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ALMATY UNIVERSITY OF POWER ENGINEERING & TELECOMMUNICATIONS

Department of Theoretical electrical engineering

THEORETICAL FUNDAMENTALS OF ELECTRICAL ENGINEERING 2

Methodological guidelines and assignments for laboratory works
for the 5B071800 – “Electrical power engineering” baccalaureate specialty students

Almaty 2017

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Methodological guidelines and assignments for preparing, execution and design of laboratory works on "Theoretical fundamentals of electrical engineering 2" discipline are provided.

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

Methodological guidelines and assignments are intended for second-year students, who are educated in English language on 5B071800 – "Electrical power engineering" baccalaureate specialty.

13 illustrations, 15 tables, 6 items of references.

Reviewer: PhD B. I. Tuzelbayev

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THEORETICAL FUNDAMENTALS OF ELECTRICAL ENGINEERING 2

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Contents

Introduction

The laboratory research are of great importance for the quality of training and formation of students' creative thinking and engineering skills. The performance of laboratory works allows students to apply theoretical principles in practical calculations in order to obtain skills of independent analysis of electrical circuits, which ultimately contributes to the successful mastery of the discipline.

The manual contains a description of the mandatory laboratory works on "Theoretical fundamentals of electrical engineering 2" (TFEE2) discipline for the 5B071800 – "Electrical power engineering" baccalaureate 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 provides 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 that consist of active and passive units and a patchbay for the assembly of electrical circuits to carry out the experiment. 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 a block of a variable resistance and blocks of a variable inductance and a variable capacitance. A patchbay 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 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 f = 50 Hz. 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 9.99μF 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 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 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 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 upon that the indicator goes out.

Requirements for the registration of report on laboratory work

The assignment for the current laboratory work the student gets in advance on the previous lesson, for one or two weeks earlier.

Each student prepares a report himself in order to carry out laboratory work, acquainted with the purpose of work and with the basic theoretical principles used in the experiment.

Before implementation of experimental part, the student is interviewed on the preparation for a laboratory work, shows the prepared report for the execution of laboratory work to the teacher and gets the 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 the results are carried out and conclusions on the work are made.

Each student defends the report on 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:

− purpose of 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;

− 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 of the work done.

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

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

Student is allowed to the next laboratory work if he has executed and defended a previous laboratory work.

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Department of “Theoretical electrical engineering”

R E P O R T
on laboratory work № ____

on the “Theoretical fundamentals of electrical engineering 2” discipline

____

(Title of the laboratory work)

____

5B071800 – “Electrical power engineering” baccalaureate specialty

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

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

_____________ ____________________ «____» ______________ ___20___ y.
(Score) (Teacher’s signature) (Date)

Almaty 20___ y.

1 Laboratory work №1. Research of transients in the first order linear electric circuits

Purpose is obtaining the skills of experimental research of transients in the first order linear electrical circuits with a single energy storage element.

1.1 Preparation for a laboratory work

Repeat section “Transients in the first order linear electric circuits” of TFEE2 discipline.

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.

3) What are named as steady and free components of the transient time function, for example, of the current or of the voltage?

4) What is the physical sense of the time constant of the circuit? What is the values of *RC*- and *RL*-circuit time constant?

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

6) Write down the expressions of instantaneous values of $u_C(t)$ and $i_C(t)$ at short circuit of *RC* - network, plot the graphs of $u_C(t)$ and $i_C(t)$.

7) How to determine experimentally the time constant of the circuit?

8) Write down the expressions of instantaneous values of $u_L(t)$, $i_L(t)$ for the circuit in figure 1.2 after the switch is opened and plot their graphs.

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 option, table 1.1. Set value of R_1 in the range of 100...300 Ω.

1.2.3 Plug in the voltage of capacitor to the oscilloscope input. Copy in a scale from the oscilloscope screen or take a screenshot of the voltage curve of $u_C(t)$.

1.2.4 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 capacitor:

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

1.2.5 Change one of the circuit parameters according to assignment option (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.

1.2.6 Assemble the electric circuit in figure 1.2.

1.2.7 Set values of the EMF E_0 and the inductance L (option 1) according to the assignment option, table 1.3. Set the resistors values of $R_1 = R = 51\ \Omega$.

1.2.8 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:

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

1.2.9 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 $u_{coil}(t)$.

1.2.10 Set the new value of inductance (option 2) according to assignment option (table 1.3). 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.

