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ALMATY UNIVERSITY OF POWER ENGINEERING & TELECOMMUNICATIONS

Department of Theoretical electrical engineering

CIRCUITS WITH DISTRIBUTED AND LUMPED PARAMETERS THEORY OF TWO-PORT CIRCUITS

Methodological guidelines and assignments for laboratory works
for the 5B070200 – "Automation and control" baccalaureate specialty students

Almaty 2017

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Methodological guidelines and assignments for preparing, execution and design of laboratory works on “Circuits with the distributed and lumped parameters” (CwD&LP) discipline are provides.

There are four laboratory works on the main section of the CwD&LP discipline as following: two-port circuits, passive filters of *K*-type, lines with distributed parameters with losses and lossless. Each laboratory work includes the following sections: purpose of the work, preparation for the laboratory work, procedure of carrying out the work, processing the results of experiments, methodological guidelines and revision questions.

Methodological guidelines and assignments are intended for the students who studying in the English language by the 5B070200 – “Automation and control” baccalaureate specialty.

18 illustrations, 16 tables, 6 items of references.

Reviewer: PhD B. I. Tuzelbayev

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CIRCUITS WITH DISTRIBUTED AND LUMPED PARAMETERS
THEORY OF TWO-PORT CIRCUITS

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Contents

Introduction

Laboratory researches are of great importance for the quality of training and formation of students' creative thinking and engineering skills. Performing laboratory works allows the student to apply theoretical principles in practical calculations, to gain the skills in independent circuit analysis that, ultimately contribute to the successful mastering of the "Circuits with distributed and lumped parameters" (CwD&LP) discipline.

The manual contains a description of the mandatory laboratory works on CwD&LP discipline for the "Automation and control" specialty.

Laboratory work is a complex of experimental and theoretical assignments in the study of linear electric circuits of direct, single-phase and three-phase sinusoidal current. All laboratory work is performed by the front way after the respective topics in the lecture material is presented.

The practical implementation of the laboratory researches at the "Theoretical electrical engineering" department is provided by using of the "UILS-2" – universal teaching and research laboratory workbenches. The UILS-2 workbench is fixed on the table and is a metal box in which the active and passive units and a patchbay for the assembly of electrical circuits to carry out the experiment are mounted. The workbench also includes 29 external components (resistors, capacitors and inductors) and a set of connecting leads with plugs.

Active blocks are located in the left side of the stand and consist of a block of DC voltage sources and blocks of the single- and three-phase sinewave voltage sources. Passive units are located in the right side of the stand and consist of blocks of a variable resistance and a variable inductance and a variable capacitance. A patch bay is located at the center of the stand.

The DC voltage unit 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 12 V or 24 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 voltage block is a functional generator of single-phase alternating voltage of adjustable frequency of sinusoidal, rectangular and triangular shape. 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 f = 50 Hz. Source contains three electrically phase independent from each other.

Each phase is equipped with an electronic protection against short-circuits and overloads. The current of protection activation is 1 A.

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

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

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

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

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

The external elements are designed as the transparent plastic boxes, in which there are plugs to connect and soldering inside 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 active unit, at the same time on front panel the "POWER LED" 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 potentiometer handle.

The frequency is adjusted stepwise with 1 kHz step by a switch and smoothly by a "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 at the output of each phase of unit of the three-phase voltage source can be adjusted stepwise from 0 to 30 V in increments 1 V using two switches: the tens of (0 ... 3) and the units of (0 ... 9) V.

In the case 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 circuit in operating state by pressing "PROTECTION" button upon that the indicator goes out

Requirements for performing laboratory work, procedure of carrying out laboratory works and design of report

Preliminary preparation and getting admission to perform laboratory work.

Before proceeding to the next laboratory work, the student should read the content of the laboratory work, to study theoretical material on the relevant topic.

The results of the preparation should be reflected in the report of the work, which should contain the following:

− answers to the questions of section “Preparation for a laboratory work” in written form;

− preliminary calculations;

− schemes of studied electrical circuits;

− tables for recording the results of measurements and theoretical calculations.

At the beginning of classes, the student has to defend the completely prepared report of the previous laboratory work and get admission to the next work, having a previously prepared individual report.

The teacher checks student’s readiness to perform laboratory work, asking questions to test their theoretical knowledge, familiarization with the execution order of the work and the expected results of the study. Questions can be given both orally and in writing.

During the classes, students should perform the laboratory work, namely to assemble electrical circuits, to carry out the necessary measurements and calculations, write the results of measurements and calculations in advance prepared tables.

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

Students who have not defended the previous laboratory work and did not get an admission to the next one, as well as students whose theoretical training is recognized as unsatisfactory, are not allowed to the work.

Students who are not admitted to the work must use the remaining time to study the theory, as well as to accomplish and to defend the works made before.

The works, which were not done in time, students do in an allotted time, specified by the teacher. The admission to the laboratory work student gets in a general order.

Work in a laboratory.

For work in the laboratory, students are combined into subgroups of 3 ... 4 people or work individually. The members of the subgroup make the experimental part of the work together, but finalization and defense of report on the performed work are done individually.

Each subgroup works on a separate workbench, where all the equipment necessary for work is located.

Students perform an external inspection of measuring instruments and equipment, before starting work. The defects should be reported immediately to the teacher.

Members of subgroups are responsible for damage caused due to non-compliance with the rules of the carrying out laboratory works or safety rules, as well as for improper using of equipment.

Students assemble the studied electrical circuit for the carrying out of experimental part of the laboratory work by themselves. The electrical circuit should be as simple as possible and easily accessible at any point.

At the very beginning of the experiment all rheostats and other adjustable devices should be adjusted so that minimum values of currents and voltages are in the circuit. The measuring instruments should be switched to the maximum measuring range. After a rough determination of the measured value, the instrument should switch to a convenient measuring range.

It is necessary to invite the teacher to check the assembled electrical circuit before turning on the power sources of the studied circuit.

The electrical circuit should be alive only during the experiment. The power supply should be turned off immediately after finishing the experiment.

Readings on the measuring instruments are written down in the "Experiment" row of the pre-prepared table in the "Experiment" row and the results of theoretical calculations are written down in the "Theory" row. By the end of carrying out of measurements the results should be shown to teacher who gives permission for disassemble scheme.

