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ALMATY UNIVERSITY OF POWER ENGINEERING AND TELECOMMUNICATIONS

Department
of Electrical Engineering

THEORY OF ELECTRICAL CIRCUITS 2

Methodological guidelines and assignments for laboratory works for the specialties:
5B071900 – Radio engineering, electronics and telecommunications;
5B071600 – Instrumentation

Almaty 2018

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Methodological guidelines for performing laboratory works contain 8 laboratory works on the main sections of the Theory of Electrical Circuits 2 (TEC2) course: transients, two-port circuits; passive *K*-type filters; circuits with distributed parameters and nonlinear DC electrical circuits.

The description of each laboratory work includes the following sections: the purpose of the work, the preparation for the laboratory work, the procedure of carrying out the work, the processing of the results of experiments and the methodological guidelines.

Methodological guidelines and assignments are intended for second-year students, who are educated in the English language.

35 illustrations, 34 Tables, 10 items of references.

Reviewer: PhD B. I. Tuzelbayev

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Introduction

The laboratory research works are of great importance for the quality of training and formation of students' creative thinking and engineering skills.

Methodological guidelines and assignments for laboratory works are an integral part of a set of methodological literature on the disciplines: "Theory of electrical circuits in telecommunications" and "Theory of electrical circuits in radio electronics" for the 5B071900 – Radio engineering, electronics and telecommunications specialty; and on the disciplines: "Fundamentals of the circuits theory" and "Theory of electrical circuits" for the 5B071600 – Instrumentation specialty.

The laboratory workshop aims to help students in the successful study of the course and in obtaining research skills with the help of a physical experiment, as well as by simulating various modes of operating of electrical circuits on a personal computer.

The present methodological guidelines contain 8 laboratory works on the main sections: transient processes, two-port circuits, passive *K*-type filters, circuits with distributed parameters; nonlinear electrical circuits.

Laboratory works on the sections "Transient processes" and "Nonlinear electrical circuits" are carried out on the Universal educational and research laboratory stands UILS, laboratory works "Research of passive two-port circuits", "Research of passive *K*-type filters", "Research of various modes in a homogeneous line without losses" - on a personal computer using simulation in the "Electronics Workbench" application, the laboratory work "Research of a homogeneous line with losses on a computer model" is carried out using the "Line" application, which has been developed at the Electrical Engineering department.

The description of each laboratory work includes next sections: the purpose of the work, preparation for work, the procedure of carrying out a laboratory work, processing experimental results and methodological guidelines. All laboratory work are performed by the front way after the respective topics in the lecture material are presented.

The workbench UILS is located on the table and it is a metal box, in which active and passive units, as well as a patchbay to assemble electrical circuits are mounted. The workbench also includes 30 external components (resistors, capacitors and inductors) and a set of connecting wires with plugs.

The power supply units are located in the left side of the workbench and consist of a unit of DC voltage sources and units of the single- and three-phase sinewave voltage sources. Passive units are located in the right side of the workbench and consist of a unit of a variable resistance and units of a variable inductance and a variable capacitance. A patchbay is located at the center of the workbench.

The unit of DC voltage source comprises:

- an adjustable DC stabilized voltage source with regulation range from 0.25 to 24 V;
- an unregulated DC voltage source with output voltage of about 20 V;
- "electronic switch" used to study transients.

Both DC voltage sources are provided with an electronic protection circuit against short-circuits and overloads. The current of protection activation is 1 A.

AC unit is a functional generator with adjustable frequency and value of voltage of sinusoidal, rectangular and triangular shapes.

The unit is provided with an electronic protection circuit against short-circuits and overloads. The current of protection activation is 1 A.

The three-phase voltage unit is a source of three-phase voltage of commercial frequency of = 50 Hz. The source contains three electrically independent from each other phases. Each phase is equipped with an electronic protection against short-circuits and overloads. The current of protection activation is 1 A.

The unit of variable resistors consists of three unregulated resistors R_1, R_2, R_3 and an adjustable R_4. Regulation of value of resistor R_4 is performed in the range from 0 to 999 Ω a stepwise in increments of 1 Ω by using three switches: the hundreds (0 ... 9), the tens (0 ... 9) and the units (0 ... 9) Ω.

The unit of variable inductance includes three unregulated inductors L_1, L_2, L_3 and an adjustable inductor L_4. Regulation of inductance L_4 can be adjusted between 0 and 99.9 mH in steps of 0.1 mH by using three switches: the tens (0 ... 9), the units (0 ... 9) and the tenths (0 ... 9) mH.

The unit of variable capacitance consists of three unregulated capacitors C_1, C_2, C_3 and an adjustable C_4. Regulation of capacitance C_4 is carried out in the range from 0 to 9.99 μF in steps of 0.01 μF using three switches: the units (0 ... 9), the tenths (0 ... 9) and the hundredths of (0 ... 9) μF.

On the front panel of the blocks are located: the light indicators (LEDs, light indicators), the controls (knobs switches, toggle switches, and buttons) and measurement devices.

A patchbay is a panel with 67 pairs connected with each other of jacks for plugging and mounting the components of the studied electrical circuits.

The external elements are designed as the transparent plastic boxes, in which there are plugs to connect, and inside there are soldered the elements of electric circuits: *R*, *L* and *C*. It is necessary to switch the toggle switch POWER in ON position to turn on the power source unit, than on front panel the POWER LED will lights.

Measuring devices of the units are designed to display the value of current and voltage of regulated sources. Regulation is performed by means of the potentiometer.

The frequency is adjusted stepwise with 1 kHz, and smoothly by the FREQUENCY SMOOTHLY potentiometer. When the potentiometer is at the right position, the frequency of the output voltage corresponds to the value indicated on the stepwise switch with an accuracy of ± 2%.

The voltage of each phase at the output of unit of the three-phase voltage source can be adjusted stepwise from 0 to 30 V in increments 1 V via two switches: tens (0 ... 3) and units (0 ... 9) of Volts.

In the event of a short circuit or an overload in the power supply units an electronic protection is activated, and PROTECTION indicator lights. After removing the causes of a short circuit or overload, it is necessary to return the power supply unit in operating state by pressing PROTECTION button, the indicator turns off.

Requirements for registration of the report on the laboratory work

The assignment for the current laboratory work the student gets in advance at the previous lesson, a week or two weeks earlier.

Each student prepares his own report in order to carry out the laboratory work, he should be acquainted with the purpose of work and with the basic theoretical principles used in the experiment.

Before implementation of the experimental part, the student is interviewed on the preparation for the laboratory work, shows the prepared report for the execution of the laboratory work to the teacher and gets admission to the work.

After executing the experimental part, the report is finalized: a comparison between theory and experiment is carried out, the necessary graphs are plotted, an analysis of the results is fulfilled and conclusions on the work are made.

Each student defends the report on the laboratory work individually at the current or following laboratory classes, or at the consultations.

The report should contain the title page and the following sections:

− the purpose of the work;

− basic theoretical principles and answers to questions of preparation for the laboratory work;

− brief information about the experiment;

− the scheme of the analyzed electric circuit;

− the formulas and the results of theoretical calculations for specific modes of the electric circuit;

− results of the study: tables, graphs, diagrams, numerical values of the circuit parameters, electric currents and voltages, etc.;

− the conclusions on the work completed.

See the template of the title page on the next page.

Reports should be performed only on one side of a white sheet or of lined paper with size of A4 (210x297mm). The text should be written neatly. When writing the text, it is allowed to use only generally accepted abbreviations or designations, decrypted when first mentioned.

The student is admitted to the next laboratory work if he has executed and defended the previous laboratory work.

Sample of the title page

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Department of Electrical engineering

R E P O R T
on laboratory work № ____

on the “____” discipline

____

(Title of the laboratory work)

____

____ specialty

Done by ____________________________________ Group ______________
(Student’s Surname and Initials) (Academic group code)

Checked by ____
(Teacher’s academic degree, academic rank, Surname and Initials)

_____________ _____________________ «____» ______________ ___201__ y.
(Score) (Teacher’s signature) (Date)

Almaty 20__ y.

1 Laboratory work № 1. Short circuit in *RC*- circuit

The purpose is obtaining the skills of experimental research of transients in a circuit with a series connection of resistive and capacitive elements.

1.1 Preparation for the laboratory work

1.1.1 Repeat the section "The emergence of transient processes and the laws of commutation. Transient, steady state and free modes", "Transients in the *RC*- circuit".

1.1.2 Answer the questions in writing and do the following assignments:

1) What is the transient process, and what are its causes? In which of electrical circuits can transients occur?

2) Write down the commutation laws and determine the independent initial condition for the *RC*-circuit after closing the electronic switch (S) (figure 1.1).

3) What modes are called transitional, steady state and free? Write down the steady state, free and transient components of current and steady state, free and transient components of voltage on the capacitor after switching (S closes) when the *RC*-circuit is shorted (figure 1.1).

4) Plot the graphs of $u_C(t)$ and $i_C(t)$.

5) What is the physical sense of the time constant of the circuit? What is the values of the *RC*- circuit time constant? How to determine experimentally the time constant of the circuit?

6) What is named as damping factor of the circuit, logarithmic decrement?

1.2 Procedure of carrying out the work

1.2.1 Assemble the electric circuit in figure 1.1.

1.2.2 Set values of the EMF E_0, the resistor R and the capacitor C according to the assignment variant, Table 1.1. Set value of the R_1 in the range of 50...100 Ω.

1.2.3 Plug in the voltage of the capacitor to the oscilloscope input.

1.2.4 Copy in a scale from the oscilloscope screen or take a screenshot of the voltage curve of $u_C(t)$.

1.2.5 Plug in the voltage of resistor R to the oscilloscope input. Copy in a scale from the oscilloscope screen or take a screenshot of the voltage curve of $u_R(t)$. This curve in the appropriate scale represents the curve of current through the capacitor:

$$i_C(t) = i_R(t) = \frac{u_R(t)}{R}.$$

1.2.6 Change one of the circuit parameters according to assignment variant (table 1.2). Copy in a scale the new curves of $u_C(t)$ and $u_R(t)$ from the oscilloscope screen or take a screenshots, aligning it with the first curve. Compare the obtained curves.

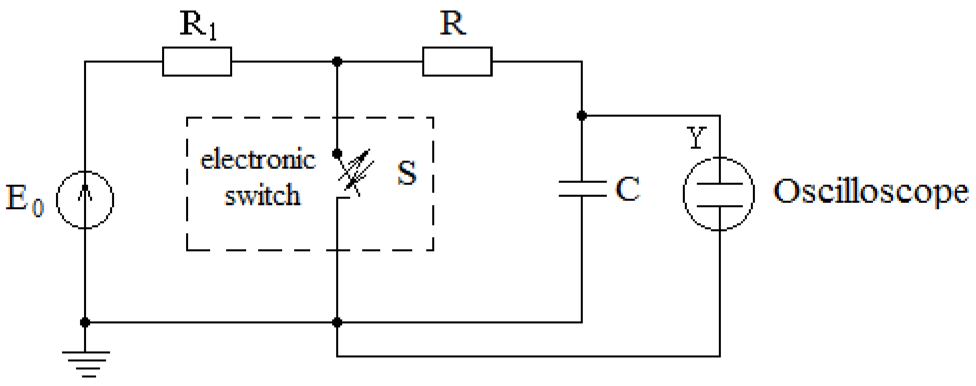


Figure 1.1 – Scheme for research of transient in *RC*-circuit

Table 1.1 – Parameters of the *RC*-circuit (variant 1)

Variant	E_0, V	R, Ω	C, μF
1	10	300	4
2	15	400	3
3	12	200	5
4	10	600	3
5	15	500	3
6	12	300	5

Table 1.2 – Parameters of the *RC* - circuit (variant 2)

Variant	E_0, V	R, Ω	C, μF
1	10	600	4
2	15	400	6
3	12	400	5
4	10	600	3
5	15	500	6
6	12	600	5

Table 1.3 – The time constant of the circuit and the attenuation coefficient

Type of research	τ_1, s	α_1, 1/s	τ_2, s	α_2, 1/s
Theoretical calculation				
Experiment				

Table 1.4 – Voltage and current on the capacitors in the *RC* – circuit

t, s	0	τ, s	2τ, s	3τ, s	4τ, s	5τ, s
$u_C(t)$						
$i(t)$						

1.3 Processing experimental results

1.3.1 Calculate the time constants τ and damping factors α of the circuit shown in figure 1.1 for two given variants of the circuit parameters (tables 1.1 and 1.2.): τ_{RC1}, α_{RC1} и τ_{RC2}, α_{RC2}. The results of the calculation are to be written down into table 1.3 (the line is "theoretical calculation").

1.3.2 Determine the time constant τ_{RC} and the damping factor α_{RC} of the *RC*-circuit in figure 1.1 by the images of the voltage curves across the capacitor of $u_C(t)$ for two given variants of the circuit parameters (points 1.2.4 and 1.2.6). Write down the results of the calculation into table 1.3 (the line is "experiment").

1.3.3 Theoretically calculate voltage time function of $u_C(t)$ by the known parameters of the circuit according to assignment variant (table 1.1).

1.3.4 Plot graphs of the calculated and experimental curves of $u_C(t)$ and $i(t)$ on the same Figure for τ_1 and τ_2.

1.3.5 Make a conclusion about the impact of the value of resistance *R* or capacitance *C* on the time constant τ of the circuit and consequently on the rate of transient process, determine the time of discharge of the capacitor.

1.4 Methodological guidelines

The voltage $u_C(t)$ and the current $i(t)$ after commutation (S is closed) with a short circuit of the *RC*-circuit are calculated by the formulas:

$$u_C(t) = U_0 e^{-\frac{t}{\tau}} = U_0 e^{-\alpha t}; \; i(t) = -\frac{U_0}{R} e^{-\frac{t}{\tau}} = -\frac{U_0}{R} e^{-\alpha t},$$

where $\tau = RC$ is time constant of the *RC*-circuit;
α is damping factor,

$$\alpha = \frac{1}{\tau} = \frac{1}{RC}.$$

The time constant of the circuit τ increases with the value of the active resistance and capacitance and, accordingly, the attenuation coefficient α decreases.

The scale of the time axis is determined from the condition that the electronic switch (S) commutes with a frequency f = 50 Hz and a period of T = 20 ms. The first half of the period (10 ms), the electronic switch is opened, the capacitor is charged. The second half of the period (10 ms), the electronic switch is closed, the capacitor discharges.

The time constant of the *RC*-circuit τ_{RC} is determined by an experimental curve of $u_C(t)$ as a subtangent (figure 1.3).

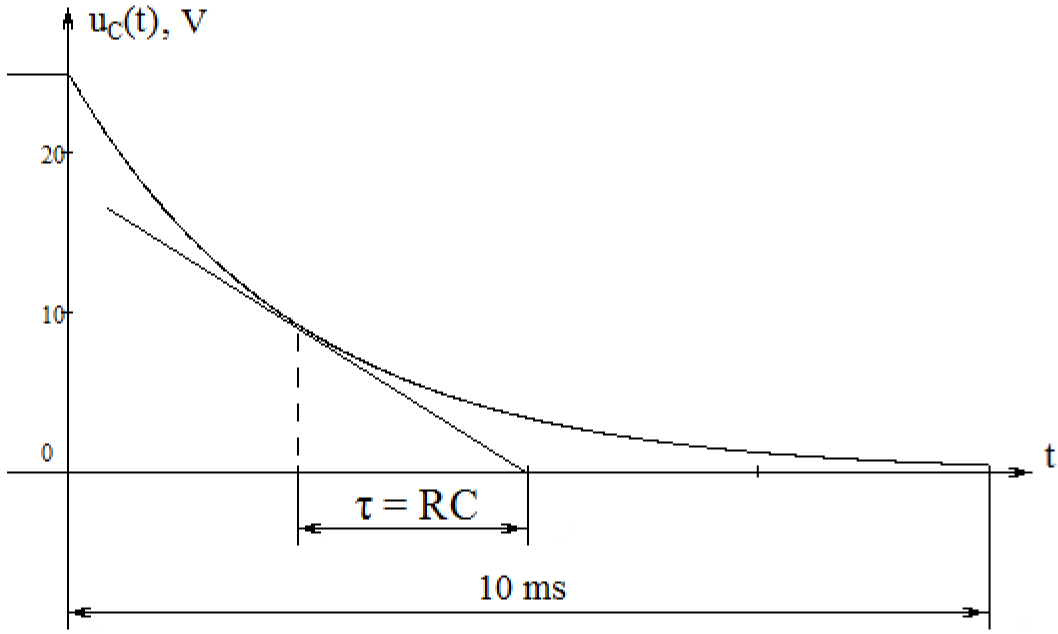


Figure 1.2 – Determination the time constant τ_{RC} of the *RC*-circuit

2 Laboratory work № 2. Short circuit in the *RL*-circuit

The purpose is obtaining the skills of experimental research of transients in a circuit with a series connection of resistive and inductive elements.

