = 360^\circ \cdot (T_2 - T_1) \cdot f$ or $\varphi = 360^\circ \frac{T_2 - T_1}{T}$. Meaning shift phases bring in V

table 2.

6. Install capacity capacitor WITH < Cut, execute p.p. 3.3 - 3.5.
7. Install capacity capacitor WITH > Cut, execute p.p. 3.3 - 3.5.
8. Installing frequency source 0.2f, 0.5f, 2f, 5f research dependence of voltage in the RLC circuit on frequency, for this, perform steps 3–5.
9. Based on the research results, construct vector diagrams of current and voltage for all cases under study.
10. Do conclusions By results done work.

Task 1.2 Study of current distribution in a parallel oscillatory circuit.

1. Collect diagram electrical chains (rice. 2).



Rice. 2 - Scheme research RLC chains

2. Install given according to option quantities resistance rubber stor R, inductance L And capacity capacitor **WITH** cut $= \frac{1}{4 \pi^2 \cdot 10^{-5} \cdot L}$, means- nie EMF And frequencies $f = 10^5$ Hz source E.

3. After completion of installation of all parameters of the scheme button  - "0- 1" translate V position 1-"On". By completion automatic calculations (a few seconds) button  Switch to position 0 - "Off". Enter the ammeter and voltmeter readings into the research results table .

4. WITH help oscilloscope define meaning temporary interval T2-T1 and enter into table 3.

Table 3 - Results research RLC chains

View chains	Parameters	U, B	I, A	I _R , A	I _L , A	I _C , A	T2-T1, with	φ (t), city
RLC-chain	S<Crease					-		
	Section=					-		
	S>Section					-		

5. Calculate shift phases between voltage $u(t)$ And electric shock $i(t)$ V degrees By formulas $\varphi(t) = 360^\circ \cdot (T_2 - T_1) \cdot f$ or $\varphi(t) = 360^\circ \cdot \frac{T_2 - T_1}{T}$.

6. Install capacity capacitor $C < C_{\text{cut}}$, execute p.p. 3.3 - 3.5.

7. Install capacity capacitor $C > C_{\text{cut}}$, execute p.p. 3.3 - 3.5.

8. By setting the source frequency to 0.2f, 0.5f, 2f, 5f, investigate the dependence current bridge in the RLC circuit from frequency $C = C_{\text{res}}$, to do this, perform steps 3–5.

9. Based on the research results, construct vector diagrams of current and voltage for all cases under study.

10. Compare the research results with the preliminary calculation results. Draw conclusions.

1.5. Prepare a report on the work performed in accordance with the requirements set out in the job description.

IN report bring:

- original data,
- performed tasks,
- compiled listings programs mathematical models,
- developed or compiled circuit design models devices;
- research results in the form of formulas used and calculation results, obtained graphs, oscillograms, time diagrams, conclusions made and findings for each task;
- general conclusions O done work.

1.6. Protection practical work

For protection practical introduce fully decorated report, free of significant errors. Complete one of the tasks assigned by the teacher, explaining all the physical phenomena and processes occurring in the task being completed.

LIST LITERATURE:

- 1) Sagdeev K.M. Physical foundations of information security [Electronic resource]: study guide / K.M. Sagdeev, V.I. Petrenko, A.F. Chipiga. - Electronic text data. - Stavropol: North Caucasus Federal University, 2015. - 394 p.
- 2) Evstifeev V.V. Physical foundations electricity and magnetism Electronic resource / Evstifeev V.V.: study guide. - Penza: PSU, 2019. - 416 p.
- 3) Bulatov V.N. Physical foundations of electronics Electronic resource / Bulatov V.N.: lecture notes for students in educational programs higher education in the following areas preparation 11.03.02 infocommunication technologies and communication systems. - Orenburg: OSU, 2018. - 178 p.
- 4) Goldstein A.E. Physical principles of obtaining information [Electronic resource]: textbook / A.E. Goldstein. — Electron. text data. — Tomsk: Tomsk Polytechnic University, 2010. — 292 p.

PRACTICAL JOB No. 11

TOPIC 12 PARASITIC PROCESSES IN ELECTRICAL CIRCUITS OF RADIOELECTRONIC EQUIPMENT

Class 11

MODELING AND STUDY TIP-INS, EMERGING FOR CHECK EXTERNAL PARASITIC CONNECTIONS

TIME – 4 hours.

Educational questions:

- 1. Modeling And study tips, emerging for check external capacitive and galvanic parasitic connections.**
- 2. Modeling And study tips, emerging for check external inductive parasitic connections.**

TARGET PRACTICAL INSTALLATION WORKS:

Competencies, being formed discipline

OPK-1: Capable use provisions, laws And methods natural sciences and mathematics to solve engineering problems.

OPK-2: Capable on one's own conduct experimental research And use main techniques processing And performances received data.

Learning outcomes achieved as a result of completing practical work:

Be able to:

- apply physical laws and methods to formalize the representation of physical phenomena and processes that occur in telecommunications .
- conduct experimental research With help mathematical models according to the accepted methodology
- model And analyze main physical phenomena And processes in telecommunications using computer technology.

Own:

- skills use knowledge physicists at decision practical problems of engineering activities
- methods of processing and presenting data obtained as a result of experimental studies.
- skills in computer modeling of the main physical methods of receiving, transmitting and storing information.

EDUCATIONAL AND MATERIAL SECURITY:

- PC With simulator electronic schemes Electronics Workbench - 5.12" And system computer mathematicians Mathcad - 15";
- electronic methodological development By practical work.

STRUCTURE PRACTICAL WORKS:

Class No. 1		90 min
Introductory Part		10 min
Examination readiness students To practical work		8 min
Introductory Part		2 min
Questions (tasks), subject research:		75 min
1. Modeling and research of interference arising from external capacitive and galvanic parasitic connections.		75 min
Final Part		5 min
Summing up results		3 min
Exercise students For independent work		2 min
Class No. 2		90 min
Introductory Part		10 min
Examination readiness students To practical work		8 min
Introductory Part		2 min
Questions (tasks), subject research:		75 min
2. Modeling And study tips, emerging for check external inductive parasitic connections.		75 min
Final Part		5 min
Summing up results		3 min
Exercise students For independent work		2 min

QUESTIONS, SUBJECTS RESEARCH

1. MODELING AND RESEARCH OF INTERFERENCES ARISING DUE TO EXTERNAL PARASITIC COMMUNICATIONS

Brief theoretical or reference materials Procedure calculation tips V channels

connections at external parallel parasitic connections

IN electronic devices more often others has place external parallel capacitive parasitic coupling. The equivalent circuit of parasitic capacitive coupling is shown in Fig. 2.1. Resistance Z_{in1} presented in the form of parallel-connected R_{in1} and C_{in1} . The second channel is shown in a simplified manner, since its parameters have little effect on the value of the interference from the second channel to the first.

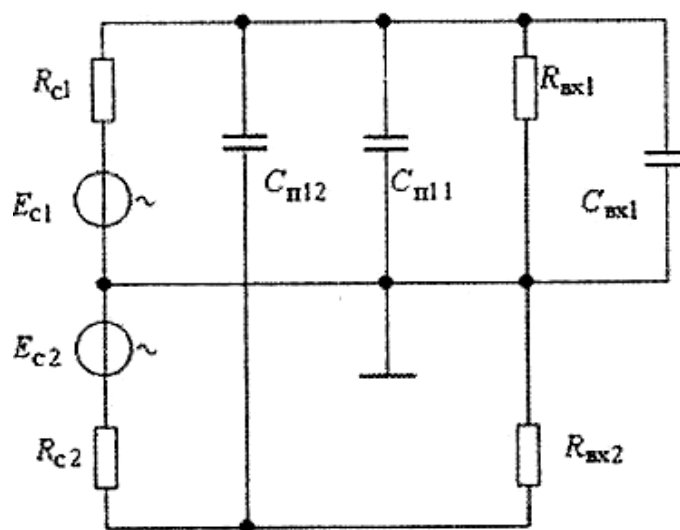


Рис. 1 - Equivalent scheme external capacitive parallel parasitic coupling between two channels

Let's consider order calculation interference $U_{p.p.12}$, induced from second channel in the first. The signal voltage in the second channel (at the resistance R_{in2}) is determined by the expression

$$U_{c2} = E_{c2} R_{вх2} / (R_{c2} + R_{вх2}). \quad (1)$$

The input resistance of the first channel for the interference signal is formed by a parallel connection of the following elements: the generator output resistance R_{c1} , the parasitic capacitance $C_{п11}$, the input resistance of the signal R_{in} and the input capacitance of the signal receiver, that is,

$$Z_{к1} = X_{c1} \parallel R_{к1},$$

Where X_{c1} - impedance parasitic capacity **From** $p1$;

With $k1 = \text{With } p11 + \text{With } вх1 + \text{With } p12$; $R_{к1} = R_{in1} R_{c1} / (R_{in1} + R_{c1})$.

Here $R_{к1}$ And **From** $k1$ - input resistance And own capacity first channel.

At harmonic signal in second channel amplitude interference V the first channel is determined by the expression

$$U_{p.p.12} = \frac{U_{c2} \cdot T_{p12} \cdot \omega_{c2}}{\sqrt{1 + T_{k1}^2 \omega_{c2}^2}}, \quad (2)$$

where $T_{k1} = R_{к1} C_{к1}$ - time constant of the first communication channel; $T_{p12} = R_{к1} C_{p12}$ - time constant of the parasitic coupling circuit of the first channel with the second; ω_{c2} - frequency of the harmonic signal in the second channel.

Transfer function channel capacitive parallel parasitic connections

$$\underline{W}_{p.p.12}(p) = \frac{PC_{п12} \cdot R_{к1}}{(p R_{к1} \cdot \text{From } k1 + 1) (T_{k1} p + 1)} = T_{p12} p, \quad (3)$$

and in accordance with the transfer function, the amplitude-frequency characteristic is determined

$$A_{p.p.12}(\omega) = \frac{T_{p12} \cdot \omega_{c2}}{\sqrt{1 + T_{k1}^2 \omega_{c2}^2}} \quad (4)$$

For the case of external resistive parallel parasitic coupling, shown in Fig. 2, the transfer function is determined by the expression

$$\frac{W_{p.p.12}(p)}{k1} = \frac{R}{R_{p12}} \cdot \frac{1}{T_{k1} r + 1} \quad (5)$$

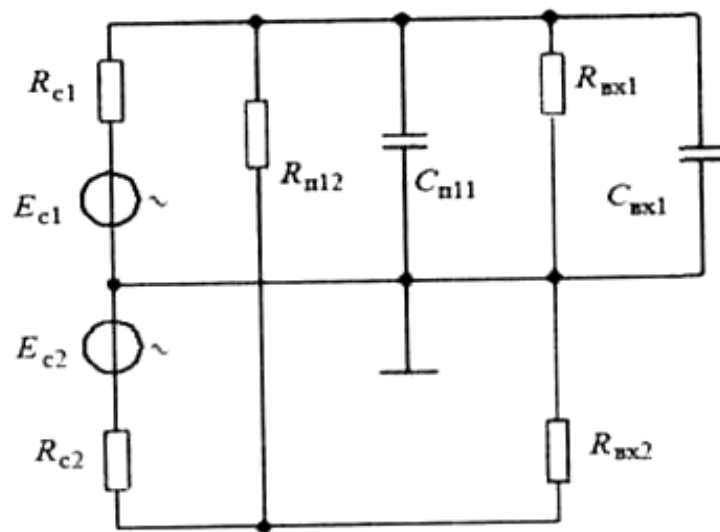


Рис. 2 - Equivalent scheme external resistive parallel parasitic coupling between two channels

For a harmonic signal E_{c2} in accordance with (5) the interference amplitude (interference) is equal to

$$\frac{U_{p.p.12}}{R_{k1}} = \frac{U_{c2}}{(R_{p12} \sqrt{1 + T_{k1}^2 \omega_{c2}^2})} \quad (6)$$

The procedure for calculating interference in communication channels with external parasitic communication of a serial type

The appearance of parasitic connections of a sequential type is possible in the presence of common wires And Not equal zero values output resistances of secondary power sources, power buses, grounding circuits.

The reason for the appearance of serial interference (crosstalk) at high frequencies is parasitic coupling due to mutual inductance between the wires (Fig. 2.3). In this case, the absence of common wires does not guarantee the absence of current crosstalk.

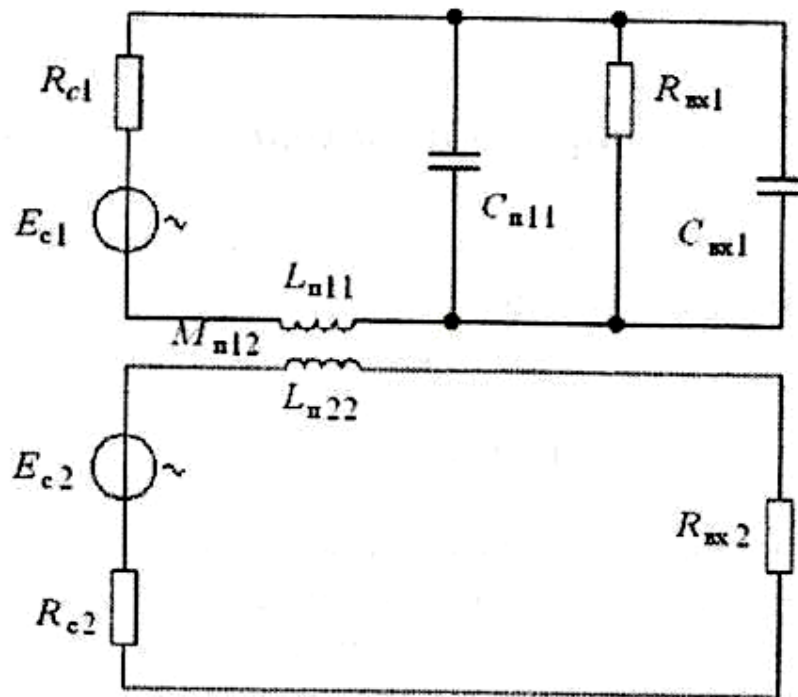
At harmonic signal current tip-off

$$U_{\tau, n12} = E_{c2} \omega_{c2} M_{n12} / (R_{bx2} + R_{c2}). \quad (7)$$

In formula (7) R_{bx2} and R_{c2} are calculated using the methodology discussed in previous question.

IN case pulsed signals magnitude current tips V first communication channel is determined by the steepness of the fronts t_f pulse in the second channel:

$$U_{\tau, n12} = M_{n12} \frac{di_2}{dt} = \frac{E_{c2}}{t_\phi} \cdot \frac{M_{n12}}{R_{c2} + R_{bx2}}. \quad (8)$$



Rice. 3 - Equivalent scheme consistent parasitic connections through parasitic mutual induction

Like this in this way, parasitic connections can manifest itself And at absence of galvanic connection between the source and the receiver of the interference.

Content practical work, performed students on the second academic question

1. Description laboratory equipment:

– PC With simulator electronic schemes Electronics Workbench - 5.12" and the computer mathematics system "MathCAD - 14".

2. Initial data For modeling And research

3. Exercise For work

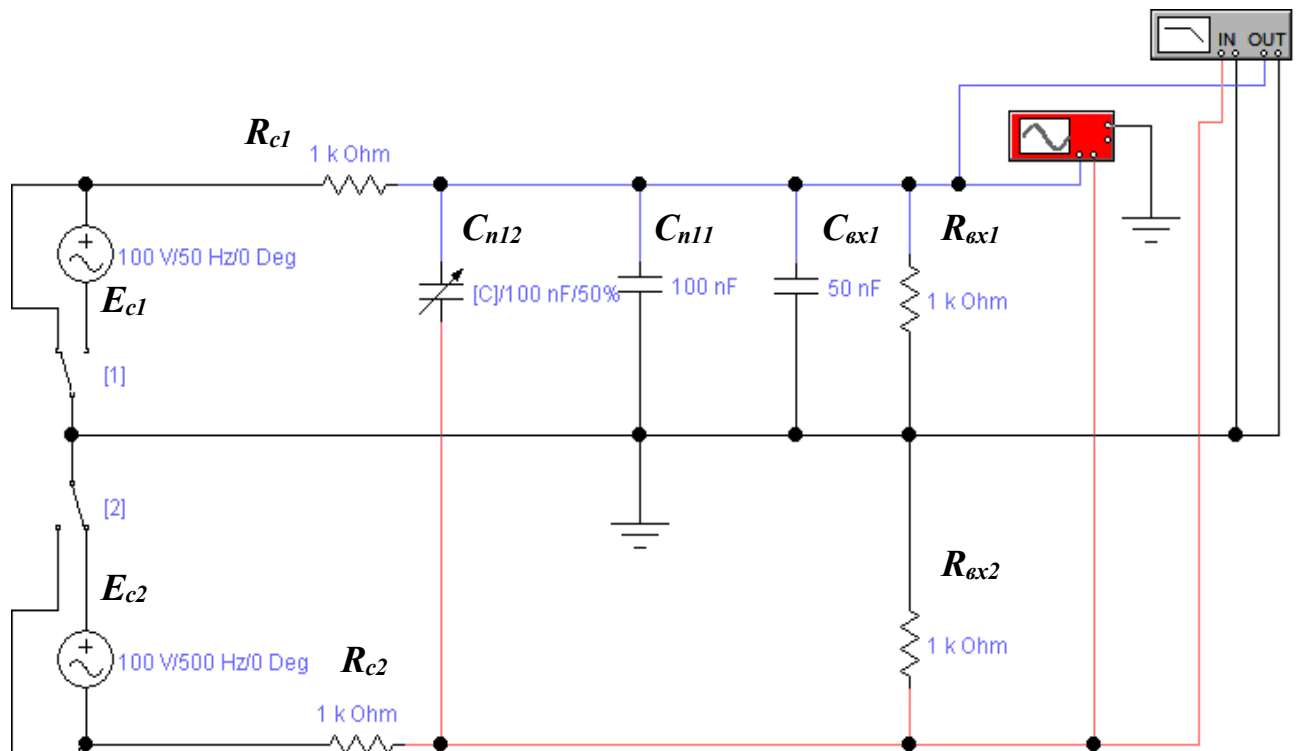
1) To simulate and investigate the equivalent circuit of external capacitive parallel parasitic coupling between two channels.

- 2) Simulate And research equivalent diagram substitutions external resistive parallel parasitic coupling between two channels.
- 3) Simulate And research equivalent diagram substitutions consistent parasitic connections through parasitic mutual inductance between two channels.

4. Order execution work

Exercise 1.1. Model And research equivalent circuit substitutions external capacitive parallel parasitic connections between two channels .

1. Launch modeling program Electronics Workbench - 5.12".
- Collect diagram By rice. 4 With specified on scheme parameters.



Rice. 4 - Simulated equivalent scheme external capacitive parallel parasitic coupling between two channels

4.1.2. Conduct calculation tips V first channel from influences second channel by given higher calculated ratios (2) And (4), having determined signal amplitude U_{c2} , interference amplitude U_{n12} in the 1st channel and the amplitude-frequency characteristic A_{p12} channel of capacitive parallel parasitic coupling.

To do this, use the Mathcad – 14 program to create a calculation program, the listing of which is shown in Fig. 5.

```

Ec1 := 100      Ec2 := 100      f1 := 50      f2 := 500

Rc1 := 1000     Rc2 := 1000     Rbx1 := 1000    Rbx2 := 1000

Cbx1 := 50·10-9    Cn11 := 100·10-9    Cn12 := 50·10-9

w1 := 2·π·f1      w2 := 2·π·f2

Uc2 :=  $\frac{Ec2 \cdot Rbx2}{Rc2 + Rbx2}$ 

Ck1 := Cn11 + Cbx1 + Cn12

Rk1 :=  $\frac{Rbx1 \cdot Rc1}{Rbx1 + Rc1}$     Tk1 := Rk1·Ck1    Tn12 := Rk1·Cn12

Un12 :=  $\frac{Uc2 \cdot Tn12 \cdot w2}{\sqrt{1 + Tk1^2 \cdot w2^2}}$ 

i := 0..10000      F(i) := i·100

W(i) := 2·π·F(i)

A(i) :=  $\frac{Tn12 \cdot W(i)}{\sqrt{1 + Tk1^2 \cdot W(i)^2}}$ 

```

Rice. 5 - Listing programs "Calculation tips at external capacitive parallel connections"

3. Conduct a study of the simulated equivalent circuit. To do this, perform the following steps:

1) At disconnected With help switch [1] source nutrition E_{c1} Use an oscilloscope to measure the interference voltage U_{p12} in the first channel. Display the voltage diagrams of the U_{c2} signal in the report and interference U_{p12} .

2) Compare measured values signals With calculated values.

3) At disconnected With help switch [2] source nutrition E_{c2} second channel And included With help switch [1] source power supply E_{c1} measure the interference voltage U_{p21} using the first channel of the oscilloscope in the second channel from the first. Display the voltage diagrams of the signal U_{c1} in the report and interference U_{p21} .

4) With both channels' power supplies turned on, use an oscilloscope to visually assess the channels' mutual influence. Display the U_{c1} signal voltage waveforms in the report. and U_{c2} .

5) At disconnected With help switch [1] source nutrition E_{c1} first channel And included With help switch [2] source power supply E_{c2} the second channel with a frequency response meter (**Bode plotter**) measure the amplitude-frequency characteristic of A_{p12} channel of capacitive parallel parasitic coupling. Compare the measured frequency response of the parasitic coupling channel with the calculated one. Determine the most dangerous frequencies for this equivalent circuit, at which tip-off in second channel has maximum

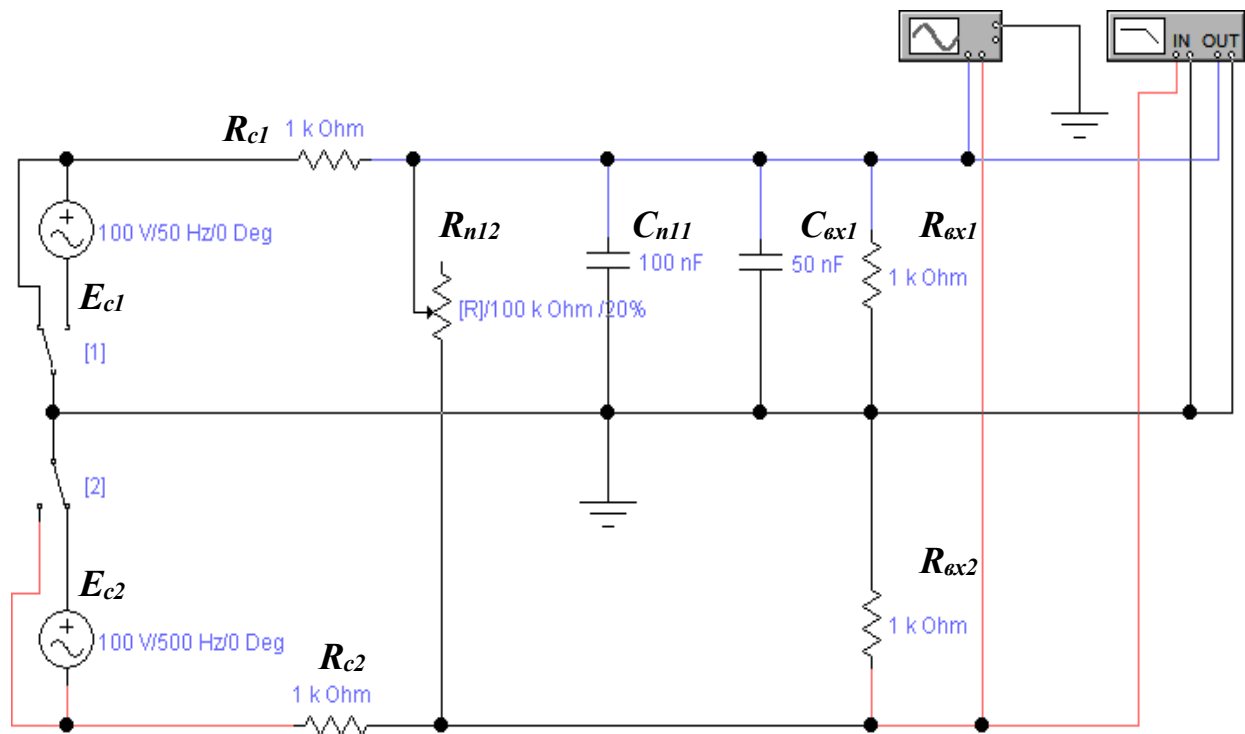
amplitude. Display the measured and calculated frequency response in the practical work report.

6) To investigate the dependence of the magnitude of the interference signal U_{n12} from the value of the parasitic capacitance C_{p12} . To do this, press the " Shift " and " C " keys to change values capacity **From** $p12$ from 0 to 100 nF, measuring oscilloscope the magnitude of the interference signal U_{n12} . Plot a graph of the dependence of U_{n12} from C_{p12} .

4. Draw conclusions about the mutual influence of communication channels on each other in the presence of capacitive parallel parasitic coupling.

Exercise 1.2. Simulate And research equivalent diagram replacement of external resistive parallel parasitic coupling between two channels

1. Launch modeling program Electronics Workbench - 5.12".
Collect diagram By rice. 6 With specified on scheme parameters.



Rice. 6 - Simulated equivalent scheme external resistive parallel parasitic coupling between two channels

2. Conduct calculation of interference V first channel from influences second channel according to the above calculation relations (5) and (6), having determined the signal amplitude U_{c2} , the interference amplitude U_{n12} in the 1st channel and the amplitude-frequency characteristic A_{p12} channel of resistive parallel parasitic coupling.

To do this, create a calculation program in the Mathcad – 14 program, the listing of which is shown in Fig. 2.7.

```

Ec1 := 100      Ec2 := 100      f1 := 50      f2 := 500

Rc1 := 1000     Rc2 := 1000     Rbx1 := 1000    Rbx2 := 1000

Cbx1 := 50·10-9    Cn11 := 100·10-9    Rn12 := 20000

w1 := 2·π·f1      w2 := 2·π·f2

Uc2 :=  $\frac{Ec2 \cdot Rbx2}{Rc2 + Rbx2}$     Ck1 := Cn11 + Cbx1    Rk1 :=  $\frac{Rbx1 \cdot Rc1}{Rbx1 + Rc1}$ 

Tk1 := Rk1·Ck1

Un12 :=  $\frac{Uc2 \cdot Rk1}{Rn12 \cdot \sqrt{1 + Tk1^2 \cdot w2^2}}$ 

Un12 :=  $\frac{Uc2 \cdot Rk1}{Rn12 \cdot \sqrt{1 + Tk1^2 \cdot w2^2}}$ 

i := 0..10000      F(i) := i·100

W(i) := 2·π·F(i)      +

A(i) :=  $\frac{Rk1}{Rn12 \cdot \sqrt{1 + Tk1^2 \cdot W(i)^2}}$ 

```

Rice. 7 - Listing programs "Calculation tips at external resistive parallel connections"

3. Conduct a study of the simulated equivalent circuit. To do this, perform the following steps:

1) At disconnected With help switch [1] source nutrition E_{c1} Use an oscilloscope to measure the interference voltage U_{p12} in the first channel. Display the voltage diagrams of the U_{c2} signal in the report and interference U_{p12} .

2) Compare measured values signals With calculated values.

3) At disconnected With help switch [2] source nutrition E_{c2} second channel And included With help switch [1] source power supply E_{c1} measure the interference voltage U_{p21} using the first channel of the oscilloscope in the second channel from the first. Display the voltage diagrams of the signal U_{c1} in the report and interference U_{p21} .

4) With both channels' power supplies turned on, use an oscilloscope to visually assess the channels' mutual influence. Display the U_{c1} signal voltage waveforms in the report. and U_{c2} .

5) At disconnected With help switch [1] source nutrition E_{c1} first channel And included With help switch [2] source power supply E_{c2} the second channel with a frequency response meter (**Bode plotter**) measure the amplitude-frequency characteristic of A_{p12} resistive parallel parasitic coupling channel. Compare the measured frequency response of the parasitic coupling channel with the calculated one. Determine the most dangerous frequencies for this equivalent circuit, at which tip-off in second channel has maximum

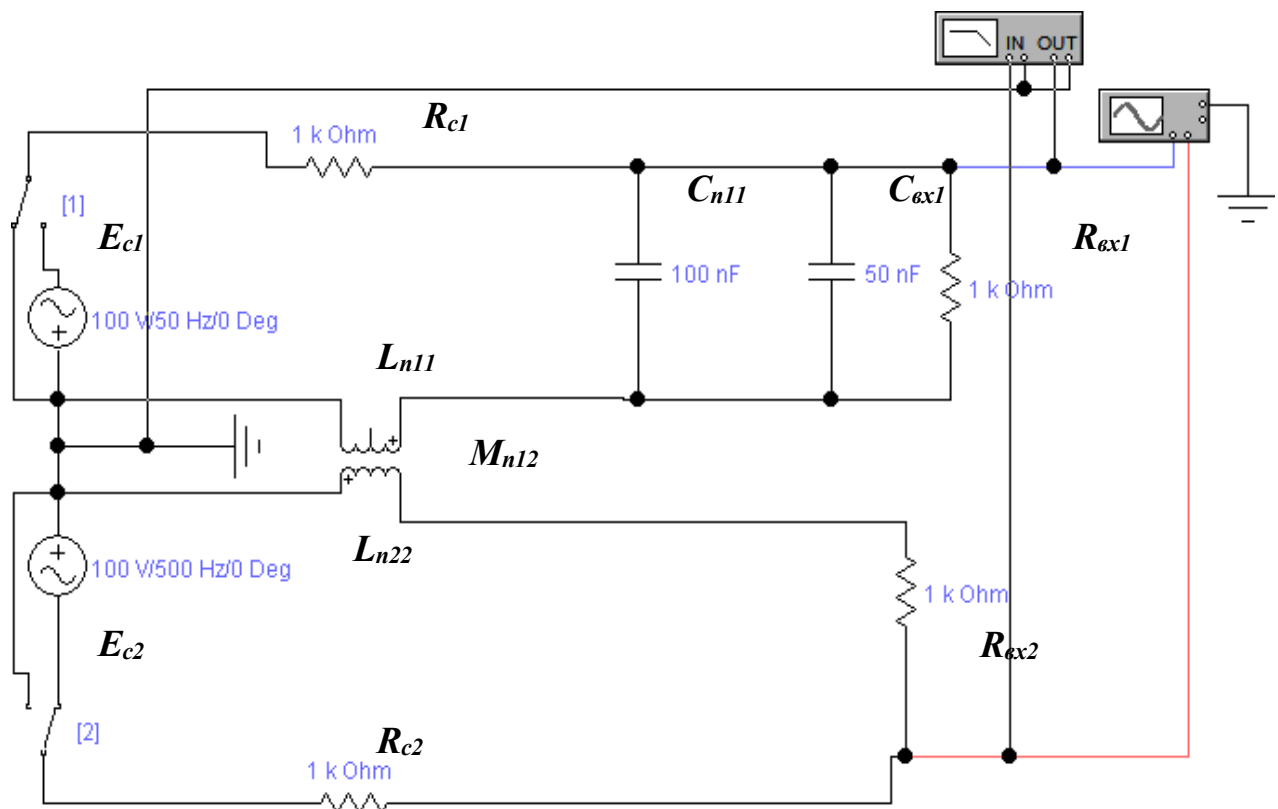
amplitude. Display the measured and calculated frequency response in the practical work report.