Finalization and defense of a report on laboratory work.

Each student must present the finalized complete report on the work carried out by the laboratory work to defense. The report should contain the title page and the following sections:

− an objective of the work;

− a preparation for the work;

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

− brief information about the experiment;

− the scheme of analyzed electric circuit;

− tables for writing down measurement results and theoretical calculations;

− 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.

− a comparison between theory and experiment results, the conclusions of the work done.

Template of the title page is presented on the next page.

Reports should be performed only on a one side of white sheet or of lined paper with size of A4 (210x297 mm) with margins: left is 25 mm, right is 18 mm, top is 20 mm, bottom is 25 mm. The text should be written neatly or by applying computer applications. When writing the text is permitted to use only generally accepted abbreviations or designations, decrypted at the first mention.

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Department of Theoretical electrical engineering

R E P O R T
on laboratory work No ____

on the “Circuits with distributed and lumped parameters” discipline

____

(Title of the laboratory work)

____

5B070200 – “Automation and control” baccalaureate specialty

Done by ________________________________ Group _____________
(Student’s Surname & Initials) (Academic group code)

Checked by ____
(Teacher’s academic degree, Academic title, Initials & Surname)

____________ ____________________ «____» _____________ ___20__ y.
(Score) (Teacher’s signature) (Date)

Almaty 20__ y.

1 Laboratory work № 1. Analysis of passive symmetrical two-port circuits

Objective is to study of various operation modes of the passive symmetrical two-port circuits and determination of its parameters using computer simulation.

1.1 Preparation for the laboratory work

Repeat the section "Two-port circuits" of CD&LP discipline.

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

1) Give a definition of two-port circuit.

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

3) What is called as 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) 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 given option of input voltage U_1 and parameters of passive symmetrical two-port circuit (table 1.1). Write down the calculation results in table 1.3 to the "Theory" row.

6) What is the restriction equation should be satisfied of the $\underline{A}$-parameters of passive symmetrical and asymmetrical two-port circuits?

7) 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 option (table 1.1). Write down the results of the calculations in table 1.4 to the "Theoretical calculation" row.

8) How is determined the input impedance of the two-port circuit?

9) 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 option given (table 1.1). The results of the calculations write down in table 1.5 to the "Theoretical calculation" row.

10) Write the expression of the characteristic propagation constant $\underline{\Gamma}_C$ for the symmetrical two-port circuit.

Table 1.1 – Assignment options for the laboratory work

Option #	Scheme #	U_1, V	f, kHz	R, Ω	L, mH	C, μF
1	1.1	10	1.0	100	30	–
2	1.2	12	1.6	130	–	0.75
3	1.3	14	1.5	160	–	0.50
4	1.4	16	1.8	190	40	–

5	1.5	18	2.0	150	–	0.30
6	1.6	20	2.2	110	25	–
7	1.7	22	2.4	120	20	–
8	1.8	24	2.6	100	–	0.25

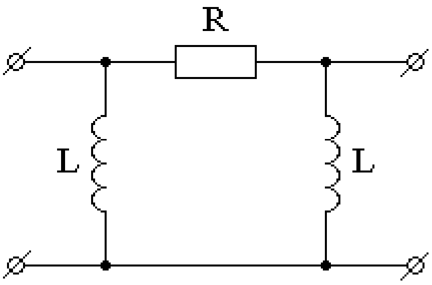


Figure 1.1

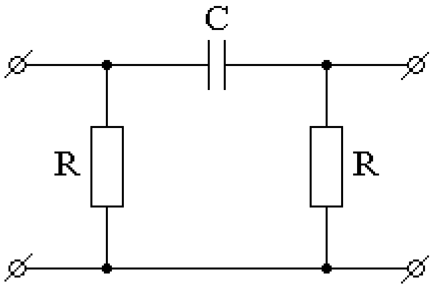


Figure 1.2

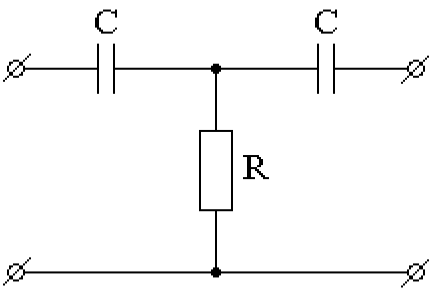


Figure 1.3

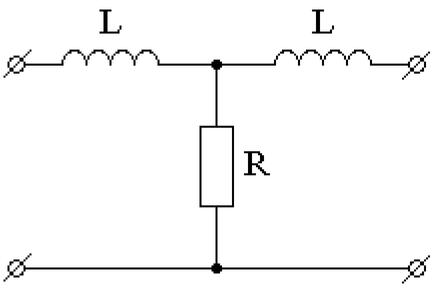


Figure 1.4

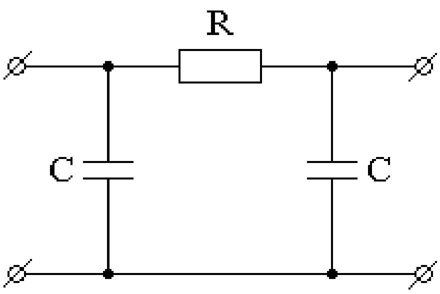
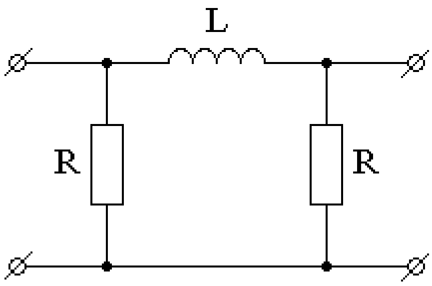


Figure 1.5



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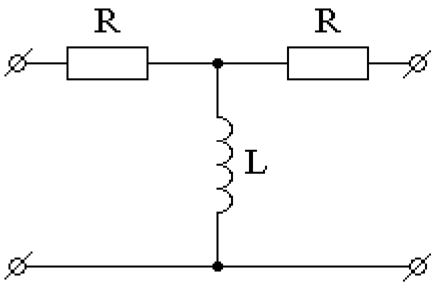