2.1 Preparation for the laboratory work

2.1.1 Repeat section "The emergence of transient processes and the laws of commutation. Transient, steady state and free modes", "Transients in the *RL*- circuit".

2.1.2 Answer the questions in writing and do the following assignments:

1) What is the transient process, and what are its causes? In which of electrical circuits can occur transients?

2) Write down the commutation laws and determine the independent initial condition for the *RL*-circuit after closing the electronic switch (S) (figure 2.1).

3) What modes are called transitional, steady state and free? Write down the steady state, free and transient components of current and steady state, free and transient components of voltage on the inductor after switching (S closes) when the *RL*-circuit is shorted (figure 2.1).

4) Plot the graphs of $i\ (t)$ and $u_L(t)$.

5) What is the physical sense of the time constant of the circuit? What is the values of the *RL*- circuit time constant? How to determine experimentally the time constant of the circuit?

6) What is named as damping factor of the circuit, logarithmic decrement?

2.2 Procedure of carrying out the work

2.2.1 Assemble the electric circuit in figure 2.1.

2.2.2 Set values of the EMF E_0 and the inductance L (variant 1) according to the assignment variant, Table 2.1. Set the resistors values of the $R = 2…6\ \Omega$, $R_1 = 50…200\ \Omega$.

2.2.3 Write down the value of the voltage E_0, the inductance value L_1 into table 2.2. resistances R_1 and R. Measure the resistance of the inductor R_{coil} (R_{coil} - resistance of the inductor with inductance L_1). Write down the results into table 2.2.

2.2.4 Plug in the voltage of resistor R to the oscilloscope input. Copy in a scale from the oscilloscope screen or take a screenshot of the voltage curve of $u_R(t)$. This curve in the appropriate scale represents the curve of current through the inductor:

$$i_L(t) = i_R(t) = \frac{u_R(t)}{R}.$$

2.2.5 Plug in the voltage of inductor to the oscilloscope input. Copy in a scale from the oscilloscope screen or take a screenshot of the voltage curve of $u_{coil}(t)$.

2.2.6 Set the new value of inductance (variant 2) according to assignment variant (table 2.3). Copy in a scale the new curves of $u_{coil}(t)$ and $u_R(t)$ from the oscilloscope screen or take a screenshots, aligning it with the first curve. Compare the obtained curves.

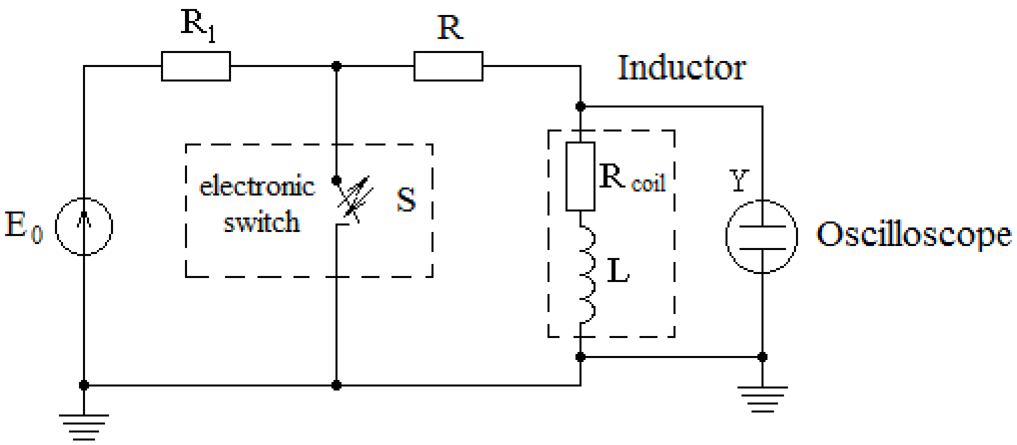


Figure 2.1 – Scheme for research of transient in *RL*-circuit

Table 2.1 – Parameters of the *RL* - circuit

Variant	E_0, V	L, mH (variant 1)	L, mH (variant 2)
1	10	20	10
2	15	25	50
3	12	30	15
4	20	65	30
5	15	40	20

Table 2.2- Input voltage and circuit parameters

U_0, V	R_1, Ω	R, Ω	L_1, mH	R_{coil1}, Ω	L_2, mH	R_{coil2}, Ω

Table 2.3 – The time constant of the circuit and the attenuation coefficient

Type of research	τ_1,s	α_1,1/s	τ_2,s	α_2,1/s
Theoretical calculation				
Experiment				

Table 2.4 – Current and voltage on the inductors in the *RL* - circuit

t,s	0	τ, s	2τ, s	3τ, s	4τ, s	5τ, s
$i(t)$						
$u_L(t)$						

2.3 Processing experimental results

The current $i(t)$ and the voltage $u_L(t)$ and the after commutation (S is closed) with a short circuit of the *RL*-circuit are calculated by the formulas:

$$i(t) = \frac{E}{R_1 + R + R_{coil}} e^{-\frac{t}{\tau}} = \frac{E}{R_1 + R + R_{coil}} e^{-\alpha t};$$

$$u_L(t) = -E \frac{R_{eq}}{R_1 + R + R_{coil}} e^{-\frac{t}{\tau}} = -E \frac{R_{eq}}{R_1 + R + R_{coil}} e^{-\alpha t},$$

where $\tau = L/R_{eq}$ is time constant of the *RL*-circuit;

α is damping factor $\alpha = 1/\tau = R_{eq}/L$;

$R_{eq} = R + R_{coil}$ is equivalent resistance of the *RL*-circuit;

R_{coil} is resistance of the coil.

The scale of the time axis is determined from the condition that the electronic switch (S) commutes with a frequency f = 50 Hz and a period of T = 20 ms.

Time constant of *RL*-circuit τ_{RL} is defined by the same way using $u_R(t)$ curve.

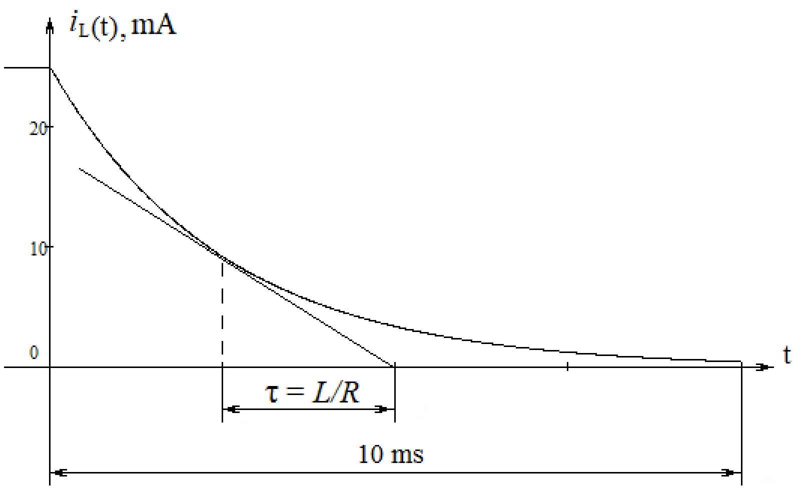


Figure 2.3 – Determination the time constant τ_{RL} of the *RL*-circuit

3 Laboratory work № 3. Research of transients in the second order linear electric circuits. Transients in the *RLC*- circuit

The purpose is obtaining the skills of experimental research of transients in an electrical circuit with two energy storage elements – with inductor and capacitor.

3.1 Preparation for the laboratory work

3.1.1 Repeat section "Transients in the second order linear electric circuits"

3.1.2 Answer the questions in writing and do the following assignments:

1) Write down the equation by Kirchhoff's voltage law (KVL) for the free components of voltages across elements of the *RLC* - circuit and the corresponding characteristic equation of the circuit.

2) Which roots of the characteristic equation of the *RLC* - circuit correspond to the overdamped character of discharge of the capacitor? Write down the expressions for the instantaneous values of the $u_C(t)$, $i(t)$ and $u_L(t)$ at overdamped character of the capacitor discharge. Draw graphs of these time functions.

3) Which roots of the characteristic equation of the *RLC* - circuit correspond to the critical overdamped character of discharge of the capacitor? Write down the expressions for the instantaneous values of the $u_C(t)$, $i(t)$ and $u_L(t)$ at critical overdamped character of the capacitor discharge.

4) Write down the expression for the calculation of the critical resistance of the *RLC* - circuit.

5) What is called logarithmic damping decrement?

6) Which roots of the characteristic equation of the *RLC* - circuit correspond to the underdamped character of the capacitor discharge? Write down the expressions for the instantaneous values of the $u_C(t)$, $i(t)$ and $u_L(t)$ at underdamped character of discharge of the capacitor. Draw graphs of these time functions.

7) How to determine the attenuation coefficient α and the natural oscillation frequency ω_0 of the circuit both by theoretical calculation and by experimental way (according to the voltage curve)? How do these values depend on the R, L and C?

3.2 Procedure of carrying out the work

3.2.1 Assemble the electric circuit as shown in figure 3.1.

3.2.2 Set values of the resistor R, the inductor L and the capacitor C according to the assignment variant, Table 3.1. Measure the coil resistance R_{coil}. Set values of the R_1 in the range of 50...100 Ω and of the EMF E_0 = 10…20 V.

3.2.3 Plug in the voltage from the capacitor to the oscilloscope input.

3.2.4 Research the oscillation discharge of a capacitor, copy the voltage curve of $u_C(t)$ in a scale from the oscilloscope screen or take a screenshot.

3.2.5 Plug in the voltage of $u_R(t)$ to the input of the oscilloscope and copy the oscillogram of these voltages at the underdamped character of the capacitor discharge. The $u_R(t)$ curve at the appropriate scale is a current curve as $i(t) = u_R(t)/R$.

3.2.6 Plug in the voltage of $u_L(t)$ to the input of the oscilloscope and copy the oscillogram of these voltages at the underdamped character of the capacitor discharge.

3.2.7 By increasing the resistance of the resistor R to achieve the disappearance of fluctuations on the voltage curve of $u_C(t)$ that corresponds to the critical overdamped character of the capacitor discharge. Write down the value of obtained critical resistance $R_{cr.exp.}$ of circuit into table 3.2 (in the "experiment" row), with taking into account the coil resistance R_{coil}. Compare the value of critical resistance obtained in the experiment with the calculated. Copy in a scale the voltage curve of $u_C(t)$ from the oscilloscope screen or take a screenshot.

3.2.8 Enlarge total resistance of the circuit R_Σ in two times in comparison with the critical. Copy in a scale the obtained voltage curves of $u_C(t)$, $u_L(t)$ and $u_R(t)$ from the oscilloscope screen for the overdamped character of the capacitor discharge.

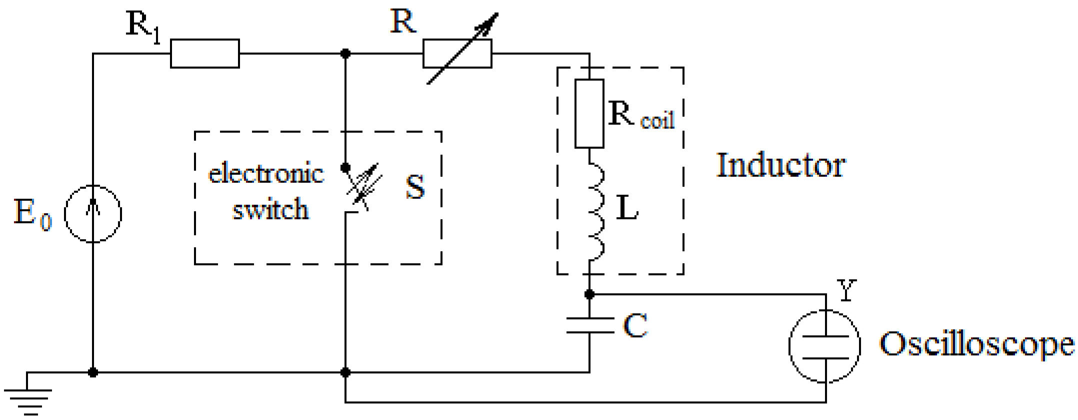


Figure 3.1 – Scheme of research of the *RLC*-circuit

Table 3.1 Parameters of the *RLC* - circuit

Variant	*R*, Ω	*L*, mH	*C*, μF
1	1	10	4
2	1	20	3
3	1	20	2
4	1	15	2
5	1	10	3

Table 3.2 - Parameters of the *RLC* - circuit

U_0 = , R = , L = , R_{coil} = , C =				
Type of research	ω_0, rad/s	T_0, s	α, 1/s	R_{cr}, Ω
Theoretical calculation				
Experiment				

3.3 Processing experimental results

3.3.1 For the circuit in figure 3.1 calculate the damping factor α_{theory} and the natural frequency $\omega_{0theory}$ by using given values of total resistance $R_\Sigma = R + R_{coil}$. Write down the results into table 3.2 (the row is “theoretical calculation”).

3.3.2 Calculate the experimental values of the damping factor $\alpha_{exp.}$ and the natural frequency $\omega_{0exp.}$ of the circuit by using the experimentally obtained image of voltage waveform across the capacitor $u_C(t)$ Write down the results into table 3.2 (in the “experiment” row).

3.3.3 Make conclusions on the work done: compare the theoretically calculated values of α, ω_0 and R_{cr} with the ones obtained experimentally. Analyze the impact of the total resistance of the circuit on the character of discharge of the capacitor.

3.4 Methodological guidelines

For the *RLC* circuit (figure 3.1), the characteristic equation has the form:

$$p^2 + \frac{R_\Sigma}{L} p + \frac{1}{LC} = 0;$$

the roots of the characteristic equation are determined by the formula:

$$p = -\frac{R_\Sigma}{2L} \pm \sqrt{\frac{R_\Sigma^2}{4L^2} - \frac{1}{LC}}\ .$$

The scale of the time axis is determined from the condition that the electronic switch (S) commutes with a frequency f = 50 Hz and a period of T = 20 ms. The first half of the period (10 ms), the electronic switch is opened, the capacitor is charged. The second half of the period (10 ms), the switch is closed, the capacitor discharges.

Theoretical values of the damping factor α_{theory}, the natural frequency $\omega_{0theory}$ and the critical resistance $R_{cr.theory}$ are determined by the formulas:

$$\alpha_{theory} = \frac{R_\Sigma}{2L}; \quad \omega_{0theory} = \sqrt{\frac{1}{LC} - \left(\frac{R_\Sigma}{2L}\right)^2}; \quad R_{cr.theory} = 2\sqrt{\frac{L}{C}}\ .$$

The experimental values of the damping factor $\alpha_{theory.}$ and the natural frequency $\omega_{0theory}$ are determined by the voltage curve $u_C(t)$ which obtained from the oscilloscope screen, as shown in figure 3.2.

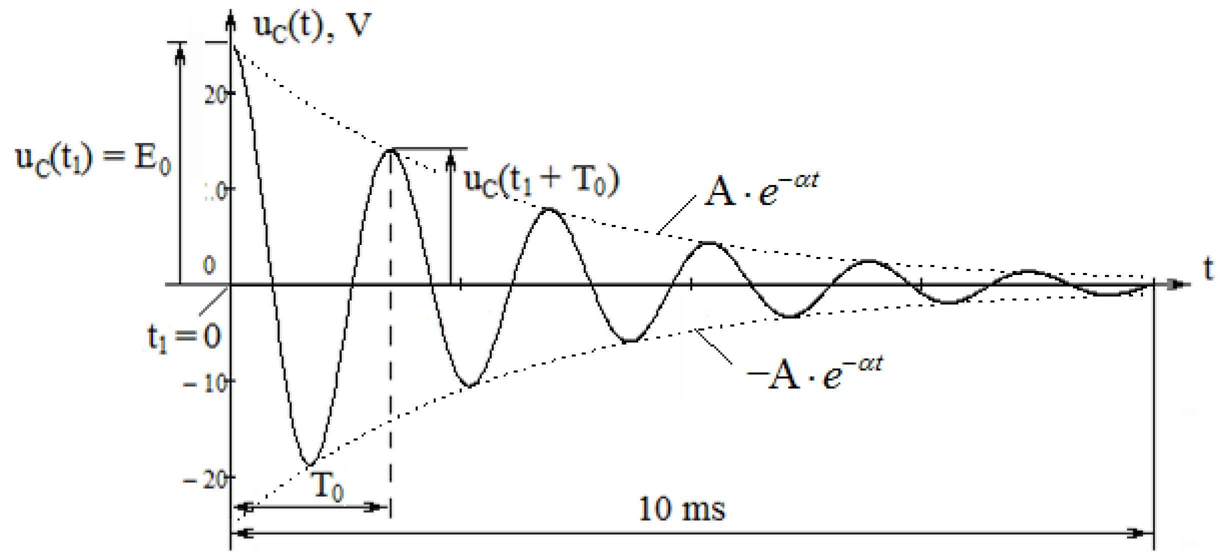


Figure 3.2 – Determination of the $\alpha_{exp.}$, T_0 and $\omega_{0theory}$ of the *RLC*-circuit

The natural frequency $\omega_{0theory}$ can be calculated by the formula:

$$\omega_0 = 2\pi f_0 = \frac{2\pi}{T_0},$$

where T_0 is the period of free oscillations, determined by the voltage curve $u_C(t)$ as shown in figure 3.2.