6) To investigate the dependence of the magnitude of the interference signal U_{n12} from the value of parasitic resistance R_{n12} . To do this, press the "Shift" keys and "C" change values capacity R_{p12} from 0 to 100 KOM, measuring Using an oscilloscope, measure the magnitude of the interference signal U_{p12} . Plot a graph of the dependence of U_{p12} from R_{p12} .

4. Draw conclusions about the mutual influence of communication channels on each other in the presence of resistive parallel parasitic communication.

4.3. Model and investigate the equivalent circuit of a series parasitic connections through parasitic mutual inductance between two channels.

4.3.1. Launch modeling program Electronics Workbench - 5.12". Collect diagram By rice. 8 With specified on scheme parameters.



Rice. 8 - Simulated equivalent scheme consistent parasitic connection through parasitic mutual induction

Install necessary parameters transformer. For this double-click on the transformer to open the "Transformer Properties" menu, in the "Library misc" library, select "Model ideal", click by button "Edit" and in the menu that opens, set the transformer parameters:

- coefficient transformations (Primary-to-secondary turns ratio $N = 1$);
- inductance scattering (Leakage inductance $LE = 0.001$, Gn);
- inductance primary windings (Magnetizing inductance $LM = 0.001$, Gn);

- Primary winding resistance (RP , Ohm - default);
- secondary winding resistance (Secondary winding resistance RS , Ohm - default).

2. Conduct calculation of interference V first channel from influences second channel according to the above calculation relation (7), having determined the signal amplitude U_{c2} , amplitude tips (interference) U_{p12} V 1st channel, at calculation take $M_{p12} = 0.001$ H. To do this, create a calculation program in the Mathcad – 14 program, the listing of which is shown in Fig. 2.9.

$$\begin{aligned}
 E_{c1} &:= 100 & E_{c2} &:= 100 & f_1 &:= 50 & f_2 &:= 500 \\
 R_{c1} &:= 1000 & R_{c2} &:= 1000 & R_{ex1} &:= 1000 & R_{ex2} &:= 1000 \\
 C_{ex1} &:= 50 \cdot 10^{-9} & C_{\pi 11} &:= 100 \cdot 10^{-9} & M_{\pi 12} &:= 0.001 \\
 w_1 &:= 2 \cdot \pi \cdot f_1 & w_2 &:= 2 \cdot \pi \cdot f_2 \\
 U_{c2} &:= \frac{E_{c2} \cdot R_{ex2}}{R_{c2} + R_{ex2}} & C_{k1} &:= C_{\pi 11} + C_{ex1} \\
 R_{k1} &:= \frac{R_{ex1} \cdot R_{c1}}{R_{ex1} + R_{c1}} & T_{k1} &:= R_{k1} \cdot C_{k1} \\
 U_{\pi 12} &:= \frac{U_{c2} \cdot M_{\pi 12} \cdot w_2}{R_{ex2} + R_{c2}}
 \end{aligned}$$

Rice. 9 - Listing programs "Calculation tips at external "series inductive coupling."

3. Conduct a study of the simulated equivalent circuit. To do this, perform the following steps:

1) At disconnected With help switch [1] source nutrition E_{c1} Use an oscilloscope to measure the interference voltage U_{p12} in the first channel. Display the voltage diagrams of the U_{c2} signal in the report and interference U_{p12} .

2) Compare measured values signals With calculated values.

3) At disconnected With help switch [2] source nutrition E_{c2} second channel And included With help switch [1] source power supply E_{c1} measure the interference voltage U_{p21} using the first channel of the oscilloscope in the second channel from the first. Display the voltage diagrams of the signal U_{c1} in the report and interference U_{p21} .

4) With both channels' power supplies turned on, use an oscilloscope to visually assess the channels' mutual influence. Display the U_{c1} signal voltage waveforms in the report. and U_{c2} .

5) At disconnected With help switch [1] source nutrition E_{c1} first channel And included With help switch [2] source power supply E_{c2} the second channel with a frequency response meter (*Bode plotter*) measure the amplitude-frequency characteristic of A_{p12} serial communication channel through parasitic mutual induction. Determine for this equivalent circuit the most dangerous frequencies, in which the interference in the second channel has

maximum amplitude. Display the measured frequency response in the practical work report.

6) To investigate the dependence of the magnitude of the interference signal U_{n12} from the value of the parasitic mutual induction M_{p12} . For this sequentially installing in the menu, set the value of the primary winding inductance parameter (Magnetizing inductance LM) to 0.0001, 0.001, 0.01, 0.1 H, measure the magnitude of the interference signal U_{p12} with an oscilloscope. Plot a graph of the dependence of U_{p12} from M_{p12} .

4. Draw conclusions about the mutual influence of communication channels on each other in the presence of resistive parallel parasitic communication.

6. Protection practical work

For protection practical introduce fully decorated report, free of significant errors. Complete one of the tasks assigned by the teacher, explaining all the physical phenomena and processes occurring in the task being completed.

LIST LITERATURE:

1) Sagdeev K.M. Physical foundations of information security [Electronic resource]: study guide / K.M. Sagdeev, V.I. Petrenko, A.F. Chipiga. - Electronic text data. - Stavropol: North Caucasus Federal University, 2015. - 394 p.

2) Evstifeev V.V. Physical foundations electricity and magnetism Electronic resource / Evstifeev V.V.: study guide. - Penza: PSU, 2019. - 416 p.

3) Bulatov V.N. Physical foundations of electronics Electronic resource / Bulatov V.N.: lecture notes for students in educational programs higher education in the following areas preparation 11.03.02 infocommunication technologies and communication systems. - Orenburg: OSU, 2018. - 178 p.

4) Goldstein A.E. Physical principles of obtaining information [Electronic resource]: textbook / A.E. Goldstein. — Electron. text data. — Tomsk: Tomsk Polytechnic University, 2010. — 292 p.

PRACTICAL JOB No. 12

TOPIC 13 TRANSITIONAL PROCESSES IN LINEAR ELECTRIC CIRCUITS

Class 12 MODELING AND STUDY TRANSITIONAL PROCESSES IN ELECTRICAL CHAINS FIRST AND SECOND ORDER.

TIME – 4 hours.

Educational questions:

- 1. Study transitional processes V chains first order.**
- 2. Study transitional processes V chains second order.**

TARGET PRACTICAL INSTALLATION WORKS:

Competencies, being formed discipline

OPK-1: Capable use provisions, laws And methods natural sciences and mathematics to solve engineering problems.

OPK-2: Capable on one's own conduct experimental research And use main techniques processing And performances received data.

Learning outcomes achieved as a result of completing practical work:

Be able to:

- apply physical laws and methods to formalize the representation of physical phenomena and processes that occur in telecommunications .
- conduct experimental research With help mathematical models according to the accepted methodology
- model And analyze main physical phenomena And processes in telecommunications using computer technology.

Own:

- skills use knowledge physicists at decision practical problems of engineering activities
- methods of processing and presenting data obtained as a result of experimental studies.
- skills in computer modeling of the main physical methods of receiving, transmitting and storing information.

EDUCATIONAL AND MATERIAL SECURITY:

- PC With simulator electronic schemes Electronics Workbench - 5.12"
- electronic methodological development By practical work.

STRUCTURE PRACTICAL WORK:

Class No. 1

90 min

Introductory Part

10 min

Examination readiness students To practical work

8 min

Introductory Part

2 min

Questions (tasks), subject research:

75 min

1. Study transitional processes V chains first order.

75 min

Final Part

5 min

Summing up results

3 min

Exercise students For independent work

2 min

Class No. 2

90 min

Introductory Part

10 min

Examination readiness students To practical work

8 min

Introductory Part

2 min

Questions (tasks), subject research:

50 min

1. Study transitional processes V chains second order.

50 min

Final Part

30 min

Protection reports By practical work

25 min

Summing up results

3 min

Exercise students For independent work

2 min

1. STUDY OF TRANSIENT PROCESSES IN FIRST-ORDER CIRCUITS

Content practical work, performed students On the first question

1.1. Description laboratory equipment:

- PC With simulator electronic schemes Electronics Workbench - 5.12"

1.2. Initial data For modeling And research

Table 1 - Options tasks For research By points 1 And 4.

Option No.	L1, mHn	R2, Ohm	R3, Ohm	Option No	L1, mHn	R2, Ohm	R3, Ohm
1	900	5	10	16	815	5	8
2	840	4	9	17	835	14	9
3	870	3	11	18	865	4	10
4	930	2	8	19	925	16	9
5	850	3	12	20	975	17	8
6	880	4	7	21	935	18	7
7	950	5	13	22	915	15	8
8	800	6	6	23	945	10	9
9	825	7	5	24	895	9	10
10	920	8	14	25	885	11	9
11	875	9	4	26	875	8	8
12	890	10	16	27	855	12	7

Option No.	L1, mH	R2, Ohm	R3, Ohm	Option No.	L1, mH	R2, Ohm	R3, Ohm
13	970	9	17	28	845	7	5
14	810	8	18	29	905	13	6
15	910	7	15	30	805	6	11

Table 2 - Options tasks For research By points 2 And 3.

Option No.	C1, mf	R2, Ohm	R3, Ohm	Variant No.	C1, mF	R2, Ohm	R3, Ohm
1	2	1000	500	16	0.5	775	925
2	1.9	950	550	17	0.75	725	600
3	1.8	900	600	18	0.85	675	625
4	1.7	850	650	19	0.95	625	650
5	1.6	800	700	20	1.15	575	625
6	1.5	750	750	21	1.25	525	675
7	1.4	975	800	22	1.35	475	500
8	1.3	925	850	23	1.45	450	550
9	1.2	600	900	24	1.55	550	1000
10	1.1	625	950	25	1.05	650	950
11	1.0	650	1000	26	1.65	600	900
12	0.9	625	975	27	1.75	625	850
13	0.8	675	925	28	1.85	700	800
14	0.7	500	875	29	0.45	725	750
15	0.6	550	825	30	1.95	750	975

1.3. Exercise For works:

Basic level:

- 1.1. Study RL circuits at inclusion on source permanent voltage.
- 1.2. Study RC circuits at inclusion on source permanent voltage.
- 1.3. Study RC circuits at inclusion on source variable voltage.
- 1.4. Study RL circuits at inclusion on source variable voltage.

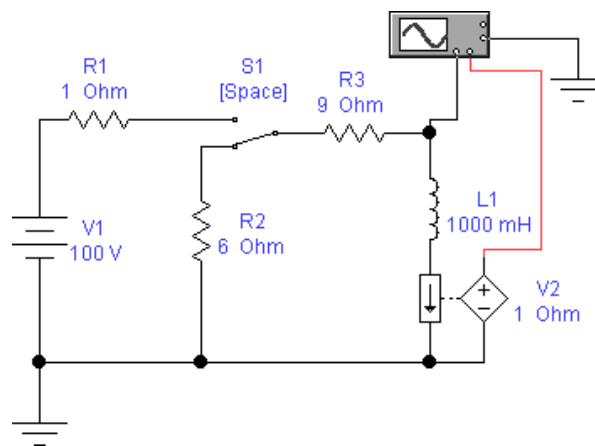
1.4. Order execution work

Description schemes research

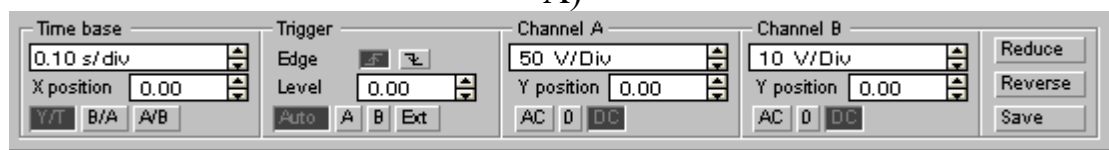
Research are being carried out on PC V environment Electronics Workbench. The research circuits contain an AC voltage source, a current-controlled voltage source, a resistor, an inductive coil, a capacitor, an oscilloscope, an ammeter, and voltmeters. The oscilloscope is used to determine the phase shifts between the current and voltage.

Exercise 1.1. Study RL circuits at inclusion on source constant voltage .

1.1. Assemble the circuit shown in Fig. 1, setting the parameters of the elements as shown in Fig. 1, a).



A)



b)

Rice. 1 - Scheme modeling transitional processes V RL circuits at inclusion on source permanent voltage (A) And view panels management oscilloscope (b)

1.2. Tune oscilloscope, How shown on rice. 1, b).

1.3. Run the EWB simulator with the power source disconnected. Make sure V performance schemes, having received on screen oscilloscope temporary diagram transitional process, For this With help switch connect source voltage, A then through 5 seconds turn off, short-circuited RL chain.

1.4. Install parameters RL circuits according to given option (cm. table 1).

1.5. Run the EWB simulator with the power source disconnected. Get on screen oscilloscope temporary diagram transitional process, for this With help switch connect source voltage, A then after 5 seconds turn it off by short-circuiting the RL circuit.

1.6. Include in the practical work report a time diagram of the transient process when turning on and off a DC voltage source .

1.7. Measure the following parameters of the RL circuit: steady-state current and voltage before switching, steady-state current and voltage after switching For transitional process inclusions source voltage And For transient short circuit process.

Measurements produce For following options primary parameters chains:

- L1, 0.5L1 And 2L1 at permanent R2, R3;
- R2, R3, 0.5R2, 0.5R3 And 2R2, 2R3 at constant L1.

Results measurements bring in V table 3.

Table 3 - Results measurements And calculation

Variable Primaries chain parameter	Measured results				Results calculation				
	$I_y(0^-)$, A	$I_y(0^+)$, A	$U_{in}(0^-)$, In	$U_{in}(0^+)$, In	$I_{in}(0^-)$, A	$I_{in}(0^+)$, A	$U_{in}(0^-)$, In	$U_{in}(0^+)$, In	τ , with
L1, R2, R3									
0.5L1, R2, R3									
2L1, R2, R3									
L1, 0.5R2, 0.5R3									
L1, 2R2, 2R3									

1.8. Calculate the following parameters of the RL circuit: steady-state current and voltage before switching, steady-state current and voltage after switching For transitional process inclusions source voltage And For short-circuit transient process, as well as the circuit time constant for both transient processes.

Calculation produce For following options primary parameters chains:

- L1, 0.5L1 And 2L1 at permanent R2, R3;
- R2, R3, 0.5R2, 0.5R3 And 2R2, 2R3 at constant L1.

Formulas calculation bring V report, results calculation bring in V table

2.

1.9. Write down mathematical expressions For studied transitions currents And stresses.

1.10. Do conclusions By results done work.

Exercise 1.2. Study RC circuits at inclusion on source constant voltage .

2.1. Assemble the circuit shown in Fig. 2, setting the parameters of the elements as shown in Fig. 2, a).

2.2. Tune oscilloscope, How shown on rice. 2, b).

2.3. Run the EWB simulator with the power source disconnected. Make sure V performance schemes, having received on screen oscilloscope temporary diagram transitional process, For this With help switch connect source voltage, A then through 5 seconds turn off, short-circuited RC circuit.

2.4. Install parameters RC circuits according to given option (cm. table 2).

2C1, R2, R3									
C1, 0.5R2, 0.5R3									
C1, 2R2, 2R3									

2.8. Calculate the following parameters of the RC circuit: steady-state current and voltage before switching, steady-state current and voltage after switching For transitional process inclusions source voltage And For short-circuit transient process, as well as the circuit time constant for both transient processes.

Calculation produce For following options primary parameters chains:

- C1, 0.5C1 And 2C1 at permanent R2, R3;
- R2, R3, 0.5R2, 0.5R3 And 2R2, 2R3 at constant C1.

Enter the formulas with calculations into the report, enter the calculation results into table 4.

2.9. Write mathematical expressions for the studied transient currents and voltages.

2.10. Do conclusions By results done work.

Task 1.3. Study of RC circuit when connected to an AC voltage source.

3.1. Assemble the circuit shown in Fig. 3, setting the parameters of the elements as shown in Fig. 3, a).

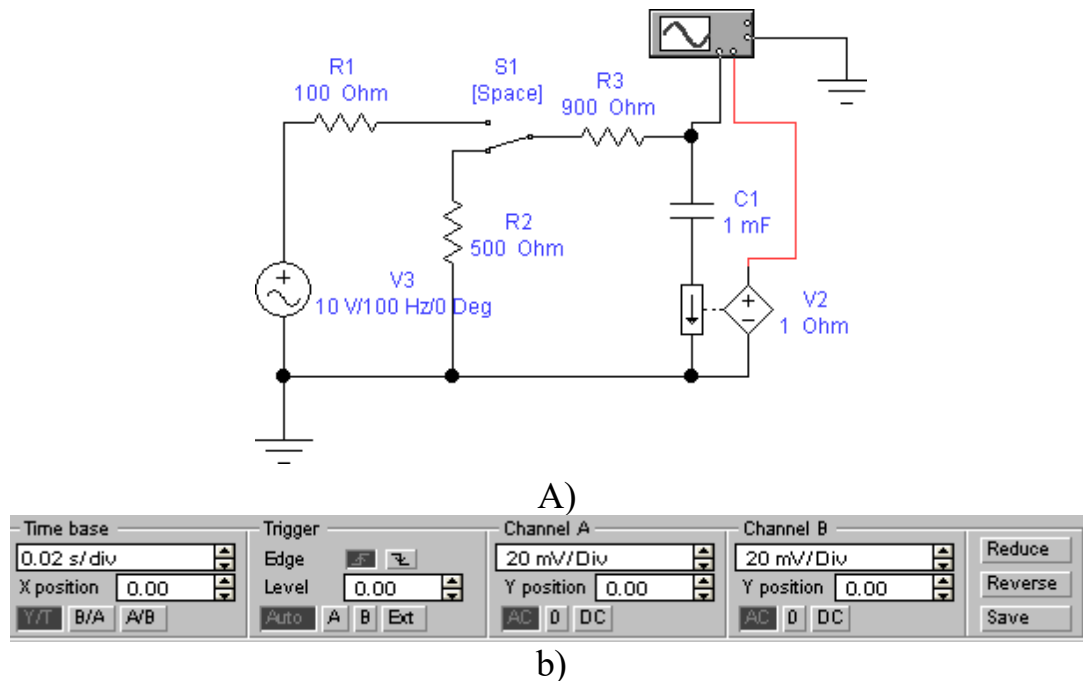


Fig. 3 – Simulation diagram of transient processes in an RC circuit when turned on on source variable voltage (A) And view panels management oscilloscope (b)

3.2. Tune oscilloscope, How shown on rice. 3, b).

3.3. Run the EWB simulator with the power source disconnected. Make sure V performance schemes, having received on screen oscilloscope temporary diagram transitional process, For this With help switch connect the voltage source, then after 1 second disconnect it by short-circuiting the RC circuit and stop the EWB simulator.

3.4. Install parameters RC circuits according to given option (cm. table 2).

3.5. Run the EWB simulator with the power source disconnected. Get on screen oscilloscope temporary diagram transitional process, for this With help switch connect source voltage, A then after 1 second turn it off by short-circuiting the RC circuit and stop the EWB simulator.

3.6. Include in the practical work report a time diagram of the transient process when turning on and off an alternating voltage source .

3.7. Do conclusions By results done work.

Task 1.4. Study of RL circuit when connected to an AC voltage source .

4.1. Assemble the circuit shown in Fig. 4, setting the parameters of the elements as shown in Fig. 4, a).

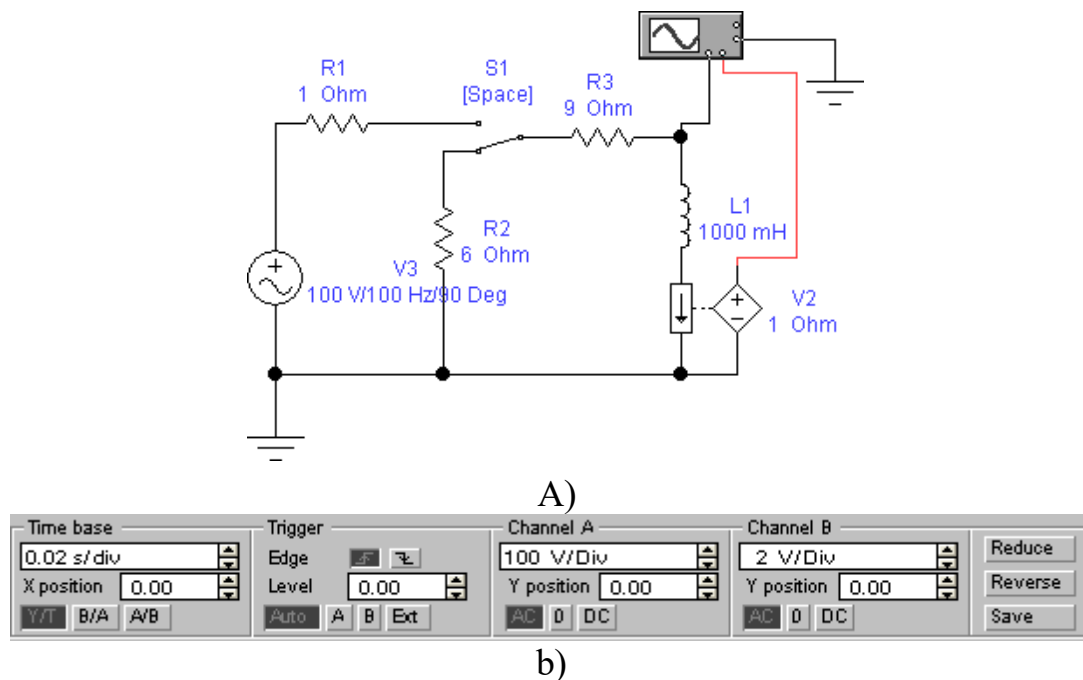


Fig. 4 – Simulation diagram of transient processes in the RL circuit when switching on on source variable voltage (A) And view panels management oscilloscope (b)

4.2. Tune oscilloscope, How shown on rice. 4, b).

4.3. Run the EWB simulator with the power supply turned on. Make sure V performance schemes, having received on screen oscilloscope time diagram of the transient process, and then after 1 second, turn it off by short-circuiting the RL circuit and turn off the EWB simulator.

4.4. Install parameters RL circuits according to given option (cm. table 1).

4.5. Run the EWB simulator with the voltage source turned on. Get on screen oscilloscope temporary diagram transitional process, and then after 1 second turn it off by short-circuiting the RL circuit and turning off the EWB simulator.

4.6. Include in the practical work report a time diagram of the transient process when turning on and off an alternating voltage source .

4.7. Do conclusions By results done work.

2. STUDY OF TRANSIENT PROCESSES IN SECOND-ORDER CIRCUITS

Content practical work, performed students On the first question

1.1. Description laboratory equipment:

– PC With simulator electronic schemes Electronics Workbench - 5.12"

1.2. Initial data For modeling And research

Table 5 - Options tasks

Option No.	L1, mH	R2, Ohm	C1, mf	Option No.	L1, mGn	R2, Ohm	C1, mF
1	10	2	10	16	36	12	1
2	40	4	10	17	49	14	1
3	90	6	10	18	25	10	1
4	160	8	10	19	16	8	1
5	250	10	10	20	9	6	1
6	1	2	1	21	4	4	1
7	4	4	1	22	10	2	10
8	9	6	1	23	40	4	10
9	16	8	1	24	90	6	10
10	25	10	1	25	160	8	10
11	100	2	100	26	250	10	10
12	100	20	1	27	25	10	1
13	100	10	4	28	100	2	100
14	81	18	1	29	100	20	1
15	64	16	1	30	100	10	4

1.3. Exercise For works:

2.1. Study aperiodic process V RCL chains at when connected to a DC voltage source.

2.2. Study oscillatory process V RCL chains at when connected to a DC voltage source.

1.4. Order execution work

Exercise 2.1. Study aperiodic process V RCL chains at switching on to a DC voltage source.

1.1. Assemble the circuit shown in Fig. 5, setting the parameters of the elements as shown in Fig. 5, a).

1.2. Tune oscilloscope, How shown on rice. 5, b).

1.3. Run the EWB simulator with the power supply turned on. Make sure V performance schemes, having received on screen oscilloscope time diagram of the aperiodic discharge, for this, using a switch, disconnect the capacitor from the voltage source, automatically connecting it to the RL circuit, and then after 1 - 2 seconds, disconnect the EWB simulator.

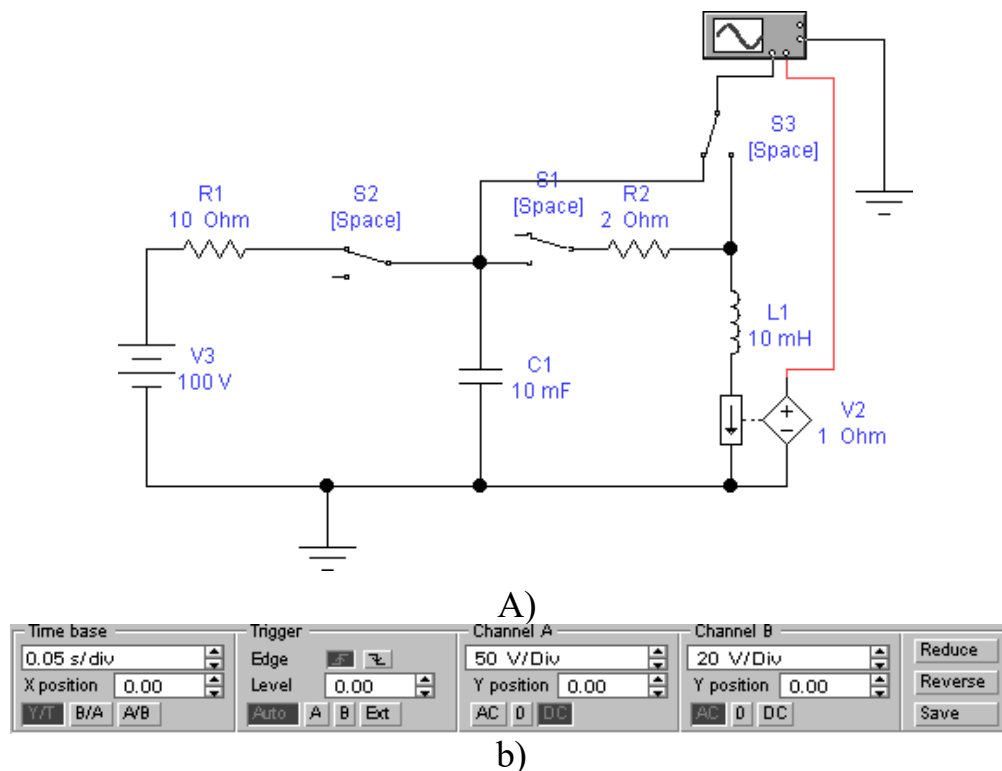


Fig. 5 – Simulation diagram of transient processes in the RL circuit when switching on on source permanent voltage (A) And view panels management oscilloscope (b)

1.4. Set the parameters of the RLC circuit according to the specified option (see Table 5).

Between given values parameters chains observed ratio:

$$R = R_{kp} = 2 \sqrt{\frac{L}{C}}$$

This means, What transition process it turns out aperiodic, But boundary with the oscillatory process.

1.5. Run the EWB simulator with the voltage source turned on. Obtain a timing diagram of the aperiodic process on the oscilloscope screen, For this With help switch turn off from source voltage

capacitor, automatically connecting it to the RL circuit, and then after 1–2 seconds, disconnect the EWB simulator.

1.6. Bring in V report By practical work temporary diagram aperiodic transitional process at discharge charged capacitor on RL chain.

1.7. Measure duration limit aperiodic discharge.

1.8. Change size active resistance, having installed meaning resistor R2 is 2 or 3 times larger.

1.9. Repeat subparagraphs 1.5 – 1.6. Then measure the duration of the aperiodic discharge.

1.10. Do conclusions By results done work.

Task 2.2. Study of the oscillatory process in an RCL circuit when connected to a DC voltage source.

2.1. In the RLC circuit diagram shown in Fig. 5, change the value of the active resistance R2, setting it to 2 times less than the specified value.

2.2. Run the EWB simulator with the power supply turned on. Make sure V performance schemes, having received on screen oscilloscope temporary diagram fading oscillatory process, For this With help switch to disconnect the capacitor from the voltage source, automatically connecting it to the RL circuit, and then after 1–2 seconds, disconnect the EWB simulator.

2.3. Bring in V report By practical work temporary diagram damped oscillatory process during the discharge of a charged capacitor into an RL circuit.

2.4. Measure T_0 - period own fluctuations And define linear frequency f of oscillations.

2.5. Calculate linear frequency frequency own fluctuations contour according to the formula:

$$f_0 = \frac{1}{2\pi} \cdot \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}.$$

Compare calculated frequency With measured frequency.

2.6. Define coefficient attenuation free component transient process according to the formula: $\alpha = R/(2L)$.

2.7. By setting the values of resistor R2 to 5 and 20 times less than the specified ones, complete points 2.2 – 2.6.

2.8. Determine the value of resistor R2 at which the oscillatory process will not damp out.

2.9. Do conclusions By results done work.

5. Prepare a report on the work performed in accordance with the requirements set out in the job description.

IN report bring:

– original data,

- performed tasks,
- compiled listings programs mathematical models,
- developed or compiled circuit design models devices;
- research results in the form of formulas used and calculation results, obtained graphs, oscillograms, time diagrams, conclusions made and findings for each task;
- general conclusions O done work.

6. Protection practical work

For protection practical introduce fully decorated report, free of significant errors. Complete one of the tasks assigned by the teacher, explaining all the physical phenomena and processes occurring in the task being completed.