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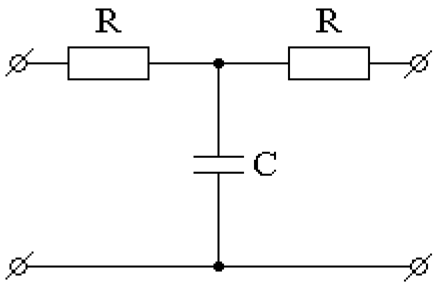

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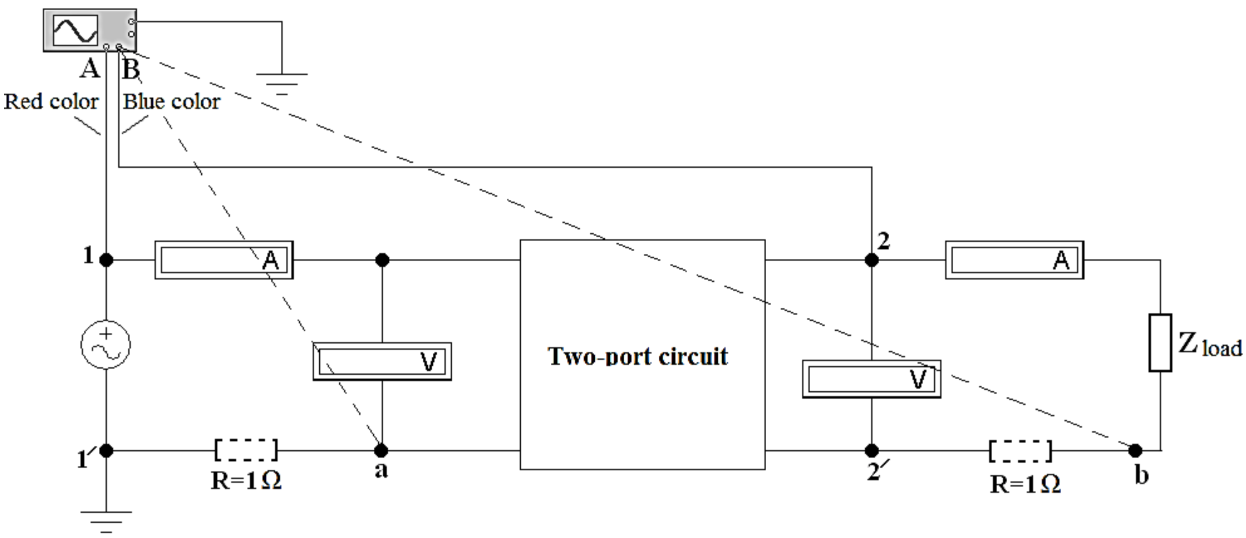


Figure 1.9

1.2 Procedure of carrying out the work

1.2.1 Assemble the electric circuit using the scheme shown in figure 1.9 with specified parameters of two-port circuit according to assignment option.

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

1.2.3 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 $2\text{-}2^{/}$ ($\underline{Z}_{load} = \infty$, $I_2 = 0$). In addition, measure the time interval $\Delta t_{u2} = T_2 - T_1$, which corresponds to 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 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 in table 1.2.

1.2.4 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 $2\text{-}2^{/}$ ($\underline{Z}_{load} = 0$, $U_2 = 0$). In addition, measure the time interval $\Delta t_{i1} = T_2 - T_1$, which corresponds to 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 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 in table 1.2.

Table 1.2 – Determination of initial phase angles of currents and voltages

Operation mode	$\underline{U}_1$, 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										
Short circuit										

Table 1.3 – Complex RMS values of the voltages and currents at various modes

Operation 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				

Table 1.4 – $\underline{A}$-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 by experimental data				

Table 1.5 – Secondary parameters of the two-port circuit

Kind of research	$\underline{Z}_{sc}$, Ω	$\underline{Z}_{oc}$, Ω	$\underline{Z}_c$, Ω	$\underline{\Gamma}_c$,
Theoretical calculation				
Calculation by experimental data				

1.3 Processing the results of experiments

1.3.1 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 operation modes by using corresponding measured values of $\Delta t = T_2 - T_1$. Write down the obtained results in table 1.2.

1.3.2 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 in table 1.3 to the “Experiment” row.

1.3.3 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 in table 1.4 to the “Calculation by experimental data” row.

1.3.4 Calculate the input impedances of two-port circuit for all studied modes by using the experimental data. Write down the obtain results in table 1.5 to the “Calculation by experimental data” row.

1.3.5. Compare the theoretical data with those obtained in the experiments. Make the conclusions on the work done.

1.4 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 1.10). In order to measure the initial phases of voltages the channel (A) of oscilloscope should be connected to the point (1) (this wire paints in red color) and the channel (B) – to the point (2) (this wire paints in blue color). 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 determine 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 paints in red color) and the channel (B) – to the point (*a*) (this wire paints in blue color). 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 oscilloscope should be connected to the point (1) (this wire paints in red color) and the channel (B) – to the point (2') (this wire paints in blue color). 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.