The experimental value of the damping factor $\alpha_{exp.}$ can be calculated by the logarithmic decrement and period of natural oscillation by the formula:

$$\alpha_{exp.} = \frac{1}{T_0} \ell n \frac{u_c(t_1)}{u_c(t_1 + T_0)},$$

where $u_C(t_1) = E_0$ – amplitude of the voltage oscillation across capacitor at the moment $t_1 = 0$. In the denominator the value of amplitude of the voltage oscillations across capacitor after the period T_0.

4 Laboratory work № 4. Analysis of passive symmetrical two-port circuits

Objective is gaining the skills of researching various operating modes of a passive symmetrical two-port network and determining its parameters by computer simulation on a personal computer using the “Electronics Workbench” program.

4.1 Preparation for the laboratory work

4.1.1 Repeat the section “Two-port circuits”.

4.1.2 In written form answer the questions and do the following assignments:

1) Give a definition of the two-port circuit.

2) What is called a passive two-port circuit?

3) What is called a symmetrical two-port circuit?

4) Write down transfer equations of two-port circuits by the $\underline{A}$-, $\underline{Z}$-, $\underline{Y}$-, $\underline{G}$- and the $\underline{H}$- parameters.

5) What conditions are satisfied by the A parameters of a passive two-port network, a symmetrical two-port network?

6) How is the input impedance of a two-port network determined? Calculate the input impedances of the two-port circuit at the idle (open-circuit) and short-circuit test modes $\underline{Z}_{oc}$, $\underline{Z}_{sc}$ according to variant given (table 4.1). The results of the calculations write down into table 4.4 to the "Theoretical calculation" row.

7) Calculate the complex RMS values of the output voltages $\dot{U}_2$, the input $\dot{I}_1$ and the output $\dot{I}_2$ currents at the idling and short-circuit modes according to the given variant of input voltage U_1 and parameters of passive symmetrical two-port circuit (table 4.1). Write down the calculation results into table 4.2 to the "Theory" row.

8) Write down the expressions to determination of the $\underline{A}$-parameters of passive symmetrical two-port circuit. Calculate the $\underline{A}$-parameters of passive symmetrical two-port circuit according to given variant (table 4.1). Write down the results of the calculations into table 4.3 to the "Theoretical calculation" row.

9) Which parameters of the two-port network are called characteristic? Write down the expressions for calculating the characteristic impedance $\underline{Z}_C$ from the values of $\underline{Z}_{oc}$, $\underline{Z}_{sc}$ and A-parameters.

10) What mode is called the matched mode and what impedance is equal to the input resistance of the two-port in the matched mode?

11) Write the expression of the characteristic propagation constant $\underline{\Gamma}_{\text{C}}$ for the symmetrical two-port circuit. What is the value called characteristic attenuation, the units of characteristic attenuation? What value is called the phase shift constant, its measurement units?

12) Write the expression of the characteristic propagation constant $\underline{\Gamma}_{\text{C}}$ for the symmetrical two-port circuit via the *A*-parameters.

Table 4.1 – Assignment variants for the laboratory work

Variant #	Scheme #	U_1, V	*f*, kHz	*R*, Ω	*L*, mH	*C*, μF	R_l, Ω
1	4.1	25	1.0	80	10	–	70
2	4.2	20	1.5	85	–	1.5	80
3	1.3	25	0.5	65	–	4	60
4	4.4	45	0.8	95	16	–	55
5	4.5	50	2.0	50	–	2	65
6	4.6	30	2.5	110	6	–	100
7	4.7	15	2.0	115	8	–	90
8	4.8	55	1.5	90	–	1	100

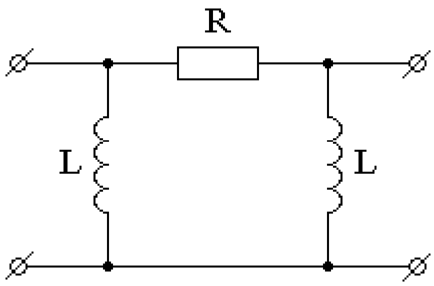


Figure 4.1

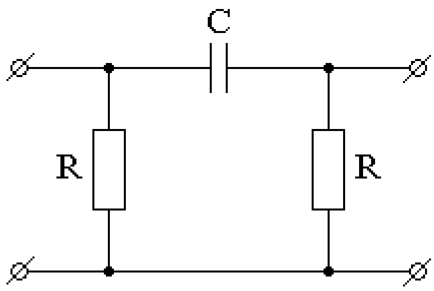


Figure 4.2

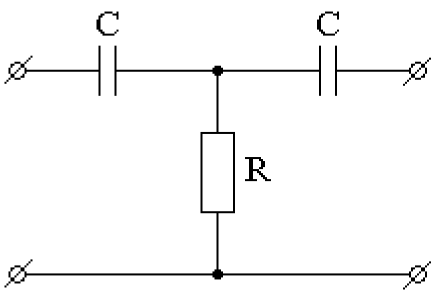


Figure 4.3

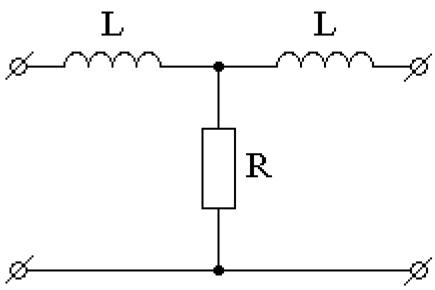


Figure 4.4

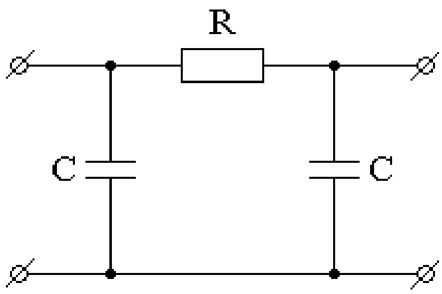


Figure 4.5

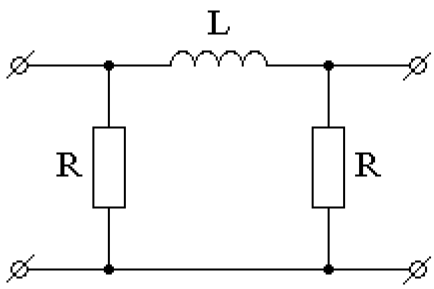


Figure 4.6

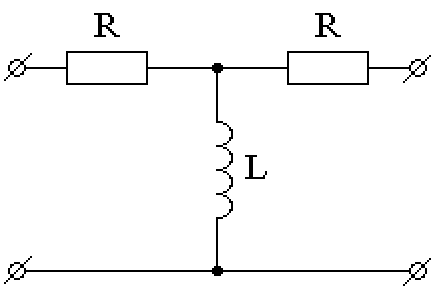


Figure 4.7

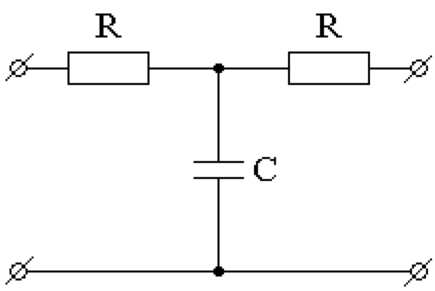


Figure 4.8

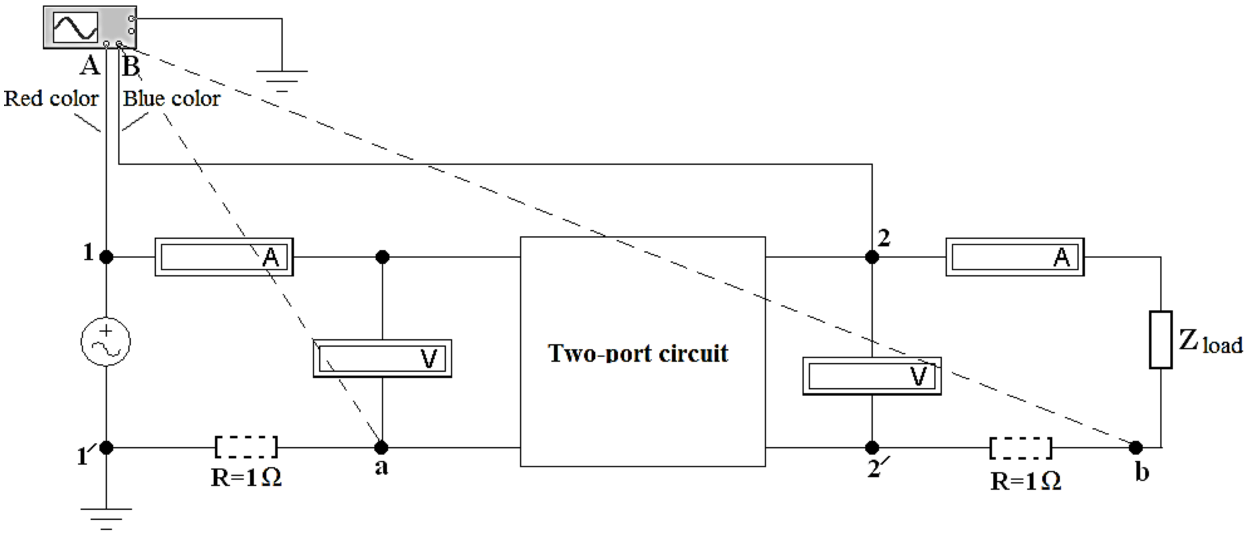


Figure 4.9

4.2 Procedure of carrying out the work

4.2.1 Assemble the electric circuit using the scheme shown in figure 4.9 with specified parameters of two-port circuit according to assignment variant.

4.2.2 Set the RMS value of the input voltage U_1 and the frequency f of the generator according to assignment variant.

4.2.3 Measure the input U_1 and output U_2 voltages, input current I_1 of the two-port circuit at the idling mode across output points *2-2′* ($\underline{Z}_{load} = \infty$, $I_2 = 0$). In addition, measure the time interval $\Delta t_{u2} = T_2 - T_1$, which corresponds to the phase shift angle between the input $u_1(t)$ and the output $u_2(t)$ voltages and the time interval $\Delta t_{i1} = T_2 - T_1$, which corresponds to the phase shift angle between the input voltage $u_1(t)$ and the input current $i_1(t)$ of the two-port circuit. Write down the measurement results into table 4.2.

4.2.4 Measure the input I_1 and output I_2 currents, input voltage U_1 of the two-port circuit at the short-circuit test mode across output points *2-2′* ($\underline{Z}_{load} = 0$, $U_2 = 0$). In addition, measure the time interval $\Delta t_{i1} = T_2 - T_1$, which corresponds to the phase shift angle between the input voltage $u_1(t)$ and the input current $i_1(t)$ and the time interval $\Delta t_{i2} = T_2 - T_1$, which corresponds to the phase shift angle between the input voltage $u_1(t)$ and the output current $i_2(t)$ of the two-port circuit. Write down the measurement results into table 4.2.

4.2.5 In the load mode ($Z_{load} = R_{load}$) measure the input I_1 and output I_2 currents, input voltage U_1 of the two-port circuit at the short-circuit test mode across output points *2-2′* ($Z_{load} = R_{load}$). In addition, measure the time interval $\Delta t_{i1} = T_2 - T_1$, which corresponds to the phase shift angle between the input voltage $u_1(t)$ and the input current $i_1(t)$ and the time interval $\Delta t_{i2} = T_2 - T_1$, which corresponds to the phase shift angle between the input voltage $u_1(t)$ and the output current $i_2(t)$ of the two-port circuit. Write down the measurement results into table 4.2.

Table 4.2 – Determination of initial phase angles of currents and voltages

Operating mode	Kind of research	$\underline{U}_1$, V	U_2, V	$T_2 - T_1$, s	ψ_{u2}, deg	I_1, A	$T_2 - T_1$, s	ψ_{i1}, deg	I_2, A	$T_2 - T_1$, s	ψ_{i2}, deg
Idling	Theory										
	Experiment										
Short circuit	Theory										
	Experiment										
Load mode $Z_{load} = R_{load}$	Theory										
	Experiment										

Table 4.3 – Complex RMS values of the voltages and currents at various modes

Operating mode	Kind of research	$\dot{U}_1, V$	$\dot{U}_2, V$	$\dot{I}_1$, A	$\dot{I}_2$, A
Idling	Theory				
	Experiment				
Short circuit	Theory				
	Experiment				
load mode $Z_{load} = R_{load}$	Theory				
	Experiment				

Table 4.4 – A-parameters of the two-port circuit

Kind of research	$\underline{A}_{11}$	$\underline{A}_{12}$, Ω	$\underline{A}_{21}$, S	$\underline{A}_{22}$
Theoretical calculation				
Calculation using experimental data				

Table 4.5 – Secondary parameters of the two-port circuit

Kind of research	$\underline{Z}_{sc}$, Ω	$\underline{Z}_{oc}$, Ω	$\underline{Z}_{in}$, Ω, load mode
Theoretical calculation			
Calculation using experimental data			

4.3 Processing experimental results

4.3.1 Calculate the initial phase angles of the output voltage Ψ_{u2} and the initial phase angles of the input Ψ_{i1} and the output currents Ψ_{i2} of the two-port circuit for all studied operating modes by using corresponding measured values of $\Delta t = T_2 - T_1$. Write down the obtained results into table 4.2.

4.3.2 Write down the complex RMS values of the voltages $\dot{U}_1$, $\dot{U}_2$ and the currents $\dot{I}_1$, $\dot{I}_2$ for all studied modes into table 4.3 to the "Experiment" row.

4.3.3 Calculate the $\underline{A}$-parameters of passive symmetrical two-port circuit: $\underline{A}_{11}$, $\underline{A}_{12}$, $\underline{A}_{21}$ and $\underline{A}_{22}$ by using the experimental data of the voltages values $\dot{U}_1$, $\dot{U}_2$ and the currents values $\dot{I}_1$, $\dot{I}_2$ in the idling (open-circuit) and short-circuit tests by following formulas:

$$\underline{A}_{11} = \left(\frac{\dot{U}_1}{\dot{U}_{2oc}}\right)_{I2=0}; \quad \underline{A}_{21} = \left(\frac{\dot{I}_{1oc}}{\dot{U}_{2oc}}\right)_{I2=0}; \quad \underline{A}_{12} = \left(\frac{\dot{U}_1}{\dot{I}_{2sc}}\right)_{U2=0}; \quad \underline{A}_{22} = \left(\frac{\dot{I}_{1sc}}{\dot{I}_{2sc}}\right)_{U2=0}.$$

Write down the calculation results into table 4.4 to the "Calculation by experimental data" row.

4.3.4 Calculate the input impedances of two-port circuit for all studied modes by using the experimental data. Write down the obtain results into table 4.5 to the "Calculation by experimental data" row.

4.3.5. Based on the experimental data, calculate the input impedances of the two-port network for all the regimes studied. The results of the calculations should be recorded into table 4.4 (the line "according to the experimental data").

4.3.6. From the experimental data, calculate the characteristic impedance $\underline{Z}_C$, the characteristic transmission constant $\underline{\Gamma}_C = A_C + jB_C$, the characteristic attenuation A_C of the two-port network, the phase constant B_C, of the two-port network, using the A- parameters calculated from the experimental data.

4.3.7 From the experimental data for the load mode, determine the transfer functions of the two-port network:

$$H_U = \dot{U}_2/\dot{U}_1;\ H_i = \dot{I}_2/\dot{I}_1;\ H_Z = \dot{U}_2/\dot{I}_1;\ H_Y = \dot{I}_2/\dot{U}_1.$$

4.4 Methodological guidelines for measurement of the initial phase angels of sinusoidally time-varying voltages and currents

It is possible to measure the initial phase angles of sinusoidally time-varying voltages and currents relatively to initial phase angle of input voltage $u_1(t)$ by means of the oscilloscope (figure 4.10). In order to measure the initial phases of voltages the channel (A) of oscilloscope should be connected to the point (1) (this wire is colored red) and the channel (B) – to the point (2) (this wire is colored blue). Set the first (red) and the second (blue) survey lines to the same phase point of the input $u_1(t)$ and the output $u_2(t)$ voltages, for example in the start zero point of sinusoidally time-varying function. Read the corresponding time shift interval $\Delta t_{u2} = T_2 - T_1$ between the voltages $u_2(t)$ and $u_1(t)$ on the third (last) subwindow of the oscilloscope beneath the main screen. Calculate the phase shift angle by formula:

$$\psi_{u2} - \psi_{u1} = 360° \cdot f \cdot (-\Delta t_{u2}) = -360° \cdot f \cdot (T_2 - T_1).$$

Assume the initial phase angle of the input voltage $u_1(t)$ of zero $\Psi_{u1} = 0$, then the above expression determines the value of Ψ_{u2} – an initial phase angle of the output voltage $u_2(t)$.