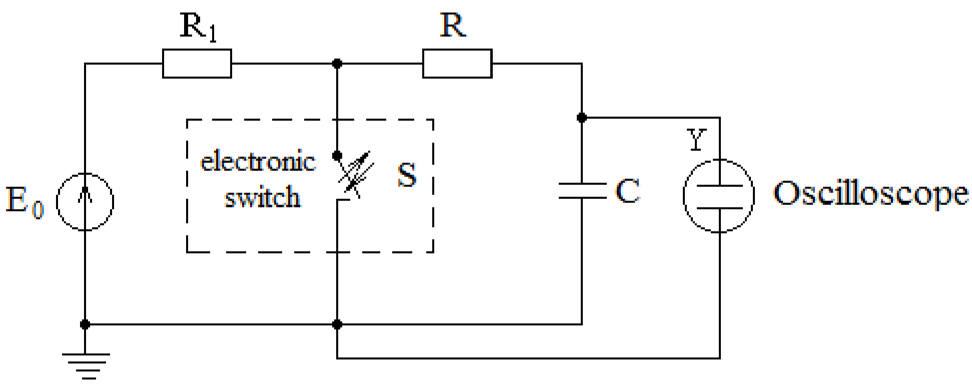


Figure 1.1 – Scheme for research of transient in *RC*-circuit

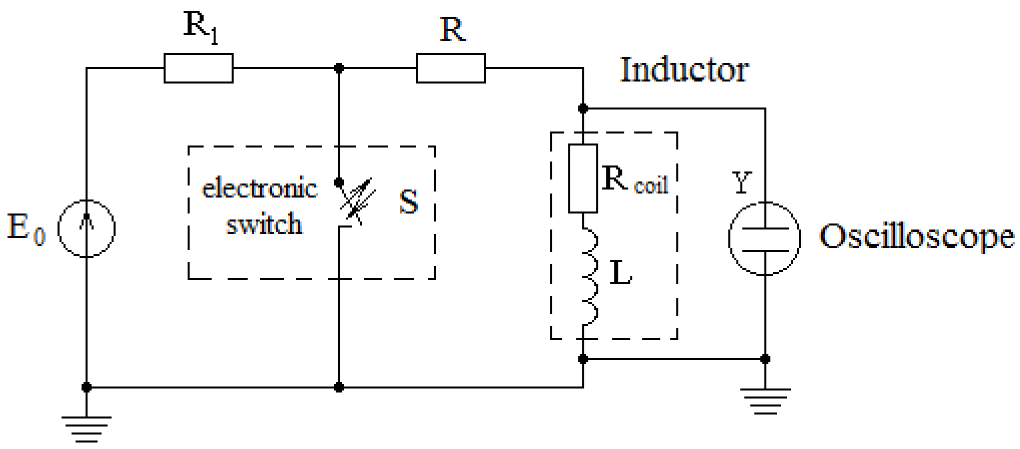


Figure 1.2 – Scheme for research of transient in *RL*-circuit

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

Option	E_0, V	R, Ω	C, μF
1	10	300	4
2	15	400	2
3	20	200	5
4	10	600	5
5	15	500	3

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

Option	E_0, V	R, Ω	C, μF
1	10	600	4
2	15	400	4
3	20	400	5
4	10	300	5
5	15	500	6

Table 1.3 – Parameters of *RL* - circuit

Option	E_0, V	L, mH (option 1)	L, mH (option 2)
1	10	100	50
2	12	45	90
3	15	80	40
4	10	35	70
5	15	94	47

1.3 Processing the results of experiments

1.3.1 Calculate the time constants τ and damping factors α of the circuit shown in figure 1.1 for two given options of the circuit parameters (tables 1.1 and 1.2.): τ_{RC1}, α_{RC1} и τ_{RC2}, α_{RC2}.

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 options of the circuit parameters (points 1.2.3 and 1.2.5).

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

1.3.4 Plot graphs of the calculated and experimental curves of $u_C(t)$ on the same figure.

1.3.5 Calculate the time constants τ and damping factors α of the circuit shown in figure 1.2 for two given options of the inductance value (table 1.3): τ_{RL1}, α_{RL1} и τ_{RL2}, α_{RL2}. It is necessary to take into account of R_{Coil} – the resistance of the inductor, then the total resistance of the circuit will be of $R = R_1 + R + R_{coil}$.

1.3.6 Determine the time constant τ_{RL} and the damping factor α_{RL} of the *RL* - circuit in figure 1.2 by the images of the voltage curves across the resistor R of $u_R(t)$ for two given options of the inductance (points 1.2.8 and 1.2.10).

1.3.7 Theoretically calculate a current of $i_L(t)$ and a voltage of $u_{coil}(t)$ time function by the known parameters of the *RL* – circuit in figure 1.2 according to assignment option (table 1.3).

1.3.8 Plot graphs of the calculated and experimental curves of $i_L(t)$ and $u_{coil}(t)$ on the same figure.

1.3.9 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. In addition, analyze the impact of the value of the inductance L on the time constant τ_{RL} of the *RL* - circuit and, accordingly, on the rate of the transient process.