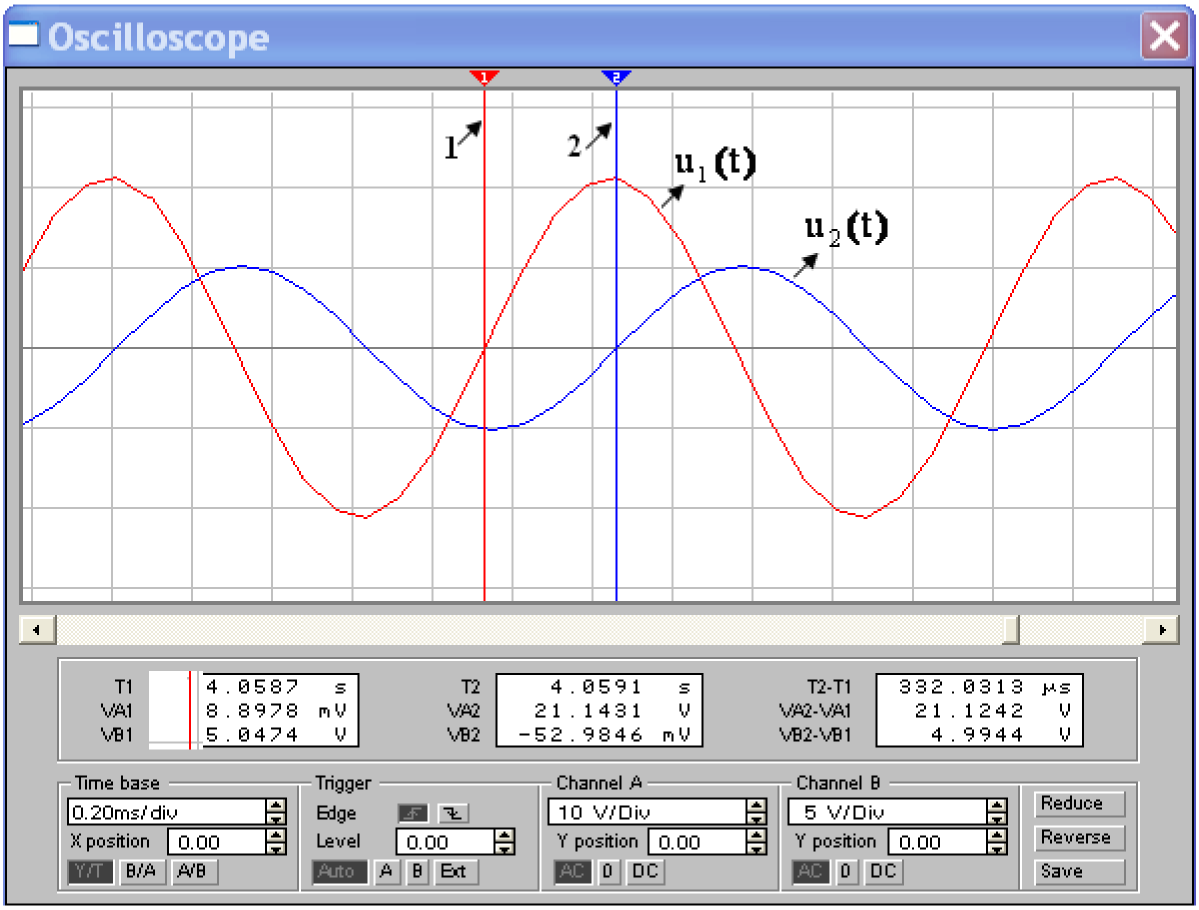


Figure 1.10

1.5 Test questions

1. Main equations of two-port circuits.
2. Determination of the $\underline{A}$-parameters of two-port circuits.
3. Equivalent schemes of two-port circuits.
4. Characteristic impedance $\underline{Z}_C$ of symmetrical two-port circuits.
5. Propagation constant $\underline{\Gamma}_C$ of symmetrical two-port circuits.
6. Input impedance of symmetrical two-port circuits at the idle and the short-circuit operation modes.

2 Laboratory work № 2. Research of *K*-type passive filters

Purpose is to research the frequency characteristics of the attenuation coefficient "*a*" and the phase coefficient "*b*" for the simplest low-pass (LPF) and high-pass (HPF) filters.

2.1 Preparation for the laboratory work

Repeat the section "Passive filters of *K*-type" of CD&LP discipline.

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 they are measured in?
4) What is the passband and the attenuation band or stopband of an ideal filter?
5) What is the matched operation mode of filter?
6) Draw the π – section and the *T*-section schemes of low-pass filter.
7) Draw the π – section and the *T*-section schemes of 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 option (table 2.1).
13) Calculate the cutoff frequency f_{cut} and characteristic resistance ρ for the chosen filter parameters. Write down the calculation results in table 2.2.

2.2 Procedure of carrying out the work

2.2.1 Assemble the circuit shown in figure 2.1. Use the chosen scheme of researched filter according to assignment option (table 2.1.).

Table 2.1 – Assignment options for the laboratory work

Option #	Filter type	Filter circuit	U_1, V	L, mH	C, μF
1	LPF	T – section	5	80	0.5
2	HPF	T – section	4	70	0.4
3	LPF	π – section	3	60	0.6
4	HPF	π – section	4	50	0.7
5	LPF	T – section	5	40	0.3

2.2.2 Set the values of U_1, L, C, $R_{load} = \rho$ according to option (table 2.1.).

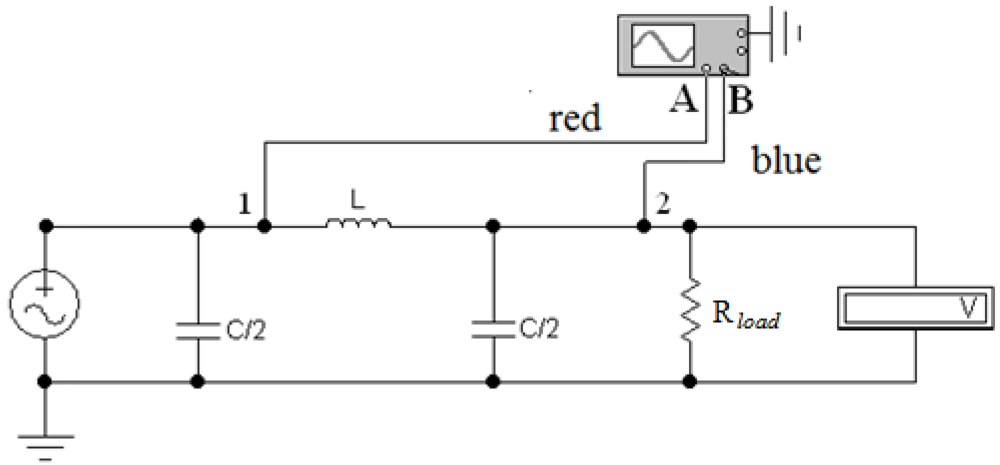
2.2.3 Measure the RMS values of output voltage U_2 across points 2 – 2' and the time phase shift $T_2 - T_1$ between the input $u_1(t)$ and the output $u_2(t)$ voltages for various values of frequency. Change the frequency f of the generator, multiplying by the corresponding coefficient to the cutoff frequency (12 values), using the table 2.3 for LPF or the table 2.4 for HPF. The voltage across the input of filter U_1 should be kept constant. Write down the measurement results in table 2.2.