To measure the initial phases of currents is used the method of converting the current to the potential by involves into the circuit a resistor with small value of resistance for measuring current by means the oscilloscope.

In order to measure the initial phase angle of input current $i_1(t)$ the resistor R with resistance of 1Ω should be plugged in between points (*a*) and (1'). Channel (A) of oscilloscope should be connected to the point (1) (this wire is colored red) and the channel (B) – to the point (*a*) (this wire is colored blue). Set the first (red) and the second (blue) survey lines to the same phase point (for example in zero point) of the input voltage $u_1(t)$ (red color curve) and the input current $i_1(t)$ (blue color curve). Read the corresponding time shift interval $\Delta t_{i1} = T_2 - T_1$ between the input current $i_1(t)$ and the input voltage $u_1(t)$. Calculate the phase shift angle Ψ_{i1} of input current $i_1(t)$ by the above formula.

In order to measure the initial phase angle of output current $i_2(t)$ switch the resistor R with resistance of 1Ω between points (2') and (*b*). Channel (A) of the oscilloscope should be connected to the point (1) (this wire is colored red) and the channel (B) – to the point (2') (this wire is colored blue). Set the first (red) and the second (blue) survey lines to the same phase point (for example in zero point) of the input voltage $u_1(t)$ (red color curve) and the output current $i_2(t)$ (blue color curve). Read the corresponding time shift interval $\Delta t_{i2} = T_2 - T_1$ between the output current $i_2(t)$ and the input voltage $u_1(t)$. Calculate the phase shift angle Ψ_{i2} of output current $i_2(t)$ by the above formula. After the measuring have been done the resistor R with resistance of 1Ω should be plugged off.

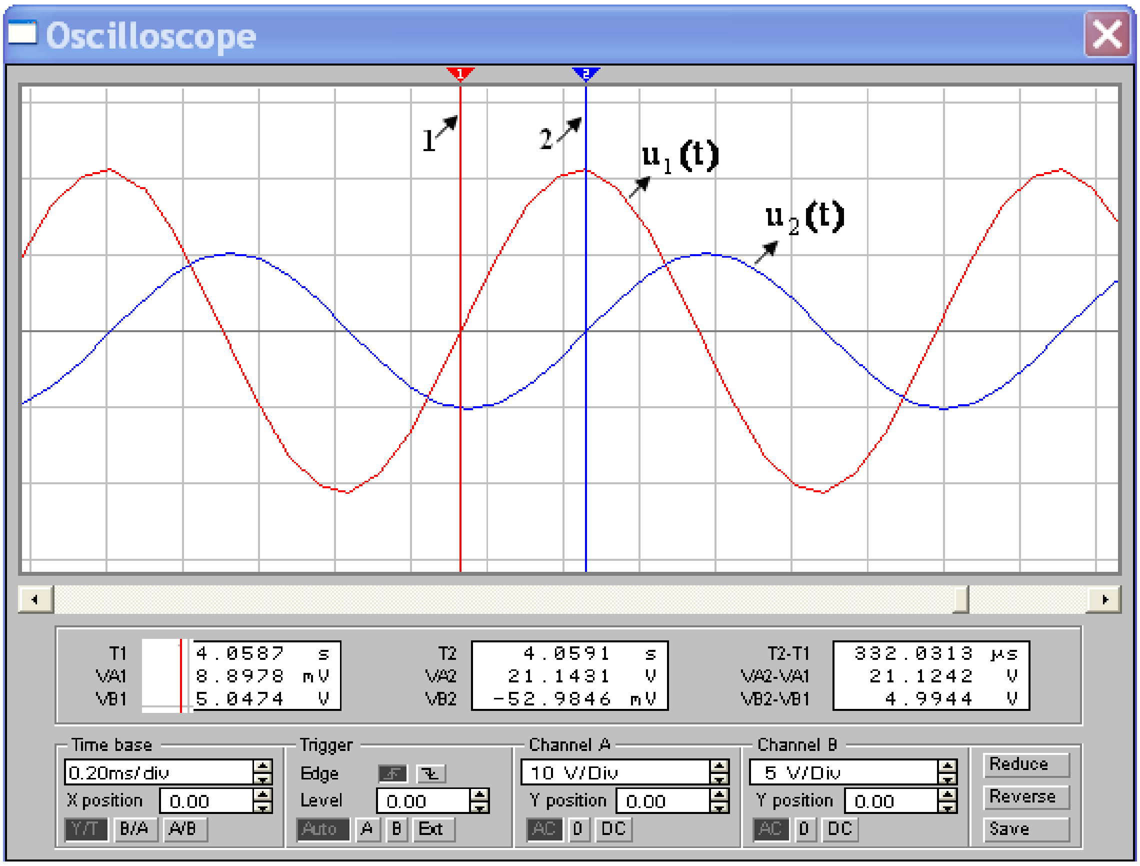


Figure 4.10

5 Laboratory work № 5. Research of passive *K*-type filters using computer simulation

The purpose is to research the frequency characteristics of the attenuation coefficient "*a*" and phase shift coefficient "*b*" for the simplest low-pass (LPF) and high-pass (HPF) passive *K*-type filters.

5.1 Preparation for the laboratory work

5.1.1 Repeat the section "Passive *K*-type filters" of TEC2 discipline.

5.1.2 Answer the questions in written form and do the following assignments:

1) Give the filter classification.
2) Give the concepts of low-pass, high- pass, band-pass and band-stop filters.
3) Give the definition of the secondary filter parameters. What units are they measured in?
4) What is the passband and the attenuation band or stopband of an ideal filter?
5) What is the matched operating mode of the filter?
6) Draw the π-section and the *T*-section schemes of a low-pass filter.
7) Draw the π-section and the *T*-section schemes of a high-pass filter.

8) Draw the graphs of frequency dependences of attenuation *a(f)* and phase *b(f)* coefficients for the LPF.

9) Draw the graphs of frequency dependences of attenuation *a(f)* and phase *b(f)* coefficients for the HPF.

10) Write down the calculation formulas of cutoff frequency f_{cut} and characteristic resistance ρ for the LPF.

11) Write down the calculation formulas of cutoff frequency f_{cut} and characteristic resistance ρ for the HPF.

12) Choose the filter scheme and the elements parameters of filter according to variant (table 5.1).

13) Calculate the cutoff frequency f_{cut} and characteristic resistance ρ for the chosen filter parameters. Write down the calculation results into table 5.2.

5.2 Procedure of carrying out the work

5.2.1 Assemble the circuit shown in figure 5.1. Use the chosen scheme of researched filter according to assignment variant (table 5.1.).

Table 5.1 – Assignment variants for the laboratory work

Variant	Filter type	Filter circuit	U_1, V	L, mH	C, μF
1	LPF	T – section	60	80	1.0
2	HPF	T – section	50	15	0.5
3	LPF	π – section	80	60	1.5
4	HPF	π – section	40	30	0.2
5	LPF	T – section	30	50	0.25

5.2.2 Set the values of U_1, L, C, $R_{load} = \rho$ according to variant (table 5.1.).

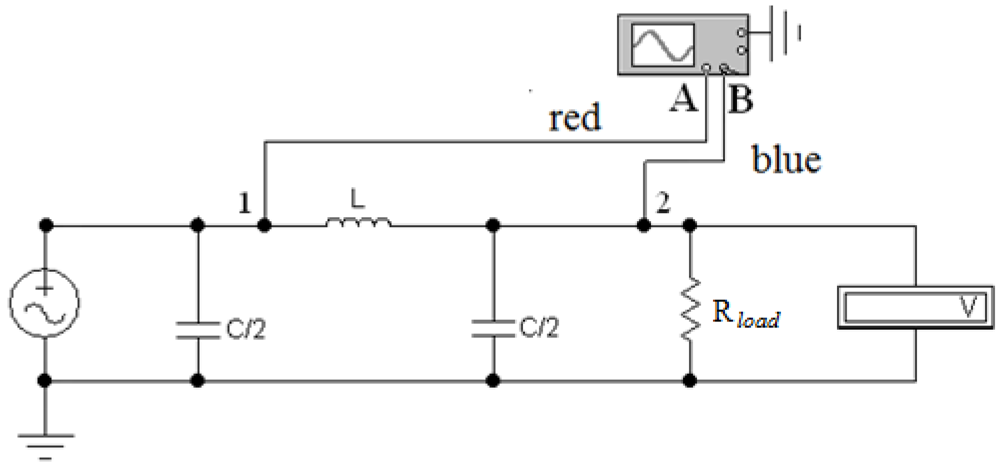
5.2.3 Measure the RMS values of output voltage U_2 across points 2 – 2' and the time phase shift $T_2 - T_1$ between the input $u_1(t)$ and the output $u_2(t)$ voltages for various values of frequency. Change the frequency f of the generator, multiplying by the corresponding coefficient to the cutoff frequency (12 values), using the Table 5.3 for LPF or the Table 5.4 for HPF. The voltage across the input of filter U_1 should be kept constant. Write down the measurement results into table 5.2.

Table 5.2 – Frequency characteristics of the attenuation *a* and phase *b* coefficients

f_{cut} = ; R_{load} = ; U_1 = ; L = ; C = .				
f, Hz	U_2, V	$T_2 - T_1$, s	a, Np	b, deg.
f_1				
...				
f_{12}				

Low-pass filters

П-section scheme of the low-pass filter



T-section scheme of the low-pass filter

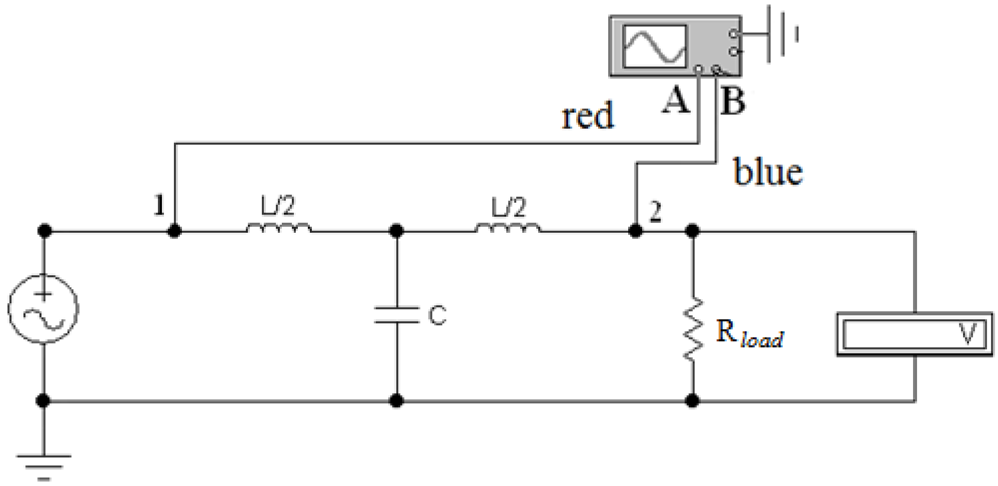
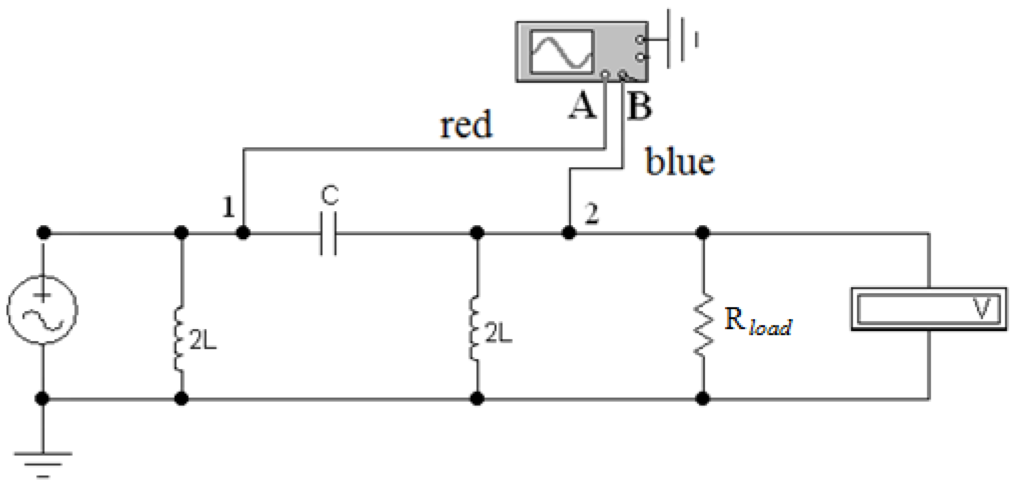


Figure 5.1 – Schemes of low-pass filters

High-pass filters

П-section scheme of high-pass filter.



T-section scheme of high-pass filter

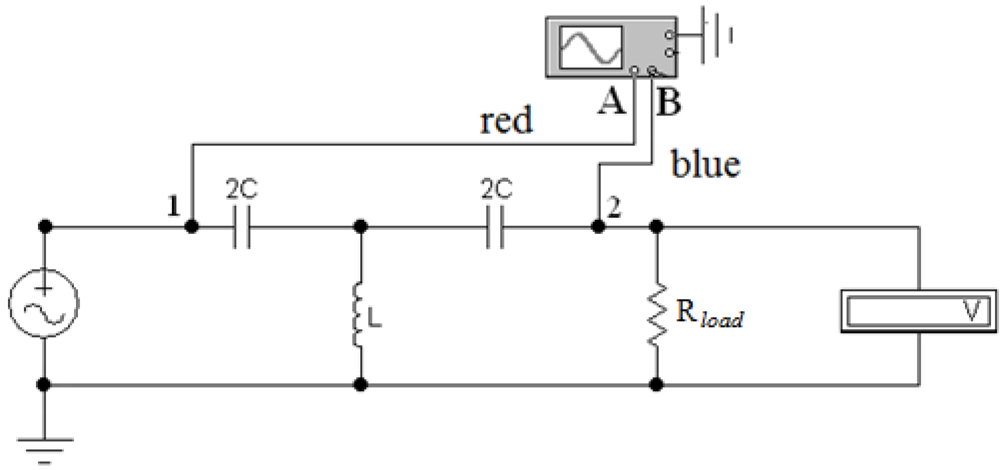


Figure 5.2 – Schemes of high-pass filters

5.3 Processing experimental results

5.3.1 Calculate the attenuation coefficients *a* (*f*) and the phase coefficients *b* (*f*) for each of frequency values. Write down the calculation results into table 5.2.

5.3.2 Draw the frequency dependence graph of attenuation coefficient *a*(*f*) using an experimental data from the Table 5.2, aligning it with the theoretical graph *a*(*f*), which is drawn using data from the Table 5.3 for LPF or the Table 5.4 for HPF.

5.3.3 Draw the frequency dependence graph of phase coefficient *b*(*f*) using an experimental data from the Table 5.2, aligning it with the theoretical graph *b*(*f*), which is drawn using data from the Table 5.3 for LPF or the Table 5.4 for HPF.

5.3.4 Compare the theoretical graphs of *a*(*f*) and *b*(*f*) with those experimental and explain their differences. Analyze the dependencies of *a*(*f*) and *b*(*f*) in the passband and the attenuation band. Make the conclusions on the work done.

Table 5.3 – Theoretical dependences of attenuation and phase coefficients of LPF

f/f_0	0.20	0.40	0.50	0.60	0.70	0.80	1.00	1.10	1.20	1.50	2.00	4.00
a, Np	0	0	0	0	0	0	0	0.90	1.26	1.94	2.74	4.16
b, deg	23	47	60	74	90	106	180	180	180	180	180	180

Table 5.4 – Theoretical dependences of attenuation and phase coefficients of HPF

f/f_0	0.25	0.50	0.67	0.83	0.90	1.00	1.25	1.43	1.67	2.00	2.5	5.0
a, Np	4.10	2.74	1.94	1.26	0.90	0	0	0	0	0	0	0
b, deg	-180	-180	-180	-180	-180	-180	-106	-90	-74	-60	-47	-23

5.4 Methodological guidelines

5.4.1 Relation between complex RMS values of input $\underline{U}_1$ and output $\underline{U}_2$ voltages at the match load of filter can be written as follow:

$$\frac{\dot{U}_1}{\dot{U}_2} = e^{\Gamma_c} = e^{a} \cdot e^{jb}.$$

Attenuation coefficient is determined by the formula:

$$a = \ell n \frac{U_1}{U_2},$$

and the phase shift coefficient $b = \psi_{u1} - \psi_{u2}$, where ψ_{u1} and ψ_{u2} – the initial phases, respectively, of the input and the output voltages.