LIST LITERATURE:

- 1) Sagdeev K.M. Physical foundations of information security [Electronic resource]: study guide / K.M. Sagdeev, V.I. Petrenko, A.F. Chipiga. - Electronic text data. - Stavropol: North Caucasus Federal University, 2015. - 394 p.
- 2) Evstifeev V.V. Physical foundations electricity and magnetism Electronic resource / Evstifeev V.V.: study guide. - Penza: PSU, 2019. - 416 p.
- 3) Bulatov V.N. Physical foundations of electronics Electronic resource / Bulatov V.N.: lecture notes for students in educational programs higher education in the following areas preparation 11.03.02 infocommunication technologies and communication systems. - Orenburg: OSU, 2018. - 178 p.
- 4) Goldstein A.E. Physical principles of obtaining information [Electronic resource]: textbook / A.E. Goldstein. — Electron. text data. — Tomsk: Tomsk Polytechnic University, 2010. — 292 p.

PRACTICAL JOB No. 13

TOPIC 14 PHYSICAL PROCESSES IN DISTRIBUTED CIRCUITS

Class 13 MODELING AND STUDY PROCESS DISTRIBUTIONS TOKA THROUGH ELECTRICAL CIRCUITS WITH DISTRIBUTED PARAMETERS.

TIME – 2 hours.

Educational questions:

1. Modeling and research of electrical circuits with distributed parameters.

TARGET PRACTICAL INSTALLATION WORKS:

Competencies, being formed discipline

OPK-1: Capable use provisions, laws And methods natural sciences and mathematics to solve engineering problems.

OPK-2: Capable on one's own conduct experimental research And use main techniques processing And performances received data.

Learning outcomes achieved as a result of completing practical work:

Be able to:

- apply physical laws and methods to formalize the representation of physical phenomena and processes that occur in telecommunications .
- conduct experimental research With help mathematical models according to the accepted methodology
- model And analyze main physical phenomena And processes in telecommunications using computer technology.

Own:

- skills use knowledge physicists at decision practical problems of engineering activities
- methods of processing and presenting data obtained as a result of experimental studies.
- skills in computer modeling of the main physical methods of receiving, transmitting and storing information.

EDUCATIONAL AND MATERIAL SECURITY:

- PC With simulator electronic schemes Electronics Workbench - 5.12" And system computer mathematicians Mathcad - 15";
- electronic methodological development By practical work.

STRUCTURE PRACTICAL WORK:

Class No. 1

Introductory Part

Examination readiness students To practical work

Introductory Part

Questions (tasks), subject research:

1. Modeling And study electrical chains With distribution divided parameters.

Final Part

Summing up results

Exercise students For independent work

90 min

10 min

8 min

2 min

75 min

75 min

5 min

3 min

2 min

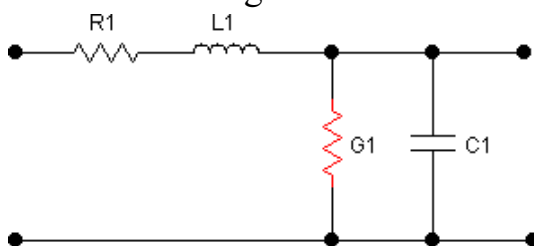
QUESTIONS, SUBJECTS RESEARCH

1. MODELING AND RESEARCH OF ELECTRICAL CIRCUITS WITH DISTRIBUTED PARAMETERS

Brief theoretical or reference and information materials

Distributed parameter circuits differ from the lumped parameter circuits discussed in the previous sections in that inductance, capacitance, resistance, and conductivity are distributed in space—usually along two conductors that form a communication line for exchanging information between different objects. If the above parameters are distributed along lines (on unit lengths) evenly (For example, For two-wire lines V view parallel conductors), That such line is called homogeneous, V otherwise case line is heterogeneous. Example Long lines can be provided by the well-known telephone (telegraph) communication lines.

Long lines (chains With distributed parameters) V EWB are modeled in the form of an equivalent circuit shown in Fig. 16.



Rice. 16 - Scheme substitutions segment long lines

The figure shows the equivalent circuit diagram of a line segment with losses, corresponding lines, having length V 1 meter. Scheme contains:

- **R1** active (ohmic) resistance of conductors long line, related to a unit of length (linear resistance), Ohm/m;
- **L1** running inductance conductors lines, H/m;

– **GI** linear conductivity between line conductors, S/m; for real lines, conductivities caused by dielectric losses of insulating materials are added to this conductivity;

– **CI** running capacity between conductors, F/m.

The processes occurring in long lines are described by the so-called telegraph equations:

$$-\frac{\partial \phi}{\partial x} = R \cdot i + L \frac{\partial i}{\partial x}, \quad -\frac{\partial i}{\partial t} = G \phi + C \frac{\partial \phi}{\partial t}. \quad (1)$$

Solution equations (30) gives next kit characteristics (secondary parameters) of a homogeneous long line:

1) Wave (characteristic) resistance

$$Z_o = \sqrt{\frac{R + j\omega L}{G + j\omega C}}. \quad (2)$$

2) Coefficient distribution

$$\gamma = \sqrt{(R + j\omega L) \cdot (G + j\omega C)} = \alpha + j\beta. \quad (3)$$

3) Coefficient attenuation

$$\alpha = \sqrt{0.5 \cdot \left(\sqrt{(R^2 + \omega^2 L^2)(G^2 + \omega^2 C^2)} + (RG - \omega^2 LC) \right)}. \quad (4)$$

4) Coefficient phases

$$\beta = \sqrt{0.5 \cdot \left(\sqrt{(R^2 + \omega^2 L^2)(G^2 + \omega^2 C^2)} - (RG - \omega^2 LC) \right)}. \quad (5)$$

If V long lines is being carried out condition, at which Not is happening distortions signals, those. $R/L = G/C$, That we will receive

$$Z_o = \sqrt{\frac{L}{C}}. \quad (6)$$

This expression means, What wave resistance, How And V case of an ideal lossless line will not depend on frequency. If these conditions are met, and also by substituting expression (35) into (33) and (34), we obtain

$$\alpha = \sqrt{RG}, \quad (7)$$

$$\beta = \omega \sqrt{LC}. \quad (8)$$

Under the same conditions, the speed of propagation of an electromagnetic field of length λ and the period T along the line is equal to

$$V = \frac{\lambda}{T} = \lambda \cdot f = \frac{2\pi \cdot f \cdot \lambda}{2\pi} = \frac{\omega}{\beta} = \frac{1}{\sqrt{LC}}, \quad (9)$$

A time delays signal at passing long lines length l

$$\Delta \tau = l/v \quad (10)$$

For overhead communication lines, the propagation speed is taken to be equal to speed Sveta **With** = $3 \cdot 10^8$ m/s; at availability dielectric speed distribution may decrease by 10...15% or more (determined by the shortening coefficient waves, approximately equal root square from permittivity of the dielectric). If we accept that the length of a long line is measured in meters and speed distribution equal $3 \cdot 10^8$ m/s, then on based on expression (38) we obtain the condition:

$$LC = \frac{1}{c^2} \approx 11,11 \cdot 10^{-18} \quad (11)$$

Note, What only at compliance conditions (40) will unambiguous connection between length lines V meters, running capacity V F/m, running inductance in H/m and, as a consequence, the ability to compare the modeling results with the calculation results.

Content practical work, performed students on the second academic question

1. Description laboratory equipment:

– PC With simulator electronic schemes Electronics Workbench - 5.12" and the computer mathematics system "MathCAD - 14".

2. Initial data for modeling and research Table 1 – Variants of tasks for research

Option No.	l, m	R, Ohm	$WITH, \mu F$	L, mcG
0	50	0.1	0.1	50
1	45	0.1	0.2	55
2	40	0.15	0.3	60
3	35	0.2	0.4	65
4	30	0.25	0.5	70
5	25	0,3	1	75
6	27	0,35	0,9	80
7	32	0,4	0,8	85
8	37	0,35	0,7	90
9	42	0,3	0,6	50
10	47	0,25	1	45
11	46	0,2	0,9	40
12	41	0,15	0,8	35
13	36	0,1	0,7	30
14	31	0,1	0,6	25
15	26	0,15	0,5	20
16	28	0,2	0,4	15
17	33	0,25	0,3	10
18	38	0,3	0,2	50

<i>Option No.</i>	<i>l, m</i>	<i>R, Ohm</i>	<i>WITH, μF</i>	<i>L, mcG</i>
19	43	0.35	0.1	40
20	48	0.4	0.2	30
21	49	0.35	0.3	25
22	44	0.3	0.4	20
23	39	0.25	0.5	25
24	34	0.2	1	30
25	29	0.15	0.5	40

3. Exercise For work

Basic level:

1) To simulate a segment of a long line in the form of a fifth category twisted pair using elements with lumped parameters in the Electronics Workbench program and conduct its study.

2) To simulate in the MathCAD program a mathematical model of a long line in the form of a twisted pair of the fifth category and calculate its secondary parameters.

Increased level:

3) Simulate a given homogeneous circuit in the Electronics Workbench program long line connections And conduct her study V various modes.

4. Order execution work

Task 1.1. Model a segment of a long line in the form of a fifth category twisted pair using elements with lumped parameters in the Electronics Workbench program and conduct its study.

1. Launch the Electronics Workbench EWB 5.12 circuit simulation program. Build a circuit that simulates a 10-meter segment of Category 5 twisted pair cable. elements with lumped parameters. Initial data for modeling:

- linear resistive resistance conductors - 0.188 Ohm/m;
- running inductance conductors - 525 nH/m;
- running conductivity between conductors - 0.2 $\mu S/m$;
- running capacity between conductors - 52 pF/m.

2. Connect a sine wave generator and a rectangular pulse generator to the input of the twisted pair via a switch, and load the output of the twisted pair with an active resistance of 100 Ohms.

3. Using a graph plotter, obtain the frequency response of a distributed circuit. Display received frequency response V report. Measure resonant frequency twisted pair segment.

4. Submit on entrance twisted couples harmonic impact With frequency 1 MHz. C help oscilloscope display temporary diagrams input And output signals. The resulting oscillograms should be included in the report.

5. Repeat the previous step, applying a harmonic signal to the input at the resonant frequency and at a frequency equal to 100 MHz.

6. Submit on entrance twisted couples pulsed impact With frequency 100 kHz. C help oscilloscope display temporary diagrams input And output signals. The resulting oscillograms should be included in the report.

7. Using a Fourier analyzer, obtain spectra of the input and output pulse sequences and record them in a report. Compare the resulting spectra and draw conclusions about the processes that cause pulse shape distortion.

8. Repeat the previous point, sequentially applying pulsed action at frequencies of 1 and 10 MHz to the input of the twisted pair.

9. Do conclusions By results done work, V volume number O throughput capacity of twisted pair.

Exercise 1.2. Simulate V program MathCAD mathematical model long lines V view twisted couples fifth categories And produce calculation of its secondary parameters.

1. In the MathCAD computer mathematics system, write formulas describing the calculation of the parameters of a homogeneous long line. To do this, use expressions (2) – (10).

2. Using the created mathematical model, calculate the following parameters of the twisted pair:

- wave (characteristic) resistance;
- coefficient distribution;
- coefficient attenuation;
- coefficient phases;
- temporary delay.

3. Build graphs dependencies coefficient attenuation And phase coefficient from the line length (1 – 100,000 m).

4. Do conclusions By results done work.

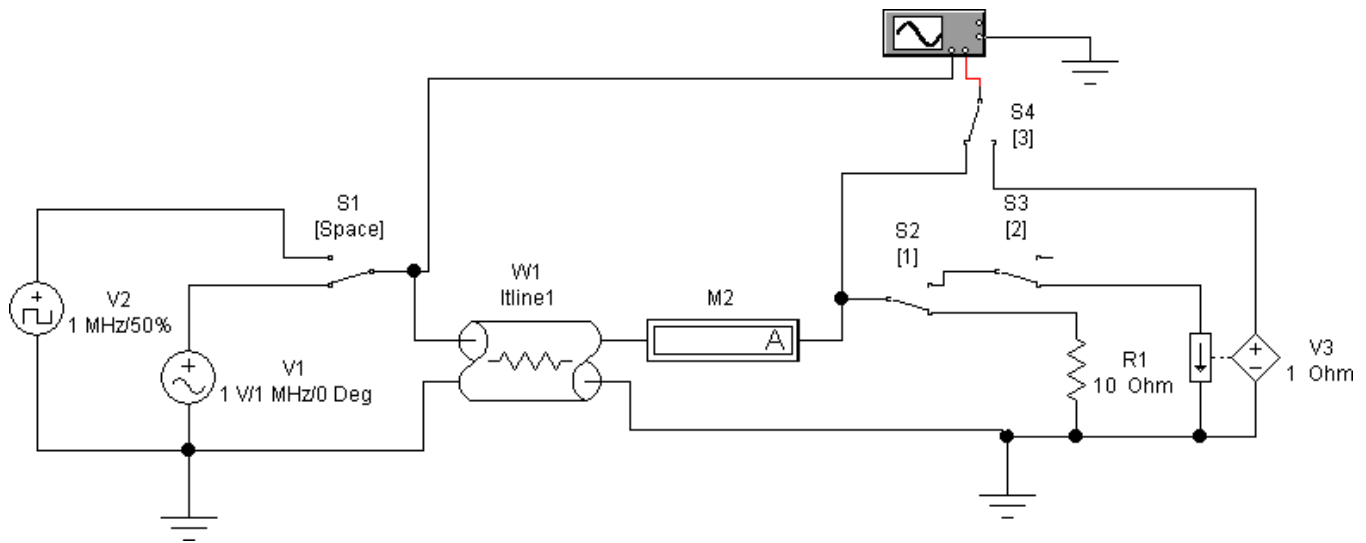
Exercise 1.3. Simulate V program Electronics Workbench» a given homogeneous long communication line and conduct its study in various modes.

1. Launch the Electronics Workbench EWB 5.12 circuit simulation program. Build a circuit that simulates a uniform long line, collected on communication lines with losses (element W10) and shown in Fig. 17. Install values primary parameters lines connections V in accordance with the given option.

2. Create a traveling wave mode in the communication line. To do this, calculate the characteristic (wave) resistance lines connections And install load resistance R1, equal to the wave impedance.

3. For research lines connections V mode running waves Set switch S2 to the down position and switch S4 to the left position. Apply a harmonic signal to the communication line input by setting switch S1 to the down position.

4. Turn on the simulator; as soon as the output voltage appears on the oscilloscope screen, turn it off. Display the input and output voltage timing diagrams in the report.



Rice. 17 - Scheme research lines connections With losses

5. Measure the amplitudes of the input and output voltages using an oscilloscope and record them in the report, using the values to calculate:

- size weekend current I_{exit} ;
- coefficient attenuation $\alpha = U_{out}/U_{in}$;

6. Measure With help oscilloscope temporary delay between the same phases of the input and output voltages. Calculate the phase coefficient in the communication line in radians and degrees according to the formulas

$$\beta = 2\pi \cdot (T_2 - T_1) \cdot f \quad \text{и} \quad \beta = 360^\circ \cdot (T_2 - T_1) \cdot f.$$

7. To test a communication line in standing wave mode with no load at the end of the line, move switches S2 and S3 to the up position. Turn on the simulator as soon as the output voltage appears on the oscilloscope screen. turn off his. Display V report temporary diagrams input and weekend voltage. Measure With help oscilloscope amplitude output voltage. Compare it with the amplitude of the output voltage in the traveling wave mode. Determine the reflection coefficients of the traveling and standing waves.

8. To study a communication line in the standing wave mode with a short circuit at the end of the line, move switch S2 to the upper position, switch S3 to the lower position, and S4 to the right position. Turn on the simulator; as soon as the output current appears on the oscilloscope screen, turn it off. his. Display V report temporary diagrams input voltage And output current. Measure the amplitude of the output current using an oscilloscope. Compare her With amplitude weekend current V mode running waves. Determine the reflection coefficients of the traveling and standing waves.

9. Repeat execution points 3 - 8 For pulsed input impact, for this switch S1 should be moved to the upper position.

Compare form impulses on exit lines connections V this models With draw conclusions based on the shape of the pulses at the output of the line, modeled on elements with concentrated parameters.

10. Do conclusions By results done work, having characterized the physical processes occurring in the communication line.

5. Prepare a report on the work done on the second question in accordance with the requirements set out in the job description .

IN report bring:

- original data,
- performed tasks,
- researched fundamental electrical schemes,
- mathematical models (formulas) And results calculations,
- research results – measured parameters entered into tables, oscillograms, frequency response and spectra;
- conclusions O done work.

6. Protection practical work

For protection practical introduce fully decorated report, free of significant errors. Complete one of the tasks assigned by the teacher, explaining all the physical phenomena and processes occurring in the task being completed.

LIST LITERATURE:

1) Sagdeev K.M. Physical foundations of information security [Electronic resource]: study guide / K.M. Sagdeev, V.I. Petrenko, A.F. Chipiga. - Electronic text data. - Stavropol: North Caucasus Federal University, 2015. - 394 p.

2) Evstifeev V.V. Physical foundations electricity and magnetism Electronic resource / Evstifeev V.V.: study guide. - Penza: PSU, 2019. - 416 p.

3) Bulatov V.N. Physical foundations of electronics Electronic resource / Bulatov V.N.: lecture notes for students in educational programs higher education in the following areas preparation 11.03.02 infocommunication technologies and communication systems. - Orenburg: OSU, 2018. - 178 p.

4) Goldstein A.E. Physical principles of obtaining information [Electronic resource]: textbook / A.E. Goldstein. — Electron. text data. — Tomsk: Tomsk Polytechnic University, 2010. — 292 p.

PRACTICAL JOB No. 14

TOPIC 15 BASICS GENERATIONS ELECTROMAGNETIC OSCILLATIONS

Class 14 MODELING AND STUDY PRINCIPLES OF GENERATION OF ELECTRICAL OSCILLATIONS

TIME – 2 hours.

Educational questions:

1. Study of the principles and process of generating high-frequency signals.

TARGET PRACTICAL INSTALLATION WORKS:

Competencies, being formed discipline

OPK-1: Capable use provisions, laws And methods natural sciences and mathematics to solve engineering problems.

OPK-2: Capable on one's own conduct experimental research And use main techniques processing And performances received data.

Learning outcomes achieved as a result of completing practical work:

Be able to:

- apply physical laws and methods to formalize the representation of physical phenomena and processes that occur in telecommunications .
- conduct experimental research With help mathematical models according to the accepted methodology
- model And analyze main physical phenomena And processes in telecommunications using computer technology.

Own:

- skills use knowledge physicists at decision practical problems of engineering activities
- methods of processing and presenting data obtained as a result of experimental studies.
- skills in computer modeling of the main physical methods of receiving, transmitting and storing information.

EDUCATIONAL AND MATERIAL SECURITY:

- PC With simulator electronic schemes Electronics Workbench - 5.12" And system computer mathematicians Mathcad - 15";
- electronic methodological development By practical work.

STRUCTURE PRACTICAL WORK:

Class No. 1

Introductory Part

Examination readiness students To practical work

Introductory Part

Questions (tasks), subject research:

1. Study principles And process generation high- frequency-nykh signals.

Final Part

Summing up results

Exercise students For independent work

90 min

10 min

8 min

2 min

75 min

75 min

5 min

3 min

2 min

QUESTIONS, SUBJECTS RESEARCH

1. STUDY PRINCIPLES AND PROCESS HIGH-FREQUENCY SIGNALS GENERATION

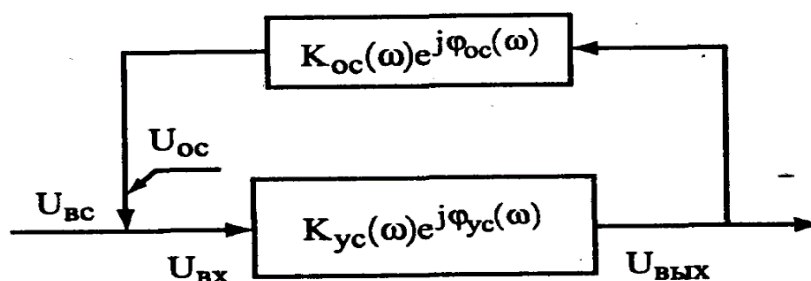
Brief theoretical or reference and information materials

Mathematical model of the amplifier regardless of the number of amplification stages Can introduce V view complex transmission functions $K_{yc}(\omega)e^{j\varphi_{yc}(\omega)}$, where $K_{us}(\omega)$ and $\varphi_{us}(\omega)$ are the gain and phase of the output signal relative to the input signal, which depend on the frequency $\omega = 2\pi f$.

IN amplifier phase weekend signal For odd numbers cascades reinforcement changes on 180° , A at even number cascades matches With phase input signal.

Since there are always capacitive, inductive and galvanic parasitic connections between the amplifier elements, at the amplifier input, along with the amplified external signal, there are signals that have penetrated into the input circuits through parasitic feedback, including from the amplifier output. Parasitic reverse connection Can Also introduce mathematical model $K_{oc}(\omega)e^{j\varphi_{oc}(\omega)}$.

Generalized mathematical model amplifier With reverse communication presented on rice. 4.



Rice. 1 - Model amplifier With reverse communication

Connection between exit And entrance amplifier is described equation:

$$U_{\text{БЫХ}} = (U_{\text{BC}} + U_{\text{OC}}) K_{\text{yc}}(\omega) e^{j\varphi_{\text{yc}}(\omega)} = [U_{\text{BC}} + U_{\text{БЫХ}} K_{\text{OC}}(\omega) e^{j\varphi_{\text{OC}}(\omega)}] K_{\text{yc}}(\omega) e^{j\varphi_{\text{yc}}(\omega)}. \quad (1)$$

Mode gain goes over V mode generations, When day off the signal reaches maximum values And supported on this level regardless of U_{in} . This condition is being carried out at zero the value of the denominator the above expression. Therefore, **for the generation mode to occur, two conditions must be met** :

- 1) $K_{\text{os}}(\omega) = 1/K_{\text{yc}}(\omega)$;
- 2) $\text{light}(\omega) = -\varphi_{\text{yc}}(\omega)$.

First condition defines minimally necessary For the occurrence of parasitic generation, the value of the coefficient parasitic feedback connections. The higher coefficient gains amplifier, those less coefficient parasitic feedback creates the preconditions for the occurrence of oscillation. For example, if $K_{\text{os}} = 10$, then for generation to occur, 0.1 part of the output signal must penetrate into the amplifier input. For an amplifier with $K_{\text{os}} = 100$, 0.01 part of the output signal must be received at its input. This dependence explains the possibility of parasitic generation in logic elements of discrete technology. The high gain of the logic element and the high frequency spectral components front discrete signal create favorable conditions For occurrence parasitic generation V logical elements .

Second condition provides for, What change phases signal The feedback phase shift must be opposite to the magnitude of the amplifier's phase shift. This means that the phases of the external signal and the feedback signal must be approximately equal. **Feedback** in which the phase of the signal at the amplifier's input coincides with the phase of the feedback signal **is called** positive. A When phases these signals opposite - negative. If positive feedback promotes parasitic oscillation, while negative feedback, on the contrary, increases the stability of the amplifier, but at the expense of some reduction in the voltage at the amplifier output. Therefore, in amplifiers with a high coefficient gains For exceptions parasitic generation create between cascades negative feedback connection, and Also apply complex measures to reduce parasitic connections. For this purpose, short ones will be used during installation. shielded wires, elements input And weekend chains are being carried around to the maximum possible distance, screen transformers amplifiers, in chains nutrition preliminary cascades are installing RC filters low frequencies, the amplifier stages are placed in one line, etc.

Content practical work, performed students on an academic issue

1. Description laboratory equipment:

- PC With simulator electronic schemes Electronics Workbench - 5.12"

2. Initial data For modeling And research

3. Exercise For work

Basic level:

1) To simulate a segment of a long line in the form of a fifth category twisted pair using elements with lumped parameters in the Electronics Workbench program and conduct its study.

2) To simulate in the MathCAD program a mathematical model of a long line in the form of a twisted pair of the fifth category and calculate its secondary parameters.

Increased level:

3) Simulate a given homogeneous circuit in the Electronics Workbench program long line connections And conduct her study V various modes.

4. Order execution work

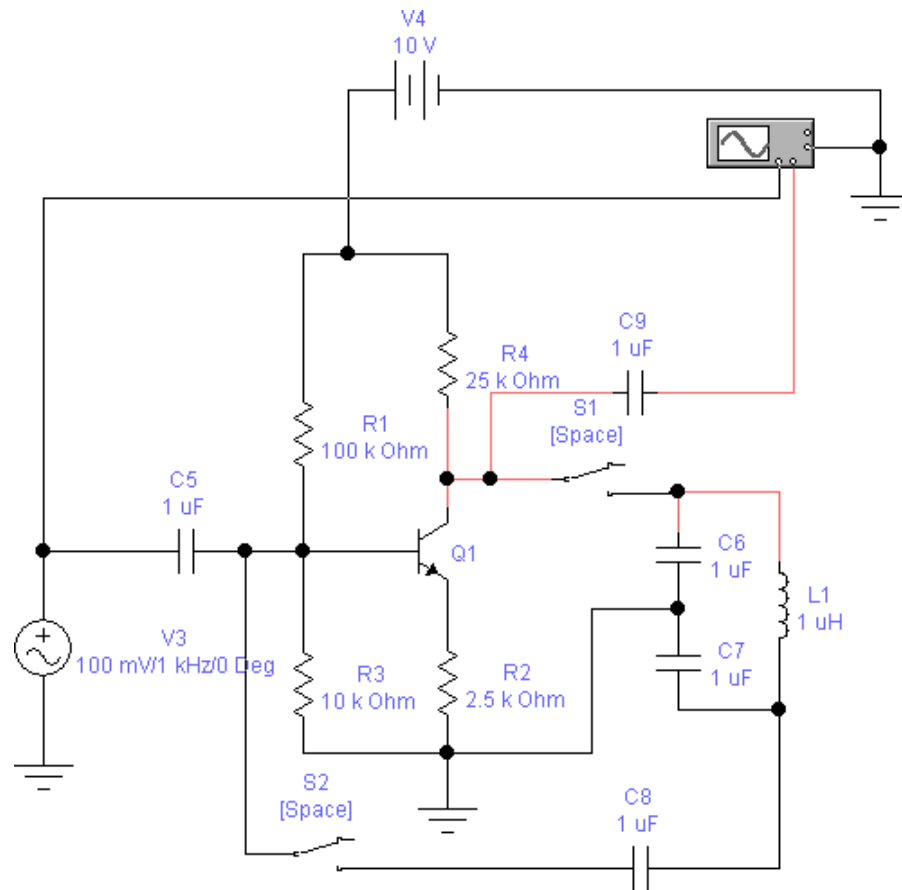
Exercise 1.1. Research effect generation on transistor strengthen-body.

1) ***Launch program EWB And collect scheme*** , given on rice. 2.

2) ***Install parameters elements schemes*** V in accordance With magnitude-us, specified on rice. 2. Scheme research, contains:

- source harmonic voltage (signal) on element V3;
- source power supply V view battery batteries V4;
- transistor amplifier, assembled on bipolar transistor Q1, resistors R1 - R4 And capacitors C5, C9;
- an oscillatory circuit consisting of an inductor coil L1 and capacitors C6, C7;
- chain reverse positive connections, formed for check parasitic capacity C8.

Amplifier and oscillatory circuit has galvanic connection via common (ground) wire. The oscillatory circuit and parasitic capacitor are connected to the amplifier using switches S1 and S2, controlled by the "Space" key.



Rice. 25 - Scheme research effect parasitic generation on a transistor amplifier

3) **Turn on emulator EWB** , make sure V performance schemes. For this double click **open oscilloscope** , And his **tune** on registration of the display of analog input and output amplified signals.

4) **Measure the frequency of** the input and amplified output signals using an oscilloscope .

5) **Define coefficient gains** transistor amplifier, having previously measured the voltage amplitudes of the input and output signals.

6) **Display V report oscillograms** input And reinforced output signals.

7) **Do conclusions** O work amplifier.

8) By pressing the space bar using switches S1 and S2, **simulate** education parasitic containers, which connect oscillatory contours To collector chains And To chains bases amplifier, forming **parasitic positive feedback circuit** .

9) **Produce** With help oscilloscope **observation effect parasitic generation** .

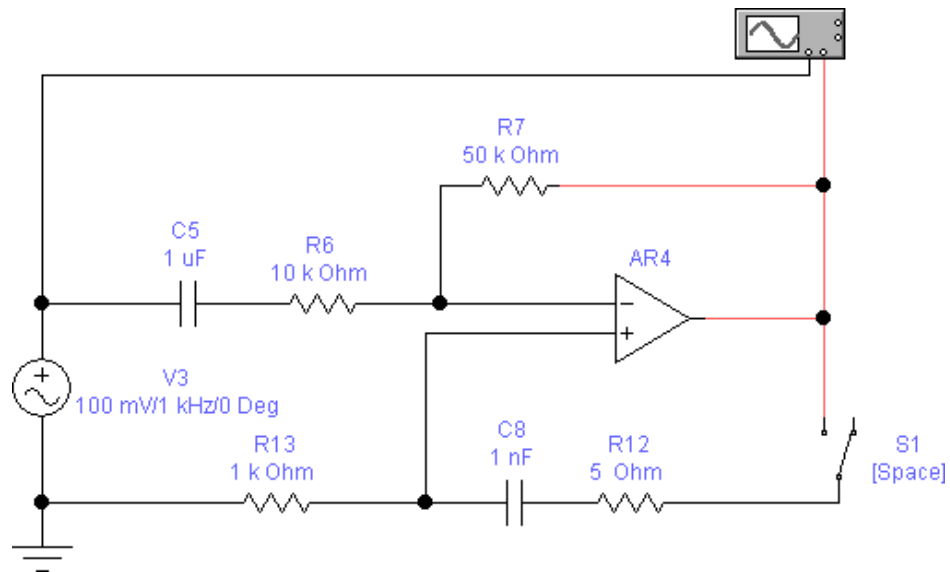
10) **Display in the** input and output **oscillogram report** amplifier signals.

11) **Measure** With help oscilloscope **frequency weekend signal** .

12) **Do conclusions** By results done work.

Exercise 2.2. Research effect generation on operating strengthen-body.

1) **Launch program EWB And collect scheme** , given on rice. 3.



Rice. 3 - Scheme research effect parasitic generation on an operational amplifier

2) **Set the parameters of the circuit elements** in accordance with the values indicated in Fig. 3. The research circuit contains:

- source harmonic voltage (signal) on element V3;
- amplifier, assembled on operating amplifier AR4, resistors R6, R7, R13 and capacitor C5;
- chain reverse positive connections, formed for check resistance R12 And capacity C8.

The positive feedback circuit is connected to the amplifier using switch S1, controlled by the space bar.

3) **Turn on emulator EWB** , make sure V performance schemes. For this double click **open oscilloscope** , And his **tune** on registration of the display of analog input and output amplified signals.

4) **Measure the frequency of** the input and amplified output signals using an oscilloscope .

5) **Determine the gain** of the operational amplifier by first measuring the voltage amplitudes of the input and output signals.