Table 2.2 – 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

π-section scheme of low-pass filter



$\underline{T}$-section scheme of low-pass filter

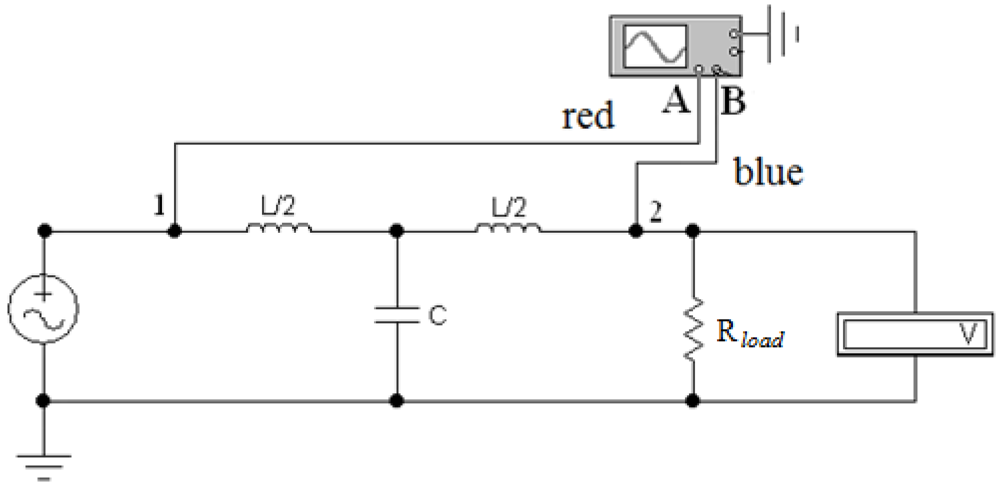
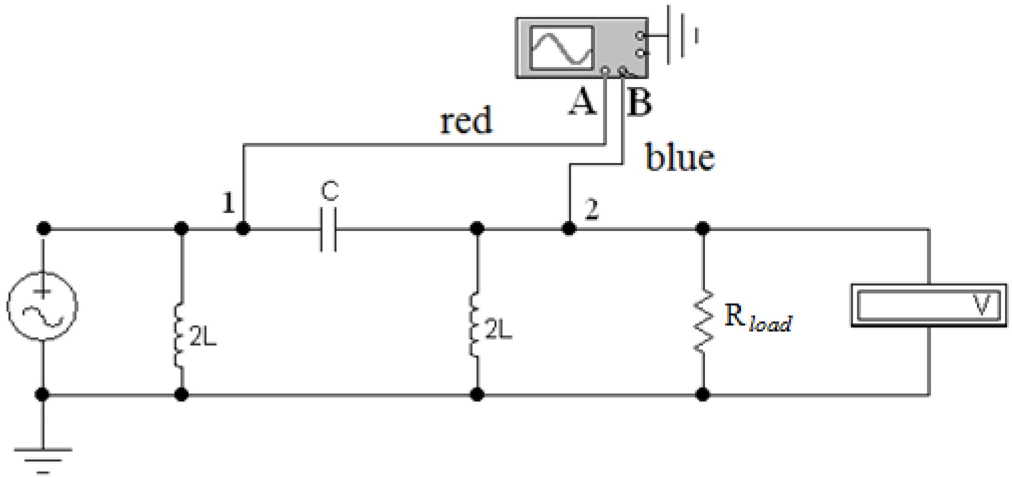


Figure 2.1 – Schemes of low-pass filters
High-pass filters

π-section scheme of high-pass filter



T-section scheme of high-pass filter

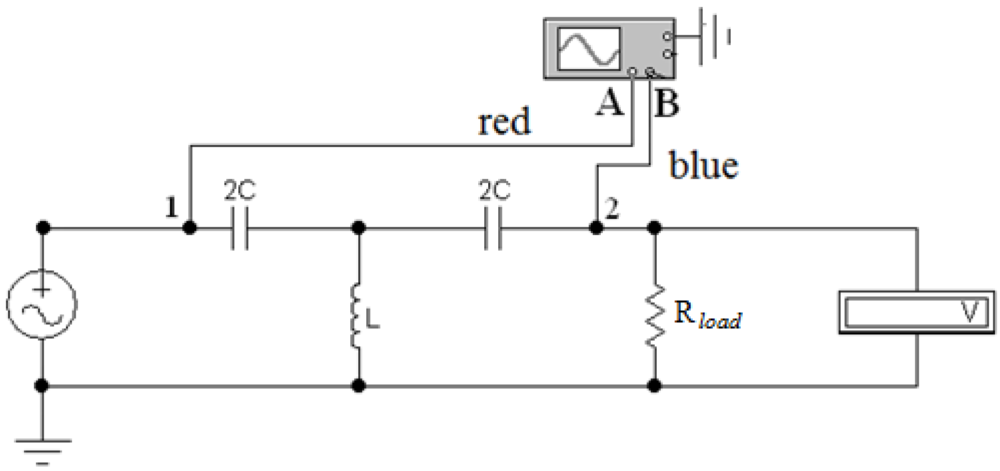


Figure 2.2 – Schemes of high-pass filters

2.3 Processing the results of experiments

2.3.1 Calculate the attenuation coefficients *a* (*f*) and the phase coefficients *b* (*f*) for each of frequency values. Write down the calculation results in table 2.2.

2.3.2 Draw the frequency dependence graph of attenuation coefficient *a*(*f*) using an experimental data from the table 2.2, aligning it with the theoretical graph *a*(*f*), which is drew using data from the table 2.3 for LPF or the table 2.4 for HPF.

2.3.3 Draw the frequency dependence graph of phase coefficient *b*(*f*) using an experimental data from the table 2.2, aligning it with the theoretical graph *b*(*f*), which is drew using data from the table 2.3 for LPF or the table 2.4 for HPF.

2.3.4 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 pass-band and the attenuation band. Make the conclusions on the work done.

Table 2.3 – 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 2.4 – 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

2.4 Methodological guideline

2.4.1 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.

2.4.2 Cutoff frequency f_{cut} of the LPF is defined by 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 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 generator is taken equal to the characteristic resistance:

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

2.4.3 Phase coefficient is determined by the phase time shift T_2-T_1 between the same 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 2.3).

In order to measure the phase shift between the input and the output voltages the channel (A) of oscilloscope should be connected to the point (1) (this wire paints in red color) and the channel (B) – to the point (2) (this wire paints in blue color). 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 above formula.