5.4.2 Cutoff frequency f_{cut} of the LPF is defined by the formula:

$$\omega_{cut} = \frac{2}{\sqrt{L \cdot C}}; \quad f_{cut} = \frac{\omega_{cut}}{2\pi} = \frac{1}{\pi\sqrt{LC}}.$$

And the cutoff frequency f_{cut} of the HPF is defined by the formula:

$$\omega_{cut} = \frac{1}{2\sqrt{L \cdot C}}; \quad f_{cut} = \frac{\omega_{cut}}{2\pi} = \frac{1}{4\pi\sqrt{LC}}.$$

The load resistance R_{load} and the internal resistance of the generator is taken equal to the characteristic resistance:

$$R_{load} = R_{in} = \rho = \sqrt{\frac{L}{C}}.$$

5.4.3 The phase shift coefficient is determined by the phase time shift T_2-T_1 between the similar phases of the input $u_1(t)$ and the output $u_2(t)$ voltages by the formula:

$$b = \psi_{u1} - \psi_{u2} = 360° \cdot f \cdot (T_2 - T_1).$$

The measuring of the initial phase of sinusoidally time-varying voltage is possible by means of the oscilloscope (figure 5.3).

In order to measure the phase shift between the input and output voltages the channel (A) of the oscilloscope should be connected to the point (1) (this wire is colored red) and the channel (B) – to the point (2) (this wire is colored blue). Set the first (red) and the second (blue) survey lines to the same phase point of the input $u_1(t)$ and the output $u_2(t)$ voltages, for example in the start zero point of sinusoidally time-varying function. Read the corresponding time shift interval $\Delta t_{u2} = T_2 - T_1$ between the voltages $u_1(t)$ and $u_2(t)$ on the third (last) subwindow of the oscilloscope beneath the main screen. Calculate the phase shift coefficient *b* by the above formula.

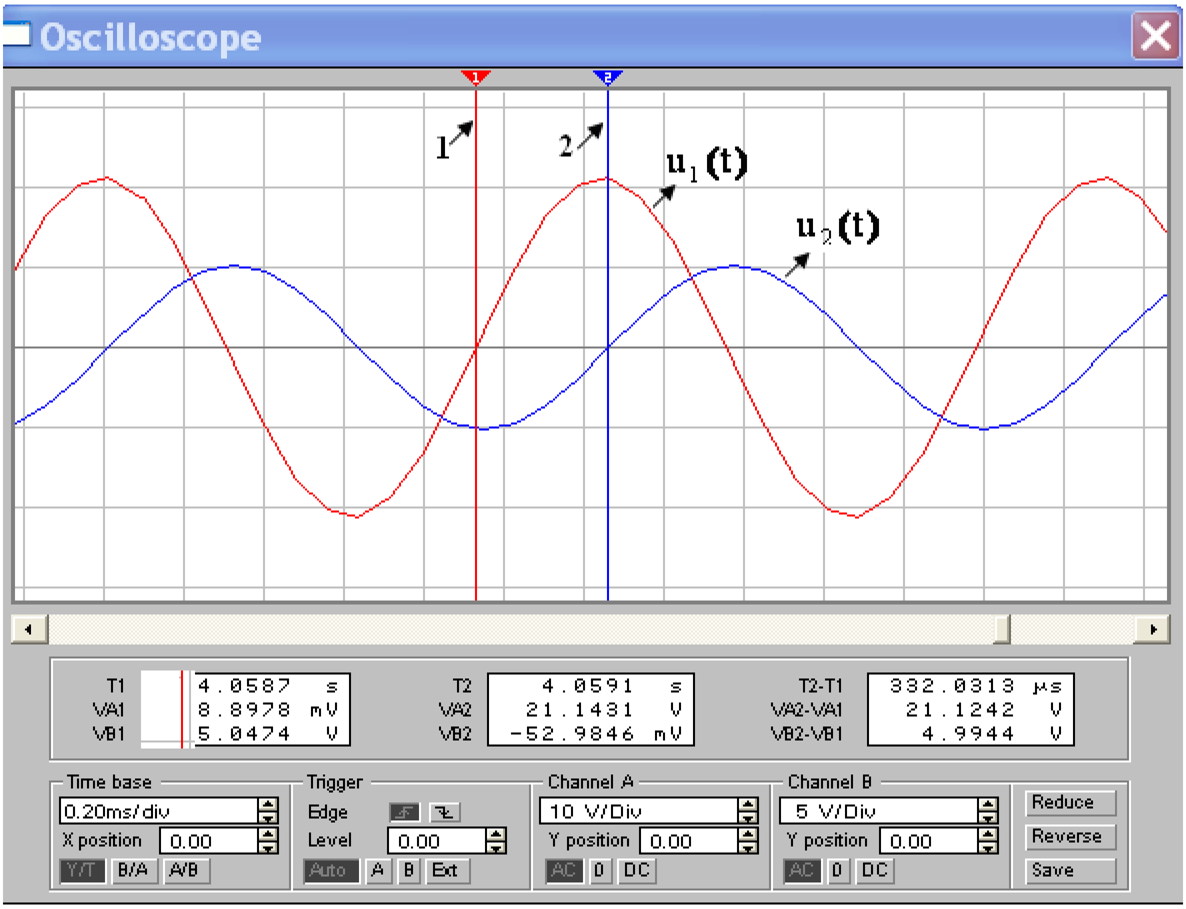


Figure 5.3

6 Laboratory work № 6. Research of various operating modes in a homogeneous lossless line using computer simulation

The purpose is obtaining the skills of studying various operating modes in a homogeneous lossless line with distributed parameters using computer simulation.

6.1 Preparation for the laboratory work

6.1.1 Repeat section “Transmission lines. The homogeneous lossless line”.

6.1.2 Answer the questions in written form and do the following assignments:

1) What quantities are called the primary parameters of a lossless line?
2) Which line is called a lossless line?
3) How are secondary parameters of a lossless line determined?

4) Write down the transfer equations of a lossless line.

5) Write down expressions to determine the propagation coefficient γ and the wave (characteristic) impedance $\underline{Z}_w$ of a lossless line.

6) What load is called matched load? What is the value of input impedance of the line with a matched load equaled?

7) At what load in the lossless line a standing wave mode is observed?

8) Write down the equations of input impedance of the lossless line.

9) Calculate $\underline{Z}_w$, λ, k_1, k_2, L, C according to the variant (table 6.1). Write down initial data and calculation results into table 6.2.

10) Calculate currents, voltages for various operating modes of the lossless line according to a given variant (see methodological guidelines). Write down calculation results into table 6.3 to the “theoretical calculations” row.

Table 6.1 – Assignment variants for the laboratory work

Variant	U_1, V	f, Hz	l, m	L_0, $\frac{\mu H}{m}$	C_0, $\frac{pF}{m}$	$\underline{R}_{load}$
1	10	10^8	0.375	1.57	7.10	800
2	15	10^8	0.500	1.67	6.67	1000
3	20	10^7	3.750	2.00	5.57	200
4	12	10^9	0.100	2.50	4.46	400
5	18	10^8	0.250	1.57	7.10	700
6	25	10^7	2.500	2.00	5.57	300

Table 6.2 – Parameters of the lossless line

U_1, V	f, Hz	l, m	L_0, $\frac{\mu H}{m}$	C_0, $\frac{pF}{m}$	Z_w, Ω	k_1	k_2	L, μH	C, pF	λ, m

Table 6.3 – Determination of initial phase angles of currents and voltages

Operating mode	Kind research	U_1, V	U_2, V	T_2-T_1 s	ψ_{u2}deg	I_1, A	T_2-T_1 s	ψ_{i1} deg	I_2,A	T_2-T_1 s	ψ_{i2} deg
Load mode $\underline{R}_{load}$ =	Theory										
	Exp-t										
Matched load $\underline{Z}_{load} = \underline{Z}_w$	Theory										
	Exp-t										
Short-circuit	Theory										
	Exp-t										
Idling	Theory										
	Exp-t										

Table 6.4 – Input impedance $\underline{Z}_{input}$ and active power at the supply and load points

Operating mode	$\underline{Z}_{input}$, Ω	P_1, W	P_2, W	η, %
Load resistance R_{load} =				
Matched load $\underline{Z}_{load} = \underline{Z}_w$				
Short-circuit				
Idling				

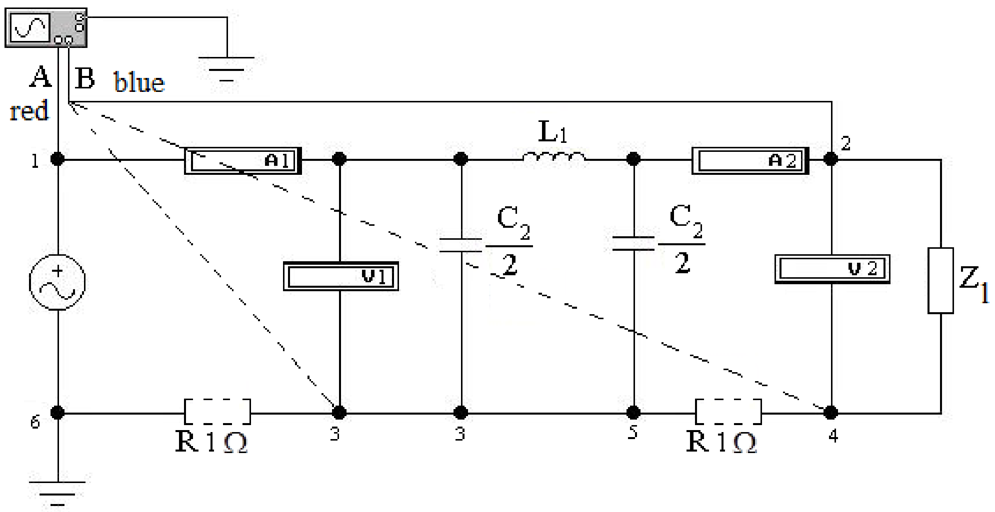


Figure 6.1

6.2 Procedure of carrying out the work

6.2.1 Assemble the electrical circuit by scheme in figure 6.1.

6.2.2 Set the generator RMS voltage value at the input of the line U_1, frequency f, according to a given variant, and precalculated parameters of the equivalent two-port circuit L and C.

6.2.3 Set the load resistance R_{load}, according to the variant given. Measure the RMS voltage value of an output voltage of a lossless line U_2, the RMS values of the input I_1 and at the output I_2 currents of the line. Measure the time shifts T_2 -T_1 between the same phases of the voltages U_1 and U_2, between the voltage U_1 and the current I_1 and between the voltage U_1 and the current I_2. Write down the obtained results into table 6.3 in the "Experiment" row.

6.2.4 Set the matched load $\underline{Z}_{load} = \underline{Z}_w$ at the end of a lossless line (matched load operating mode). Measure the RMS value of output voltage U_2, the RMS values of input I_1 and output I_2 currents of a lossless line, the initial phase angle of the output voltage ψ_{u2} and the initial phase angles of the input ψ_{i1} and output ψ_{i2} currents of a lossless line. Write down the results into table 6.3 in the "Experiment" row.

6.2.5 Set a jumper between the output terminals of a lossless line (short-circuit mode U_2=0). Measure the RMS values of input I_1 and output I_2 currents, the initial phase angles of input ψ_{i1} and output ψ_{i2} currents of a lossless line. Write down the results into table 6.3 in the "Experiment" row.

6.2.6 Remove jumper from the output terminals of a lossless line (idling mode I_2=0). Measure the RMS values of the output voltage U_2 and the input current I_1 of a lossless line, the initial phase angles of the output voltage ψ_{u2} and the input current ψ_{i1} of a lossless line. Write down the results into table 6.3 in the "Experiment" row.

6.3 Processing experimental results

6.3.1 Calculate the initial phase angle of the output voltage ψ_{u2} and the initial phase angles of the input ψ_{i1} and output ψ_{i2} currents of a transmission line. Write down the results into table 6.3 in the "Experiment" row.

6.3.2 Write down the complex RMS values of the voltages $\dot{U}_1$, $\dot{U}_2$ and the currents $\dot{I}_1$, $\dot{I}_2$ for all studied modes.

6.3.3 Calculate the input impedances of a lossless line $\underline{Z}_{1in}$, the active power at the beginning of the transmission line P_1, at the end of the line P_2 and the line efficiency η for all researched operating modes by using the experimental data. Write down the obtained results into table 6.4.

4.3.4 Analyze the effect of the value of load resistance on $\dot{U}_2$, $\dot{I}_1$, $\dot{I}_2$, on the input resistance of the line $\underline{Z}_{1in}$ and on the active power at the beginning P_1 and end P_2 of the line. Make conclusions on the work done.

6.4 Methodological guidelines

For the high-frequency short-length lines the conditions $R_0 << \omega L_0$ and $G_0 << \omega C_0$ are satisfied, so with a sufficiently high accuracy for practical purposes the resistance R_0 can be neglected as well as the leak conductivity G_0. This short-length lines can be considered as a lossless line.

At study of various modes in the line by computer simulation, the actual line is replaced by an equivalent symmetrical two-port circuit, which can be represented by a symmetrical T- or π-section.

The actual lossless line is represented by an equivalent symmetrical two-port circuit in form of π-section shown in figure 6.2.

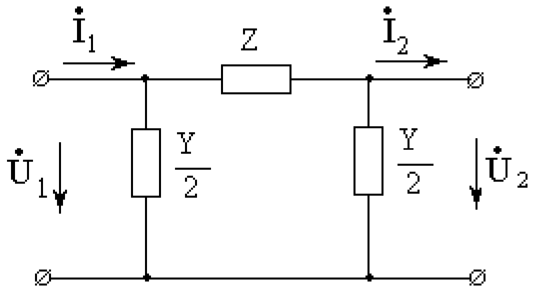


Figure 6.2

Impedance $\underline{Z}_1$ and conductivity $\underline{Y}_2$ for symmetrical π-section circuits are:

$\underline{Z} = j\omega L_0 l k_1 = j\omega L$;

$\underline{Y} = j\omega C_0 l k_2 = j\omega C$;

$$\begin{cases} L = L_0 \cdot l \cdot k_1 \\ C = C_0 \cdot l \cdot k_2 \end{cases},$$

where l – the length of the lossless line;

L_0, C_0 – primary parameters of the lossless line;

$k_1 = \frac{\sin \beta l}{\beta l}$, $k_2 = \frac{2(1-\cos\beta l)}{\beta l \cdot \sin \beta l}$ – coefficients;

ω = 2π*f* – angular frequency, $\beta = \omega\sqrt{L_0 C_0}$ - phase coefficient, units of βl is radians.

The currents and voltages for various operating modes of the line are calculated by the following formulas:

Arbitrary load operating mode:

$$\dot{U}_2 = \frac{\dot{U}_1}{\cos\beta l + j(\underline{Z}_w / R_{load})\sin\beta l};$$

$$\dot{I}_2 = \dot{U}_2 / R_{load};$$

$$\dot{I}_1 = \dot{I}_2(\cos\beta l + j\frac{R_{load}}{\underline{Z}_w}\sin\beta l).$$

Idling mode:

$$\dot{U}_2 = \frac{\dot{U}_1}{\cos\beta l}; \quad \dot{I}_2 = 0; \quad \dot{I}_1 = j\frac{\dot{U}_2}{\underline{Z}_w}\sin\beta l.$$

Short circuit mode:

$$\dot{U}_2 = 0; \quad \dot{I}_2 = \frac{\dot{U}_1}{j\underline{Z}_w \sin\beta l}; \quad \dot{I}_1 = \dot{I}_2 \cos\beta l.$$

Matched load operating mode:

$$\underline{Z}_{load} = \underline{Z}_w; \quad \dot{U}_2 = \dot{U}_1 e^{-j\beta l}; \quad \dot{I}_2 = \dot{U}_2 / \underline{Z}_w; \quad \dot{I}_1 = \dot{U}_1 / \underline{Z}_w .$$