6) **Display V report oscillograms** input And reinforced output signals.

7) **Do conclusions** O work amplifier.

8) By pressing the Space key using switch S1, **simulate** the formation of parasitic capacitance, which forms **a parasitic positive feedback circuit** .

9) **Produce** With help oscilloscope **observation effect parasitic generation** .

- 10) **Display oscillograms in the report** input and weekend amplifier signals.
- 11) **Measure** With help oscilloscope **frequency weekend signal** .
- 12) **Change parameters elements** chains R12, R13 And C8 V in accordance with specified teacher option and **repeat fulfillment of points** 8 – 11 tasks.

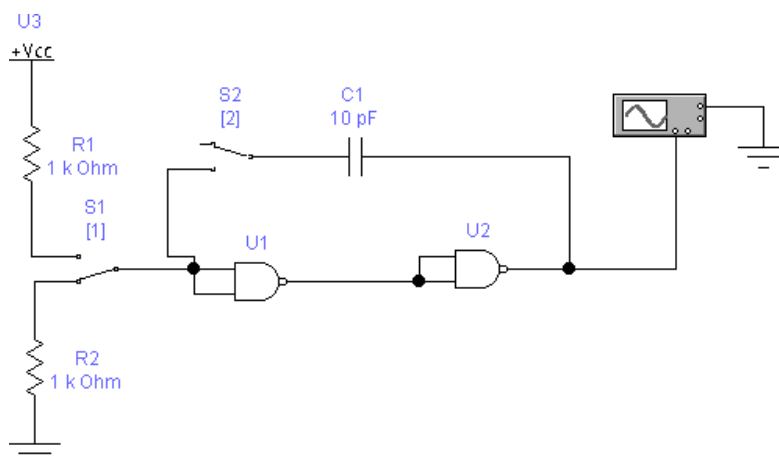
Table 2 -Initial data For tasks 2.2.

Option number	R1,2 , Ohm	C8, nF	R13 , Ohm
1.	5	5	900
2.	5	120	10
3.	5	4	900
4.	5	115	10
5.	3	3	900
6.	3	110	10
7.	3	2	900
8.	3	95	10
9.	2	0,5	900
10.	2	90	10
11.	2	0,2	900
12.	2	80	10

- 13) **Do conclusions** By results done work.

Exercise 1.3. Research effect generation on logical elements.

- 1) **Launch program EWB And collect scheme** , given on rice. 4.



Rice. 4 - Scheme research effect parasitic generation on logical elements

- 2) **Set the parameters of the circuit elements** in accordance with the values indicated in Fig. 4. The research circuit contains:
 - source permanent voltage U3 size - 5 IN;
 - logical elements 2 AND-NOT U1 And U2, united sequentially in the form of inverters;
 - resistance R1 And R2 For filing on entrance logical element U1

potential logical units And potential logical zero respectively, which are connected With help switch S1, controlled key

"1";

– parasitic capacitance C1, connected to the positive feedback circuit using switch S2, controlled by key "2".

3) **Turn on emulator EWB** , make sure V performance schemes. For this double click **open oscilloscope** , And his **tune** on registration of the display of discrete signals.

4) **Observe digital signals** using an oscilloscope by switching switch S1 using key "1".

5) **Display V report oscillograms** digital signals.

6) **Do conclusions** O work logical elements.

7) By pressing the "2" key using switch S2, **simulate** the formation of parasitic capacitance, which forms **a parasitic positive feedback circuit** .

8) **Produce** With help oscilloscope **observation effect parasitic generation** .

9) **Display V report oscillogram** weekend digital signal.

10) **Measure** With help oscilloscope **frequency weekend signal** .

11) **By changing the parameters of the parasitic capacitance** C1, setting it in series to 1 pF, 10 pF, 100 pF and 1000 pF, Measure the frequency of parasitic generation. Determine how the frequency of parasitic generation depends on the value of parasitic capacitance.

12) **Do conclusions** By results done work.

5. Prepare a report on the work done on the second question in accordance with the requirements set out in the job description .

IN report bring:

- original data,
- performed tasks,
- researched fundamental electrical schemes,
- mathematical models (formulas) And results calculations,
- research results – measured parameters entered into tables, oscillograms, frequency response and spectra;
- conclusions O done work.

6. Protection practical work

For protection practical introduce fully decorated report, free of significant errors. Complete one of the tasks assigned by the teacher, explaining all the physical phenomena and processes occurring in the task being completed.

LIST LITERATURE:

- 1) Sagdeev K.M. Physical foundations of information security [Electronic resource]: study guide / K.M. Sagdeev, V.I. Petrenko, A.F. Chipiga. - Electronic text data. - Stavropol: North Caucasus Federal University, 2015. - 394 p.
- 2) Evstifeev V.V. Physical foundations electricity and magnetism Electronic resource / Evstifeev V.V.: study guide. - Penza: PSU, 2019. - 416 p.
- 3) Bulatov V.N. Physical foundations of electronics Electronic resource / Bulatov V.N.: lecture notes for students in educational programs higher education in the following areas preparation 11.03.02 infocommunication technologies and communication systems. - Orenburg: OSU, 2018. - 178 p.
- 4) Goldstein A.E. Physical principles of obtaining information [Electronic resource]: textbook / A.E. Goldstein. — Electron. text data. — Tomsk: Tomsk Polytechnic University, 2010. — 292 p.

PRACTICAL JOB No. 15

TOPIC 16 PROCESSES MODULATIONS AND DEMODULATION. FREQUENCY SELECTION

Class 15 MODELING AND STUDY MODULATION AND DEMODULATION PROCESSES

TIME – 2 hours.

Educational questions:

- 1) Modeling And study modulations signals.**
- 2) Modeling And study demodulation signals.**

TARGET PRACTICAL INSTALLATION WORKS:

Competencies, being formed discipline

OPK-1: Capable use provisions, laws And methods natural sciences and mathematics to solve engineering problems.

OPK-2: Capable on one's own conduct experimental research And use main techniques processing And performances received data.

Learning outcomes achieved as a result of completing practical work:

Be able to:

- apply physical laws and methods to formalize the representation of physical phenomena and processes that occur in telecommunications .
- conduct experimental research With help mathematical models according to the accepted methodology
- model And analyze main physical phenomena And processes in telecommunications using computer technology.

Own:

- skills use knowledge physicists at decision practical problems of engineering activities
- methods of processing and presenting data obtained as a result of experimental studies.
- skills in computer modeling of the main physical methods of receiving, transmitting and storing information.

EDUCATIONAL AND MATERIAL SECURITY:

- PC With simulator electronic schemes Electronics Workbench - 5.12"
- electronic methodological development By practical work.

STRUCTURE PRACTICAL WORK:

Class No. 1

Introductory Part

Examination readiness students To practical work

Introductory Part

Questions (tasks), subject research:

1. Modeling And study modulations signals
2. Modeling And study demodulation signals

Final Part

Summing up results

Exercise students For independent work

90 min

10 min

8 min

2 min

75 min

75 min

5 min

3 min

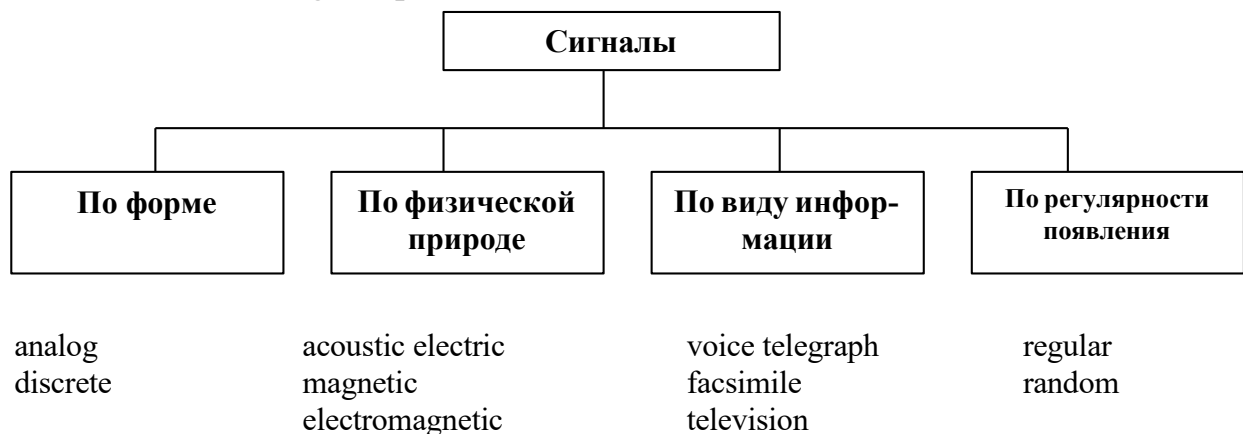
2 min

1.MODELING AND STUDY MODULATIONS SIGNALS

Brief theoretical or reference and information materials

Under *signal understood* spreading V space a carrier containing information in the values of its physical parameters. These include: electromagnetic fields And electric current from created human sources of signals, such as radio-electronic means, devices and instruments .

Classification signals presented on rice. 1.



Rice. 1 - Classification signals

Analog signals are signals whose level (amplitude) can take arbitrary values within a certain interval for the signal. Amplitude simple And enough widespread V nature the harmonic signal changes according to a sinusoidal law:

$$s(t) = A \sin(\omega t + \varphi), \quad (1)$$

where A is the amplitude, $\omega = 2\pi f$ is the circular frequency of oscillation, φ - oscillation phase. Frequency f is measured in Hz and is called linear.

Most analog signals have a more complex shape. Periodic (repeating after time T_n – period) arbitrary waveform signals can be presented in accordance with formula Fourier in view sum of harmonic oscillations:

$$s(t) = C_0 + \sum_{k=1}^n C_k \cos(k\omega t - \varphi_k), \quad (2)$$

where C_0 – constant component of the signal; C_k – amplitude of the k -th harmonic of the signal ($k=1,2,\dots,n$); $k\omega$ and φ_k – frequency and phase of the k -th harmonic of the signal.

The Fourier series is a mathematical model of a periodic signal. Also, how many colors may be laid out on components red, green and blue colors.

The set of harmonic components of a signal forms its spectrum. Amplitude of each spectral component characterizes energy corresponding to the harmonic of the basic signal frequency. The higher the rate of change of the signal's amplitude, the more it has high-frequency harmonics. The difference between the maximum and minimum frequencies of the signal spectrum, between which the main part, for example, 95% of the energy is concentrated, is called ***width spectrum*** ΔF . Graphic image of the spectrum of a periodic signal is shown in Fig. 2.

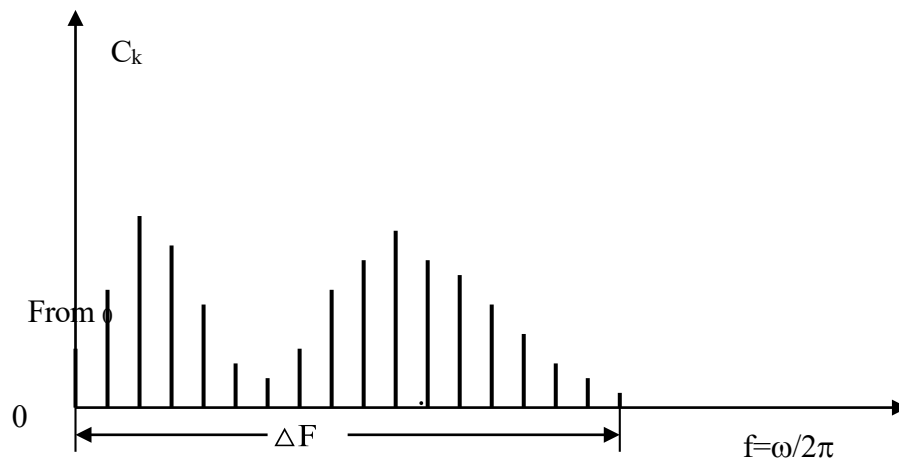


Fig. 2 – Spectrum of a periodic multi-tone analog signal

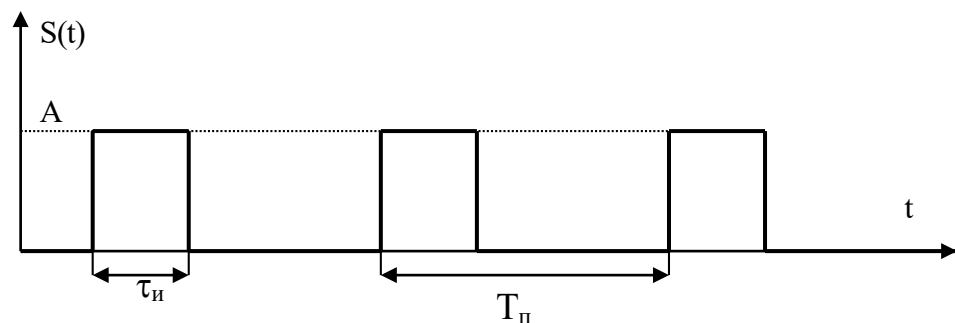
spectrum non-periodic analog signal
continuously changing. When observing the spectrum of such a signal on the screen of a spectrum analyzer, the position and level of the various spectral components continuously change, and the spectrum appears continuous.

In accordance with the change in the amplitude of the analog signal, its energy or power changes (since the power is proportional to the square of the amplitude). Depending on the time of measurement of the signal energy, a distinction is made between average and instantaneous power. The decimal logarithm of the ratio of the maximum power signal to minimal it's called ***dynamic signal range***.

Thus, *an analog signal is described by a set of parameters that are its characteristics* . These include:

- frequency or range frequencies;
- phase signal;
- duration signal;
- amplitude or power signal;
- width spectrum signal;
- dynamic range signal.

U discrete signals amplitude has final , in advance a certain set of values. The most widely used binary discrete signal is in computers, telegraphy, and data transmission. Information signals, circulating V computer IBM RS, have two level amplitudes: low (L-level, 0 IN) And high (H-level, 5 IN). Oscillogram binary signal is shown in Fig. 5.

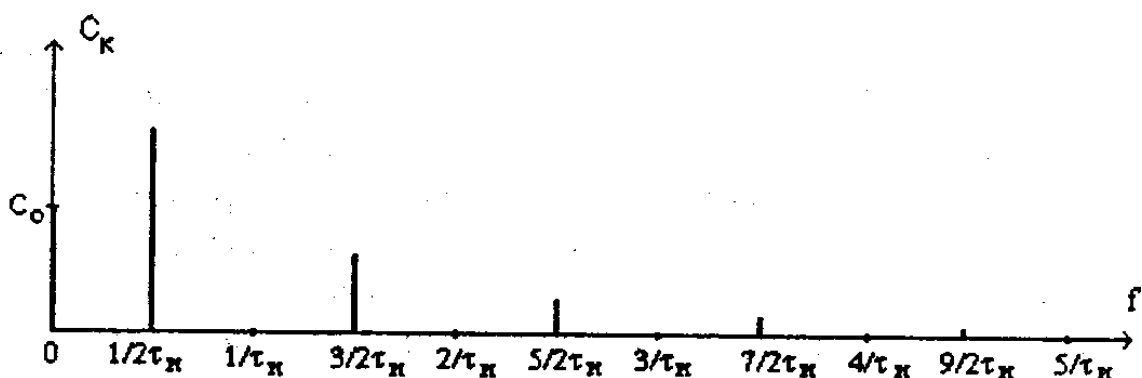


Rice. 3 - Oscillogram binary signal

Discrete signal characterized by next parameters :

- amplitude A or power R ;
- duration impulse τ and ;
- period T_p or frequency $F_n = 1 / T_n$ pulse repetition (for periodic discrete signals;
- width spectrum signal ΔF_c ;
- porosity impulses $\alpha = T_n / \tau_u$.

The spectrum of a discrete periodic signal contains an infinite number of decreasing By amplitude harmonics. For binary A fragment of the spectrum of a periodic signal is shown in Fig. 4.



Rice. 4 - Spectrum binary periodic signal with duty cycle 2

He characterized by next properties:

- form envelope spectrum is described function $|\sin x/x|$;
- amplitude harmonics **With** k . has zero meaning V points to/τ and, $k = 1, 2, \dots$;
- V areas frequencies spectrum ($0-1/\tau$ and) are located $\alpha -1$ harmonics;
- constant component signal equal A/α .

Considering, What big Part energy signal focused V areas frequencies $0-1/\tau$ and , ***the spectrum width of the binary periodic signal*** is approximately estimated by the formula: $\Delta F = 1/\tau$ and .

When discrete signals pass through real electrical circuits of radio equipment with a limited bandwidth, their shape is distorted and the steepness of the pulse slope decreases. The rectangular pulse acquires bell-shaped form. IN result this blurs the border between form analog And discrete signals. Distortions forms And decrease amplitudes pulsed signals V wires cables limit range their transmissions, for example, For providing inter-machine communication exchange data in local networks.

By physical nature signals can be acoustic, electrical, magnetic, electromagnetic (***in the radio range - radio signals***), corpuscular (*in the form of streams of elementary particles*) and material-substance, *for example, odorous additives in gas give a signal about its leak* .

Signals, depending on the type of information transmitted, are divided into voice, telegraph, telecode, facsimile, television, O radioactive radiation and conditional. Telegraph and telecode signals are used to transmit alphanumeric information at low and high speeds, respectively. Facsimile And television signals provide transmission still and moving images. Radioactive radiation signals are unmasking signs radioactive substances. Conditional signals carry information, the content of which is predetermined between its source And recipient, For example, pot With flower on windowsill V literary works about intelligence officers - about the failure of the turnout.

Signals from sources messages are transmitted By channels electrical communication to receivers and further to message recipients. As a rule, information signals are low-frequency And limited By width spectrum. Channels electrical connections, against, are high-frequency, broadband and designed to transmit signals from multiple sources simultaneously With frequency division channels. Transfer spectrum signals from low-frequency areas V highlighted For their transmissions region high frequencies is performed by the modulation operation.

AM corresponds transfer information O signal $s(t)$ on amplitude bearing signal. Amplitude modulation was first view modulations, mastered in practice. Currently, AM is used mainly only for radio broadcasting on low frequencies (Not higher short waves) And For transmissions image-

reflection in television broadcasting. This is due to the low efficiency of using the energy of modulated signals. The AM signal is the product of the envelope $U(t)$ and a high-frequency harmonic oscillation. The form of recording an amplitude-modulated signal:

$$u(t) = U(t) \cos(2\pi f_0 t + \varphi_0) \quad (3)$$

Where $U(t)$ - envelope AM signal, IN;

f_0 - frequency bearing signal, Hz;

φ_0 - initial phase bearing signal, rad;

U_0 - constant amplitude bearing fluctuations at absence of modulating signal $s(t)$, V;

At frequency modulations (World Cup, frequency modulation - FM) V bearing harmonic signal

$$s(t) = S \cos(2\pi f t + \varphi) = S_0 \cos\{2\pi f [x(t)]t + \varphi\} = S_0 \cos[\Psi(t)], \quad (4)$$

Content practical work, performed students

1.1. Description laboratory equipment:

– PC With simulator electronic schemes Electronics Workbench - 5.12" and the computer mathematics system "Mathcad – 14";

1.2. Initial data For modeling And research

Table 1 - Initial data For modeling

1.3. Exercise For works:

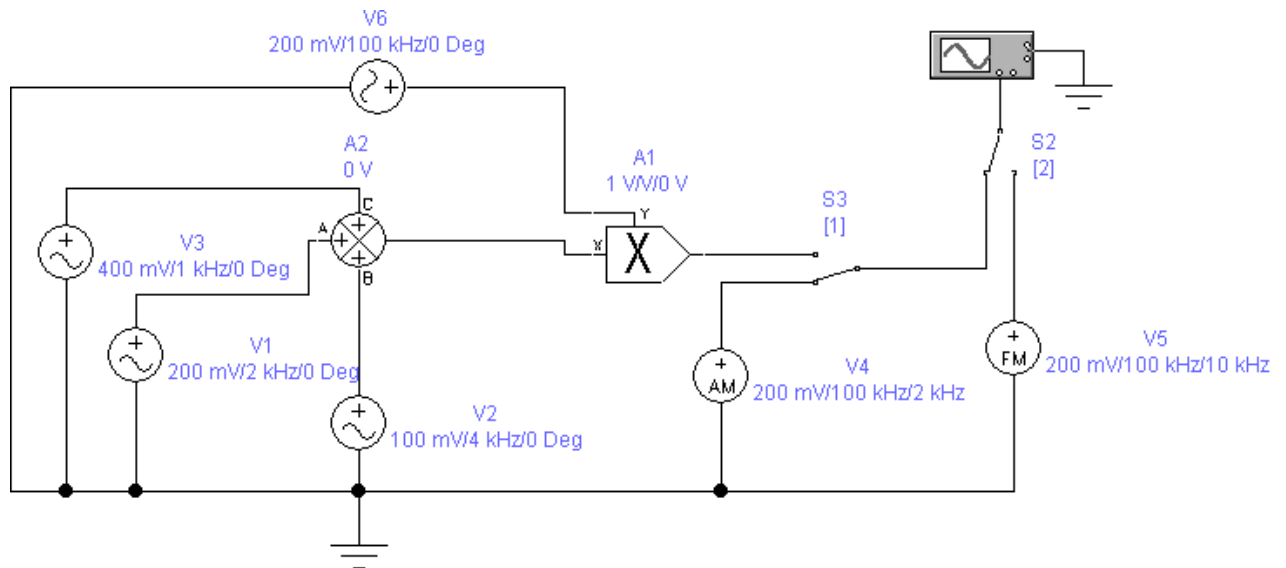
1) To investigate the characteristics of amplitude- and frequency-modulated signals.

2) Research characteristics manipulated signals.

1.4. Order execution work

Task 1.1. Research the characteristics of amplitude- and frequency-modulated (AM and FM) signals .

1) ***Launch program EWB And collect scheme*** , given on rice. 5.



Rice. 5 - Scheme research AM And World Cup signals

2) **Set the parameters of the circuit elements** in accordance with the values indicated in Fig. 5. The research scheme shown in Fig. 5 contains the following models:

- source single-tone amplitude-modulated signal (V4);
- source single-tone frequency modulated signal (V5);
- source of a multi-tone speech-like signal composed of three generators variable sinusoidal voltage (V1, V2, V3) And voltage adder (A2);
- generator bearing high-frequency fluctuations (V6);
- balanced modulator (multiplier A1).

3) **Conduct a study of a single-tone amplitude-modulated signal** . To do this, perform the following steps:

- switch S3 (key 1) install V lower position, A switch S2 (key 2) – to the left position, thereby connecting the output of the AM signal source (V4) to the input of the oscilloscope;
- turn on oscilloscope And tune his For registration AM signal;
- measure parameters and display in the report a time diagram or oscillogram of a single-tone AM signal;
- measure and calculate the modulation coefficient (depth) using the formula

$$M_{AM} = \frac{U_{\max} - U_{\min}}{U_{\max} + U_{\min}} ; \quad (5)$$

- compare the calculated and set modulation coefficients, determining the relative error;

– obtain and measure the spectrum of a single-tone AM signal using a Fourier analysis simulator, setting in it the number of the output node of the circuit connected To oscilloscope, the main one frequency (Fundamental frequency), equal to 1 kHz, and the number of harmonics (Number of harmonics) equal to 200;

- display the spectrum (frequency representation) of a single-tone AM signal in the report;
- determine how the appearance of the diagram and spectrum of a single-tone AM signal is affected by a change in the frequency of the modulating (information, low-frequency) signal;
- determine how the appearance of the diagram and spectrum of a single-tone AM signal is affected by changing the modulation coefficient, sequentially setting it equal to 0.25; 0.5, 0.75 and 1;
- draw conclusions about what signal unmasking features single-tone AM signals have.

4) **Conduct study multi-tonal amplitude-modulated signal** . To do this, follow these steps:

- switch S3 (key 1) install V upper position, A switch S2 (key 2) – to the left position, thereby connecting the output of the balanced modulator (A1), as a source of a multi-tone AM signal, to the input of the oscilloscope;
- turn on oscilloscope And tune his For registration AM signal;
- measure and display in a report a time diagram or oscillogram of a multi-tone AM signal;
- obtain and measure the spectrum of a multi-tone AM signal using a Fourier analysis simulator, setting in it the number of the output node of the circuit connected To oscilloscope, the main one frequency (Fundamental frequency), equal to 1 kHz, and the number of harmonics (Number of harmonics) equal to 200;
- display V report spectrum (frequency performance) multi-tone AM signal;
- determine how the appearance of the diagram and spectrum of a multi-tone AM signal is affected by changes in the amplitude and frequency of the modulating (information, low-frequency) signal by changing the values of the voltage amplitude and oscillation frequency of the generators (V1, V2, V3);
- draw conclusions about what signal unmasking features single-tone AM signals have.

5) **Conduct study single-tone frequency-modulated signal** . To do this, follow these steps:

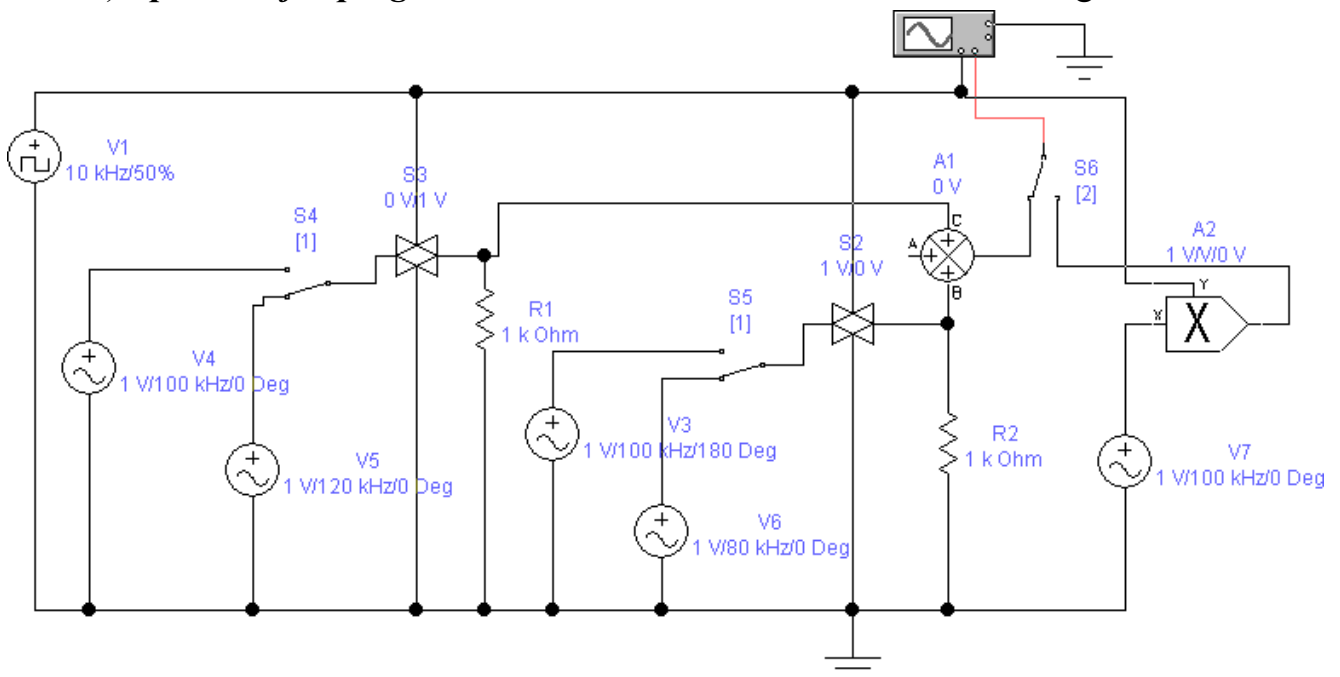
- set switch S2 (key 2) to the right position, thereby connecting the output of the FM signal source (V5) to the input of the oscilloscope;
- turn on oscilloscope And tune his For registration World Cup signal;
- measure parameters and display in the report a time diagram or oscillogram of a single-tone FM signal;
- measure and calculate the frequency deviation ΔF and the modulation index, using the formula

$$M_{\text{World Cup}} = \frac{\Delta F}{F_H} = \frac{F_{\max} - F_{\min}}{2 \cdot F_H} ; \quad (6)$$

- compare the calculated and established modulation indices, determining the relative error;
- obtain and measure the spectrum of a single-tone FM signal using a Fourier analysis simulator, setting in it the number of the output node of the circuit connected To oscilloscope, the main one frequency (Fundamental frequency), equal to 1 kHz, and the number of harmonics (Number of harmonics) equal to 400;
- display the spectrum (frequency representation) of a single-tone FM signal in the report;
- define, How influences on view diagrams And spectrum single-tone FM signal change in the frequency of the modulating (information, low-frequency) signal;
- define, How influences on view diagrams And spectrum single-tone FM signal change of modulation index, successively setting it equal to 1; 2.4; 5; 10 and 100;
- draw conclusions about what signal unmasking features single-tone FM signals have.

Exercise 1.2. Research signal signs manipulated signals .

1) ***Open new file programs EWB And collect scheme , shown in Fig. 6.***



Rice. 6 - Scheme research manipulated signals

2) ***Set the parameters of the circuit elements*** in accordance with the values indicated in Fig. 6. The research scheme shown in Fig. 6 contains the following models:

- amplitude modulator (manipulator), consisting from balanced

modulator (A2), carrier wave generator (V7) and bit sequence source based on clock pulse generator (V1);

- frequency modulator (manipulator), consisting of analog switches (S3 and S2), loaded accordingly on resistances R1 and R2, summator stresses (A2), generators load-bearing fluctuations (V5 And V6) And bit sequence source based on a clock pulse generator (V1);

- a phase modulator (manipulator) consisting of analog switches (S3 and S2), loaded respectively onto resistances R1 and R2, a voltage adder (A2), oscillation carrier generators (V4 and V3) and a bit sequence source based on a clock pulse generator (V1).

3) **Conduct a study of the amplitude-keyed (AM) signal** . To do this, perform the following steps:

- set switch S6 (key 2) to the right position, thereby connecting the output of the balanced AM modulator (A2) to the second input of the oscilloscope ;

- turn on oscilloscope And tune his For AMN signal;

- measure parameters and display a time diagram or oscillogram of the AMN signal in the report;

- obtain and measure the spectrum of the AMN signal using a Fourier simulator analysis, having installed V him weekend number node schemes, connected to the second entrance oscilloscope, the main one frequency (Fundamental frequency), equal to 1 kHz, and the number of harmonics (Number of harmonics) equal to 200;

- display V report spectrum (frequency performance) AMN signal;

- define, How influences on view diagrams And spectrum AMN signal changing the frequency of the bit sequence, sequentially setting its value equal to 25%, 50% and 75%;

- define, How influences on view diagrams And spectrum AMN signal change amplitudes modulating bit sequences, installing its equal to 0.5; 1 and 2 V;

- draw conclusions about what signal unmasking features AMN signals have.