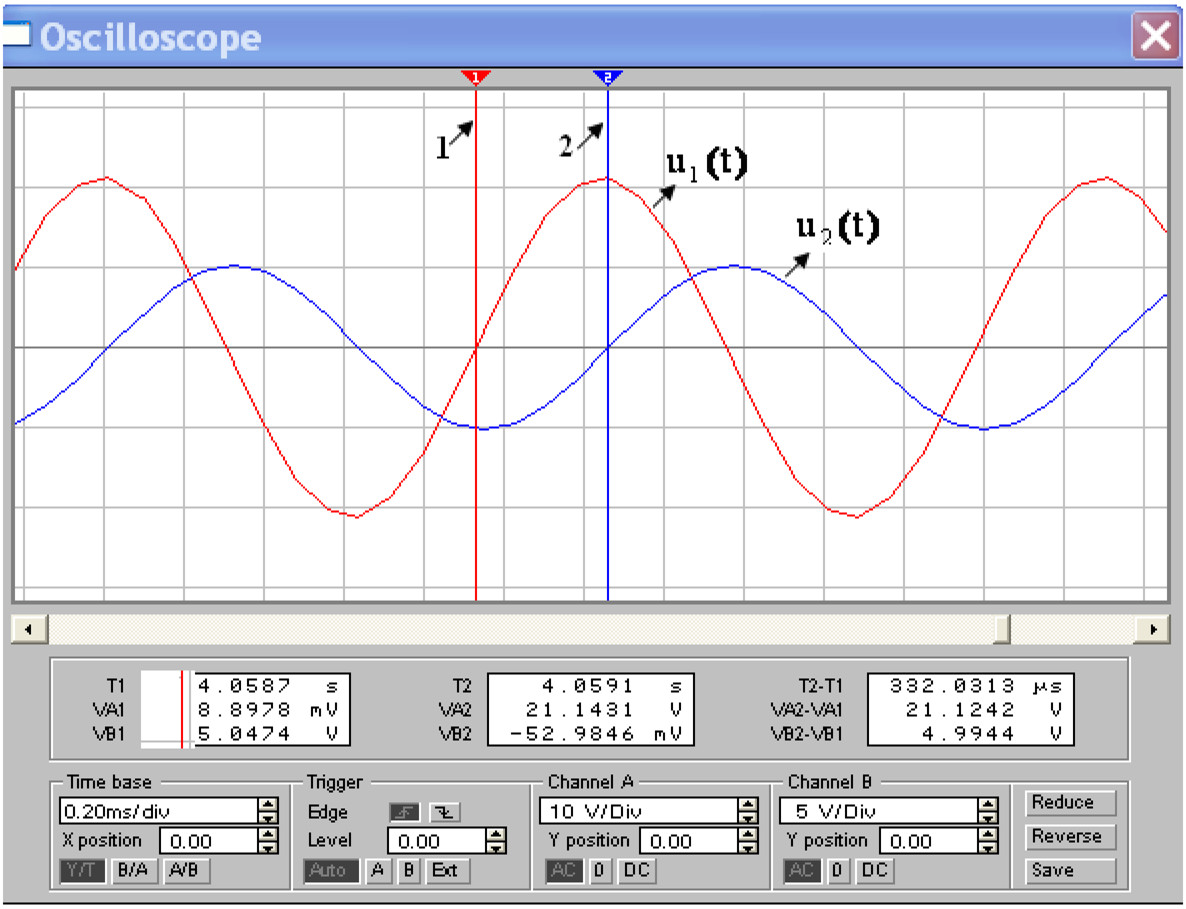


Figure 2.3

2.5 Test questions

1. Filter's classification.
2. Low-pass filters.
3. High- pass filters.
4. Band-stop filters.
5. Band-pass filters.
6. Secondary parameters of filters.

3 Laboratory work № 3. Research of various operating modes of the transmission lines

Purpose is obtaining the skills in study of various modes in the transmission lines using computer simulation.

3.1 Preparation for a laboratory work

Repeat section "Transmission lines" of CD&LP course.
Answer the questions in written form and do the following assignments:

1) What quantities are called the primary parameters of the transmission line?

2) Which line is called homogeneous?

3) Write down the formulas for determining $\underline{Z}_0$, $\underline{Y}_0$.

4) What quantities are called secondary transmission line parameters?

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

6) Write down the equations of a transmission line with hyperbolic functions.

7) How is the input impedance of the transmission line calculated?

8) What load is called matched?

9) How to calculate 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?

10) Calculate parameters R_1, L, C, R_2, $\underline{Z}_w$ according to a given option.

3.2 Procedure of carrying out the work

3.2.1 Choose the value of input voltage of a transmission line U_1, the line and the load parameters according to assignment option by the data in table 3.1.

Table 3.1 – Assignment option of original data

Option	U_1, kV	l, km	$\lvert k_1 \rvert$	$\lvert k_2 \rvert$	R_0, $\frac{\Omega}{km}$	L_0, $\frac{mH}{km}$	G_0, $\frac{\mu S}{km}$	C_0, $\frac{nF}{km}$	$\underline{R}_{load}$
1	400	700	1.037	0.930	0.07	1.00	0.20	9.0	450
2	600	800	1.055	0.899	0.09	1.20	0.08	8.3	400
3	110	1000	1.111	0.814	0.10	1.30	0.30	9.5	500
4	220	900	1.090	0.845	0.08	1.40	0.06	8.8	470
5	330	1100	1.159	0.754	0.06	1.35	0.10	10.0	550

3.2.2 Assemble the electric circuit of a transmission line (figure 3.1), plug in the power supply source, the load and the measuring instruments (figure 3.2).

3.2.3 Set the given value of supply source voltage U_1 at the input of a transmission line, the frequency f = 50 Hz and the precalculated parameters of the equivalent two-port circuit.