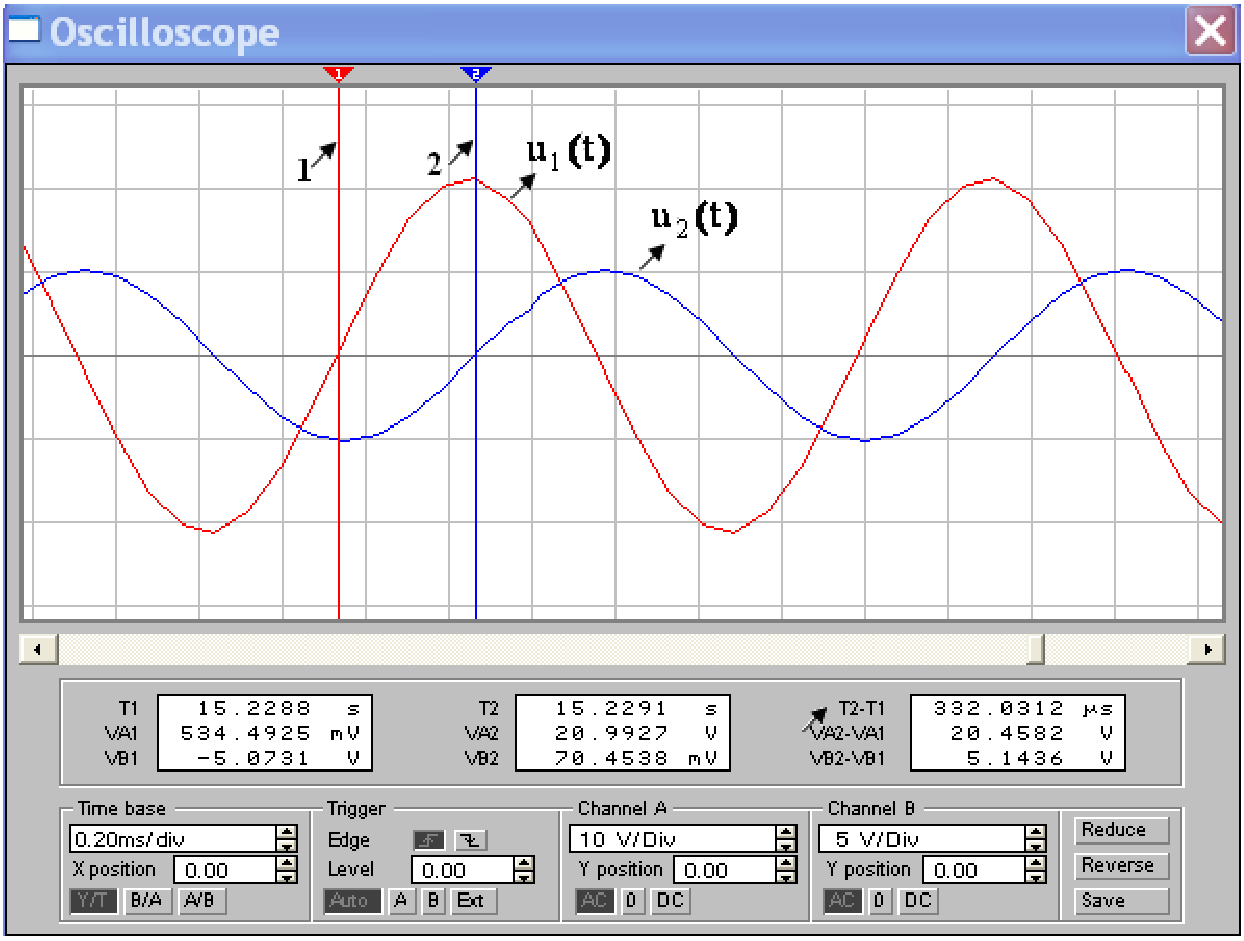


Figure 6.2

7 Laboratory work № 7. Research of a homogeneous lossless line using computer application

The purpose is obtaining the skills of studying various operating modes in a homogeneous lossless line with distributed parameters using computer application.

7.1 Preparation for the laboratory work

7.1.1 Repeat section “Transmission lines. The homogeneous lossless line” of TEC2 discipline.

7.1.2 Answer the questions in written form and do the following assignments:

1) What quantities are called the primary parameters of a lossless line?
2) Which line is called a lossless line?

3) How are secondary parameters of a lossless line determined? Calculate, according to the given variant, the wave impedance, the phase shift coefficient, the wavelength.

4) Write down expressions to determine the propagation coefficient γ and the wave (characteristic) impedance $\underline{Z}_w$ of a lossless line.

5) Write down the transfer equations of a lossless line.

6) What load is called matched load? What is the value of input impedance of the line with a matched load equaled?

7) At what load in the lossless line a standing wave mode is observed?

8) How is the input impedance of a short-circuited lossless line determined?

9) How is the input impedance of an open lossless line determined?

10) Draw a graph of the distribution of the effective values of voltage and current in the matched mode.

11) Draw a graph of the distribution of the effective values of voltage and current in idle and short circuit modes.

Table 7.1 – Parameters of the lossless line

Variant	U_1, V	f, MHz	l, cm	L_0, $\frac{\mu H}{m}$	C_0, $\frac{pF}{m}$	$\underline{R}_{load}$, Ω
1	10	100	250	1.57	7.1	900
2	15	100	200	1.67	6.67	700
3	20	50	1000	2.0	5.57	300
4	12	500	100	2.5	4.46	500
5	18	200	200	1.57	7.1	800
6	25	80	300	2.0	5.57	400

7.2 Procedure of carrying out the work

7.2.1 Launch the program “Lossless Line” by clicking the left mouse button on the shortcut on the desktop of the computer (figure 7.1).

Figure 7.1

The main application window opens (figure 7.2).

7.2.2 Choose the operating mode of the line “Idle”.

7.2.3 Set, according to the variant, the line parameters: the length of the line, the primary parameters of the line L_0, C_0.

7.2.4 Set, according to the variant, the effective value and the frequency of the voltage at the beginning of the line.

7.2.5 Write down the values of the wave impedance, wavelength, and phase shift coefficient.

7.2.6 Measure the voltage, current, power and input impedance at various points of the line in the “Idle” mode, write down the obtained values into table 7.2.

7.2.7 Click on the button to plot the current values of voltage and current and save the resulting graphs. Click on the button to plot the instantaneous values of voltage and current, plot the voltage and current graphs corresponding to different time points, and save the obtained graphs.

7.2.8 Choose the operating mode of the “Short circuit” line.

7.2.9 Measure the voltage, current, power and input impedance at different points of the line in the “Short-circuit” mode, write down the values into table 7.3.

Click on the button to plot the current values of voltage and current and save the resulting graphs. Click on the button to plot the instantaneous values of voltage and current, plot the voltage and current graphs corresponding to different time points, and save the obtained graphs.

7.2.10 Choose the operating mode of the “Matched load” line.

7.2.11 Measure the voltage, current, power and input impedance at various points of the line in the “Matched load” mode, write down the obtained values into table 7.4.

Click on the button to plot the current values of voltage and current and save the resulting graphs. Click on the button to plot the instantaneous values of voltage and current, plot the voltage and current graphs corresponding to different time points, and save the obtained graphs.

7.2.12 Choose the operating mode of the “Load mode” line.

7.2.13 Set, according to the variant, the load resistance.

7.2.14 Measure the voltage, current, power and input impedance at various points of the line in the “ Load mode “ mode, write down the obtained values into table 7.5.

Click on the button to plot the current values of voltage and current and save the resulting graphs. Click on the button to plot the instantaneous values of voltage and current, plot the voltage and current graphs corresponding to different time points, and save the obtained graphs.

Table 7.2 - Idling mode

x, cm									
U, V									
I, A									
P, W									
z_{in}, Ω									

Table 7.3 - Short circuit mode

x, cm									
U, V									
I, A									
P, W									
z_{in}, Ω									

Table 7.4 - Matched load mode

x, cm									
U, V									
I, A									
P, W									
z_{in}, Ω									

Table 7.5 - Load mode

x, cm											
U, V											
I, A											
P, W											
z_{in}, Ω											

7.3 Processing experimental results

7.3.1 Compare the calculated values of the wave impedance, wavelength, and phase shift coefficient with those obtained on a PC.

7.3.2 Based on the measurement results for the “Idle” mode, plot the effective values of voltage and current and compare it to the graphs obtained with the computer model; plot the input impedance graph of the line.

7.3.3 For the “Idle” mode, analyze the obtained dependences of the effective values of voltage, current, input impedance and power from the distance from the end of the line.

7.3.4 For the “Idle” mode, analyze the distribution of the instantaneous values of voltage and current along the line.

7.3.5 Based on the measurement results for the “Short circuit” mode, plot the effective values of voltage and current and compare it to the graphs obtained with the computer model; plot the input impedance graph of the line.

7.3.6 For the “ Short circuit “ mode, analyze the obtained dependences of the effective values of voltage, current, input impedance and power from the distance from the end of the line.

7.3.7 For the “Short circuit” mode, analyze the distribution of the instantaneous value of voltage and current along the line.

7.3.8 Based on the measurement results for the “Matched load” mode, plot the effective values of voltage and current and compare it to the graphs obtained with the computer model; plot the input impedance graph of the line.

7.3.9 For the “Matched load” mode, analyze the obtained dependences of the effective values of voltage, current, input impedance and power from the distance from the end of the line.

7.3.10 For the “Matched load” mode, analyze the distribution of the instantaneous value of voltage and current along the line.

7.3.11 Based on the measurement results for the “Load” mode, plot the effective values of voltage and current and compare it to the graphs obtained with the computer model; plot the input impedance graph of the line.

7.3.12 For the “Load” mode, analyze the obtained dependences of the effective values of voltage, current, input impedance and power from the distance from the end of the line. For the “Load” mode, analyze the distribution of the instantaneous value of voltage and current along the line.

7.4 Methodological guidelines

7.4.1 Description of the interface of the program “Line”.

The main window of the program interface (figure 7.2) contains a work area and two side panels on which measuring instruments and control buttons are located.

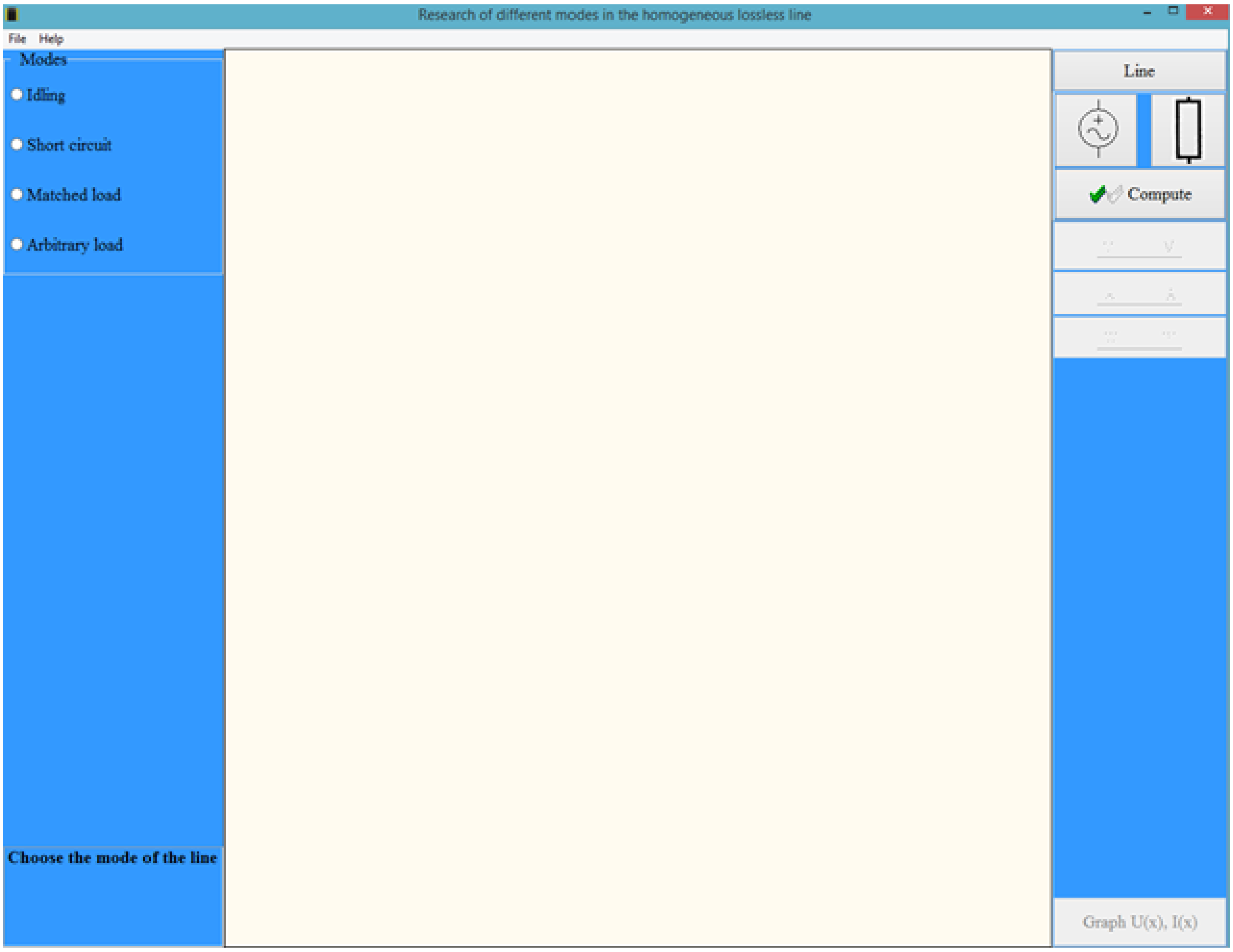
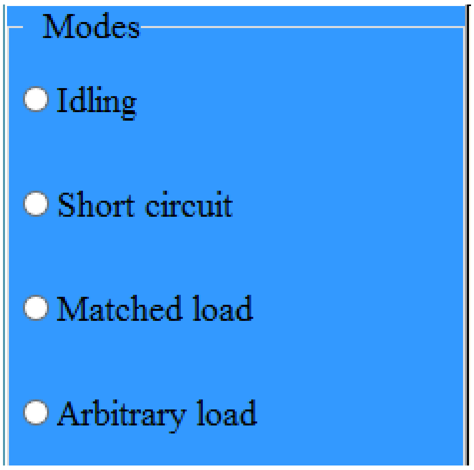
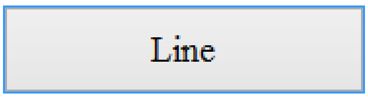


Figure 7.2 – Main window of the program interface

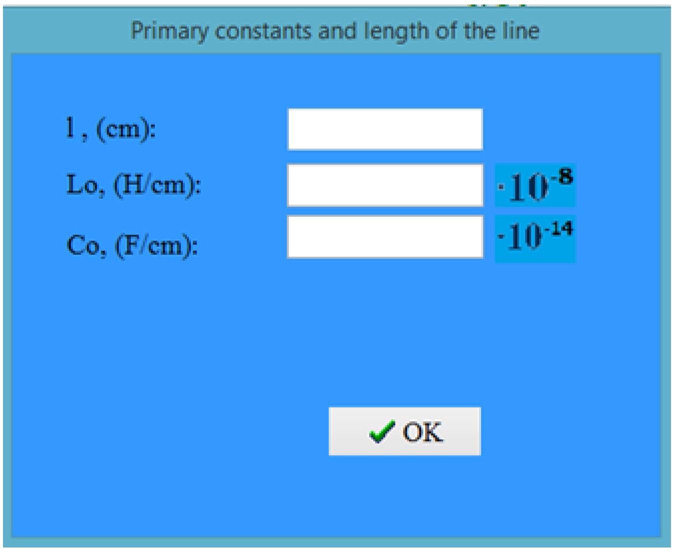
Panel of a group of buttons for choosing the operating mode of the line.



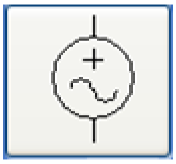
Button to enter the length of the line and primary parameters.



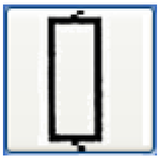
Window for entering the length of the line and its primary parameters.



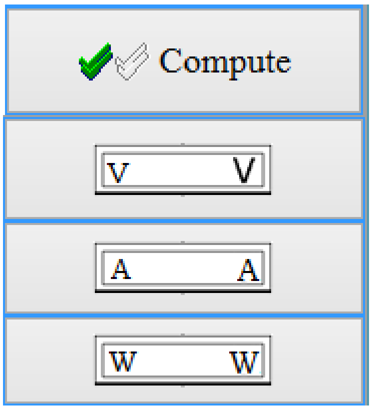
Button for input voltage and frequency of power source.



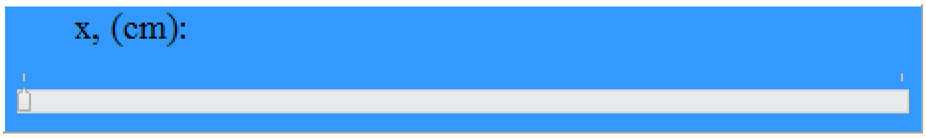
Button for inputting the load resistance value.



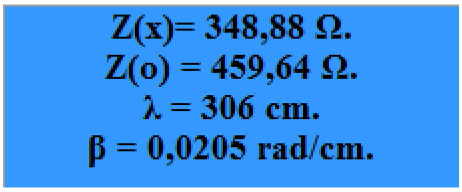
Buttons for determining the voltage, current and power in a given section of the line.



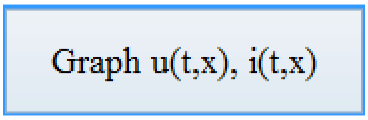
Slider for setting a given section of the line (the distance is measured from the beginning of the line).