4) **Conduct a study of the frequency-shifted (FSK) signal** . To do this, perform the following steps:

- set switch S6 (key 2) to the left position, and switches S4 and S5 (key 2) to the lower position, thereby connecting the frequency manipulator And having connected his exit (exit adder A1) ko the second input of the oscilloscope;

- turn on oscilloscope And tune his For CMN signal;

- measure parameters and display in the report a time diagram or oscillogram of the FMN signal;

- obtain and measure the spectrum of an FM signal using a Fourier simulator analysis, having installed V him weekend number node schemes, connected to the second entrance oscilloscope, the main one frequency (Fundamental frequency), equal to 1 kHz, and the number of harmonics (Number of harmonics) equal to 200;

- display V report spectrum (frequency performance) CMN signal;
- define, How influences on view diagrams And spectrum CMN signal change frequencies load-bearing fluctuations, sequentially installing their values equal to 80 and 120 kHz, 85 and 115 kHz, 90 and 110 kHz;
- define, How influences on view diagrams And spectrum CMN signal changing the frequency of the bit sequence, sequentially setting its value equal to 25%, 50% and 75%;
- define, How influences on view diagrams And spectrum CMN signal changing the frequency of the modulating bit sequence, setting it equal to 10 kHz, 16 kHz, 20 kHz;
- draw conclusions about what signal unmasking features the FM signals have.

5) *Conduct study phase-shifted (FMn) signal .*

For this execute next actions:

- set switch S6 (key 2) to the left position, and the switches S4 And S5 (key 2) V upper position, those the most connecting phase manipulator and connecting its output (output of adder A1) to the second input of the oscilloscope;
- turn on oscilloscope And tune his For FMN signal;
- measure parameters and display in the report a timing diagram or oscillogram of the FMN signal;
- obtain and measure the spectrum of a PSK signal using a Fourier simulator analysis, having installed V him weekend number node schemes, connected to the second entrance oscilloscope, the main one frequency (Fundamental frequency), equal to 1 kHz, and the number of harmonics (Number of harmonics) equal to 200;
- display V report spectrum (frequency performance) FMN signal;
- define, How influences on view diagrams And spectrum FMN signal changing the phase of the carrier oscillations by successively setting the phase value of the generators (V4 and V3) equal to 315 and 45 degrees, 270 and 90 degrees, 180 and 180 kHz;
- define, How influences on view diagrams And spectrum FMN signal changing the frequency of the bit sequence, sequentially setting its value equal to 25%, 50% and 75%;
- define, How influences on view diagrams And spectrum FMN signal changing the frequency of the modulating bit sequence, setting it equal to 10 kHz, 16 kHz, 20 kHz;
- draw conclusions about what signal unmasking features FMn signals have.

2. MODELING AND STUDY SIGNAL DEMODULATION

Brief theoretical or reference and information materials

Examples protozoa demodulators

Let's consider the simplest demodulator. The schematic diagram of the device is shown on rice. 7 He consists of from antennas, oscillatory contours L1C1, diode VD1, capacitor C2 and measuring device.

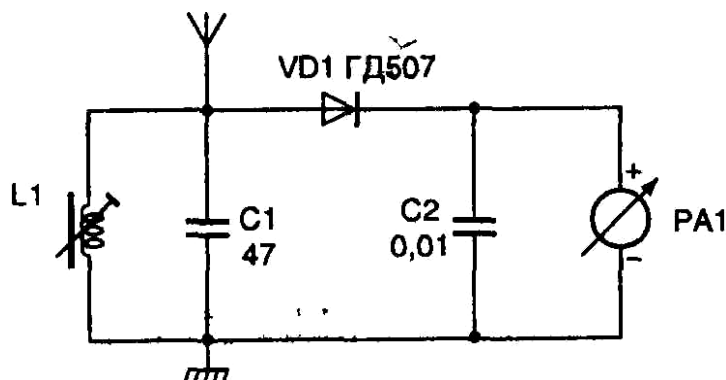


Fig. 7 – The simplest indicator of the field strength of the 27 MHz range. Works

device next way. Through antenna on oscillator- High-frequency oscillations are fed into the circuit. The circuit filters out 27 MHz range oscillations from the frequency mixture. The isolated high-frequency oscillations are detected by diode VD1, due to which only the positive half-waves of the received frequencies pass to the diode output. The envelope of these frequencies represents low-frequency oscillations. Remains HF fluctuations are filtered capacitor C2. At this through measuring device will flow current, which contains variable And constant components. Measurable device constant current approximately proportional to the field strength acting at the receiving location. This detector can be implemented as an attachment to any tester.

Coil L1 diameter 7 mm With tuning core has 10 turns of wire PEV-1 0.5 mm. Antenna completed from steel wires length 50 see The sensitivity of the device can be significantly increased if there is a install amplifier HF. This scheme, By comparison With previous, has more high sensitivity transmitter. Now radiation Maybe be recorded on distance some meters.

Content practical work, performed students

1.1. Description laboratory equipment:

- PC With simulator electronic schemes Electronics Workbench - 5.12"

1.2. Initial data For modeling And research

Table 1 - Initial data For modeling

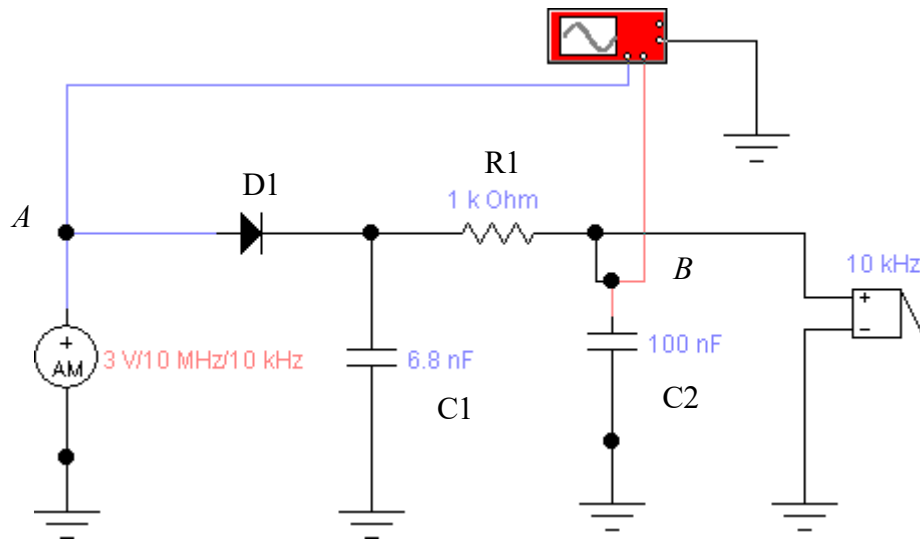
1.3. Exercise For works:

1) *Modeling And study simplest demodulator*

1.4. Order execution work

Exercise 1.1 . Modeling And study simplest demodulator

1) Collect diagram demodulator given on rice. 8 .



Drawing 8 - Simplified principled scheme demodulator

2) Edit the circuit diagram, setting the values of the radio component parameters as indicated. For the AM signal generator, set the voltage amplitude to 3 V, the carrier frequency to 10 MHz, the modulation frequency to 10 kHz, and the internal resistance to 1 ohm. For the sound indicator, set the signal frequency to 10 kHz and the voltage to 9 V.

3) Take off temporary diagram input signal, representing itself is high-frequency radiation. For this first channel electronic connect the oscilloscope to the generator output (*point A*).

4) Take off temporary diagram detected And filtered signal. To do this, connect the second channel of the electronic oscilloscope to the detector output (*point B*).

5) Take off spectrum input And weekend signal indicator fields. For turning this off simulator, log in V menu Analysis → Fourier → Simulate. At this To measure the spectrum of the input high-frequency signal, in the Fourier menu, set the fundamental frequency to 10 kHz and the number of harmonics to 1200, and to measure the spectrum of the output low-frequency signal, set the fundamental frequency to 1 kHz and quantities harmonics - 50. Removal spectrum produce only after Togo, Once the Fourier processor has completed its calculations, “Ready” will appear in the lower left corner of the screen.

6) Research dependence of the quality of the demodulator's operation from parameters of elements C1, C2 and R1. To do this, establish their purpose and, changing their parameters from the nominal values indicated in the diagram by a value 10 times smaller and larger, take off temporary diagram weekend signal V point IN. By view

draw conclusions from the output signal by comparing it with the signal with normal parameters of elements C1, C2 and R1.

7) Bring in researched data V report By practical work And draw conclusions.

5. Prepare a report on the work performed in accordance with the requirements set out in the job description.

IN report bring:

- original data,
- performed tasks,
- compiled listings programs mathematical models,
- developed or compiled circuit design models devices;
- research results in the form of formulas used and calculation results, obtained graphs, oscillograms, time diagrams, conclusions made and findings for each task;
- general conclusions O done work.

6. Protection practical work

For protection practical introduce fully decorated report, free of significant errors. Complete one of the tasks assigned by the teacher, explaining all the physical phenomena and processes occurring in the task being completed.

LIST LITERATURE:

- 1) Sagdeev K.M. Physical foundations of information security [Electronic resource]: study guide / K.M. Sagdeev, V.I. Petrenko, A.F. Chipiga. - Electronic text data. - Stavropol: North Caucasus Federal University, 2015. - 394 p.
- 2) Evstifeev V.V. Physical foundations electricity and magnetism Electronic resource / Evstifeev V.V.: study guide. - Penza: PSU, 2019. - 416 p.
- 3) Bulatov V.N. Physical foundations of electronics Electronic resource / Bulatov V.N.: lecture notes for students in educational programs higher education in the following areas preparation 11.03.02 infocommunication technologies and communication systems. - Orenburg: OSU, 2018. - 178 p.
- 4) Goldstein A.E. Physical principles of obtaining information [Electronic resource]: textbook / A.E. Goldstein. — Electron. text data. — Tomsk: Tomsk Polytechnic University, 2010. — 292 p.

PRACTICAL JOB No. 16

TOPIC 16 PROCESSES MODULATIONS AND DEMODULATION. FREQUENCY SELECTION

Class 16 MODELING AND STUDY PROCESS OF FREQUENCY FILTERING OF SIGNAL.

TIME – 4 hours.

Educational questions:

- 1) Modeling And study LF And HF filters.**
- 2) Modeling And study striped filters.**

TARGET PRACTICAL INSTALLATION WORKS:

Competencies, being formed discipline

OPK-1: Capable use provisions, laws And methods natural sciences and mathematics to solve engineering problems.

OPK-2: Capable on one's own conduct experimental research And use main techniques processing And performances received data.

Learning outcomes achieved as a result of completing practical work:

Be able to:

- apply physical laws and methods to formalize the representation of physical phenomena and processes that occur in telecommunications .
- conduct experimental research With help mathematical models according to the accepted methodology
- model And analyze main physical phenomena And processes in telecommunications using computer technology.

Own:

- skills use knowledge physicists at decision practical problems of engineering activities
- methods of processing and presenting data obtained as a result of experimental studies.
- skills in computer modeling of the main physical methods of receiving, transmitting and storing information.

EDUCATIONAL AND MATERIAL SECURITY:

- PC With simulator electronic schemes Electronics Workbench - 5.12"
- electronic methodological development By practical work.

STRUCTURE PRACTICAL WORK:

Class No. 1	90 min
Introductory Part	10 min
Examination readiness students To practical work	8 min
Introductory Part	2 min
Questions (tasks), subject research:	75 min
1. Modeling And study LF And HF filters.	75 min
Final Part	5 min
Summing up results	3 min
Exercise students For independent work	2 min
Class No. 2	90 min
Introductory Part	10 min
Examination readiness students To practical work	8 min
Introductory Part	2 min
Questions (tasks), subject research:	50 min
1. Modeling And study striped filters.	50 min
Final Part	30 min
Protection reports By practical work	25 min
Summing up results	3 min
Exercise students For independent work	2 min

1. MODELING AND RESEARCH OF SIGNAL FILTERING PROCESSES

Brief theoretical or reference and information materials

Filtration is the main and effective means of suppression (weakening) conductive interference (tips) V chains power supply, V signal chains interface And on printed boards, V wires grounding. Noise suppression filters allow you to reduce conductive (induced) interference from both external and internal interference sources.

According to the location of the filter passband relative to stripes interference suppression V frequency spectrum distinguish four class of noise suppression filters, the amplitude-frequency characteristics (AFC) of which are shown in Fig. 5.1:

- low-pass filters (low-pass) – LPFs that pass signals in the frequency range from $\omega_1 = 0$ to ω_2 (Fig. 5.1, a);
- filters top frequencies (high frequency) - HPF, permeable signals in the frequency range from ω_1 to $\omega_2 = \infty$ (Fig. 5.1, b);
- striped (band-pass) PF, permeable signals in the frequency range from ω_1 to ω_2 (Fig. 5.1, c);
- barriers or rejector (band-stop) ZF, transmitting signals in the frequency range from 0 ω_1 and from ω_2 to ∞ (Fig. 1, g).

Depending on the types of elements that the filters are made of, they are divided into:

- passive reactive, consisting from elements L And WITH;
- piezoelectric, consisting from quartz plates;
- non-inductive passive, consisting from elements R And C.

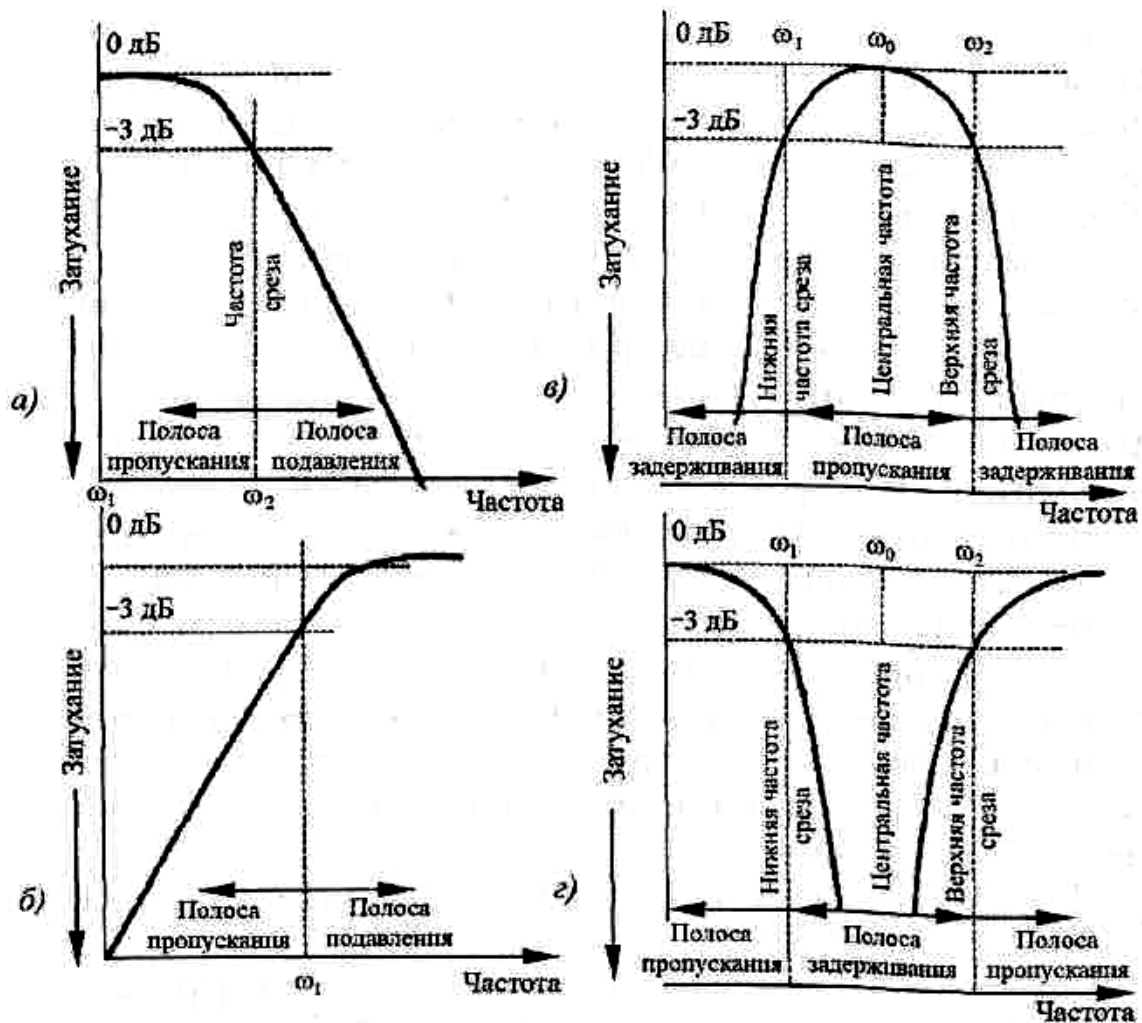


Рис. 1 - frequency response interference suppression filters

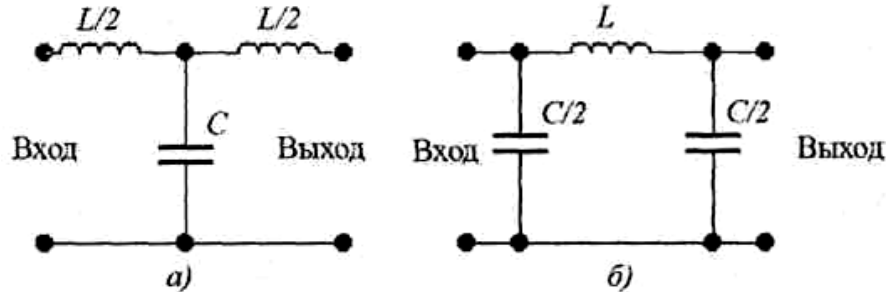
Maybe application active RC filters on basis microcircuits (operational amplifiers). This Maybe be it is appropriate V those cases, When Passive LC filters become very bulky when the cutoff frequency is lowered to audio frequencies, when even when choosing a relatively small capacity (for example, 0.01 μF), the choke becomes disproportionately large in size and weight. IN active filter operating amplifier transforms impedance connected to it RC circuit so that the device behaves like an inductor.

Methodology calculation parameters passive LF And HF filters

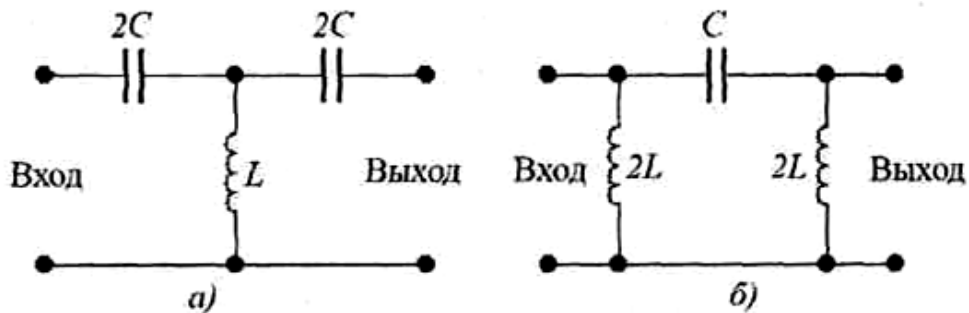
To filter information signals in the form of conductive interference, apply symmetrical LC filters lower or high frequencies type K (rice. 2 And 3). IN filters this type work full resistances capacity And inductance at change frequencies remains approximately permanent (because of back proportional changes their jet resistances at from-

change frequencies). For example, If capacitive reactive resistance is decreasing at increase frequencies, That inductive reactive resistance increases by the corresponding amount.

Figures 2 and 3 show the schematics of typical T-shaped low-pass and high-pass LC filters. and U-shaped structures. U-shaped Filters are used to increase the steepness of the transition region of the frequency response.



Rice. 2 - Symmetrical filters lower frequencies: a) - T-shaped, b) - U-shaped



Rice. 3 - Symmetrical filters high frequencies: a) - T-shaped, b) - U-shaped

IN LF filters values parameters are selected By next expression-niyam :

$$L \approx \frac{2R}{\omega_2}; \quad \omega_2 \approx \frac{2}{\sqrt{LC}}; \quad C \approx \frac{2}{\omega_2 R}; \quad R \approx \sqrt{\frac{L}{C}}, \quad (1)$$

Where R - active or complex resistance loads filter; $\omega_2 = 2\pi F_o$ - circular frequency cut filter; F_2 - linear frequency cut.

Formulas (1) can be expressed through linear frequency cut:

$$L \approx \frac{R}{3.14 F_2}; \quad F_2 \approx \frac{1}{3.14 \sqrt{LC}}; \quad C \approx \frac{1}{3.14 F_2 R}, \quad (2)$$

The total inductance of the T-shaped filter is distributed equally between the coils (Fig. 2, a) and the total capacitance of the U-shaped filter is distributed equally between the filter capacitors (Fig. 2, b).

Calculated equations For HF filters:

$$L \approx \frac{R}{2\omega_1}; \quad \omega_1 = 2\pi F_1; \quad F_1 \approx \frac{1}{4\pi \sqrt{LC}}; \quad C \approx \frac{1}{4\omega_1 R}; \quad R \approx \sqrt{\frac{L}{C}}, \quad (3)$$

Formulas (3) can be expressed through linear frequency cut:

$$L \approx \frac{R}{4\pi F_1}; \quad F_1 \approx \frac{1}{4\pi\sqrt{LC}}; \quad C \approx \frac{1}{8\pi F_1 R}; \quad R \approx \sqrt{\frac{L}{C}}, \quad (4)$$

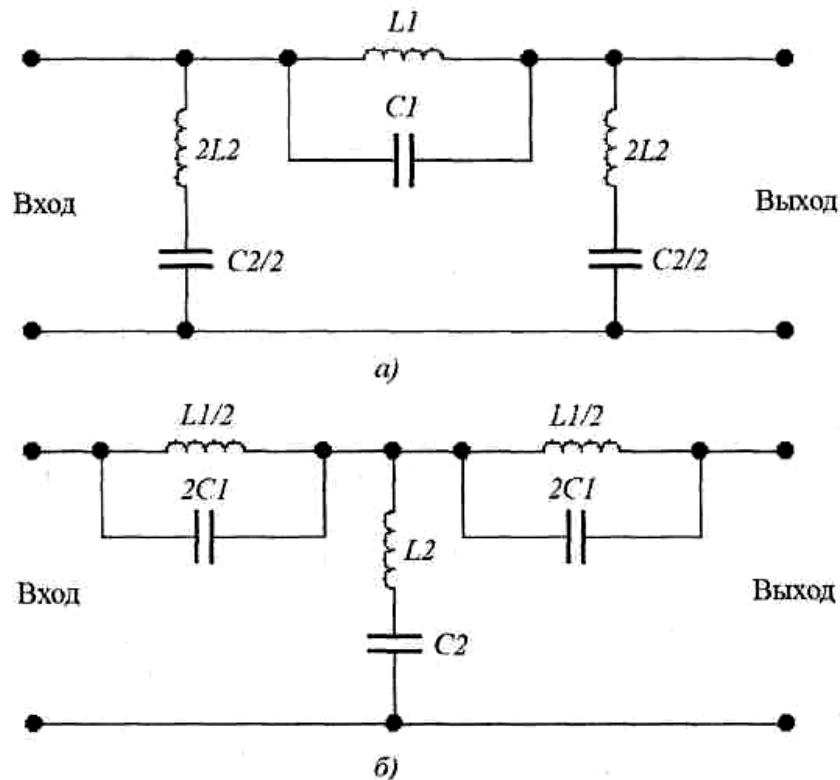
High-pass filters also have the advantage that for AC, capacitors and inductors work in opposite directions. Therefore, in LC high-pass filters, the series element increases with increasing frequencies signal has more low reactive resistance. Such element skips high-frequency signals, A For signals low its frequencies reactive resistance great. Parallel element provides shunting influence on signals low frequencies, A For high-frequency signals its reactance is high.

The required total capacitance of the T-filter is distributed equally between the filter capacitors so that each capacitor has a capacitance equal to twice the calculated value. In a U-filter, the total inductance is distributed equally between two coils So, What each of them has an inductance equal to twice the calculated value.

For increases steepness frequency characteristics filters LF And HF are performed according to a U-shaped structure.

Methodology calculation parameters passive striped filters

On rice. 4 given schemes typical band-stopping LC filters of T-shaped and U-shaped structures.

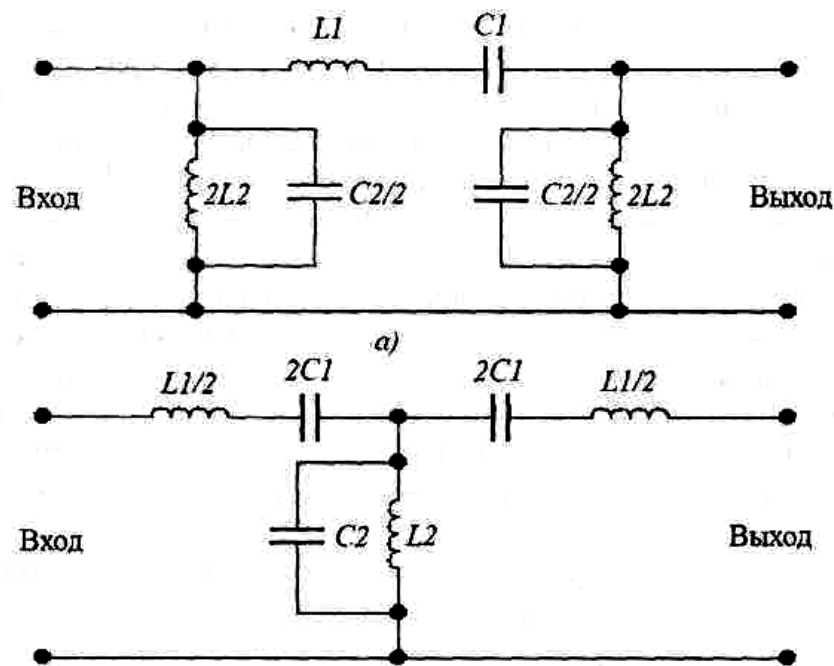


Rice. 4 - Schemes band-stopping filters: a) - U-shaped;
b) - T-shaped

The band-stop filter has the advantage that successive And parallel resonant chains have various

The characteristics of their impedances. A parallel LC circuit creates the highest impedance at the resonant frequency, while a series circuit has the lowest impedance. By connecting these two LC circuits in a specific manner, as shown in Figure 8, a band-stop filter circuit can be created. The series branch has the lowest impedance at the center frequency of the desired range. Its impedance begins to increase on both sides of the resonant frequency. At the center frequency, this branch has a shunting effect. The parallel branch has the highest impedance at the center frequency, and its impedance decreases on both sides of the resonance. This branch prevents the passage of signals in the frequency range on both sides of the center frequency.

On rice. 5 given schemes typical bandpass LC filters of T-shaped and U-shaped structures.



Rice. 5 - Schemes bandpass filters: a) - U-shaped; b) - T-shaped

A bandpass filter has the advantage that series and parallel resonant circuits have different impedance characteristics, just like a bandstop filter. A parallel LC circuit creates the highest impedance at the resonant frequency, while a series circuit has the lowest. A bandpass filter can be implemented using these two LC circuits. The series branch has the lowest impedance at the center frequency of the desired range, which increases on both sides of the resonant frequency. This branch has a shunting effect on signals with frequencies above and below the center of the specified frequency. stripes. As a result this How consistent, So And parallel

branch ensure passage signals V range frequencies lying along both sides of a given center frequency.

For calculation parameters rejector (barriers) filters for both structures the following formulas can be used:

$$L_1 \approx \frac{1}{\pi} \left(\frac{\omega_2 - \omega_1}{2} \right) \cdot \frac{4\pi R}{\omega_1 \omega_2} \approx \frac{(F_2 - F_1)R}{\omega_1 \omega_2}; \quad L_2 \approx \frac{R}{2(\omega_2 - \omega_1)} \approx \frac{R}{4\pi(F_2 - F_1)}; \quad (5)$$

$$C_1 \approx \frac{1}{2(\omega_2 - \omega_1)R} \approx \frac{1}{4\pi R(F_2 - F_1)}; \quad C_2 \approx \frac{2(\omega_2 - \omega_1)}{R\omega_1\omega_2} \approx \frac{F_2 - F_1}{\pi R F_1 F_2}; \quad (6)$$

$$F_{cut} (kHz) \approx \frac{159}{\sqrt{L_{(mkH)} \cdot C_{(mkF)}}}; \quad (7)$$

For calculation parameters striped filters both structures You can use the following formulas:

$$L_1 \approx \frac{2R}{\omega_2 - \omega_1} \approx \frac{R}{\pi(F_2 - F_1)}; \quad L_2 \approx \frac{(\omega_2 - \omega_1)R}{2\omega_1\omega_2} \approx \frac{(F_2 - F_1)R}{4\pi F_1 F_2}; \quad (8)$$

$$C_1 \approx \frac{(\omega_2 - \omega_1)}{2\omega_1\omega_2} \approx \frac{F_2 - F_1}{4\pi F_1 F_2 R}; \quad C_2 \approx \frac{2}{R(\omega_2 - \omega_1)} \approx \frac{1}{\pi R(F_2 - F_1)}; \quad (9)$$

$$F_{cut} (kHz) \approx \frac{159}{\sqrt{L_{(mkH)} \cdot C_{(mkF)}}}; \quad (10)$$

Content practical work, performed students

1.1. Description laboratory equipment:

– PC With simulator electronic schemes Electronics Workbench - 5.12" and the computer mathematics system "Mathcad – 14";

1.2. Initial data For modeling And research

Table 1 - Initial data For modeling

No. var.	F ₂ , kHz	F ₁ , kHz	R, Ohm	No. var.	F ₂ , kHz	F ₁ , kHz	R, Ohm
1.	5.0	7.0	600	2.	5.5	7.5	500
3.	6.0	8.0	500	4.	6.5	8.5	600
5.	7.0	9.5	800	6.	7.5	9.5	700
7.	8.0	10.0	1000	8.	8,5	10,5	800
9.	9,0	11,0	600	10.	9,5	11,5	1000
11.	10,0	12,0	500	12.	10,5	12,5	500
13.	11,0	13,0	800	14.	10,0	13,0	600
15.	8,5	12,5	1000	16.	8,0	11,0	700
17.	7,5	10,5	600	18.	7,0	10,0	800
19.	6,5	9,5	500	20.	6,0	9,0	1000
21.	5,5	8,5	800	22.	5,0	8,0	500

23.	4,5	7,5	1000	24.	4,0	7,0	600
25.	3.5	6.5	700	26.	3.0	6.0	1000

1.3. Exercise For works:

Basic level:

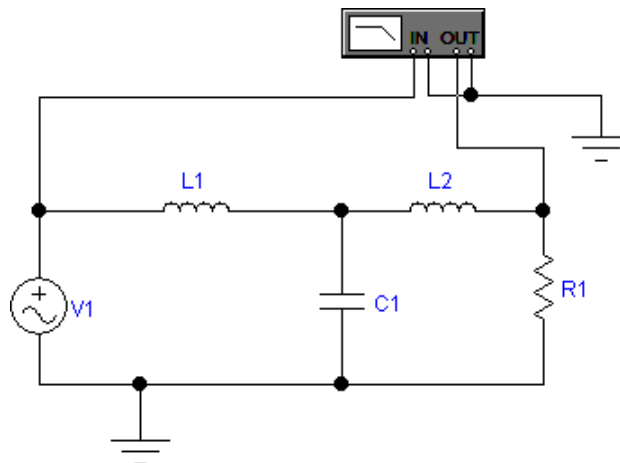
- 1) Simulate And research passive filter low frequencies.
- 2) Model and research passive filter high frequencies.
- 3) Simulate And research passive bandpass filter.
- 4) Simulate And research passive band-stop filter.