1.4 Methodological guidelines

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 experimental curve of $u_C(t)$ as a subtangent (figure 1.3).

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

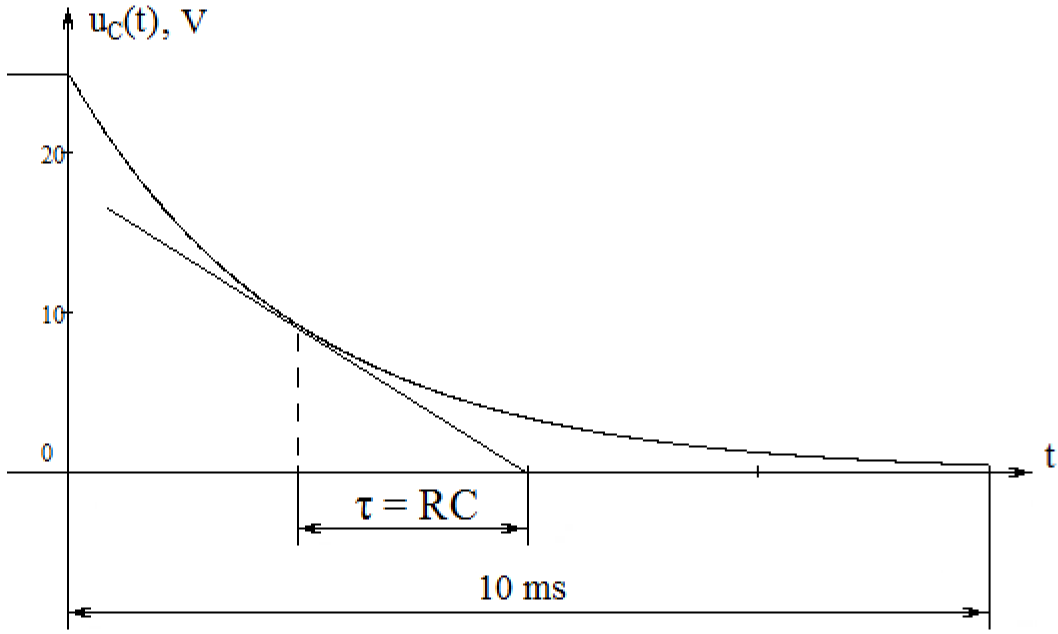


Figure 1.3 – Determination the time constant τ_{RC} of *RC*-circuit

2 Laboratory work №2. Research of transients in the second order linear electric circuits

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

2.1 Preparation for a laboratory work

Repeat section “Transients in the second order linear electric circuits” of TBEE2 discipline.

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 *RLC* - circuit and the corresponding characteristic equation of the circuit.

2) Which roots of the characteristic equation of *RLC* - circuit corresponds 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 *RLC* - circuit corresponds 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 *RLC* - circuit.

5) What is called logarithmic damping decrement?

6) Which roots of the characteristic equation of *RLC* - circuit corresponds 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 *R*, *L* and *C*?

2.2 Procedure of carrying out the work

2.2.1 Assemble the electric circuit as shown in figure 2.1.

2.2.2 Set values of the resistor *R*, the inductor *L* and the capacitor *C* according to the assignment option, table 2.1. Measure the coil resistance R_{coil}. Set values of the R_1 in the range of 100...300 Ω and of the EMF E_0 = 15…20 V.

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

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

2.2.5 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 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.

2.2.6 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.

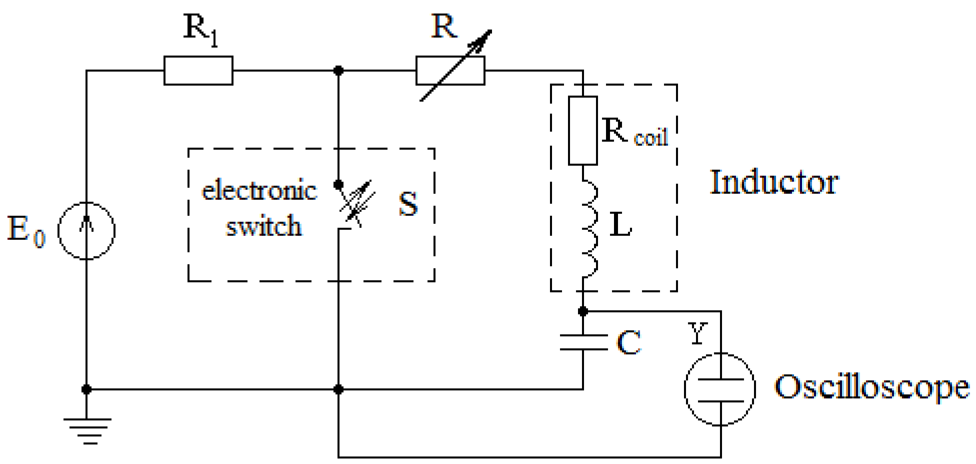


Figure 2.1 – Scheme of research the *RLC*-circuit

Table 2.1

Option	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

2.3 Processing the results of experiments

2.3.1 For the circuit in figure 2.1 theoretically calculate the damping factor $\alpha_{\text{theory.}}$ and the natural frequency $\omega_{0\text{theory}}$ by using given values of total resistance $R_\Sigma = R + R_{\text{coil}}$, L and C (according to the assignment option, table 2.1.