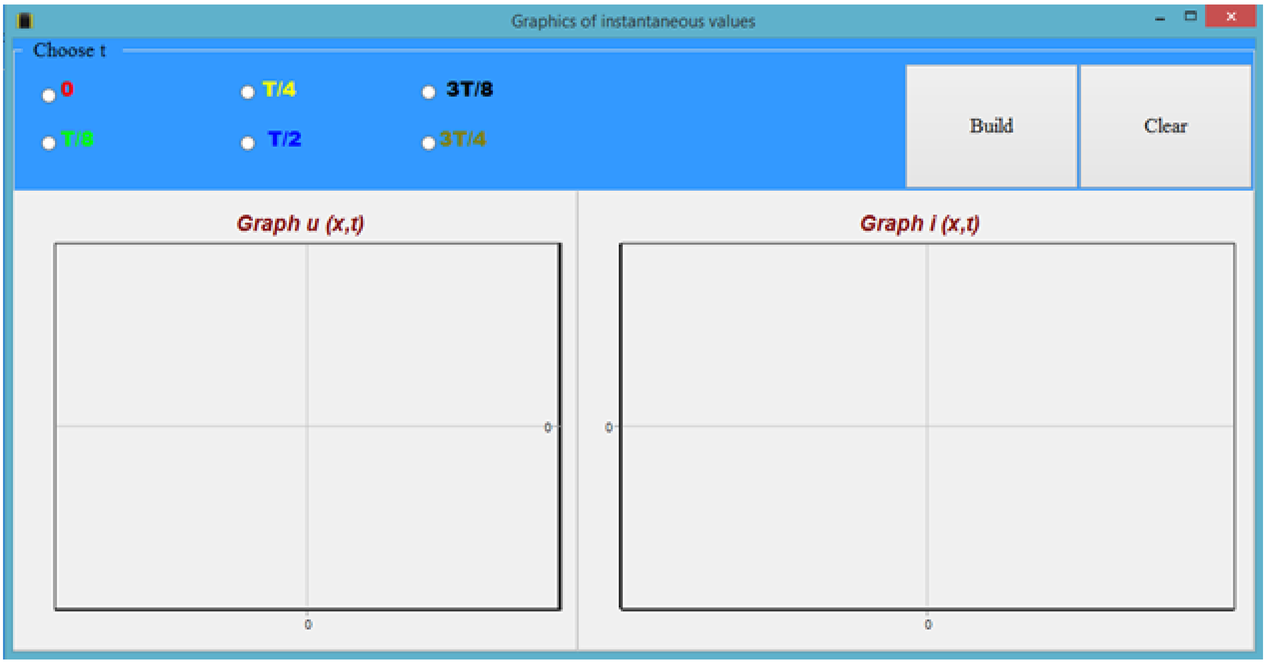
The area at the bottom of the right panel, where the values of wave and input resistances, wavelength and phase coefficient are displayed.



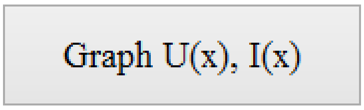
Button to open a window in which graphs of the instantaneous voltage and current values are plotted.



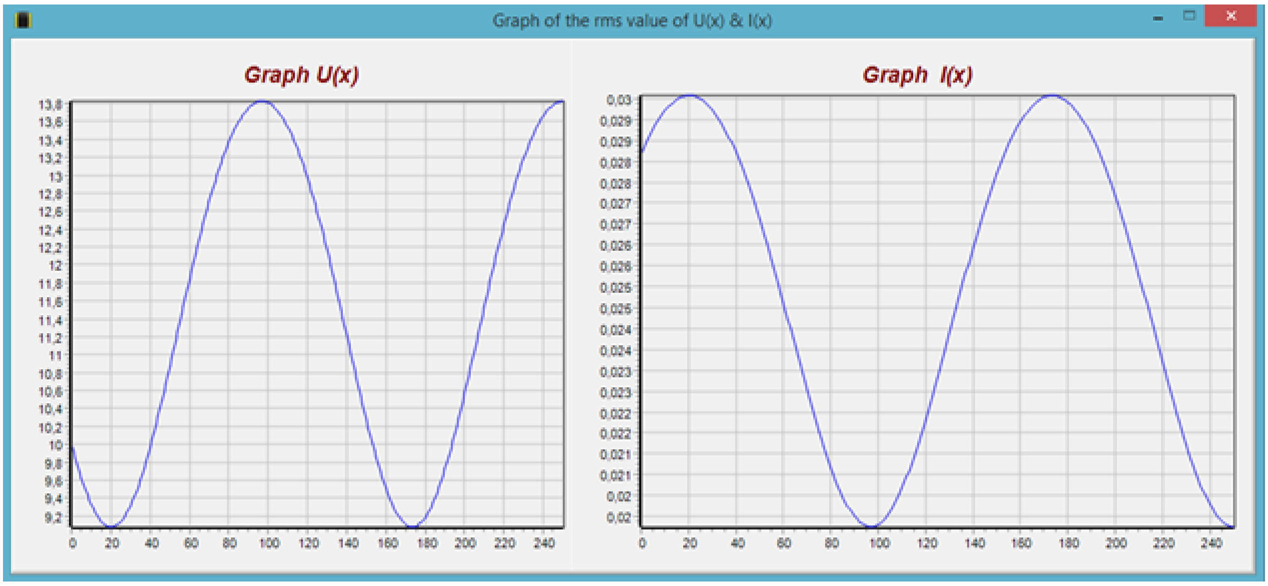
A window in which the graphs of the instantaneous values of voltage and current are plotted.



Button to open a window in which the graphs of the current values of voltage and current are plotted.



A window in which the graphs of the current values of voltage and current are plotted.



7.4.2 Methodological guidelines for carrying out of the laboratory work.

1. We choose the operating mode of the line, for example, "Load mode". In the working area of the main window, a two-wire line diagram appears in the preset mode, all control buttons become active (figure 7.3).

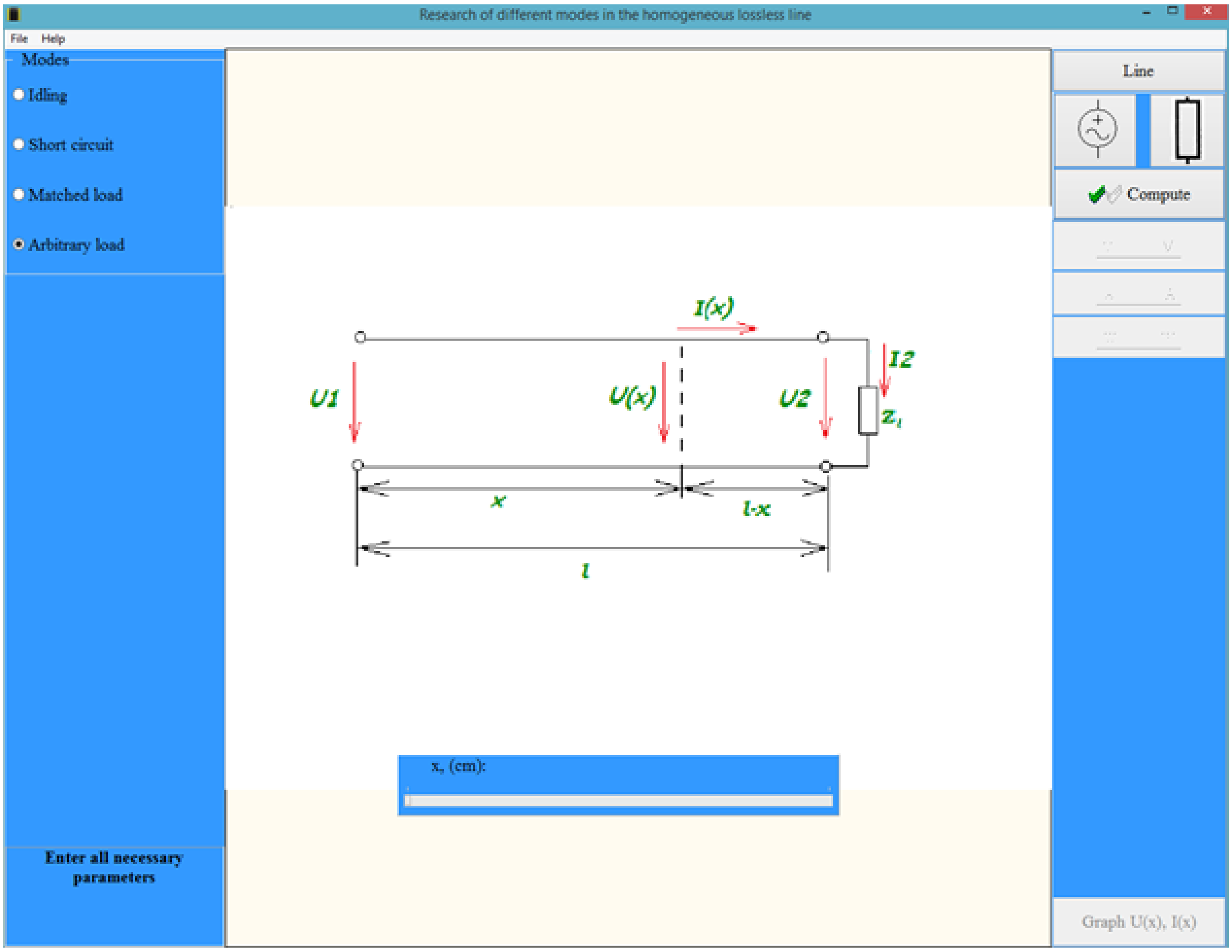
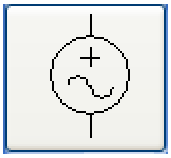


Figure 7.3 – Main window of the program in loading mode

2. To open the “Primary parameters” window, click on the “Line” button. In the window that opens, enter the length of the line and its primary parameters (figure 7.4) and click “OK”.

3. To set the voltage and frequency of the source, click on the button:



In the window that opens, enter the voltage value and frequency of the source (figure 7.5).

4. To measure the power, the effective values of voltage and current at different points of the line, set the slider at the desired point of the line and click on the buttons to determine the voltage, current and power in a given section of the line (figure 7.6).

5. To obtain a graph of the distribution of the current values of voltage and current along the line, click on the button “Graphs U(x), I(x)” (figure 7.7).