1.4. Order execution work

Task 1.1. Model and investigate a passive low- pass filter.

1.1. For filter low frequencies calculate parameters elements L And WITH for T-shaped and U-shaped structures for a given cutoff frequency F_2 and load R. For this, using formulas (2), in the computer mathematics system Mathcad - 14" calculate at first size coils inductance L, then capacity C.

1.2. Assemble the model in the Electronics Workbench electronic circuit simulator T-shaped filter lower frequencies according to scheme, given on Fig. 6.



Rice. 6 - Simulated scheme T-shaped LF filter

1.3. Set the calculated values of the inductance coil L and capacitance C in the assembled circuit. In this case, the total inductance of the T-shaped LF filter is distributed equally between coils L1 And L2. Set the voltage in source V1 to 1 V and the frequency to 1 kHz.

1.4. Conduct a study of the passive T-shaped low-pass filter circuit. To do this, perform the following steps:

- 1) Using a frequency response meter (*Bode plotter*), plot the amplitude-frequency response (AFR) of a T-shaped low-pass filter on a logarithmic scale.

2) Define frequency cut filter, compare her With given meaning and calculate the relative error.

3) Define maximum deviation input signal And his sign V filter passband.

4) Define steepness decline frequency response filter, How degree weakening signal level per octave, i.e. dB/octave, to do this:

- measurement level frequency response on frequency, V 2 times exceeding measured cutoff frequency,

- Subtract the attenuation value at the measured cutoff frequency from the measured value.

5) Do conclusions By results done research.

1.5. Conduct a study of the passive low-pass filter's response to a pulsed input. To do this, perform the following steps:

1) Modify the filter research circuit by replacing the harmonic voltage generator with a rectangular pulse generator with a pulse repetition frequency of 1 kHz, and the frequency response meter with an oscilloscope.

2) Using an oscilloscope, record the voltage waveforms of the input pulse sequence and the signal at the filter output. Add the oscillograms to the report.

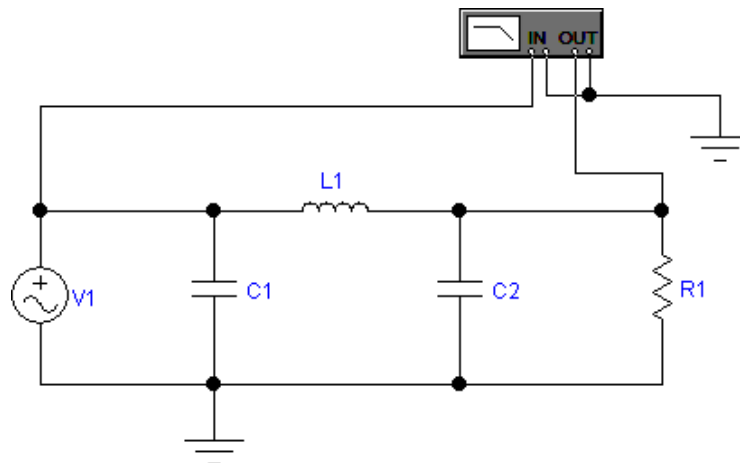
3) WITH help Fourier analyzer get And measure spectrum input pulse sequence and the spectrum of the signal at the filter output.

4) Explain reasons distortions signal on exit filter.

5) Change the input signal clock frequency to 5 kHz. Repeat steps 2–4.

6) Do conclusions By results done research.

1.6. In the Electronics Workbench electronic circuit simulator, assemble a model of a U-shaped low-pass filter according to the diagram shown in Fig. 7.



Rice. 7 - Simulated scheme U-shaped LF filter

1.7. Set the calculated values of the inductance coil L and capacitance C in the assembled circuit, while the total capacitance of the U-shaped low-pass filter is distributed equally between capacitors C1 and C2. Set the voltage in source V1 to 1 V, and the frequency to 1 kHz.

1.8. Conduct a study of the passive U-shaped low-pass filter circuit. To do this, perform the following steps:

- 1) Using a frequency response meter (*Bode plotter*)

build V logarithmic scale frequency response U-shaped LF filter.

- 2) Define frequency cut filter, compare her With given meaning and calculate the relative error.

- 3) Define maximum deviation input signal And his sign V filter passband.

- 4) Define steepness decline frequency response filter, How degree weakening signal level per octave, i.e. dB/octave, to do this:

- measurement level frequency response on frequency, V 2 times exceeding measured cutoff frequency,
- Subtract the attenuation value at the measured cutoff frequency from the measured value.

- 5) Do conclusions By results done research.

1.9. Conduct a study of the passive low-pass filter's response to a pulsed input. To do this, perform the following steps:

- 1) Modify the filter research circuit by replacing the harmonic voltage generator with a rectangular pulse generator with a pulse repetition frequency of 1 kHz, and the frequency response meter with an oscilloscope.

- 2) Using an oscilloscope, record the voltage waveforms of the input pulse sequence and the signal at the filter output. Add the oscillograms to the report.

- 3) WITH help Fourier analyzer get And measure spectrum input pulse sequence and the spectrum of the signal at the filter output.

- 4) Explain reasons distortions signal on exit filter.

- 5) Change the input signal clock frequency to 5 kHz. Repeat steps 2–4.

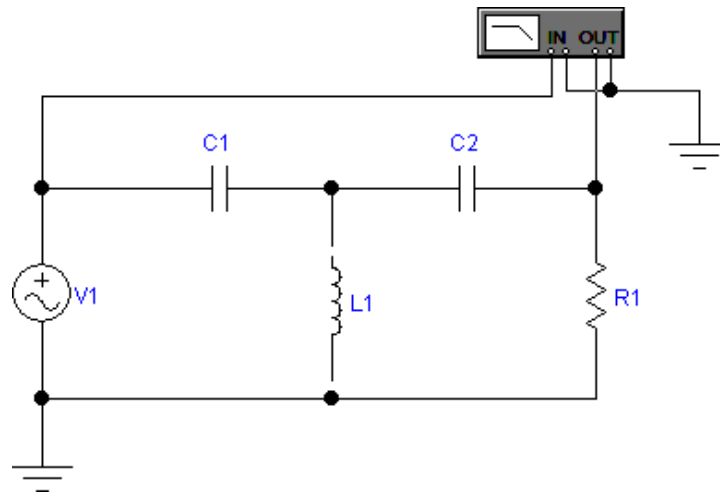
- 6) Do conclusions By results done research.

1.10. Do comparative conclusions By results research passive low-pass filters.

Exercise 1.2. Simulate And research passive filter high frequencies.

2.1. For a high-pass filter, calculate the parameters of the elements L and C for the T-shaped and U-shaped structures at a given cutoff frequency F_1 and load R. To do this, using formulas (4), first calculate in the computer mathematics system “Mathcad – 14” the value of the inductance coil L, then the capacitance C.

2.2. In the Electronics Workbench electronic circuit simulator, assemble a model of a T-shaped high-pass filter according to the diagram shown in Fig. 8.



Rice. 8 - Simulated scheme T-shaped HF filter

2.3. Set the calculated values of the inductor L and capacitance C in the assembled circuit, with the total capacitance of the T-shaped high-pass filter being distributed equally between capacitors $C1$ and $C2$, so that each capacitor has a capacitance equal to twice the calculated value. Set the voltage in source $V1$ to 1 V and the frequency to 1 kHz.

2.4. Conduct a study of the passive T-shaped high-pass filter circuit. To do this, perform the following steps:

1) WITH help measuring instrument frequency characteristics (*Bode plotter*) build V logarithmic scale frequency response T-shaped HF filter.

2) Define frequency cut filter, compare her With given meaning and calculate the relative error.

3) Define maximum deviation input signal And his sign V filter passband.

4) Define steepness decline frequency response filter, How degree weakening signal level per octave, i.e. dB/octave, to do this:

- measurement level frequency response on frequency, V 2 times exceeding measured cutoff frequency,
- Subtract the attenuation value at the measured cutoff frequency from the measured value.

5) Do conclusions By results done research.

2.5. Conduct a study of the passive high-pass filter's response to a pulsed input. To do this, perform the following steps:

1) Modify the filter research circuit by replacing the harmonic voltage generator with a rectangular pulse generator with a pulse repetition frequency of 1 kHz, and the frequency response meter with an oscilloscope.

2) Using an oscilloscope, record the voltage waveforms of the input pulse sequence and the signal at the filter output. Add the oscillograms to the report.

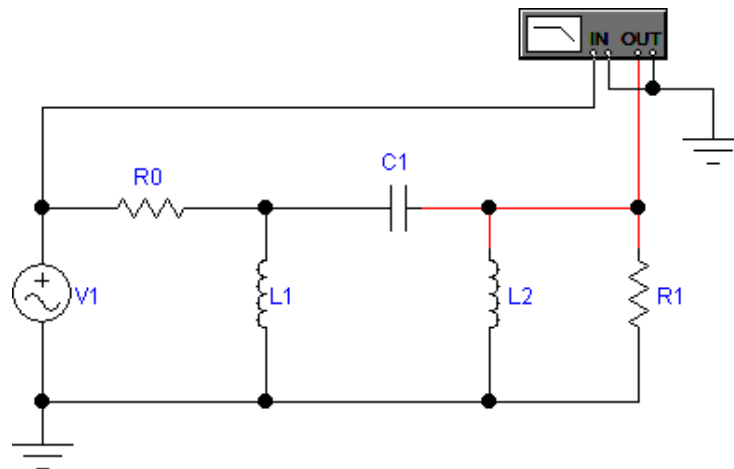
3) WITH help Fourier analyzer get And measure spectrum input pulse sequence and the spectrum of the signal at the filter output.

4) Explain reasons distortions signal on exit filter.

5) Change the input signal clock frequency to 5 kHz. Repeat steps 2–4.

6) Do conclusions By results done research.

2.6. In the Electronics Workbench electronic circuit simulator, assemble a model of a U-shaped high-pass filter according to the diagram shown in Fig. 9.



Rice. 9 - Simulated scheme U-shaped HF filter

2.7. Set the calculated values of the inductance coil L and capacitance C in the assembled circuit, while the total inductance of the U-shaped filter is distributed equally between coils $L1$ and $L2$, So What Each coil has an inductance equal to twice the calculated value. Set V source $V1$ voltage, equal 1 IN, With frequency - 1 kHz, A also the value of the internal resistance of the source – $R0=1$ Ohm.

2.8. Conduct a study of the passive U-shaped high-pass filter circuit. To do this, perform the following steps:

1) WITH help measuring instrument frequency characteristics (*Bode plotter*) build V logarithmic scale frequency response U-shaped HF filter.

2) Define frequency cut filter, compare her With given meaning and calculate the relative error.

3) Define maximum deviation input signal And his sign V filter passband.

4) Define steepness decline frequency response filter, How degree weakening signal level per octave, i.e. dB/octave, to do this:

- measurement level frequency response on frequency, V 2 times exceeding measured cutoff frequency,

- Subtract the attenuation value at the measured cutoff frequency from the measured value.

5) Do conclusions By results done research.

2.9. Conduct a study of the passive high-pass filter's response to a pulsed input. To do this, perform the following steps:

1) Modify the filter research circuit by replacing the harmonic voltage generator with a rectangular pulse generator with a pulse repetition frequency of 1 kHz, and the frequency response meter with an oscilloscope.

2) Using an oscilloscope, record the voltage waveforms of the input pulse sequence and the signal at the filter output. Add the oscillograms to the report.

3) WITH help Fourier analyzer get And measure spectrum input pulse sequence and the spectrum of the signal at the filter output.

4) Explain reasons distortions signal on exit filter.

5) Change the input signal clock frequency to 5 kHz. Repeat steps 2–4.

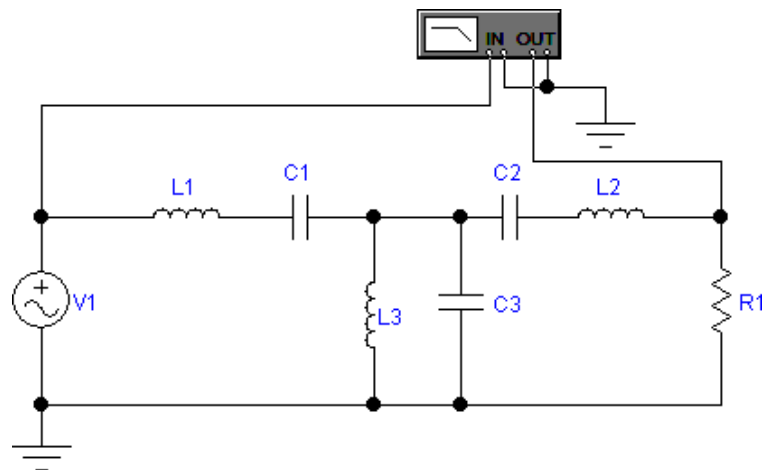
6) Do conclusions By results done research.

2.10. Do comparative conclusions By results research passive high-pass filters.

Exercise 1.3. Simulate and explore passive bandpass filter.

3.1. For a bandpass filter, calculate the parameters of the elements L And WITH For T-shaped And U-shaped structures By given strip transmission $F_1 - F_2$ and load R. For this, using formulas (8) and (9), in the system computer mathematicians Mathcad - 14" calculate at first the value of the inductance coils L, then the capacitances C.

3.2. In the Electronics Workbench electronic circuit simulator, assemble a model of a T-shaped bandpass filter according to the diagram shown in Fig. 5.10.



Rice. 5.10 - Simulated scheme T-shaped striped filter

3.3. Set the calculated values of the inductance coil L and capacitance C in the assembled circuit, while the total capacitance of the series circuit of the T-shaped bandpass filter is distributed equally between the capacitors C1 And C2, So What every capacitor has capacity, equal

double the calculated value, and the total inductance of the series filter circuit is distributed equally between coils L1 and L2. Set the voltage in source V1 to 1 V and the frequency to 1 kHz.

3.4. Conduct a passive T-bandpass filter design study. To do this, perform the following steps:

1) Using a frequency response meter (*Bode plotter*), plot the frequency response of a T-bandpass filter on a logarithmic scale.

2) Determine the filter passband, compare it with the specified value and calculate the relative error.

3) Define maximum deviation input signal And his sign V filter passband.

4) To determine the slope of the filter's frequency response as the degree of attenuation of the signal level by one octave, i.e. dB/octave, do the following:

- measurement level frequency response on frequencies, V 2 times exceeding measured cutoff frequencies,

- subtract the attenuation values at the measured cutoff frequencies from the measured values.

5) Do conclusions By results done research.

3.5. Conduct a study of the passive bandpass filter's response to a pulsed input. To do this, perform the following steps:

1) Modify the filter research circuit by replacing the harmonic voltage generator with a rectangular pulse generator with a pulse repetition rate equal to the central frequency of the passband, and the frequency response meter with an oscilloscope.

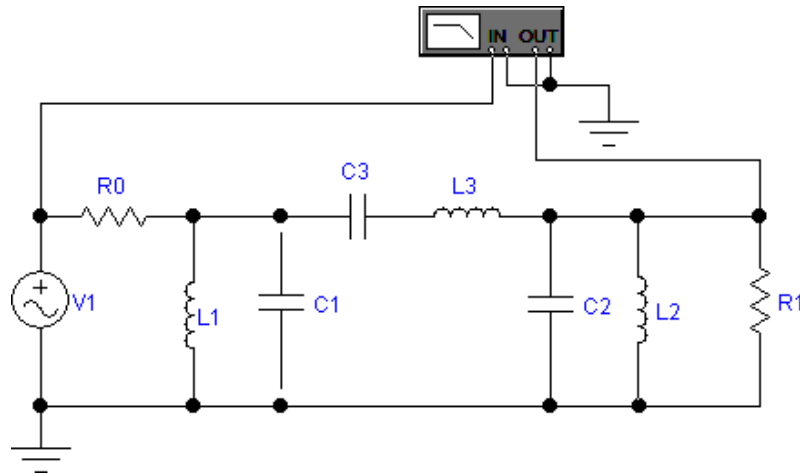
2) Using an oscilloscope, record the voltage waveforms of the input pulse sequence and the signal at the filter output. Add the oscillograms to the report.

3) WITH help Fourier analyzer get And measure spectrum input pulse sequence and the spectrum of the signal at the filter output.

4) Explain the reasons for signal distortion at the filter output and draw conclusions based on the results of the research.

4.3.6. In the Electronics Workbench electronic circuit simulator, assemble a model of a U-shaped bandpass filter according to the diagram shown in Fig. 11.

3.7. Set the calculated values of the coil in the assembled circuit inductance L And capacity WITH, at this total capacity parallel circuit U-shaped striped filter is distributed equally between capacitors C1 And C2, A total inductance parallel chains filter distributed equally between L coils 1 And L2, so What each coil has inductance, equal doubled calculated meaning. Install V source V1 voltage equal to 1 V with a frequency of 1 kHz, and also the value of the internal resistance of the source is $R_0 = 1 \text{ Ohm}$.



Rice. 11 - Simulated scheme U-shaped striped filter

3.8. Conduct a study of the passive U-shaped bandpass filter circuit. To do this, perform the following steps:

- 1) Using a frequency response meter (*Bode plotter*), plot the frequency response of a U-shaped bandpass filter on a logarithmic scale.
- 2) Determine the filter passband, compare it with the specified value and calculate the relative error.
- 3) Define maximum deviation input signal And his sign V filter passband.
- 4) To determine the slope of the filter's frequency response as the degree of attenuation of the signal level by one octave, i.e. dB/octave, do the following:
 - measurement level frequency response on frequencies, V 2 times exceeding measured cutoff frequencies,
 - subtract the attenuation values at the measured cutoff frequencies from the measured values.
- 5) Do conclusions By results done research.

3.9. Conduct a study of the passive bandpass filter's response to a pulsed input. To do this, perform the following steps:

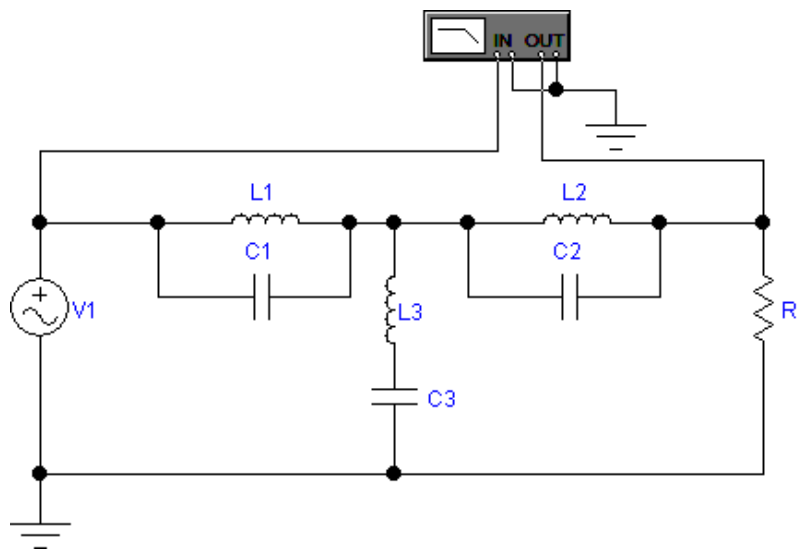
- 1) Modify the filter research circuit by replacing the harmonic voltage generator with a rectangular pulse generator with a pulse repetition rate equal to the central frequency of the passband, and the frequency response meter with an oscilloscope.
- 2) Using an oscilloscope, record the voltage waveforms of the input pulse sequence and the signal at the filter output. Add the oscillograms to the report.
- 3) WITH help Fourier analyzer get And measure spectrum input pulse sequence and the signal spectrum at the output of the bandpass filter.
- 4) Explain the reasons for signal distortion at the filter output and draw conclusions based on the results of the research.

3.10. Do comparative conclusions By results research passive bandpass filters.

Exercise 1.4. Simulate And research passive band-stop filter.

4.1. For a band-stop filter, calculate the parameters of the elements L And WITH For T-shaped And U-shaped structures By given strip transmission $F_1 - F_2$ and load R. To do this, using formulas (5) and (5.6), in the computer mathematics system “Mathcad – 14” first calculate the value of the inductance coils L, then the capacitance C.

4.2. In the Electronics Workbench electronic circuit simulator, assemble a model of a T-stop filter according to the diagram shown in Fig. 12.



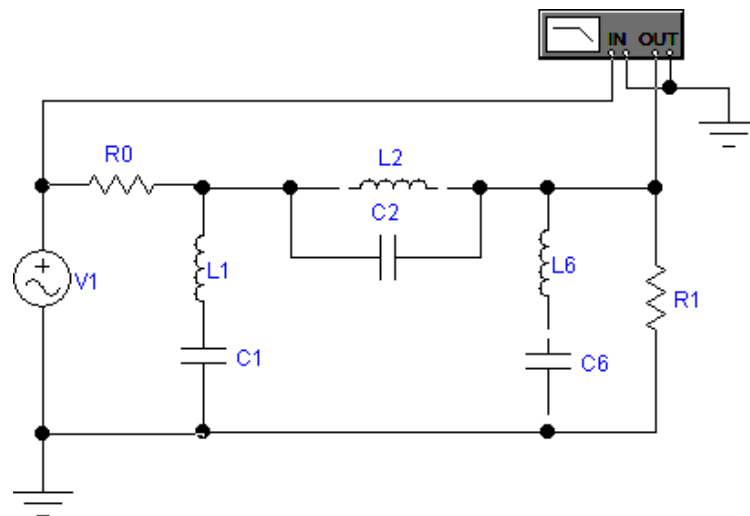
Rice. 12 - Simulated scheme T-shaped obstructing filter

4.3. Set the calculated values of the coil in the assembled circuit inductance L And capacity WITH, at this total capacity in a parallel T-stop filter circuit the current is distributed equally between the capacitors C1 And C2, So What every capacitor has capacity, equal double the calculated value, and the total inductance of the parallel filter circuit is distributed equally between coils L1 And L2. Install V source V1 voltage equal to 1 V, and frequency – 1 kHz.

4.4. Conduct a study of the passive T-stop filter circuit. To do this, perform the following steps:

- 1) Using a frequency response meter (*Bode plotter*), plot the frequency response of a T-notch filter on a logarithmic scale.
- 2) Determine the filter stop band, compare it with the specified value and calculate the relative error.
- 3) Define maximum deviation input signal And his sign V filter passband.

- 4) Define steepness recessions frequency response filter, How degree to weaken the signal level by one octave, i.e. dB/octave, to do this:
- measurement level frequency response on frequencies, V 2 times exceeding measured cutoff frequencies,
 - subtract the attenuation values at the measured cutoff frequencies from the measured values.
- 5) Do conclusions By results done research.
- 4.5. Conduct study reactions (response) passive A notch filter for a pulsed input signal. To do this, follow these steps:
- 1) Modify the filter research circuit by replacing the harmonic voltage generator with a rectangular pulse generator with a pulse repetition rate equal to the central frequency of the passband, and the frequency response meter with an oscilloscope.
 - 2) Using an oscilloscope, record the voltage waveforms of the input pulse sequence and the signal at the filter output. Add the oscillograms to the report.
 - 3) WITH help Fourier analyzer get And measure spectrum input pulse sequence and the spectrum of the signal at the filter output.
 - 4) Explain the reasons for signal distortion at the filter output and draw conclusions based on the results of the research.
- 4.6. In the Electronics Workbench electronic circuit simulator, assemble a model of a U-shaped band-stop filter according to the diagram shown in Fig. 13.



Rice. 13 - Simulated scheme U-shaped obstructing filter

4.7. Set the calculated values of the coil in the assembled circuit inductance L And capacity WITH, at this total inductance parallel circuit of the U-shaped rejection filter is distributed equally between coils $L1$ And $L2$, A total capacity parallel chains filter is distributed equally between capacitors $C1$ And $C2$, So What every condensation-

The torus has a capacitance equal to twice the calculated value. Set the voltage in the source V1 equal to 1 V with a frequency of 1 kHz, and also the value of the internal resistance of the source $R_0 = 1 \text{ Ohm}$.

4.8. Conduct a study of the passive U-shaped band-stop filter circuit. To do this, perform the following steps:

- 1) Using a frequency response meter (*Bode plotter*), plot the frequency response of a U-shaped band-stop filter on a logarithmic scale.
- 2) Determine the filter stop band, compare it with the specified value and calculate the relative error.
- 3) Define maximum deviation input signal And his sign V filter passband.
- 4) To determine the slope of the filter's frequency response as the degree of attenuation of the signal level by one octave, i.e. dB/octave, do the following:
 - measurement level frequency response on frequencies, V 2 times exceeding measured cutoff frequencies,
 - subtract the attenuation values at the measured cutoff frequencies from the measured values.
- 5) Do conclusions By results done research.

4.9. Conduct study reactions (response) passive A notch filter for a pulsed input signal. To do this, follow these steps:

- 1) Modify the filter research circuit by replacing the harmonic voltage generator with a rectangular pulse generator with a pulse repetition rate equal to the central frequency of the passband, and the frequency response meter with an oscilloscope.
- 2) Using an oscilloscope, record the voltage waveforms of the input pulse sequence and the signal at the filter output. Add the oscillograms to the report.
- 3) WITH help Fourier analyzer get And measure spectrum input pulse sequence and the spectrum of the signal at the filter output.
- 4) Explain the reasons for signal distortion at the filter output and draw conclusions based on the results of the research.

4.4.10. Draw comparative conclusions based on the results of studies of passive band-stop filters.

1.5. Prepare a report on the work performed in accordance with the requirements set out in the job description.

IN report bring:

- original data,
- performed tasks,
- compiled listings programs mathematical models,
- developed or compiled circuit design models devices;

- research results in the form of formulas used and calculation results, obtained graphs, oscillograms, time diagrams, conclusions made and findings for each task;
- general conclusions of done work.

6. Protection practical work

For protection practical introduce fully decorated report, free of significant errors. Complete one of the tasks assigned by the teacher, explaining all the physical phenomena and processes occurring in the task being completed.

LIST LITERATURE:

- 1) Sagdeev K.M. Physical foundations of information security [Electronic resource]: study guide / K.M. Sagdeev, V.I. Petrenko, A.F. Chipiga. - Electronic text data. - Stavropol: North Caucasus Federal University, 2015. - 394 p.
- 2) Evstifeev V.V. Physical foundations electricity and magnetism Electronic resource / Evstifeev V.V.: study guide. - Penza: PSU, 2019. - 416 p.
- 3) Bulatov V.N. Physical foundations of electronics Electronic resource / Bulatov V.N.: lecture notes for students in educational programs higher education in the following areas preparation 11.03.02 infocommunication technologies and communication systems. - Orenburg: OSU, 2018. - 178 p.
- 4) Goldstein A.E. Physical principles of obtaining information [Electronic resource]: textbook / A.E. Goldstein. — Electron. text data. — Tomsk: Tomsk Polytechnic University, 2010. — 292 p.

MINISTRY SCIENCES AND HIGHER EDUCATION RUSSIAN FEDERATION FEDERAL
STATE AUTONOMOUS EDUCATIONAL INSTITUTION OF HIGHER EDUCATION
"NORTH CAUCASIAN FEDERAL UNIVERSITY"

METHODOLOGICAL INSTRUCTIONS

on organizing and conducting independent work on
discipline "Experimental Physics II/College Physics

Experiment II" for students in the field of study

11.03.02 Infocommunication technologies And systems connections

Direction (profile)

"Intellectual processing data V infocommunication systems and networks"

TABLE OF CONTENTS

INTRODUCTION	3
1. GENERAL CHARACTERISTIC INDEPENDENT WORKS	9
2. METHODOLOGICAL RECOMMENDATIONS BY STUDY THEORETICAL MATERIAL	12
3. METHODOLOGICAL INSTRUCTIONS BY IMPLEMENTATION PRACTICAL WORKS	13
4. SELF-STUDY INTERVIEW QUESTIONS LITERATURE	14
5. COMPUTER TESTS FOR SELF-TESTING, PREPARATIONS TO TESTING	18
6. SET MULTI-LEVEL TASKS FOR COMPUTER MODELING WITH USE GRAPHIC EDITORS	22
8. QUESTIONS TO EXAM	28

INTRODUCTION

1. Target And tasks development discipline (module)

Target development disciplines : formation at students general professional competencies in the direction of scientific thinking and research activities.

Tasks mastering the discipline :

1) Systematization of fundamental knowledge in the field of physics and mathematics, use their For solutions practical tasks By formalization And analysis physical the essence of processes associated with receiving, transmitting, processing and storing information in information and telecommunication systems.

2) Practical training for conducting experimental research by modeling physical phenomena and processes arising in information and telecommunications systems, A Also To use main receptions processing And presentation of the obtained data.

2. Place disciplines (module) V structure educational programs

The discipline “Physical foundations of telecommunications” refers to the disciplines of the compulsory part of Block 1 of the Discipline (modules).