2.3.2 Calculate the experimental values of the damping factor $\alpha_{\text{exp.}}$ and the natural frequency $\omega_{0\text{exp.}}$ of the circuit by using the experimentally obtained image of voltage waveform across the capacitor $u_C(t)$ (see point 2.2.3).

2.3.3 Theoretically calculate the critical resistance $R_{\text{cr.theory}}$ of the circuit.

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

2.4 Methodological guidelines

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.

Theoretical values of the damping factor α_{theory}, the natural frequency $\omega_{0\text{theory}}$ and the critical resistance $R_{\text{cr.theory}}$ 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 $\alpha_{\text{theory.}}$ and the natural frequency $\omega_{0\text{theory}}$ are determined by the voltage curve $u_C(t)$ which obtained from the oscilloscope screen, as shown in figure 2.2.

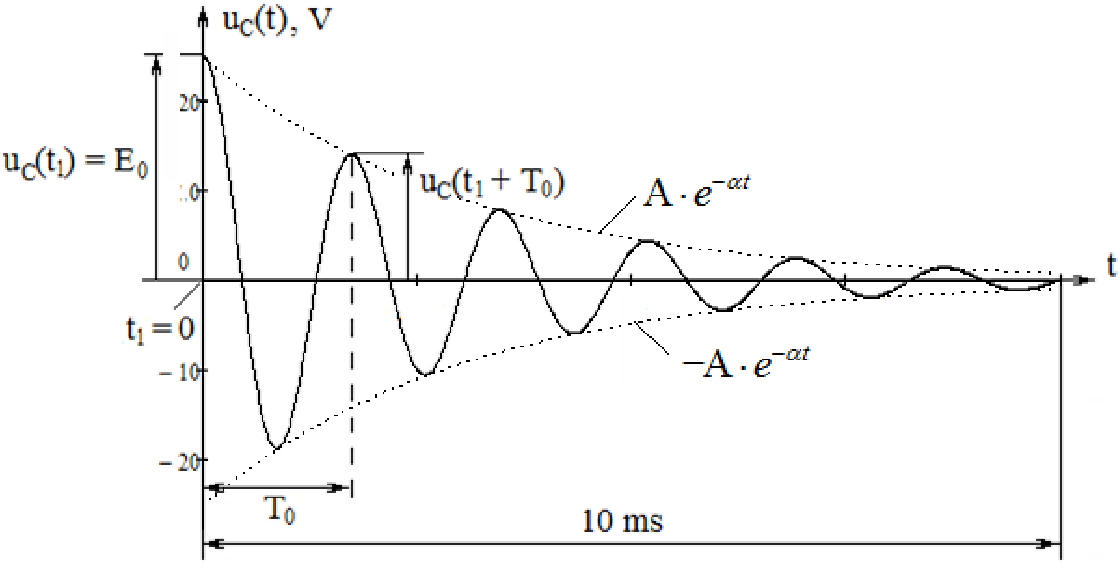


Figure 2.2 – Determination the $\alpha_{exp.}$, T_0 and $\omega_{0theory}$ of *RLC*-circuit

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 period of free oscillations is determined by the voltage curve $u_C(t)$ as shown in figure 2.2.

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 denominator the value of amplitude of the voltage oscillations across capacitor after the period T_0.

3 Laboratory work № 3. 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.

3.1 Preparation for the laboratory work

Repeat the section “*K*-type passive filters” of TFEE2 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 3.1).

13) Calculate the cutoff frequency f_{cut} and characteristic resistance ρ for the chosen filter parameters. Write down the calculation results in table 3.2.

3.2 Procedure of carrying out the work

3.2.1 Assemble the circuit shown in figure 3.1. Use the chosen scheme of researched filter according to assignment option (table 3.1.).

Table 3.1 – 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

3.2.2 Set the values of U_1, L, C, $R_{load} = \rho$ according to option (table 3.1.).

3.2.3 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 3.3 for LPF or the table 3.4 for HPF. The voltage across the input of filter U_1 should be kept constant. Write down the measurement results in table 3.2.