3.2.4 Set the value of a load resistance R_{load} according to the option given.

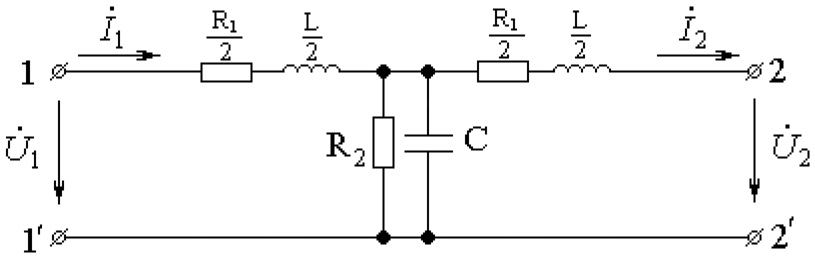


Figure 3.1

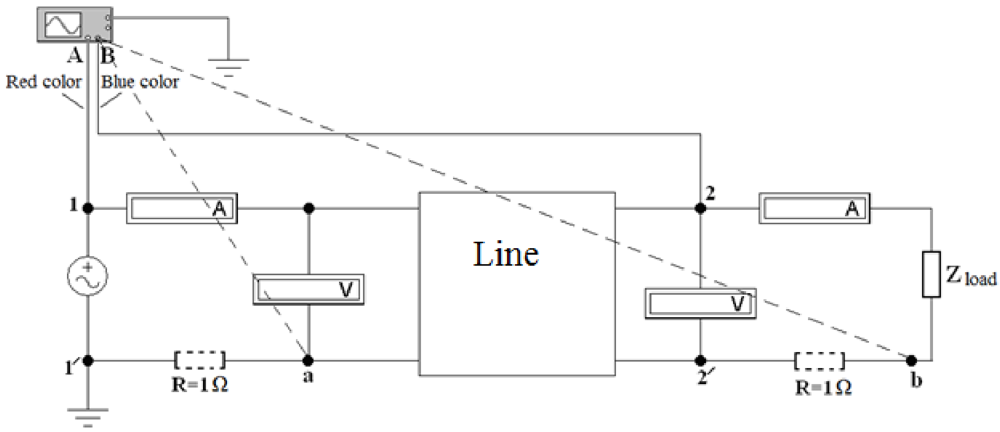


Figure 3.2

Measure the RMS value of an output voltage of a transmission line U_2, the RMS values of input I_1 and output I_2 currents of a transmission line. Measure the initial phase angles of output voltage of a transmission line ψ_{u2} and of the input and the output currents of a transmission line: ψ_{i1} and ψ_{i2}. Write down the obtain results in table 3.2.

3.2.5 Set the matched load $\underline{Z}_{load} = \underline{Z}_w$ at the end of a transmission line (matched load operation mode). Measure the RMS value of output voltage U_2, the RMS values of input I_1 and output I_2 currents of a transmission line, the initial phase angle of output voltage ψ_{u2} and the initial phase angles of input ψ_{i1} and output ψ_{i2} currents of a transmission line. Write down the results in table 3.2.

3.2.6 Set a jumper between the output terminals of a transmission 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 transmission line. Write down the results in table 3.2.

3.2.7 Remove jumper from the output terminals of a transmission line (idling mode I_2=0). Measure the RMS values of the output voltage U_2 and the input current I_1 of a transmission line, the initial phase angles of the output voltage ψ_{u2} and the input current ψ_{i1} of a transmission line. Write down the results in table 3.2.

Table 3.2 – Determination of initial phase angles of currents and voltages

Operation mode	U_1, kV	U_2, kV	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 R_{load} =										
Matched load $\underline{Z}_{load} = \underline{Z}_w$										
Short-circuit		0	–	–						
Idling								0	-	-

3.3 Processing the results of experiments

3.3.1 Calculate the initial phase angle of output voltage ψ_{u2} and the initial phase angles of input ψ_{i1} and output ψ_{i2} currents of a transmission line. Write down the results in table 3.2.

3.3.2 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 in table 3.3.

3.3.3 Calculate the input impedances of a transmission 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 operation modes by using the experimental data. Write down the obtain results in table 3.3.

3.3.4 Analyze the results obtained in experiments for various operation mode of a transmission line. Make the conclusions on the work done.

Table 3.3 – The results of the measurements and calculation

Operation mode	$\underline{Z}_{1in}$, Ω	$\dot{I}_1$, A	$\dot{U}_2$, kV	$\dot{I}_2$, A	P_1, kW	P_2, kW	η, %
Load mode R_{load} =							
Matched load $\underline{Z}_{load} = \underline{Z}_w$							
Short-circuit							
Idling							

3.4 Methodological guideline

In order to research the various operation modes in a transmission line by computer simulation it is considered as a symmetrical two-port circuit, represented by a symmetrical T- section equivalent circuit (figure 3.3).

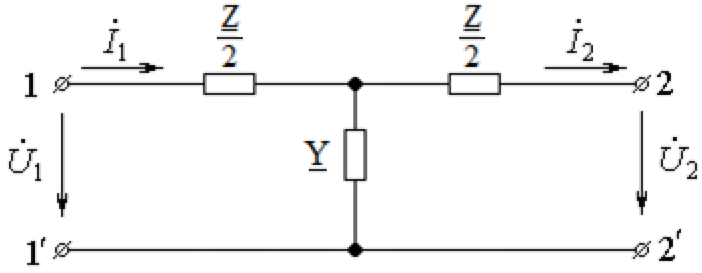


Figure 3.3

$$\underline{Z} = \underline{Z}_0 l k_1 = \left(R_0 + j\omega L_0\right) l k_1 = R_1 + j\omega L_1 \ ,$$

$$\begin{cases} R_1 = R_0 l \left|k_1\right| \\ L = L_0 l \left|k_1\right| \end{cases} ,$$

$$\underline{Y} = \underline{Y}_0 l k_2 = \left(G_0 + j\omega C_0\right) l k_2 = G + j\omega C \ ,$$

$$\begin{cases} G = G_0 l \left|k_2\right|; \ R_2 = \dfrac{1}{G} \\ C = C_0 l \left|k_2\right| \end{cases} ,$$

where R_0, L_0, G_0, C_0 – primary constants of the transmission line;

l – length of the line;

$k_1 = \dfrac{2(\text{ch}\gamma l - 1)}{\gamma l \cdot \text{sh}\gamma l}$, $k_2 = \dfrac{\text{sh}\gamma l}{\gamma l}$ – complex coefficients, with sufficient accuracy for practical calculations can use the modules $\left|k_1\right|$ *and* $\left|k_2\right|$.

$\underline{\gamma} = \sqrt{\left(R_0 + j\omega L_0\right)\left(G_0 + j\omega C_0\right)} = \alpha + j\beta$ – The propagation coefficient,

where α and β – attenuation and phase coefficients, respectively.