3. Scroll planned results training By discipline (module), correlated with the planned results of mastering the educational program

Code, formulation of competence	Code, formulation indicator	Planned learning outcomes for the discipline (module), characterizing the stages of formation development of competencies, indicators
OPK-1. Capable of using provisions, laws And methods of natural sciences and mathematics for solving engineering problems	ID-1 OPK-1 understands the fundamental laws of nature and the basic physical mathematical laws and methods of accumulation, transmission and processing of information .	Understands the fundamental laws of nature, physical phenomena and processes that take place in telecommunications systems; the basic physical methods and mathematical techniques used in telecommunications for accumulation, transmissions And processing information.
	ID-2 OPK-1 applies physical laws and mathematical methods to solve theoretical problems And applied Ha-racter.	Applies physical laws and methods to formalize the representation of physical phenomena And processes, having place V telecommunications.
	ID-3 OPK-1 uses knowledge of physics And mathematicians at solving practical problems.	Uses knowledge of physics to solve practical engineering problems in the field of telecommunications .
OPK-2. Capable of independently conducting experimental research And use basic techniques processing and presentation of the obtained data	ID-3 OPK-2 understands the basic methods and means of conducting experimental research, systems standardization And certification.	Understands the basic methods and means of conducting experimental research using computer technology.
	ID-4 OPK-2 selects measurement methods and means and conducts experiments research-niya.	Chooses necessary methods and means measurements, conducts experimental research.
	ID-5 OPK-2 owns ways	Owens ways processing And

Code, formulation of competence	Code, formulation indicator	Planned learning outcomes for the discipline (module), characterizing the stages of formation development of competencies, indicators
	processing And performances received data And assessments By-sinfulness results measurements .	presentation of obtained laboratory data and error assessment results measurements.

4. Volume educational disciplines (module) And forms control

Amount of classes: total: 3 credits, 108 academican	OFO, V academic hours
Contact Job:	24
Lectures/from they have practical training	0 / -
Laboratory works/from them practical Preparation	0 / -
Practical classes/from them practical training toverka	24 / -
Independent Job	48
Forms of control	
Exam	36
Credit	-
Credit with grade	-
Calculation and graphic work	-
Coursework Job	-
Control work	-

5. Content disciplines (module), structured By topics (sections) indicating the number of hours and types of classes

No.	Section (topic) of the discipline and brief content	Developed competencies, indicators	full-time education				Current Progress Monitoring Form
			Contact work of students with a teacher/of which in the form of practical training, hours			Independent work, hours	
			Lectures	Practical classes	Laboratory work		
3rd semester							
1	Information and telecommunication infrastructure as a complex physical system. The physical layer of infocommunication systems and the fundamentals of information transmission. Physical principles of interaction between infocommunication systems and external physical fields. Representation of information at the	OPK-1 ID-1 OPK-1 ID-2 OPK-1 ID-3 OPK-1 OPK-2 ID-3 OPK-2 ID-4 OPK-2 ID-5 OPK-2		2		4	Interview

	<p>physical layer. Characteristics of physical fields as information carriers. Physical transmission media.</p> <p>Modeling and research of simple analog and digital signals.</p> <p>Modeling and research of the process of propagation of simple signals in a physical environment</p> <p>Practical work No. 1 SIMULATION AND RESEARCH OF SIMPLE ANALOG AND DIGITAL SIGNALS</p>						
2	<p>Elements of field theory, fundamentals of vector analysis.</p> <p>Scalar and vector description of fields. Vector multiplication. Integral characteristics of vector fields: flow and circulation. Gradient.</p> <p>Hamiltonian (Nabla) and Laplace operators. Differential vector operators: divergence and curl.</p> <p>Fundamental theorems of field theory.</p> <p>Modeling and research of characteristics of physical fields and processes of their transformation.</p> <p>Practical work #2 MODELING AND RESEARCH OF THE PROCESS OF PROPAGATION OF SIMPLE SIGNALS IN A PHYSICAL ENVIRONMENT</p>	<p>OPK-1 ID-1_{OPK-1} ID-2_{OPK-1} ID-3_{OPK-1} OPK-2 ID-3_{OPK-2} ID-4_{OPK-2} ID-5_{OPK-2}</p>		2		4	Interview
3	<p>Fundamentals of Electromagnetism.</p> <p>Physical principles of electrical interaction. Types of electric fields and their comparative characteristics.</p> <p>Electrostatic field, its characteristics and properties. Effect of electric field on substances. Electric field in a conductor. Physical principles of magnetic interaction. Magnetic field and its characteristics. Manifestations of magnetic field. Ampere and Lorentz forces. Properties of magnetic field. Properties of magnetic field. Magnetic storage media.</p> <p>Modeling and research of electric fields.</p> <p>Modeling and research of magnetic fields and electromagnetic induction phenomena.</p> <p>Practical work #3</p>	<p>OPK-1 ID-1_{OPK-1} ID-2_{OPK-1} ID-3_{OPK-1} OPK-2 ID-3_{OPK-2} ID-4_{OPK-2} ID-5_{OPK-2}</p>		2		4	Interview

	MODELING AND RESEARCH OF CHARACTERISTICS OF PHYSICAL FIELDS, PROCESSES OF THEIR TRANSFORMATION						
4	Electromagnetic fields. Electromagnetic induction. Eddy electric field, displacement current. Maxwell's equations and their physical meaning. Modeling and research of electromagnetic waves. Practical work #4 MODELING AND RESEARCH PROPERTIES AND CHARACTERISTICS OF WAVE PROCESSES	OPK-1 ID-1 _{OPK-1} ID-2 _{OPK-1} ID-3 _{OPK-1} OPK-2 ID-3 _{OPK-2} ID-4 _{OPK-2} ID-5 _{OPK-2}		2		4	Double interview
5	Wave processes. General characteristics of waves. Wave frequency distribution. Harmonic waves and their parameters. The equation of a plane traveling wave. The wave equation. Wave phenomena. Modeling and study of properties and characteristics of wave processes. Practical work #5 MODELING AND RESEARCH OF ELECTRIC FIELDS	OPK-1 ID-1 _{OPK-1} ID-2 _{OPK-1} ID-3 _{OPK-1} OPK-2 ID-3 _{OPK-2} ID-4 _{OPK-2} ID-5 _{OPK-2}		2		4	Double interview
46	Electromagnetic waves. The concept of an electromagnetic wave, its characteristics and properties. Fields of elementary electromagnetic emitters. Near and far zones. Energy transfer by electromagnetic waves. Propagation of radio waves. Registration of electromagnetic waves. Interference of electromagnetic waves. Diffraction of electromagnetic waves. Fresnel zones. Dispersion of electromagnetic waves. Modeling and study of fields of elementary electromagnetic emitters. Modeling and research of the process of registration of electromagnetic fields (waves). Practical work #6 MODELING AND RESEARCH OF MAGNETIC FIELDS AND PHENOMENA OF ELECTROMAGNETIC INDUCTION	OPK-1 ID-1 _{OPK-1} ID-2 _{OPK-1} ID-3 _{OPK-1} OPK-2 ID-3 _{OPK-2} ID-4 _{OPK-2} ID-5 _{OPK-2}		2		4	Interview
7	Physical processes in linear electrical circuits of the first and	OPK-1 ID-1 _{OPK-1}		2		4	Interview

	second order. Concepts of electrical circuits and electronic equipment. Equivalent circuits for physical processes in electrical circuits. Features of alternating current electrical circuits. Electromagnetic processes in first-order circuits. Voltage resonance in a series circuit. Current resonance in a parallel circuit. Modeling and research of alternating current electric circuits. Modeling and research of resonance phenomenon in electrical circuits. Practical work #7 MODELING AND RESEARCH OF ELECTROMAGNETIC WAVES	ID-2 <small>OPK-1</small> ID-3 <small>OPK-1</small> OPK-2 ID-3 <small>OPK-2</small> ID-4 <small>OPK-2</small> ID-5 <small>OPK-2</small>					
8	Transient processes in linear electrical circuits. General information about transient processes in electrical circuits. Analysis of transient processes in RL circuits. Analysis of transient processes in RC circuits. Analysis of transient processes in an oscillatory circuit. Modeling and research of transient processes in first and second order electrical circuits. Practical work #8 MODELING AND RESEARCH OF THE PROCESS OF SHIELDING ELECTROMAGNETIC FIELDS	OPK-1 ID-1 <small>OPK-1</small> ID-2 <small>OPK-1</small> ID-3 <small>OPK-1</small> OPK-2 ID-3 <small>OPK-2</small> ID-4 <small>OPK-2</small> ID-5 <small>OPK-2</small>		2		4	Double interview
9	Physical processes in distributed circuits (long lines). Basic concepts of long-line theory. Differential (telegraph) equations of a long line. Physical meaning of solutions of telegraph equations. Wave processes in a line with distributed parameters. Long lines as oscillatory systems. Modeling and research of the process of current propagation through electrical circuits with distributed parameters. Practical work #9 MODELING AND RESEARCH OF AC ELECTRIC CIRCUITS	OPK-1 ID-1 <small>OPK-1</small> ID-2 <small>OPK-1</small> ID-3 <small>OPK-1</small> OPK-2 ID-3 <small>OPK-2</small> ID-4 <small>OPK-2</small> ID-5 <small>OPK-2</small>		2		4	Double interview
10	Physical foundations of functional processes in radio-electronic means of the physical level. Fundamentals of electromagnetic oscillation generation. Free oscillations in an ideal oscillatory	OPK-1 ID-1 <small>OPK-1</small> ID-2 <small>OPK-1</small> ID-3 <small>OPK-1</small> OPK-2 ID-3 <small>OPK-2</small>		2		4	Double interview

	<p>circuit. Conservation of energy in harmonic oscillations. Damping of free oscillations in a real oscillatory circuit. Forced oscillations in an oscillatory circuit. Self-oscillating system. Conditions for generating sinusoidal self-oscillations. Generation of electromagnetic waves. Fundamentals of modulation. Time and frequency representation of signals. Fundamentals of amplitude modulation. Fundamentals of frequency modulation. Fundamentals of demodulation. Modeling and research of processes of generation of electrical oscillations, modulation and demodulation.</p> <p>Practical work #10 MODELING AND RESEARCH OF THE RESONANCE PHENOMENON IN ELECTRIC CIRCUITS</p>	<p>ID-4 OPK-2 ID-5 OPK-2</p>					
11	<p>Physical principles of electromagnetic compatibility of radio-electronic equipment. Basic concepts of electromagnetic compatibility. Parasitic coupling in electrical circuits of electronic equipment and the causes of its occurrence. Parasitic capacitive coupling. Parasitic inductive coupling. Parasitic galvanic coupling. Grounding. Fundamentals of shielding electromagnetic fields. Shielding of electric fields. Shielding of magnetic fields. Electromagnetic shielding. Fundamentals of selection. Frequency filtering (selection). Fundamentals of spatial selection. Modeling and research of interference arising from external parasitic connections. Modeling and research of the process of shielding electromagnetic fields.</p> <p>Practical work #11 MODELING AND RESEARCH OF INFLUENCE, ARISING DUE TO EXTERNAL PARASITIC CONNECTIONS</p>	<p>OPK-1 ID-1 OPK-1 ID-2 OPK-1 ID-3 OPK-1 OPK-2 ID-3 OPK-2 ID-4 OPK-2 ID-5 OPK-2</p>		2		4	Double interview
12	<p>Physical principles of fiber-optic communication. General information about fiber-optic transmission systems. Structure, types, and operating principles of optical fiber. The effect of intermode</p>	<p>OPK-1 ID-1 OPK-1 ID-2 OPK-1 ID-3 OPK-1 OPK-2 ID-3 OPK-2</p>		2		4	Interview

	dispersion on signal propagation. Chromatic dispersion. Attenuation in optical fiber.	ID-4 <small>OPK-2</small> ID-5 <small>OPK-2</small>					
	Practical work #12 MODELING AND RESEARCH OF TRANSIENTS PROCESSES IN ELECTRIC CIRCUITS OF THE FIRST AND SECOND ORDER						
	TOTAL for 3rd semester			24.00		48.00	
	Exam					36.00	
	TOTAL			24.00		84.00	

1. GENERAL CHARACTERISTIC INDEPENDENT WORKS

All types of independent work on the subject "Physical Foundations of Telecommunications" are given in table "Technological map of independent work". IN the basis for independent work of students The discipline requires taking notes from lectures and recommended sources, preparing for computer-based knowledge testing, preparing and defending reports on practical work, and completing individual assignments at various levels during practical work. Each type of independent work is provided with certain forms reporting, which students present teacher during practical classes or during individual consultation hours.

Table 1 - Technological map independent work.

Code of the assessed competencies , indicators	Formation stage competencies (Topic number) <i>(in accordance with the work program disciplines)</i>	tools and technologies	Type of control, certification <i>(current /interim)</i>	Type control <i>(oral, written or With using technical means)</i>	Name evaluation tool
3rd semester					
OPK -1 ID-1 OPK- 1 ID-2 OPK- 1 ID-3 OPK- 1 OPK- 2 ID-3 OPK- 2 ID-4 OPK- 2 ID-5 OPK- 2	Topics No. 1–17	Interview, grade answers By questions for data those	current	oral	questions For sobe-sedan
OPK -1 ID-1 OPK- 1 ID-2 OPK- 1 ID-3 OPK- 1 OPK- 2 ID-3 OPK- 2 ID-4 OPK- 2 ID-5 OPK- 2	Topics No. 1–17	Testing With help computer those-stovs tasks	current	with the use of niy technical-skih funds	computer-nye test tasks
OPK -1 ID-1 OPK- 1 ID-2 OPK- 1 ID-3 OPK- 1 OPK- 2 ID-3 OPK- 2 ID-4 OPK- 2 ID-5 OPK- 2	Topics No. 1–17	Passable task-nie (control-naya dot), You-completion individual (group) for-Danium from Lab-ratornykh works	current	writing	Set multi-level-out tasks
OPK -1 ID-1 OPK- 1 ID-2 OPK- 1 ID-3 OPK- 1 OPK- 2 ID-3 OPK- 2 ID-4 OPK- 2 ID-5 OPK- 2	Topics No. 1–17	Grade knowledge examination-nykh questions	intermediate	oral	Questions To ex-replacement

To successfully master the discipline, it is necessary to complete the types of independent

work indicated in Table 1, using the recommended sources of information.

Main literature:

1. Sagdeev K.M., Goncharov D.G. Physical basics telecommunications: Textbook / K. M. Sagdeev, D. G. Goncharov. – Stavropol: North Caucasus Federal University, 2022. - 442 p. - The book is in the basic version of the IPRbooks electronic library system.

2. Goldstein A.E. Physical Foundations of Obtaining Information Electronic resource: Textbook / A.E. Goldstein. - Tomsk: Tomsk Polytechnic University, 2010. - 292 p. - The book is in the premium version of the IPR BOOKS electronic library system. - ISBN 978-5-98298-650-4.

3. Evstifeev V.V. Physical foundations electricity and magnetism Electronic resource / Evstifeev IN. IN.: educational allowance. - Penza: PGU, 2019. - 416 pp.

Additional literature:

1. Sagdeev K.M. Physical basics protection information Electronic resource: textbook / A.F. Chipiga / V.I. Petrenko / K.M. Sagdeev. - Stavropol: North Caucasus Federal University, 2015. - 394 p. - The book is in the basic version of the IPRbooks electronic library system.

2. Physical principles of recording and storing information: teaching aid / compiled by V.I. Drozdova, G.V. Shagrova, M.G. Romanenko; North-Caucasian Federal University. - Stavropol: SKFU, 2014. - 84 p.

3. Feynman R. Feynman lectures on physics / R. Feynman, R. Leighton, M. Sands; under ed. I S. Smorodinskogo, Issue. 5, Electricity and magnetism. - M.: URSS, 2013. - 300 p. : ill. - ISBN 978-5-397-04029-7. - ISBN 978-5-453-00051-7.

4. Feynman R. Feynman's lectures By physics / R. Feynman, R. Leighton, M. Sands; ed. Y.A. Smorodinsky, Issue 3, Radiation. Waves. Quanta. - 9th ed. - M.: URSS, 2014. - 240 pp.: ill. - Bibliography sublinearly approx. - ISBN 978-5-453-00059-3. - ISBN 978-5-397-04361-8.

5. Feynman R. The Feynman lectures by physics / R. Feynman, R. Leighton, M. Sands; under ed. Y.A. Smorodinskogo, Issue. 6, Electrodynamics. - 7th ed. - M.: USSR, 2014. - 347 p.: take. - Bibliogr. in the subscript. approx. - ISBN 978-5-453-00058-6. - ISBN 978-5-397-04359-5.

A system for assessing knowledge, skills, and abilities that characterize stages formation of competencies

Within the framework of the rating system established at the university, students' academic performance in a discipline is assessed during ongoing monitoring and midterm assessment.

Current monitoring is carried out at each lesson, as well as during established control points (CP), the time of which and the types of reports on them are given in Table 2.

Examination preparedness for practical work is carried out in shape interviews at the beginning of each practical work.

Table 2.

C T No.	View reporting activities students	Deadlines execution	Number of points
1.	Protection reports By lab. works No. 1–4, V during which the implementation is checked multi-level individual tasks.	Practical Job 9 6 week of the semester	10
2.	Protection reports By lab. works No. 5–7, V during which the completion of individual tasks at different levels is checked. Execution 1st computer testing.	Practical Job 15 Week 10 of the semester	15

3.	Protection reports By lab. works No. 8–12, V during which the implementation is checked multi-level individual tasks. Interview And examination notes lectures based on the results of independent study of literature.	Practical Job 21 Week 15 of the semester	15
C T No.	View reporting activities students	Deadlines execution	Number of points
4.	Protection reports By lab. works No. 13–16, V during which the implementation is checked multi-level individual tasks. Execution 2nd computer testing.	Practical Job 26 Week 17 of the semester	15
	Total		55

Maximum possible score for all current control is being installed equal to **55**. The current test is considered passed if the student received at least 60% from established For this control maximum points. Rating score, you- put on display student for current control event, handed over student V the deadlines established by the schedule of control activities are determined as follows:

<i>Level execution control tasks</i>	<i>Rating score (V % from maximum score for the test task)</i>
<i>Great</i>	<i>100</i>
<i>Good</i>	<i>80</i>
<i>Satisfactory</i>	<i>60</i>
<i>Unsatisfactory</i>	<i>0</i>

The midterm assessment in the form of an exam provides for mandatory examination procedures And is being assessed 40 points out of 100. IN case If rating score student By discipline By results semesters equal 60, That program 32 bonus points are automatically added and the rating is “excellent”.

Positive answer student on exam is being assessed rating points V range from **20** to **40** ($20 \leq \text{Seq} \leq 40$), a score of **less than 20** points is considered unsatisfactory .

Scale conformity rating points exam By 5-point system:

Rating score by discipline	Grade By 5-point system
35 – 40	Great
28 – 34	Fine
20 – 27	Satisfactorily

Final grade By discipline, studied V one semester, is determined By the sum of the points scored for work during the semester and the points received upon passing the exam:

Scale for converting the rating score for a discipline into a grade on a 5-point system :

<i>Rating score By discipline</i>	<i>Grade By 5-point system</i>
<i>88- 100</i>	<i>Great</i>
<i>72- 87</i>	<i>Fine</i>
<i>53- 71</i>	<i>Satisfactorily</i>
<i><53</i>	<i>Unsatisfactory</i>

2. METHODOLOGICAL RECOMMENDATIONS BY STUDY OF THEORETICAL MATERIAL

At independent studying those lectures classes And given Students are recommended to read the following literature:

— on the day of the class, work through the educational material covered in the class notes. At this necessary highlight questions, on which follows turn More attention during further study of the current topic. After working through the educational material, you must answer the recommended control questions;

— With purpose high-quality fastening studied material V subsequently The course material should be studied in more detail using the recommended literature. Students are advised to highlight questions that require more detailed study with the help of the teacher;

— On the eve of the lecture, the student is advised to review previously studied theoretical material and prepare questions that require clarification from the teacher.

Recommendations By organizations work With literature

To master, consolidate and systematize knowledge, students are recommended to study independently. Job With recommended literature And notes lectures. At When working independently with recommended literature, students are advised to take notes on the educational material presented in the recommended sources.

Note-taking of sources is carried out during a detailed study of the topic, and students are advised to:

— Supplement the lecture notes by expanding them on the most important issues discussed in the lesson. Taking notes on sources involves supplementing the notes with the following provisions:

- main definitions And their physical meaning;
- main mathematical relationships with revealing them physical meaning;
- conclusions By educational questions, studied topics classes.

Control this species independent work is being carried out on educational classes by checking the lecture notes and interviewing the teacher.

At note-taking sources students should proceed from rational volume of the material being summarized. The summary should be brief and understandable when used after studying the current topic.

When taking notes from sources, it is recommended to highlight individual drawings, their most important fragments, and the most important formulas in color. When taking notes in class, it is recommended to fill two-thirds of the notebook page vertically, and use the remaining space to supplement the notes on the topic being studied.

To successfully master the course, you must independently and thoroughly study the presented topics using the recommended sources of information.

Source summaries are graded as satisfactory or unsatisfactory. Source summaries are graded as satisfactory if:

— the notes contain a sufficient amount of detail on the topic being studied, ensuring the specified level of mastery of the theoretical material of the discipline;

— abstract decorated carefully, studied material outlined sequentially V in accordance With in order study of the discipline, contains generalizing conclusions By each topic.

The work on summarizing sources is assessed as unsatisfactory if the requirements for a satisfactory assessment are not met.

3. METHODOLOGICAL INSTRUCTIONS BY IMPLEMENTATION PRACTICAL WORK

When completing practical training in a discipline (practical work), in order to achieve a basic level of competence development, the student must be able to apply basic knowledge By sections disciplines, own skills independent solutions educational basic level tasks.

When completing practical training in a discipline (practical work), in order to achieve an advanced level of competence development, the student must be able to apply advanced knowledge in the sections of the discipline and possess the skills to independently solve advanced level learning problems.

Methodological instructions at preparation To practical work

Preparation To practical work recommended conduct V next sequences :

- to understand topic And target, upcoming practical work;
- study theoretical material V in accordance With theme practical work (it is recommended to use the recommended literature, lecture notes, textbook (workshop on practical work);
- familiarize yourself with the equipment and materials used in practical work (when using specialized equipment or software, it is necessary to study the procedure and rules for its use).

Methodological instructions at execution practical work

When performing practical work, students must strictly adhere to established safety requirements.

At execution practical work students recommended:

- to understand target, performed tasks And methods their decisions;
- tasks, specified V practical work fulfill V that one sequences, in which they are indicated in the practical training;
- when completing practical assignments and studying theoretical material, use the help of a teacher;
- design report By practical work;
- answer on control questions.

Methodological instructions at preparation To protection practical work

At preparation To protection practical work Students are advised to:

- prepare report By practical work;
- prepare justification, made conclusions;
- to consolidate knowledge of theoretical material on the topic of practical work (it is recommended to use test questions);
- know order conducting calculations (of the research being conducted);
- be able to show and explain the procedure for conducting research using specialized equipment or software.

The defense of the practical work is carried out through an interview between the student and the teacher. During the interview, the student submits a report on the practical work for review. Interview with student, claiming on assessment "Great" is being carried out By questions and practical assignments of the advanced level of study. An interview with a student who is not aiming for an "excellent" grade is conducted on questions and practical assignments of the basic level of study.

4. QUESTIONS FOR INTERVIEWS BY INDEPENDENT STUDY OF LITERATURE

Base level:

Topic 1. Information and telecommunications infrastructure How complex physical system.

1) Physical level infocommunication systems And basics process transmission of information.

2) Physical basis of interaction infocommunication systems And external physical fields.

Topic 2. Physical fields and transmission media .

3) Characteristic physical fields How carriers information. Topic 3.

Elements of field theory.

4) Introduction V theory physical fields.

5) Characteristics physical fields: flow.

6) Characteristics physical fields: Divergence. Topic 4.

Wave processes.

7) General characteristic waves. Distribution waves by frequency.

8) Harmonic waves, their parameters.

Topic 5. Electric fields.

9) Basics electrical interaction.

10) Types electrical fields, their comparative characteristics. Topic 6.

Magnetic fields and magnetic storage media.

11) Basics magnetic interaction.

12) Magnetic field, its characteristics.

13) Magnetic carriers information.

Topic 7. Phenomenon electromagnetic induction, electromagnetic fields And waves.

14) Electromagnetic induction.

15) Vortex electric field, current displacements.

Topic 8. Radiation, spreading And registration electromagnetic fields (waves).

16) Fields elementary electromagnetic emitters. Nearby And distant zones. Topic 9.

Shielding of electromagnetic fields.

17) Basics field screening .

18) Shielding of electric fields.

19) Shielding magnetic fields.

Topic 10. Physical processes V protozoa electrical chains radio-electronic means.

20) Concepts electrical chains And radio-electronic funds.

21) Schemes substitutions physical processes V electrical chains.

22) Peculiarities electrical chains variable current.

Topic 11. Physical processes V oscillatory contours. The phenomenon of resonance.

23) Resonance stresses V sequential contour.

Topic 12. Parasitic processes V electrical circuits radio-electronic means.

24) Reasons the emergence of parasitic connections.

25) Parasitic capacitance connection.

26) Parasitic inductive coupling.

Topic 13. Transient processes V linear electrical circuits.

27) General information about transient processes.

28) Analysis transient processes V RL chains.

29) Analysis transient processes RC circuits.

Topic 14. Physical processes V distributed chains.

30) Main concepts theories long lines. Differential (telegraph) equations of a long line.

31) The physical meaning of solutions of telegraph equations.

Topic 15. Basics generation electromagnetic fluctuations.

32) Free fluctuations V ideal oscillatory circuit.

33) Preservation energy at harmonic oscillations.

34) Attenuation free fluctuations V real oscillatory circuit.

35) Forced fluctuations V oscillatory contour. Topic 16.

Modulation and demodulation processes.

36) Basics modulations. Temporary And frequency signal representation .

37) Amplitude modulated fluctuations.

38) Basics demodulation.

Topic 17. Frequency And spatial selection.

39) Types selection signals.

40) Frequency selection.

Increased level:

Topic 1. Information and telecommunications infrastructure How complex physical system.

41) Performance information on physical level. Topic 2.

Physical fields and transmission media.

42) media .

Topic 3. Elements field theory .

43) Characteristics physical fields: circulation, rotor.

44) Characteristics physical fields: gradient. Topic

4. Wave processes.

45) Equation flat running waves. Wave equation.

46) Wave phenomena.

Topic 5. Electric fields.

47) Electrostatic field, his characteristics and properties.

48) Action electric fields on substances. Electric field V conductor. Topic 6. Magnetic fields and magnetic storage media.

49) Manifestation magnetic fields. Forces Ampere And Lorenz.

50) Properties magnetic fields.

Topic 7. Phenomenon electromagnetic induction, electromagnetic fields And waves.

51) Equations Maxwell, their physical meaning.

52) Concept electromagnetic waves, her characteristics And properties.

Topic 8. Radiation, spreading And registration electromagnetic fields (waves).

53) Transfer energy electromagnetic waves. Spreading radio waves.

54) Registration electromagnetic fields.

Topic 9. Shielding fields electromagnetic nature.

55) Electromagnetic shielding.

Topic 10. Physical processes in the simplest electrical circuits of electronic equipment.

56) Electromagnetic processes V chains ideal inductance And V chains ideal capacity.

Topic 11. Physical processes V oscillatory contours. The phenomenon of resonance.

57) Resonance currents V parallel contour.

Topic 12. Parasitic processes V electrical circuits radio-electronic means.

58) Parasitic galvanic connection.

Topic 13. Transient processes V linear electrical circuits.

59) Analysis transitional processes V oscillatory contour. Topic

14. Physical processes in distributed circuits.

60) Wave processes V lines With distributed parameters.

61) Long lines V quality oscillatory systems.

Topic 15. Basics generation electromagnetic oscillations.

62) Devices generation sinusoidal fluctuations.

63) Generation electromagnetic waves.

Topic 16. Modulation processes And demodulation.

64) Frequency modulated fluctuations.

Topic 17. Frequency And spatial selection.

65) Basics h spatial selection.

Criteria assessments competencies:

Grade "Great" is exhibited to a student, If student gave full, expanded answer to delivered question, at this shown totality conscious knowledge By topic disciplines, evidentially revealed main provisions question; V answer can be traced A clear structure and logical sequence reflecting the essence of the concepts being explored. The answer is presented in literary language using technical terminology. There may be admitted shortcomings V definition concepts, corrected student on one's own in the process of answering. The situational task on the topic was solved correctly.

Grade "Fine" is exhibited to a student, If student gave full, expanded answer to the question posed, demonstrating the ability to identify essential and non-essential features, cause-and-effect relationships. Answer clearly structured, logical, presented in literary language using technical terminology. 2-3 may be allowed inaccuracies or insignificant mistakes, corrected student With help teacher. Situational task the topic has been resolved that's right, but with her the decision was made no more than one error.

A "satisfactory" grade is given to a student if the answer is insufficiently complete or detailed. The logic and consistency of presentation are flawed. Errors were made in the clarification of concepts and the use of terms. The student is unable to independently identify essential and nonessential features and cause-and-effect relationships. The answer lacks conclusions. Ability to reveal the significance of generalized knowledge Not shown. Speech design requires amendments, corrections. Situational The problem on the topic was solved correctly, but no more than two mistakes were made in solving it.

Grade unsatisfactory is exhibited to a student, If answer represents The knowledge is fragmented and contains significant errors on the issue. The presentation is fragmentary and illogical. The student does not understand the connection between the issue under discussion and other issues. topics. None conclusions, specification And evidentiality presentation. Speech illiterate, terminology Not is used. Additional And clarifying questions The teacher's comments do not lead to the student's answer being corrected, or the answer to the question is completely missing, or the student refuses to answer. The situational problem on the topic is solved incorrectly.

Description of the rating scale

Grade for answers on questions V in the course interviews is determined V in accordance With tab-

lyceum.

Grade	Assessment for theoretical question base-vogo level	Grade for theoretical question of increase shennogo level	Note
Great	Great (Fine)	Great	Grade Fine only allowed By basic level question
Fine	Good (satisfactory)	Fine	Grade satisfactory acceptable only By in-I'll ask basic level
satisfactorily	Satisfactorily	Satisfactorily	
unsatisfactory	By alone or two questions received an unsatisfactory grade		

According to rating systems current control event counts handed over if student received for him Not less 60% from established For this control maximum points. Rating score, exhibited student for current control event handed over student V established schedule control events deadlines, is defined as follows:

Level execution control tasks	Rating score (V % from maximum points for the test task)
Great	100
Good	80
Satisfactory	60
Unsatisfactory	0

Methodological materials defining the procedures for assessing knowledge, skills, and abilities and (or) experience of activities characterizing the stages of formation of competencies

The procedure for conducting this assessment event includes an interview By two theoretical questions from numbers listed. One question refers to To basic level, and the second one – to the advanced level. During the interview, the student has the right to use his own notes.

Suggested student questions allow check general professional competencies OPK-1, OPK-2. The fundamental differences between the tasks of the basic level and the advanced level lie in the complexity of the questions at the “understanding” level of training.

Preparation for this assessment requires 9 hours per semester (*approximately 0.5 hours per topic*). The student must prepare written answers to the theoretical questions listed. V in the form of a summary educational material and on their basis to prepare To specified V methodological materials questions For discussions.