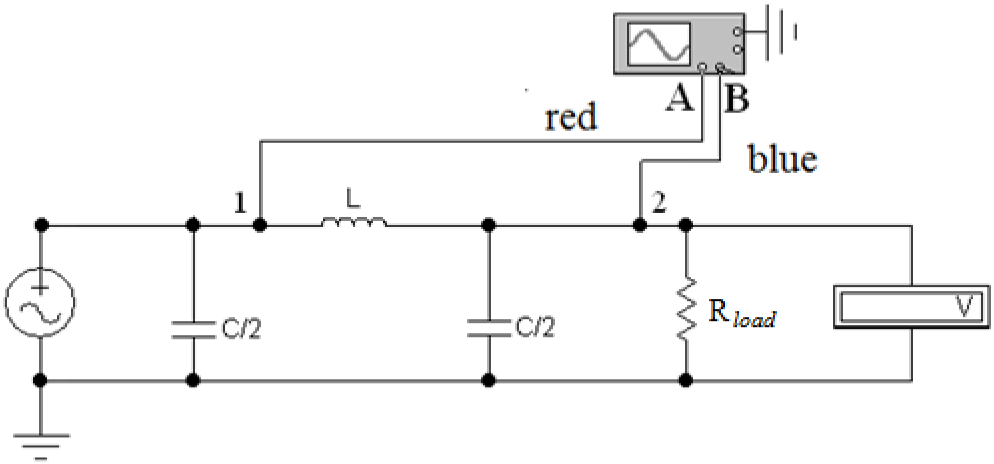
Table 3.2 – Frequency characteristics of the attenuation *a* and phase *b* coefficients

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 low-pass filter



T-section scheme of low-pass filter

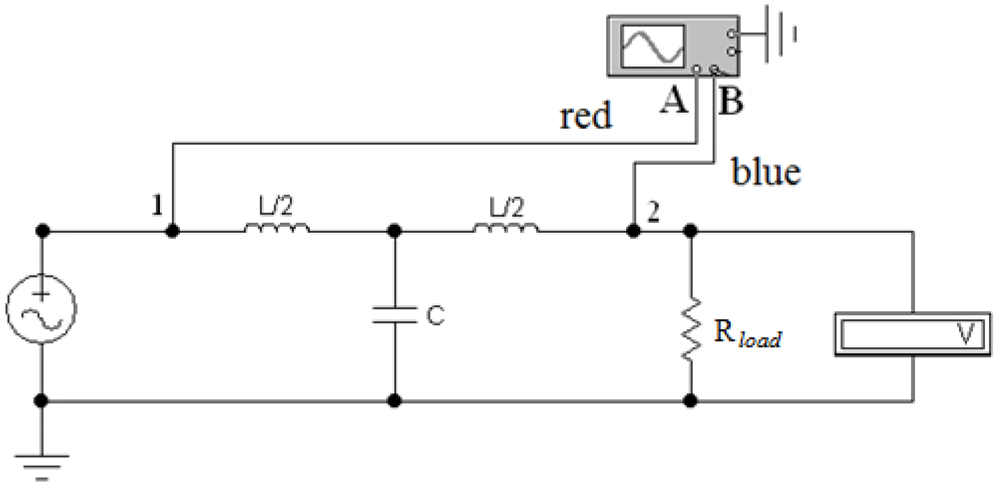
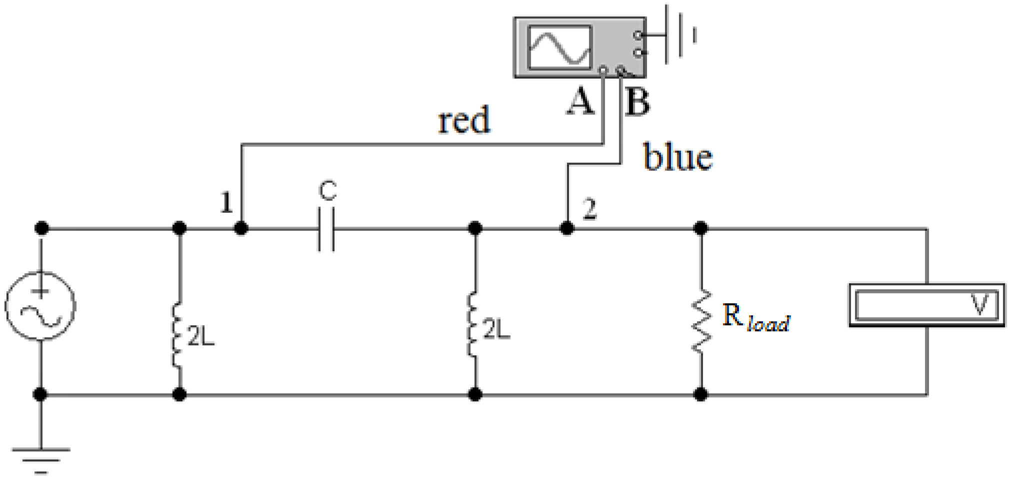


Figure 3.1 – Schemes of low-pass filters

High-pass filters

П-section scheme of high-pass filter.