$\underline{Z}_w = \sqrt{\dfrac{\underline{Z}_0}{\underline{Y}_0}} = \sqrt{\dfrac{R_0 + j\omega \cdot L_0}{G_0 + j\omega \cdot C_0}} = z_w \cdot e^{j\theta}$ – The wave or the characteristic impedance of the transmission line.

For the measurement and calculation the initial phase angles of voltages and currents used guidelines for the laboratory work № 1 (see § 1.4).

3.5 Test questions

1. Equations of a transmission line.
2. Characteristics of a transmission line.
3. Input impedance of a transmission line.
4. Equations of a transmission line with hyperbolic functions.
5. Propagation coefficient γ and wave (or characteristic) impedance $\underline{Z}_w$.
6. Matched load of a transmission line
7. Idle, short-circuit and matched load operation modes of a transmission line.

4 Laboratory work № 4. Research of various operating modes of the lossless line with distributed parameters

Purpose is obtaining the skills of studying various operating modes in a lossless line by computer simulation.

4.1 Preparation for a laboratory work

Repeat section "Transmission lines. Lossless homogeneous line" of CD&LP discipline.

Answer the questions in written form and do following:

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 is observed a standing wave mode?
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 option (table 4.1). Write down initial data and calculation results in table 4.2.
10) Calculate currents, voltages for various operation modes of the lossless line according to a given option (see methodological guidelines). Write down calculation results in table 4.3 to the "theoretical calculations" row.

Table 4.1 – Assignment options for the laboratory work

Option	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 4.2 – 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 4.3 – Determination of initial phase angles of currents and voltages

Operation 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 4.4 – Input impedance $\underline{Z}_{input}$ and active power at the supply and load points

Operation 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				

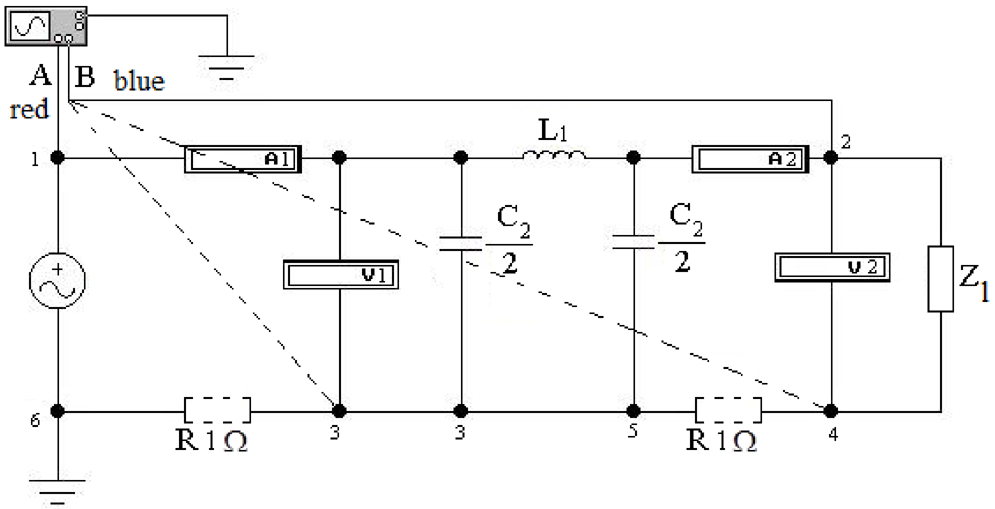


Figure 4.1

4.2 Procedure of carrying out the work

4.2.1 Assemble the electrical circuit by scheme in figure 4.1.

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

4.2.3 Set the load resistance R_{load}, according to the option 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 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 obtain results in table 4.3 in the "Experiment" row.

4.2.4 Set the matched load $\underline{Z}_{load}$ = $\underline{Z}_w$ at the end of a lossless line (matched load operation 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 output voltage ψ_{u2} and the initial phase angles of input ψ_{i1} and output ψ_{i2} currents of a lossless line. Write down the results in table 4.3 in the "Experiment" row.

4.2.5 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 in table 4.3 in the "Experiment" row.

4.2.6 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 in table 4.3 in the "Experiment" row.

4.3 Processing the results of experiments

4.3.1 Calculate the initial phase angle of output voltage ψ_{u2} and the initial phase angles of input ψ_{i1} and output ψ_{i2} currents of a transmission line. Write down the results in table 4.3 in the "Experiment" row.

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.

4.3.3 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 operation modes by using the experimental data. Write down the obtain results in table 4.4.

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.

4.4 Methodological guideline

For the high-frequency signal the short length lines are satisfy the conditions $R_0 << \omega L_0$ and $G_0 << \omega C_0$, so with a sufficiently high accuracy for practical purposes can be neglected the resistance R_0 and the leak conductivity G_0. This short length lines can be consider 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 4.2.

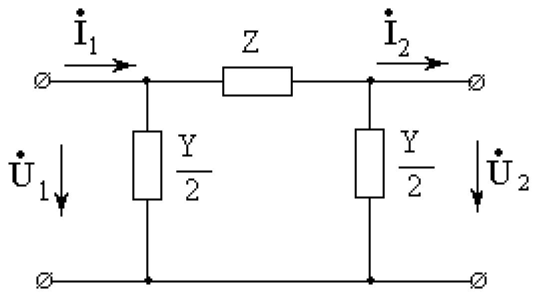


Figure 4.2

Impedance $\underline{Z}_1$ and conductivity $\underline{Y}_2$ for symmetrical π -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 lossless line;

$k_1 = \dfrac{\sin \beta l}{\beta l}, \quad k_2 = \dfrac{2(1-\cos\beta l)}{\beta l \cdot \sin\beta l}$ – 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:

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

For the measurement and calculation of the initial phase voltages and currents used guidelines for laboratory work № 1 (see § 1.4).

4.5 Test questions

1. Input impedance of lossless line.
2. Standing waves.
3. The propagation coefficient $\underline{\gamma}$, attenuation coefficient α, phase coefficient β and characteristic impedance $\underline{Z}_w$ of a lossless line.
4. Matched load of lossless line.
5. Idle, short-circuit and matched load operation modes of a lossless line.

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