When assessing the assignment, the following are assessed: active participation in the work; confident mastery of the material; the ability to clearly and logically express one's thoughts; the ability to creatively approach the main issues of the topic; independent thinking, full compliance of the notes with the established requirements; independent oral speech that fully reveals the essence of the interview issues.

Evaluative sheet

Item No.	Last name, first name of the student.	Type of work						Result
		Working with additional sources of information	Answers to the pro-intermediate questions	Logic and scientific presentation	Formulating conclusions and evidence	Presentation of the results of the work	Participation in discussion, skill conduct a dialogue	
1								
2								
...								

5. COMPUTER TESTS FOR SELF-TESTING, TEST PREPARATION

The test tasks are designed as two tests in the Iren program, each with 100 tasks. 200 test tasks different level: on choice answer; on input answer; on compliance; for classification.

Examples test tasks basic level: a) test task to choose the answer:

Градиент – это

- ☐ вектор по величине (модулю) равный скорости роста некоторой физической величины поля в направлении указанном вектором
- ☐ вектор, своим направлением указывающий направление наискорейшего возрастания некоторой физической величины поля
- ☐ скаляр, своим направлением указывающий направление наискорейшего изменения некоторой физической величины поля
- ☐ вектор, длина и направление которого в каждой точке пространства, характеризует направление вращения некоторой физической величины поля
- ☐ скаляр по величине (модулю) равный скорости изменения некоторой физической величины поля в направлении указанном скаляром

Скорость распространения гармонической волны в среде равна

- ☐ произведению длины волны и частоты колебания
- ☐ отношению длины волны к частоте колебания
- ☐ отношению периода колебания к длине волны
- ☐ произведению длины волны и периода колебания

b) test task on simple match:

Установить соответствие между уравнением и его видом

Уравнение колебания частицы		$\phi = \omega \cdot \left(t - \frac{x}{V} \right)$
Уравнение фазы волны		$y(t) = y_0 \cdot \sin(\omega \cdot t)$
Общее уравнение волнового движения		$y(x, t) = y_0 \cdot \sin \left(\omega \cdot t \pm \frac{2\pi \cdot x}{\lambda} \right)$
Уравнение плоской обратной бегущей волны		$y(x, t) = y_0 \cdot \sin(\omega \cdot t + k \cdot x)$
Уравнение сферической прямой бегущей волны		$y(r, t) = \frac{y_0}{r} \cdot \sin(\omega \cdot t - k \cdot r)$

V) test task on input simple answer:

Электрическое поле проявляется в том, что на любой заряд, помещенный в любую точку этого поля, будет действовать ###

Ответ:

Examples test tasks increased level: a) test task for complex matching:

Установить соответствие уравнением Максвелла и его математическим выражением

первое уравнение Максвелла	$\operatorname{rot} \vec{H} = \vec{j} + \frac{\partial \vec{D}}{\partial t}$
второе уравнение Максвелла	$\oint_L \vec{E} d\vec{l} = - \int_S \frac{\partial \vec{B}}{\partial t} d\vec{S}$
третье уравнение Максвелла	$\operatorname{div} \vec{D} = \rho$
четвертое уравнение Максвелла	$\oint_S \vec{B} d\vec{S} = 0$
	$\vec{D} = \epsilon_0 \epsilon \vec{E}$

b) test task on input answer with calculation answer:

Электромагнитный экран обеспечивает десятикратное отражение и стократное поглощение электромагнитной волны. В этом случае полное экранирование в децибельном исчислении равно ### дБ

Ответ:

V) test exercise on classification (correspondence):

Провести классификацию формул и формулировок потоков вектора напряженности электрического поля

Поток вектора напряженности электрического поля через малую площадку	$\Phi_E = \int_S (\vec{E} \cdot d\vec{n}) dS$
Поток вектора напряженности электрического поля через произвольную поверхность	скалярное произведение векторов напряженности $\vec{E}$ поля и нормали $\vec{n}$ к поверхности dS, умноженное на площадь поверхности dS
Поток вектора напряженности однородного электрического поля через плоскую поверхность	$\Phi_E = E_n \cdot S$
	алгебраическая сумма электрических зарядов, охватываемых этой поверхностью, деленной на электрическую постоянную
	произведение проекции вектора напряженности поля на нормаль к поверхности и площади поверхности
Полный поток вектора напряженности электрического поля через замкнутую объемную поверхность произвольной формы в вакууме	$d\Phi_E = E \cdot dS \cdot \cos \alpha$
	$\Phi_E = \oint_S E_n dS = \frac{1}{\epsilon_0} \cdot \sum_i q_i$
	интеграл по всей поверхности от скалярного произведения векторов напряженности $\vec{E}$ поля и нормали $\vec{n}$ к этой поверхности

Установить верную последовательность вывода волнового уравнения

1		Определить частную производную колебания частицы по расстоянию
2		Составить линейное дифференциальное уравнение второго порядка в частных производных
3		Определить вторую частную производную колебания частицы по расстоянию
4		Определить вторую частную производную колебания частицы по времени
5		Оценить размерности вторых производных и определить величину, на которую они различаются
6		Определить частную производную колебания частицы по времени

Description rating scales computer testing

One basic-level test assignment is worth 1 point, and one advanced-level test assignment is worth 2 points. The Iren program randomly selects the number of test assignments specified by the teacher (usually 15-20 assignments).

General quantity points for the test is determined according to the formula:

$$TO = \frac{m_b + 2 \cdot m_p}{n_b + 2 \cdot n_p} \cdot 100\% \text{ at this } n_b + n_p = N$$

where m_b – the number of correct answers to basic level test tasks, m_p - quantity correct answers on test tasks increased level, n_b – quantity given test tasks basic level, n_p - quantity given test tasks advanced level, N is the total number of test tasks.

The current test is considered passed if the student received no. less 53 % from established For this control maximum points. Rating the score awarded to a student for the current test, submitted by the student within the timeframe established by the schedule of test activities, is determined as follows:

Level execution control tasks	Rating score (V % from maximum points for the test task)
Great	Not less 88
Good	from 72 up to 87
Satisfactory	from 53 to 71
Unsatisfactory	less 53

Methodological materials, defining procedures assessments knowledge, skills, abilities and (or) experience of activities characterizing the stages of formation of competencies Procedure conducting this evaluative events includes V myself computer testing With help test programs "Iren".

This program By random law you- chooses from general list tasks, indicated teacher number tasks By each topic disciplines . As a rule one test contains 15-20 test tasks. To answer for one task provided 1 - 2 minutes.

TO test questions basic level relate questions With choice answer, questions With input answer And simple questions on establishment compliance. TO test questions advanced level includes complex questions on establishing correspondence, tasks with calculation and input answer, questions on classification And ordering actions (operations).

The questions offered to the student allow testing the general professional competencies OPK-1, OPK-2.

For preparation To given evaluative event necessary 9 hours V semester (4.5

hours on each test).

The student must prepare for computer testing by mastering the tests and conducting self-testing. Self-testing is produced With help exe files With training test tasks, issued students V beginning semesters training.

Evaluative sheet

No. p/p	Surname, student's name .	Quantity test tasks	Number of correct answers	Typed points	Total grade
1					
2					
...					

6. SET MULTI-LEVEL TASKS FOR COMPUTER MODELING USING GRAPHIC EDITORS

Base level

Practical Job 1. Modeling And study simple analog And digital signals.

- 1) Simulate V program Mathcad harmonic signal And conduct study of its characteristics.
- 2) Conduct a study in the Mathcad program of the operations of transforming a harmonic signal, which have the nature of differentiation and integration.
- 3) Simulate a sequence of rectangular pulses from harmonic components in the Mathcad program.
- 4) Simulate V program Electronics Workbench» And conduct study sequences rectangular impulses, formed from harmonic components .
- 5) Conduct V program Electronics Workbench» modeling And study an encoding device that converts data into digital NRZ code for transmission over a communication channel.

Practical work 2. Modeling and research of the process of propagation of simple signals in a physical environment.

- 6) Conduct a study in the Mathcad program of the process of propagation of simple signals through a physical environment modeled as an integrating RC circuit.
- 7) Conduct a study in the Mathcad program of the process of propagation of simple signals through a physical environment modeled as an integrating RL circuit.

Practical Job 3. Modeling And study characteristics physical fields, processes of their transformation.

- 8) To model and investigate in the Mathcad system a static physical field formed by a system of independent sources in scalar form.
- 9) To model and explore in the Mathcad system a static physical field formed by a system of independent sources in vector form.
- 10) Model a scalar physical field in the Mathcad system and transform it into a gradient vector field.

Practical work 4. Modeling and research of properties and characteristics of wave processes.

- 11) Simulate a harmonic wave in the Electronics Workbench and MathCAD programs and measure its characteristics.
- 12) To simulate a damped harmonic wave process in the Electronics Workbench and MathCAD programs and to investigate its characteristics.
- 13) Simulate And research V programs Electronics Workbench» And "MathCAD" phenomenon of interference of two waves.
- 14) Simulate V program Electronics Workbench» wave plastic bag And determine its characteristics.

Practical Job 5. Modeling And study electrical fields.

- 15) Simulate And research V system Mathcad non-relativistic movement charged particles in the electric field of a flat capacitor.
- 16) Simulate And research V system Mathcad electric field from discrete set of electric charges.

Practical Job 6. Modeling And study magnetic fields And And phenomena of electromagnetic induction.

- 17) Simulate And research V system Mathcad non-relativistic movement charged particles in a magnetic field.
- 18) Simulate And research V system Mathcad magnetic field from discrete set of direct electric currents.

Practical Work 7. Modeling and study of electromagnetic waves.

19) Simulate And research V system Mathcad parameters flat electromagnetic wave.

20) Simulate And research V system Mathcad spatio-temporal distribution of the intensity vectors of a plane electromagnetic wave.

Practical Job 8. Modeling And study process shielding electromagnetic fields

21) To simulate and investigate the equivalent circuit of the process of shielding a source of electromagnetic radiation.

22) Simulate And research equivalent equivalent circuit the process of electrical shielding of coaxial cable.

Practical Job 9. Modeling And study electrical chains alternating current.

23) Calculate electric current and distribution in the Mathcad system voltages in an unbranched RL circuit.

24) Calculate electric current and distribution in the Mathcad system voltages in an unbranched RC circuit.

25) Simulate and investigate an unbranched RL circuit in the Electronics Workbench program.

26) Model and investigate an unbranched RC circuit in the Electronics Workbench program.

Practical Job 10. Modeling And study phenomena resonance V electrical circuits

27) Calculate electric current and distribution in the Mathcad system voltages in a series oscillatory circuit (unbranched RLC circuit).

28) Simulate And research V program Electronics Workbench» series oscillatory circuit (unbranched RLC circuit).

Practical Job 11. Modeling And investigation of leads, emerging for due to external parasitic connections.

29) Simulate V system Mathcad external capacitive parallel parasitic coupling between two channels.

30) To simulate in the Mathcad system an external resistive parallel parasitic connection between two channels.

31) Simulate And research V program Electronics Workbench» equivalent circuit substitutions external capacitive parallel parasitic connections between two channels.

32) Simulate And research V program Electronics Workbench» equivalent circuit of external resistive parallel parasitic coupling between two channels .

Practical Job 12. Modeling And study transitional processes V electrical circuits of the first and second order.

33) Simulate transient processes in an RL circuit when a DC voltage source is turned on and off using the Electronics Workbench program.

34) Simulate transient processes in an RC circuit when a DC voltage source is turned on and off using the Electronics Workbench program.

35) Simulate And conduct research V program Electronics Workbench» transient processes in the RC circuit when connected to an AC voltage source.

36) Simulate And conduct research V program Electronics Workbench» transient processes in the RL circuit when connected to an AC voltage source.

Practical Job 13. Modeling And study process propagation of current through electrical circuits with distributed parameters.

37) To simulate a segment of a long line in the form of a fifth category twisted pair cable using elements with lumped parameters in the Electronics Workbench program and conduct its study.

38) To simulate a mathematical model of a long line in the form of a fifth category twisted pair cable in the MathCAD program and calculate its secondary parameters.

Practical work 14. Modeling and research of the principles of generation of electrical oscillations.

39) Simulate And research V program Mathcad free And fading oscillations in an oscillatory circuit.

40) Simulate And research V program Electronics Workbench» generators alternating and pulsed voltages.

Practical Job 15. Modeling And study processes modulations And demodulation .

41) Model and explore amplitude and frequency modulators in the Electronics Workbench program.

42) Simulate And research V program Electronics Workbench» principles amplitude modulation on a semiconductor diode.

43) Model and explore an amplitude manipulator in the Electronics Workbench program .

44) Simulate And research V program Electronics Workbench» frequency manipulator .

Practical Job 16. Modeling And study process frequency signal filtering.

45) Model and investigate a passive low-pass filter in the Mathcad program .

46) Simulate And research V program Mathcad passive filter high frequencies.

47) Simulate And research V program Electronics Workbench» passive low-pass filter.

48) Simulate And research V program Electronics Workbench» passive high-pass filter.

Increased level

Practical Job 1. Modeling And study simple analog And digital signals.

49) Simulate V program Mathcad multi-tone signal and conduct study of its characteristics and transformation operations.

50) Conduct a study of the amplitude-frequency and phase-frequency spectra of a sequence of rectangular pulses in the Electronics Workbench program.

Practical work 2. Modeling and research of the process of propagation of simple signals in a physical environment.

51) Conduct a study in the Electronics Workbench programs of the process of propagation of simple signals through a physical medium modeled as an integrating RC circuit.

52) Conduct a study in the Electronics Workbench programs of the process of propagation of simple signals through a physical environment modeled as an integrating RL circuit.

Practical Job 3. Modeling And study characteristics physical fields, processes of their transformation.

53) Model a vector physical field in the Mathcad system and transform it into a scalar divergence field.

54) Model a vector physical field in the Mathcad system and transform it into a rotor vector field.

Practical work 4. Modeling and research of properties and characteristics of wave processes.

55) To simulate and investigate the wave dispersion process in the Electronics Workbench program.

56) Simulate And research V program Electronics Workbench» running And standing waves in a long line.

Practical Job 5. Modeling And study electrical fields.

57) To simulate and investigate the electric field of charged thin conductors in the Mathcad system.

Practical work 6. Modeling and research of magnetic fields and electromagnetic induction phenomena.

58) To simulate and investigate in the Mathcad system an alternating magnetic field and the phenomenon of electromagnetic induction.

Practical Job 7. Modeling And study electromagnetic waves.

59) Simulate And research V system Mathcad peculiarities spatio-temporal distribution of intensity vectors of spherical and cylindrical electromagnetic waves.

Practical Job 8. Modeling And study process shielding electromagnetic fields

60) To simulate and investigate the equivalent circuit of the magnetic shielding process of a coaxial cable.

Practical Job 9. Modeling And study electrical chains alternating current.

61) Calculate V system Mathcad electric current And distribution stresses in a branched RL circuit.

62) Calculate V system Mathcad electric current And distribution stresses in a branched RC circuit.

63) Simulate And research V program Electronics Workbench» branched RL chain.

64) Simulate And research V program Electronics Workbench» branched RC circuit.

Practical Job 10. Modeling And study phenomena resonance V electrical circuits

65) Calculate V system Mathcad electric current And distribution stresses in a parallel oscillatory circuit (branched RLC circuit).

66) Simulate And research V program Electronics Workbench» parallel oscillatory circuit (branched RLC circuit).

Practical Job 11. Modeling And investigation of leads, emerging for due to external parasitic connections.

67) Simulate V system Mathcad consistent parasitic connection through parasitic mutual inductance between the two channels.

68) Simulate And research V program Electronics Workbench» equivalent circuit substitutions consistent parasitic connections through parasitic mutual inductance between two channels.

Practical Job 12. Modeling And study transitional processes V electrical circuits of the first and second order.

69) Simulate V system Mathcad transitional processes V RL circuits at switching on to a DC voltage source.

70) To simulate transient processes in an RL circuit during a short circuit of a DC voltage source in the Mathcad system.

71) Simulate V system Mathcad transitional processes V RC circuits at switching on to a DC voltage source.

72) To simulate in the Mathcad system transient processes in an RC circuit during a short circuit of a DC voltage source.

73) To simulate and investigate in the Electronics Workbench program the aperiodic process in the RCL circuit when connected to a DC voltage source.

74) To simulate and investigate in the Electronics Workbench program the oscillatory process in the RCL circuit when connected to a DC voltage source.

Practical Job 13. Modeling And study process propagation of current through electrical circuits with distributed parameters.

75) Simulate V program Electronics Workbench» given homogeneous long communication line and conduct its study in various modes.

Practical work 14. Modeling and research of the principles of generation of electrical oscillations.

76) To simulate and investigate forced oscillations in a generator using the Mathcad program .

Practical Job 15. Modeling And study processes modulations And demodulation .

77) Simulate And research Electronics Workbench» amplitude detector.

78) Simulate And research V program Mathcad frequency detector.

Practical Job 16. Modeling And study process frequency signal filtering.

79) Simulate And research Electronics Workbench» passive band-pass filter.

80) Simulate And research Electronics Workbench» passive band-stop filter.

Criteria assessments:

Criteria assessments competencies:

An “excellent” grade is awarded if the student has demonstrated a high level of skill in applying received knowledge on practice through execution specific tasks advanced level, coped with the assigned task freely and without difficulty, demonstrating mastery of various techniques and skills for its implementation, and did not make any mistakes or inaccuracies.

A grade of “good” is given if the student has demonstrated the ability to apply the acquired knowledge in practice by solving a specific advanced level task and has completed it With delivered task, showing ownership necessary techniques And skills its implementation, at this allowed Not more one mistakes, corrected after instructions teacher .

A grade of “satisfactory” is given if the student has demonstrated mediocre skill apply received knowledge on practice through solution specific advanced level tasks, coped with the task with difficulty, while making no more than two mistakes, corrected after instructions teacher, or successfully completed setting a basic level.

The grade “unsatisfactory” is given if the student has not demonstrated the ability to apply the acquired knowledge in practice by solving a specific basic task. level, Not coped With delivered task or allowed at her execution serious mistakes.

Description scales assessments

The current test is considered passed if the student received no. less 60% from established For this control maximum points. Rating the score awarded to a student for the current test, submitted by the student within the timeframe established by the schedule of test activities, is determined as follows:

Level execution control for-Denmark	Rating score (in % from maximum score for the test task)
Great	100
Good	80
Satisfactory	60
Unsatisfactory	0

Methodological materials, defining procedures assessments knowledge, skills, abilities And (or) experience activities, characterizing stages formations competencies

Procedure conducting this evaluative events includes V myself:

- performance designed report By practical work With completed multi- level tasks;
- protection by way execution specified teacher multi-level tasks, Moreover, the level of the task being completed is determined by the student independently.

Suggested student tasks allow check general professional competencies of OPK-1, OPK-2.

For preparation To given evaluative event student is allocated V semester 9 hours in framework his independent work.

At preparation To answer student provided right use report By laboratory work.

Evaluative sheet

No. p/p	Last name, first name of the student.	Type of work						Result
		Proficiency in the methodology for completing the task	Correctness of circuit modeling	Performance models	Accuracy measurement s and correctness of calculations parameters and characteristic s teristic	Correctne ss design of diagrams, graphs of characteristics stick	Formulation conclusions, their compliance with theory	
1								
2								
...								

8. QUESTIONS TO EXAM

Questions For checks level training

Base level

- 1) Physical level infocommunication systems And basics process transmission of information.
- 2) Physical basics interactions infocommunication systems And external physical fields.
- 3) Characteristic physical fields How carriers information.
- 4) Introduction V theory physical fields.
- 5) Characteristics physical fields: stream.
- 6) Characteristics physical fields: divergence.
- 7) General characteristic waves. Distribution waves by frequency.
- 8) Harmonic waves, their parameters.
- 9) Basics electric interactions.
- 10) Types electrical fields, their comparative characteristic.
- 11) Basics magnetic interaction.
- 12) Magnetic field, its characteristics.
- 13) Magnetic carriers information.
- 14) Electromagnetic induction.
- 15) Vortex electric field, current displacements.
- 16) Fields elementary electromagnetic emitters. Nearby And far zone.
- 17) Basics field screening .
- 18) Shielding of electric fields.
- 19) Shielding magnetic fields.
- 20) Concepts electrical chains And radio-electronic funds.
- 21) Schemes substitutions physical processes V electrical chains.
- 22) Peculiarities electrical chains variable current.
- 23) Resonance stresses V sequential contour.
- 24) Reasons the emergence of parasitic connections.
- 25) Parasitic capacitance connection.
- 26) Parasitic inductive coupling.
- 27) General intelligence O transitional processes.
- 28) Analysis transient processes V RL chains.
- 29) Analysis transient processes RC circuits.
- 30) Main concepts theories long lines. Differential (telegraph) equations of a long line.
- 31) Physical meaning decisions telegraph equations.
- 32) Free fluctuations V ideal oscillatory contour. Preservation energy during harmonic oscillations.
- 33) Attenuation free fluctuations V real oscillatory circuit.
- 34) Forced fluctuations in oscillatory circuit.
- 35) Basics modulations. Temporary And frequency signal representation .
- 36) Amplitude modulated fluctuations.
- 37) Basics demodulation.

Increased level

- 38) Performance information on physical level.
- 39) media .
- 40) Characteristics physical fields: circulation, rotor.
- 41) Characteristics physical fields: gradient.
- 42) Equation flat running waves. Wave equation.
- 43) Wave phenomena.
- 44) Electrostatic field, his characteristics and properties.

- 45) Action of electric fields on substances. Electrical field V conductor.
- 46) Manifestation magnetic fields. Forces Ampere And Lorenz.
- 47) Properties magnetic fields.
- 48) Equations Maxwell, their physical meaning.
- 49) Concept electromagnetic waves, her characteristics And properties.
- 50) Transfer energy electromagnetic waves. Spreading radio waves.
- 51) Registration electromagnetic fields.
- 52) Electromagnetic shielding.
- 53) Electromagnetic processes V chains ideal inductance And V chains ideal capacity.
- 54) Resonance currents V parallel contour.
- 55) Parasitic galvanic connection.
- 56) Analysis transitional processes V oscillatory contour.
- 57) Wave processes V lines With distributed parameters.
- 58) Long lines V quality oscillatory systems.
- 59) Devices generation sinusoidal fluctuations.
- 60) Generation electromagnetic waves.
- 61) Frequency modulated fluctuations.
- 62) Basics frequency filtration (selection).

Practical tasks For checks level of training

- 1) Simulate V program Mathcad harmonic signal And conduct study of its characteristics.
- 2) Conduct a study in the Mathcad program of the operations of transforming a harmonic signal, which have the nature of differentiation and integration.
- 3) Simulate a sequence of rectangular pulses from harmonic components in the Mathcad program.
- 4) Simulate in the ElectronicsWorkbench program and conduct a sequence study rectangular impulses, formed from harmonic components .
- 5) Use the ElectronicsWorkbench program to simulate and study an encoding device that represents data in a digital NRZ code for transmission over a communication channel.
- 6) Conduct a study in the ElectronicsWorkbench programs of the process of propagation of simple signals through a physical medium modeled as an integrating RC circuit.
- 7) Conduct a study in the ElectronicsWorkbench programs of the process of propagation of simple signals through a physical environment modeled as an integrating RL circuit.
- 8) To model and investigate in the Mathcad system a static physical field formed by a system of independent sources in scalar form.
- 9) To model and explore in the Mathcad system a static physical field formed by a system of independent sources in vector form.
- 10) Model a scalar physical field in the Mathcad system and transform it into a gradient vector field.
- 11) To simulate a damped harmonic wave process in the ElectronicsWorkbench and MathCAD programs and investigate its characteristics.
- 12) Simulate And research V programs ElectronicsWorkbench And "MathCAD" phenomenon of interference of two waves.
- 13) Simulate V program ElectronicsWorkbench wave plastic bag And determine its characteristics.
- 14) Simulate And research V system Mathcad non-relativistic movement charged particles in the electric field of a flat capacitor.

- 15) Simulate And research V system Mathcad electric field from discrete set of electric charges.
- 16) Simulate And research V system Mathcad non-relativistic movement charged particles in a magnetic field.
- 17) Simulate And research V system Mathcad magnetic field from discrete set of direct electric currents.
- 18) Simulate And research V system Mathcad parameters flat electromagnetic wave.
- 19) To simulate and investigate in the Mathcad system the spatio-temporal distribution of the intensity vectors of a plane electromagnetic wave.
- 20) Simulate And research V program ElectronicsWorkbench equivalent circuit for the process of shielding a source of electromagnetic radiation.
- 21) Simulate And research V program ElectronicsWorkbench equivalent circuit diagram of the process of electrical shielding of a coaxial cable.
- 22) Simulate And research V program ElectronicsWorkbench equivalent circuit substitutions external capacitive parallel parasitic connections between two channels.
- 23) Simulate And research V program ElectronicsWorkbench equivalent circuit of external resistive parallel parasitic coupling between two channels .
- 24) Simulate And research passive filter low frequencies.
- 25) Simulate And research passive filter high frequencies.
- 26) Simulate V program Mathcad multi-tone signal And conduct study of its characteristics and transformation operations.
- 27) Conduct V program ElectronicsWorkbench study amplitude-frequency and phase-frequency spectra of a sequence of rectangular pulses.
- 28) Conduct study V programs Mathcad process distribution simple signals through a physical environment modeled as an integrating RC circuit.
- 29) Conduct a study in the Mathcad programs of the process of distribution of simple signals through physical Wednesday, simulated V view integrating RL -chains.
- 30) Simulate V system Mathcad vector physical field And transform it into a scalar divergence field.
- 31) Simulate V system Mathcad vector physical field And transform it into a rotor vector field.
- 32) Simulate And research V program ElectronicsWorkbench process wave dispersion.
- 33) Simulate And research V program ElectronicsWorkbench running And standing waves in a long line.
- 34) Simulate And research V system Mathcad electric field charged thin conductors.
- 35) Simulate And research V system Mathcad variable magnetic field and the phenomenon of electromagnetic induction.
- 36) Simulate And research V system Mathcad peculiarities spatio-temporal distribution of the intensity vectors of spherical and cylindrical electrons tromagnetic waves.
- 37) Simulate And research V program ElectronicsWorkbench equivalent circuit of the process of magnetic shielding of a coaxial cable.
- 38) Model and explore the equivalent in the ElectronicsWorkbench program diagram substitutions consistent parasitic connections through parasitic mutual inductance between two channels.
- 39) Simulate And research passive striped permeable filter.
- 40) Simulate And research passive striped barrage filter.

Criteria assessments competencies
(*V in accordance With results development disciplines*)

Criteria assessments For checks level theoretical training :

An “excellent” grade is given to a student if he has demonstrated a deep, solid and reasoned mastery of the program educational material, while the question posed is disclosed consistently, clearly and logically, in a full and exhaustive manner, the main categories, concepts and terms the course materials were formulated correctly, no mistakes were made in the answers

A “good” grade is given to a student if he/she has demonstrated a solid knowledge of the program educational material, while the question posed was answered competently and to the point, in sufficiently full volume, the main categories, concepts and terms of the course were formulated correctly, and individual inaccuracies or one mistake were made in the answer.

A “satisfactory” grade is given to a student if he/she has demonstrated knowledge of only the main part of the educational material without its specific details, while the question posed is answered With violation logical sequences, Not V full volume; were Inaccurate formulations of the main categories, concepts and terms of the course were allowed, as well as errors (no more than two) or a number of minor inaccuracies that did not significantly distort the essence of the answer.

Grade unsatisfactory is exhibited to a student, which Not knows A significant portion of the program material contains significant errors (more than two) that significantly distort its essence. A failing grade is also given if the answer to a question is missing or the student refuses to submit it.

Criteria assessments For checks practical training:

An “excellent” grade is given if he has demonstrated a high ability to apply acquired knowledge in practice through solving a specific problem, freely and without difficulty coped with the task at hand, demonstrating mastery of various techniques and skills for its implementation, and did not make mistakes or inaccuracies;

A grade of “good” is given if he has demonstrated the ability to apply the acquired knowledge knowledge on practice through solution specific tasks, coped With delivered task, demonstrating mastery of the necessary techniques and skills for its implementation, while making no more than one mistake;

a “satisfactory” grade is given if he demonstrated a mediocre ability to apply the acquired knowledge in practice by solving a specific problem, coped with the assigned task with difficulty, and made no more than two mistakes;

The grade "unsatisfactory" is given if the student has not demonstrated the ability to apply the acquired knowledge in practice by solving a specific problem, has not completed the assigned task, or has made three or more serious mistakes in solving it.

Description of the rating scale

The midterm assessment in the form of an exam provides for the mandatory examination procedures And is being assessed 40 points from 100. IN case If rating score student By discipline By results semesters equal 60, That program automatically is added 32 premium points And is exhibited grade "Great". Positive student 's answer on exam is being assessed rating points V range from **20** to **40** ($20 \leq S_{\text{copy}} \leq 40$), a score of less than 20 points is considered unsatisfactory.

Scale conformity rating points exam 5-point system

Rating score By discipline	Grade By 5-point system
35 - 40	Great
28 - 34	Fine
20 - 27	Satisfactorily

Positive answer student on exam is being assessed rating points V range from 5 to 10 for control question basic level And practical exercise, from 10 to 20 for an advanced level test question. The scale of correspondence between grades and rating points is presented in the table.

Grade	Rating points		
	Control question No. 1 (base level)	Control question No. 2 (advanced level)	Practical task
Great	10	20	10
Fine	7	15	7
Satisfactorily	5	10	5
Unsatisfactory	0	0	0

If student on exam allowed happening violations educational disciplines (cheating, use of mobile communications, personal or tablet computers, audio- or video players, others technical devices), That given student is being removed With exam with an unsatisfactory grade.

Methodological materials defining the procedures for assessing knowledge, skills, and abilities and (or) experience of activities characterizing the stages of formation of competencies

The tasks offered to the student allow them to test the general professional competencies of OPC-1 and OPC-2. Students are given 40.5 hours of independent work to prepare for the exam.

The examination procedure is carried out in accordance with the Regulation on the current monitoring of academic performance and midterm assessment of students in higher education programs at SKFU.

Exam By discipline provided V oral form By tickets. IN The examination ticket includes two theoretical questions and one practical task.

For preparation By ticket is allocated 30 minutes - on theoretical questions, 10 minutes to complete a practical assignment.

When preparing for an answer, the student is given the right to use the course work program and his own lecture notes for no more than 10 minutes.

The practical assignment is completed on a personal computer. When assessing the practical assignment, the following is assessed: right modeling, methods research, accuracy results measurements, error assessment.