T-section scheme of high-pass filter

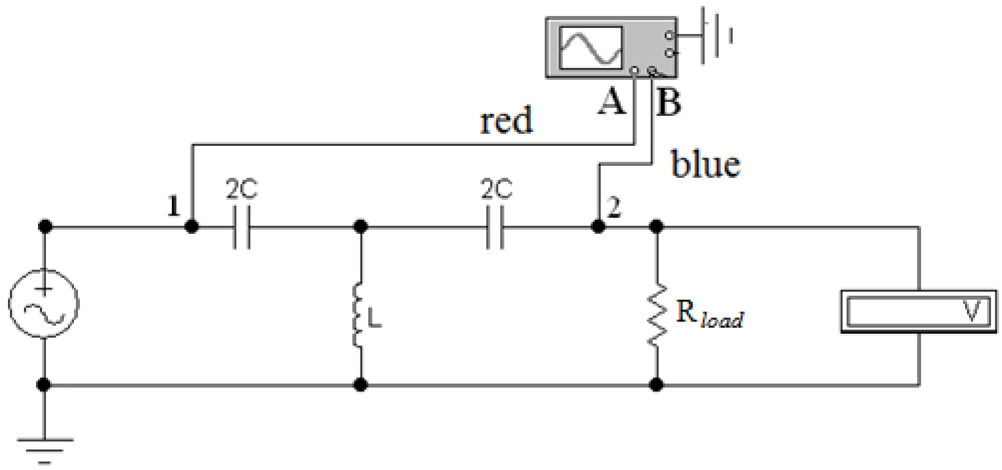


Figure 3.2 – Schemes of high-pass filters

3.3 Processing the results of experiments

3.3.1 Calculate the attenuation coefficients *a* (*f*) and the phase coefficients *b* (*f*) for each of frequency values. Write down the calculation results in table 3.2.

3.3.2 Draw the frequency dependence graph of attenuation coefficient *a*(*f*) using an experimental data from the table 3.2, aligning it with the theoretical graph *a*(*f*), which is drew using data from the table 3.3 for LPF or the table 3.4 for HPF.

3.3.3 Draw the frequency dependence graph of phase coefficient *b*(*f*) using an experimental data from the table 3.2, aligning it with the theoretical graph *b*(*f*), which is drew using data from the table 3.3 for LPF or the table 3.4 for HPF.

3.3.4 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 3.3 – 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 3.4 – 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

3.4 Methodological guideline

3.4.1 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.

3.4.2 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:

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

3.4.3 Phase 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 3.3).

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.