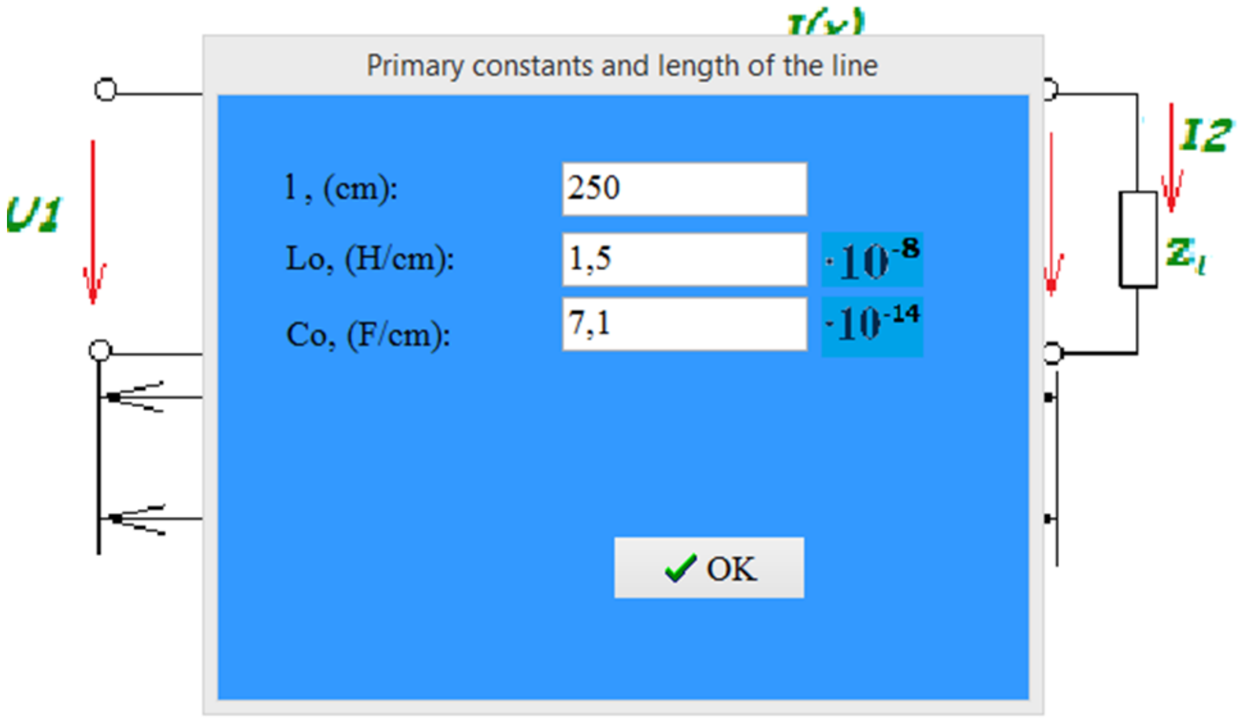


Figure 7.4 – Entering line parameters

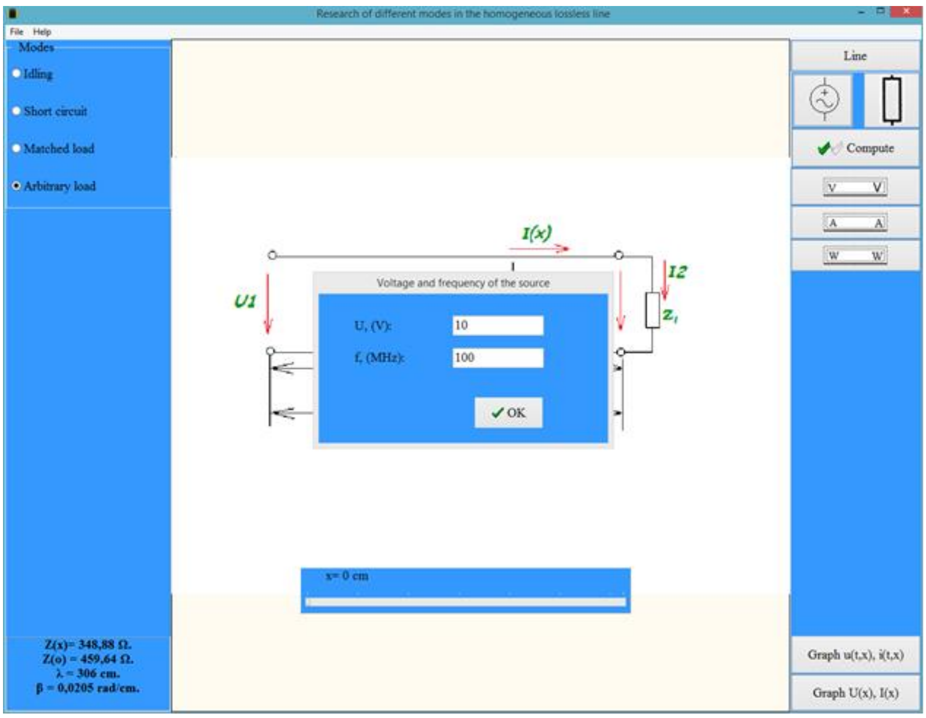


Figure 7.5 – Entering the parameters of the voltage source

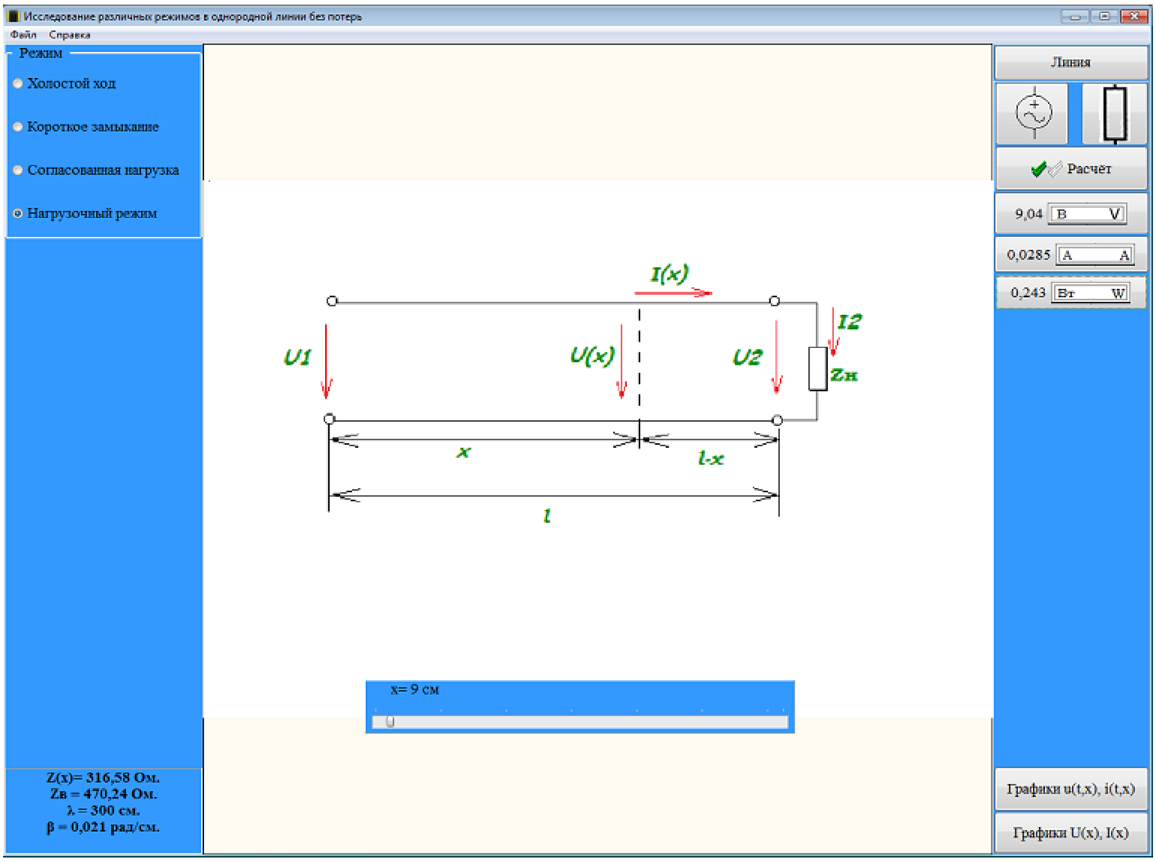


Figure 7.6 – Determination of voltage, current, power and impedance

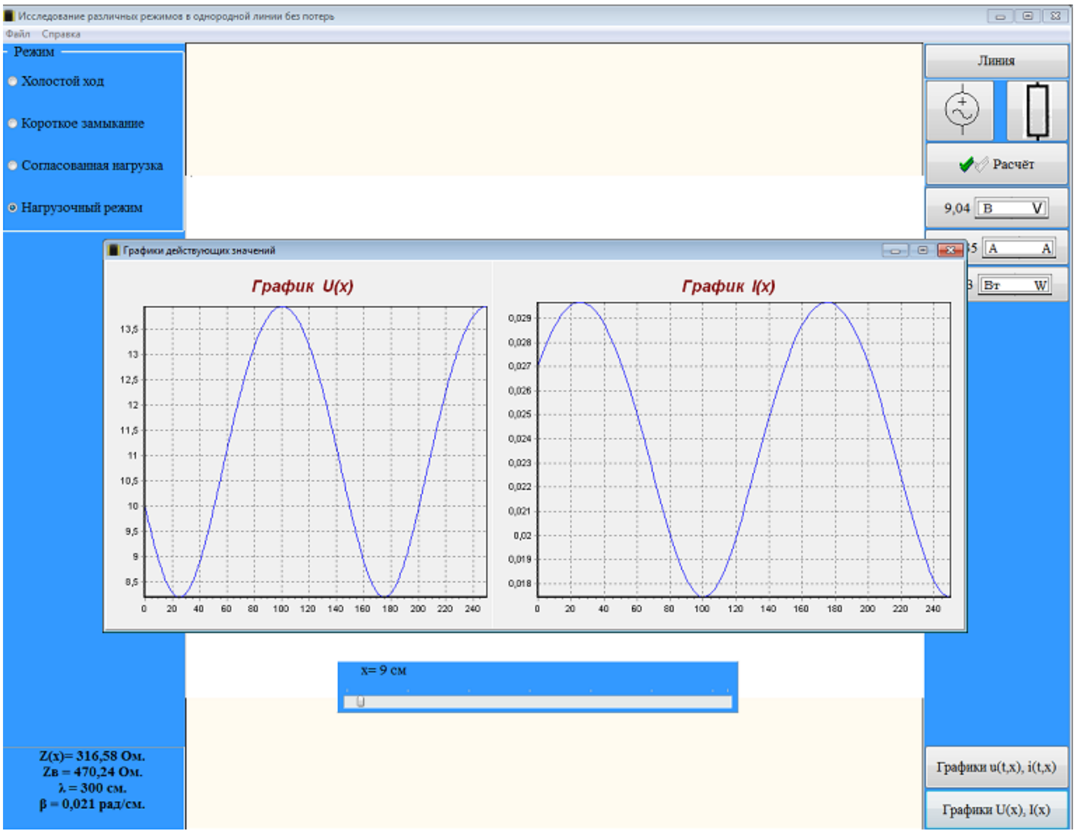


Figure 7.7 – Graphs of the effective voltage and current

6. To obtain the graphs of the distribution of the instantaneous values of voltage and current along the line at different time moments, click on the “Graphs” *u*(t, x), *i*(t, x) graphs, in the resulting window, click on the “Get graphics” button and then in sequential order buttons corresponding to different time points: 0, T/8, T/4, T/2, 3T/8, 3T/4 (figure 7.8).

7. The values of the input and wave impedances, wavelength and phase shift coefficient are displayed at the bottom of the right panel.

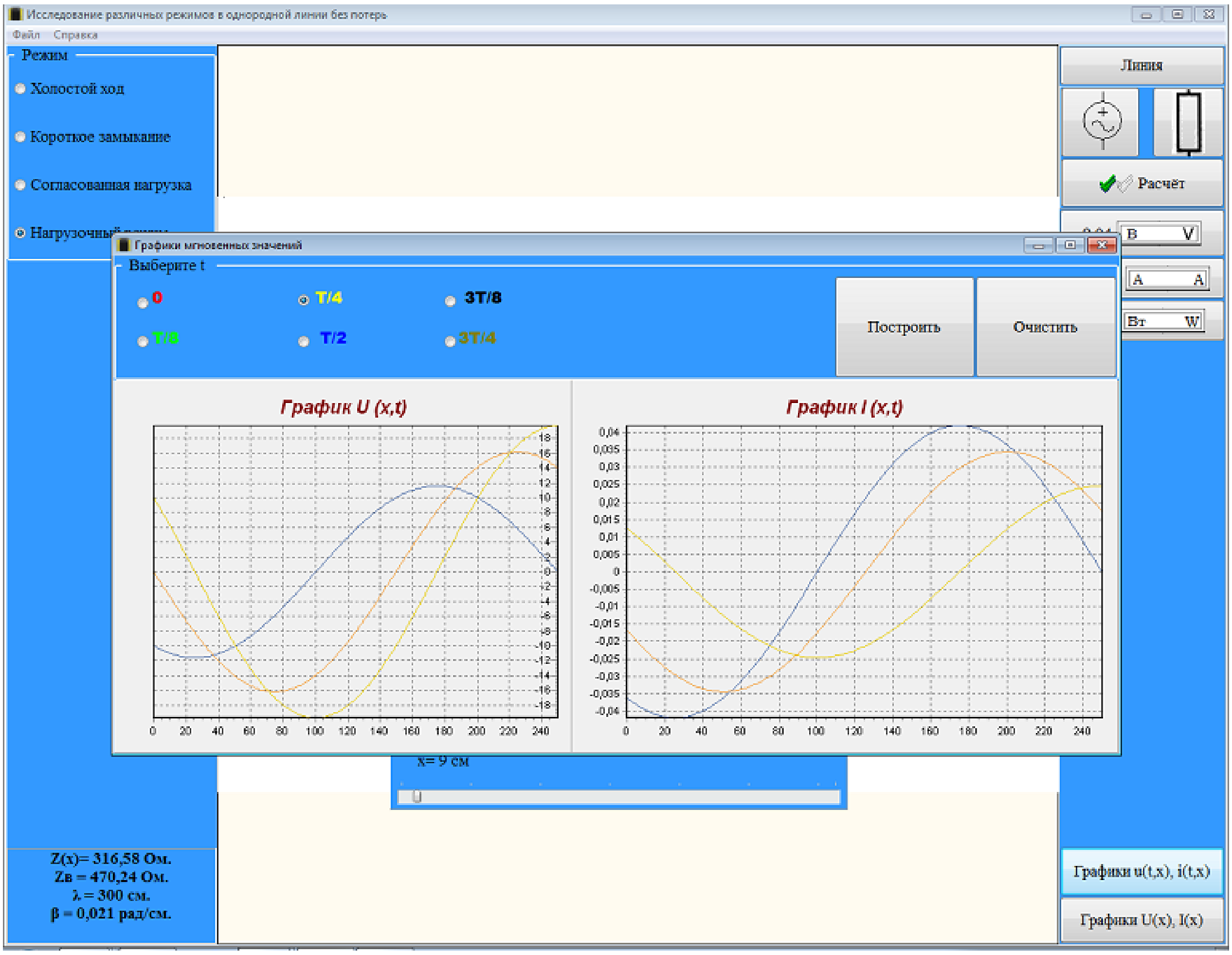


Figure 7.8 – Graphs of the instantaneous voltage and current values

8 Laboratory work № 8. Analysis of a DC electric circuit with non-linear elements

The purpose of laboratory work is to obtain the skills of experimental research of electrical DC circuits with nonlinear elements.

8.1 Preparation for the laboratory work

8.1.1 Repeat section "Nonlinear electric DC circuits".

8.1.2 Answer the questions in writing and do the following assignments:

1) What resistive elements are called non-linear?

2) Which non-linear elements are called symmetric and which ones are called asymmetric? Show their current-voltage characteristics.

3) What is the difference between the static and the differential resistances of nonlinear elements?

4) Give an example of the graphical calculation method of the electric circuit with one EMF source and series connection of nonlinear and linear resistive elements (figure 8.2).

5) How is the operating point of a nonlinear resistive element determined?

6) Give an example of the graphical calculation method of the electric circuit with one EMF source and parallel connection of nonlinear and linear resistive elements (figure 8.3).

7) Give an example of the graphical calculation method of the branched electric circuit with two EMF sources and NE (figure 8.4).

8.2 Procedure of carrying out the work

8.2.1 Get the readings for the construction of the current-voltage characteristics of two non-linear elements and one linear element (as directed by the teacher) according to the scheme in figure 8.1. Fill in the Table 8.1 for each nonlinear element.

8.2.2 Assemble an electrical circuit with a series connection of nonlinear and linear resistive elements (figure 8.2). Set the value of the input voltage U and the linear resistance R, according to a predetermined variant (table 8.1). Write down the readings of all measuring instruments into table 8.3 (in the "experiment" row).

8.2.3 Assemble an electrical circuit with a parallel connection of two nonlinear resistive elements (figure 8.3). Set the value of the input voltage U and the linear resistance R, according to a predetermined variant (table 8.1). Write down the readings of all measuring instruments into table 8.4 (in the "experiment" row).

8.2.4 Assemble a circuit with two sources of EMF. Set the value of the input voltage U and the linear resistance R, according to a predetermined variant (table 8.1). Write down the measurement results into table 8.5 (in the "experiment" row).

Table 8.1

Variant	1	2	3	4	5
U, V	12	10	8	15	10
E_1, V	20	15	20	10	16
E_2, V	10	20	12	20	20
R, Ω	60	70	80	50	90

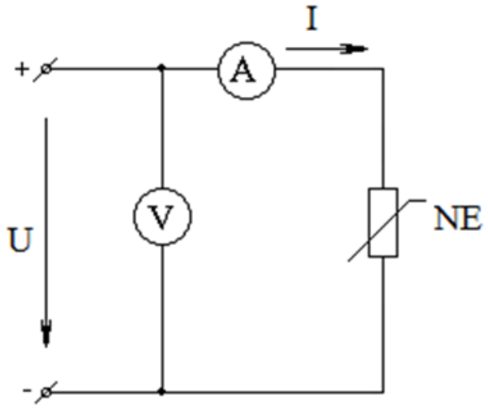


Figure 8.1

Table 8.2 – A-V characteristics

NE_1	U, V					
	I, mA					
NE_2	U, V					
	I, mA					
R	U, V					
	I, mA					

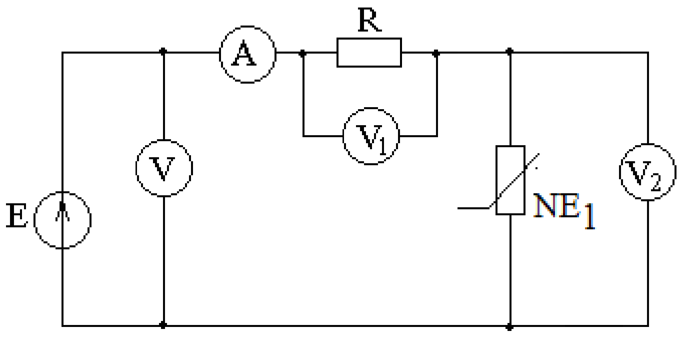


Figure 8.2

Table 8.3 – Series connection elements

Type of research	U, V	U_1, V	U_2, V	I, mA
Experiment				
Graphical calculation				

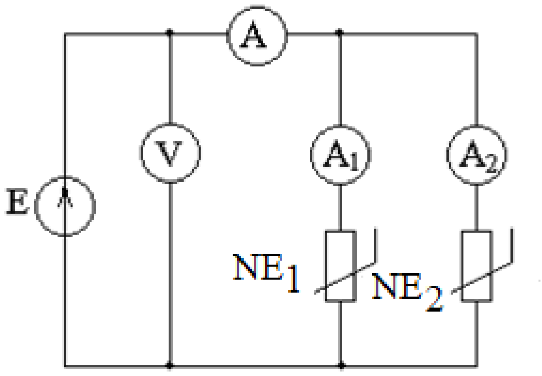


Figure 8.3

Table 8.4 - Parallel connection elements

Type of research	*U*, V	*I*, mA	I_1, mA	I_2, mA
Experiment				
Graphical calculation				

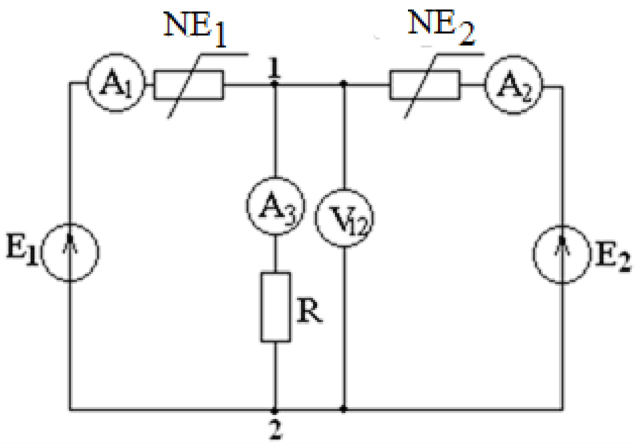


Figure 8.4

Table 8.5- Branched nonlinear electrical circuit

Type of research	E_1,V	E_2,V	U_{12},V	I_1,mA	I_2,mA	I_3,mA
Experiment						
Graphic calculation						

8.3 Processing experimental results

8.3.1 Draw current-voltage characteristics of two nonlinear elements and linear resistive elements.

8.3.2 Make the graphical calculation for the electrical circuit (figure 8.2, p. 8.2.2), write down the results into table 8.3 (in the row - "graphical calculation"), compare the calculated values with the experimental ones.

8.3.3 Determine the operating point of a nonlinear element. Calculate the static and differential resistance at the operating point of the *NE*.

8.3.4 Make the graphical calculation for the electrical circuit (figure 8.3, p. 8.2.3), write down the results into table 8.4 (in the row - “graphical calculation”), compare the calculated values with the experimental ones.

8.3.5 Make the graphical calculation for the electrical circuit (figure 8.4, p. 8.2.4), write down the results into table 8.5 (in the row - “graphical calculation”), compare the calculated values with the experimental ones.

8.3.6 Make conclusions about the work done: compare the experimental values of voltages and currents with the calculated ones, estimate the accuracy of the graphical method for calculating nonlinear electrical circuits.

8.4 Methodological guidelines

A nonlinear resistive element (NE) is an element with a nonlinear current-voltage characteristic (IVC). Important parameters of the nonlinear resistive element are its resistance: static and differential.

The static resistance is determined by the formula:

$$R_{st} = \frac{U_0}{I_0} = m_R tg\beta ,$$

where U_0, I_0 are the constant voltage and current at the operating point a on the IVC of the NE;

β is the slope angle of the straight line to the axis of currents passing through the origin and the operating point on the IVC of the NE (figure 8.5);

$m_R = \frac{m_U}{m_I}$ is resistance scale;

m_U is voltage scale;

m_I is current scale.

$$R_d = \frac{dU}{dI} = m_R tg\alpha ,$$

where α is the angle of inclination of the tangent drawn at the operating point of the current-voltage characteristic to the axis of the currents.

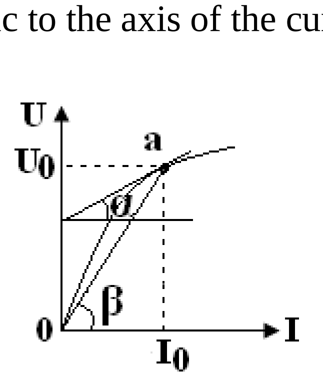


Figure 8.5

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THEORY OF ELECTRICAL CIRCUITS 2

Methodological guidelines and assignments for laboratory works for the following specialties: 5B071900 – Radio engineering, electronics and telecommunications; 5B071600 – Instrumentation

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