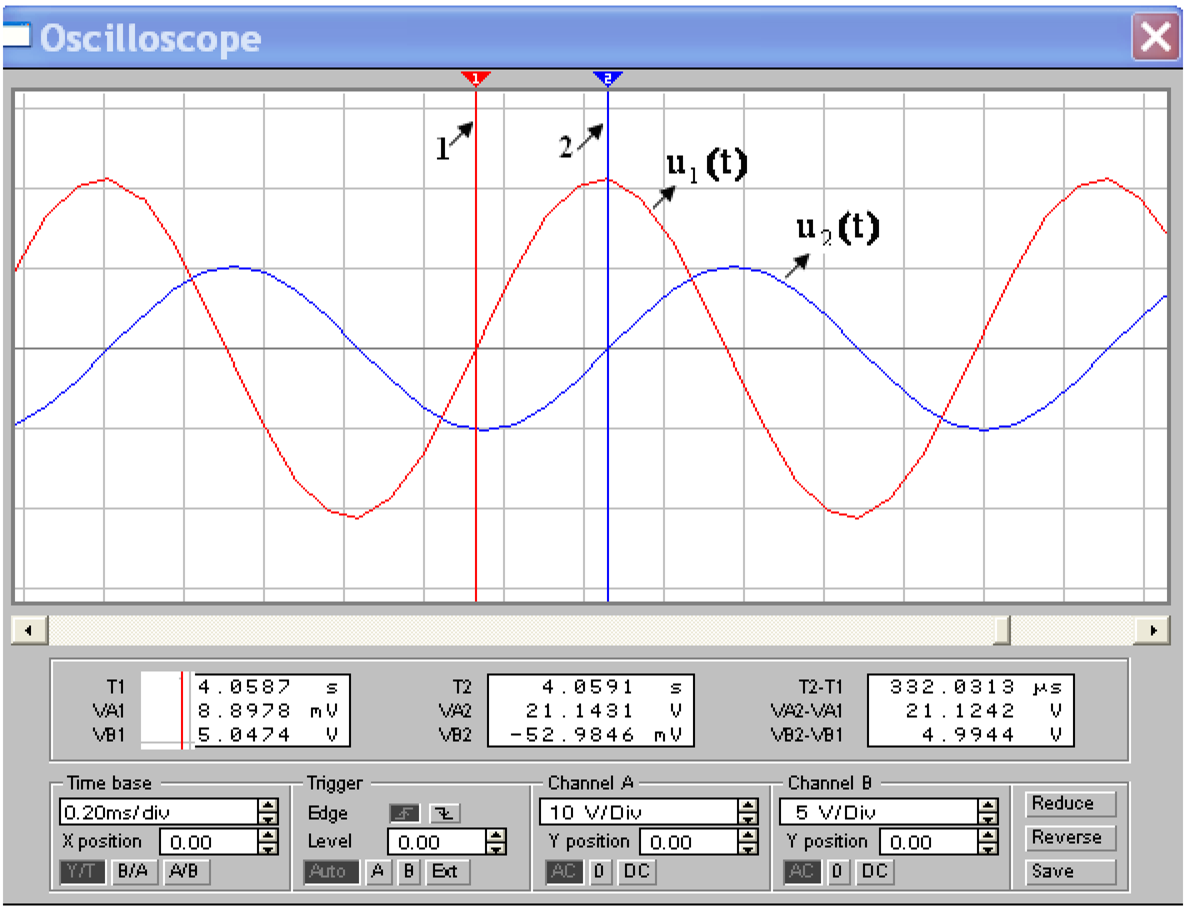


Figure 3.3

4 Laboratory work № 4. 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.

4.1 Preparation for a laboratory work

Repeat section “Transmission lines” of TFEE2 discipline.

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.

4.2 Procedure of carrying out the work

4.2.1 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 4.1.

Table 4.1 – 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

4.2.2 Assemble the electric circuit of a transmission line (figure 4.1), plug in the power supply source, the load and the measuring instruments (figure 4.2).

4.2.3 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.

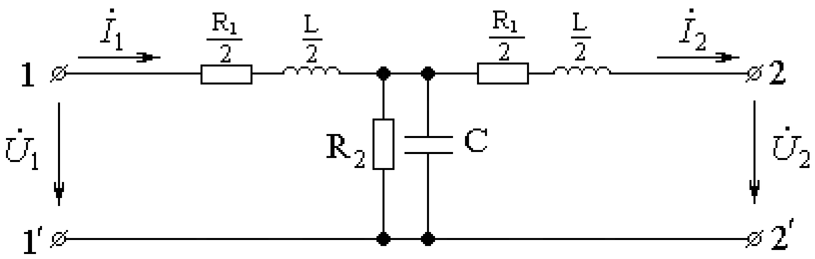


Figure 4.1 – Equivalent scheme of the transmission line

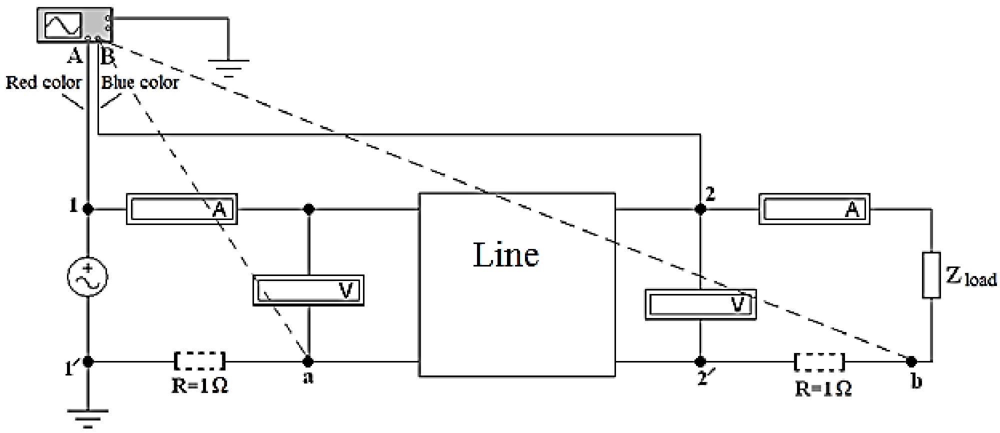


Figure 4.2 – Connection diagram for measuring instruments

4.2.4 Set the value of a load resistance R_{load} according to the option given. 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 4.2.

4.2.5 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 4.2.

4.2.6 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 4.2.

4.2.7 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 4.2.

Table 4.2 – 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	-	-

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 4.2.

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 in table 4.3.

4.3.3 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 4.3.

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

Table 4.3 – 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							

4.4 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 4.3).

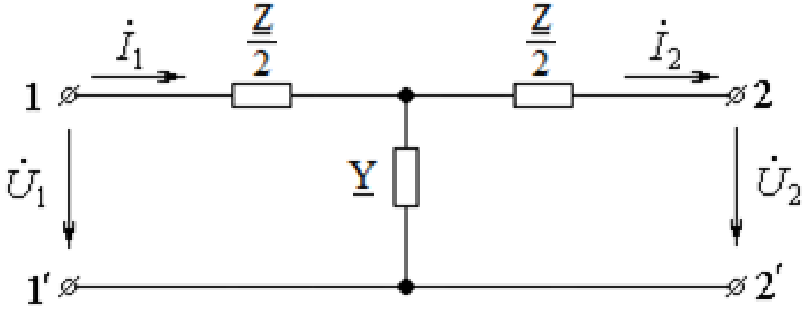


Figure 4.3

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

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

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

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

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 $|k_1|$ *and* $|k_2|$.

$\underline{\gamma} = \sqrt{(R_0 + j\omega L_0)(G_0 + j\omega C_0)} = \alpha + j\beta$ – 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 № 3 (see point 3.4.3).

5 Laboratory work № 5. Research of various operating modes of the lossless homogeneous line

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

5.1 Preparation for a laboratory work

Repeat section "Transmission lines. Lossless homogeneous line" of TFEE2 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 Z_w, λ, k_1, k_2, L, C according to the option (table 5.1). Write down initial data and calculation results in table 5.2.
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 5.3 to the "theoretical calculations" row.

Table 5.1 – 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 5.2 – 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 5.3 – 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 5.4 – Input impedance $\underline{Z}_{input}$ and active power at the supply and load terminals

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				

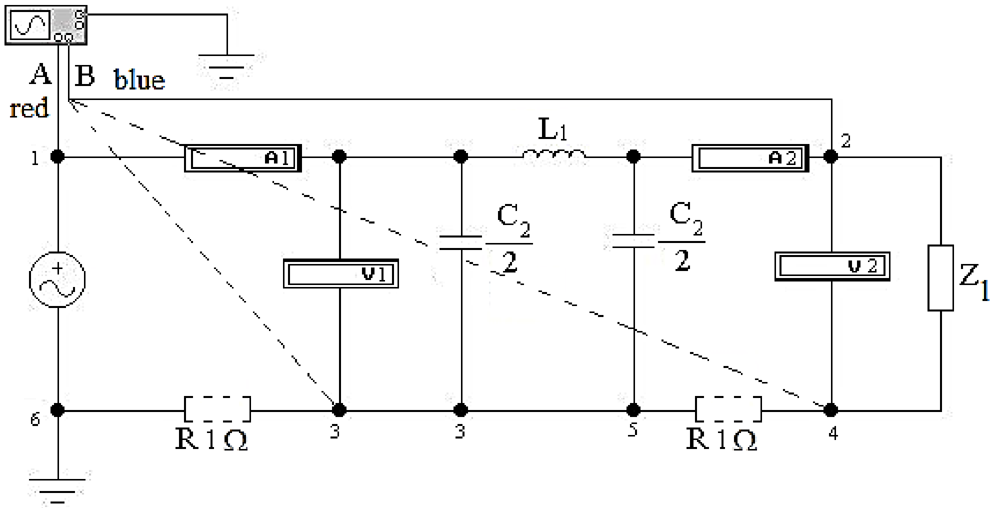


Figure 5.1

5.2 Procedure of carrying out the work

5.2.1 Assemble the electrical circuit by scheme in figure 5.1.

5.2.2 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.

5.2.3 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 5.3 in the “Experiment” row.

5.2.4 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 5.3 in the “Experiment” row.

5.2.5 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 5.3 in the “Experiment” row.

5.2.6 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 5.3 in the "Experiment" row.

5.3 Processing the results of experiments

5.3.1 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 5.3 in the "Experiment" row.

5.3.2 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.

5.3.3 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 5.4

5.3.4 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.

5.4 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 the study of various modes in the line by computer simulation, the actual homogeneous 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 5.2.

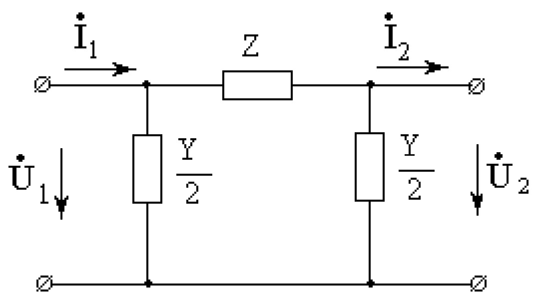


Figure 5.2

Impedance Z_1 and conductivity $У_2$ 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;

$\omega = 2\pi f$ – 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 phases of voltages and currents used guidelines for laboratory work № 3 (see point 3.4.3)

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