MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
ODESSA NATIONAL ACADEMY OF TELECOMMUNICATIONS n.a. A.S. Popov

METHODICAL INSTRUCTIONS

for implementation of laboratory work

"Research of operating modes of waveguide transmission line"

on discipline

«ENGINEERING ELECTROMAGNETICS»

Module 1 – Theoretical Fundamentals of Electromagnetics

for students of full-time and part-time forms of education
on telecommunications training area

Odessa 2013

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Goal of the methodical instructions is to help students during independent study theoretical principles of discipline "Engineering Electrodynamics", part 1 – theoretical foundations of electromagnetics and in the performance of individual tasks and laboratory work. The description of the laboratory work includes along with methodical recommendations on theoretical and experimental research (study) of the basic processes in a microwave path, measuring methods of their parameters and performances. Laboratory work named research of operating modes of waveguide transmission line.

Methodical instructions are intended for students of full-time and part-time forms of education on telecommunications training area.

The methodical instructions reviewed and approved at a meeting of the TED and SRC Department. (Protocol № 9 from June 8, 2012)

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CONTENTS

1 LABORATORY WORK
"Research of operating modes of waveguide transmission line"

1.1 Goal of the work

Research of operating modes of waveguide transmission line; measurement of traveling and standing wave ratio, of reflection coefficient from load.

1.2 Key points

According to wave model an electromagnetic field on a section of regular transmission line is possible to be presented in the form of superposition of the incident and reflected waves (fig. 1.1).

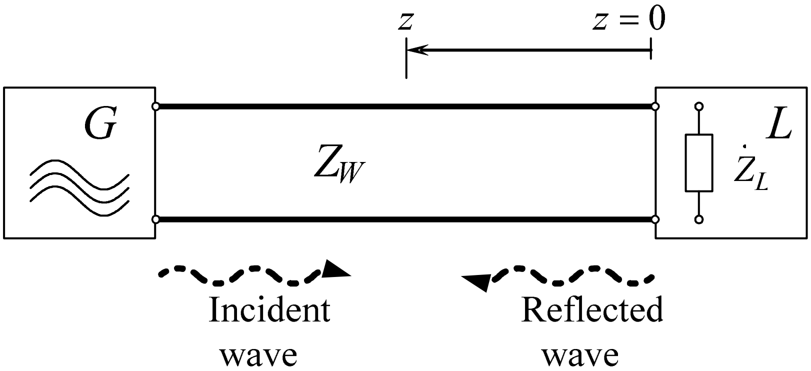

Figure 1.1 – Incident and reflected waves in transmission line

Incident wave is created by the oscillator and propagates in guiding structure from the oscillator to load.

Assuming that the transmission line has negligibly small losses and is set in the coordinates along z axis and its beginning corresponds to the place where load is connected ($z=0$) (fig. 1.1), it is possible to write down incident wave complex amplitude in a following form

$$\dot{E}_m^{\text{inc}} = E_0 e^{i\beta z}, \tag{1.1}$$

where z is longitudinal co-ordinate of guiding structure which is measured from load, placed in position $z=0$;

E_0 is amplitude of an incident wave;

$\beta = 2\pi/\lambda_w$ is phase factor or the longitudinal wave number;

λ_w is wavelength of microwave oscillation in guiding structure which is defined by expression

$$\lambda_w = \frac{\lambda}{\sqrt{1-(\lambda/\lambda_{\text{cut}})^2}},$$

where $\lambda = v_0/f$ is wave length of microwave oscillation in the medium filling a waveguide;

v_0 is velocity of light in the medium filling a waveguide;

f is frequency of microwave oscillation formed by the oscillator;

λ_{cut} is critical wave length of microwave oscillation in guiding structure (for the basic type of a wave H_{10} of a rectangular waveguide $\lambda_{\text{cut}} = 2a$).

Reflected is wave reflected by load (or some inhomogeneity) and propagates in the opposite direction, i.e. from load to the oscillator. In the adopted coordinates reflected wave phasor has the following form

$$\dot{E}_m^{\text{ref}} = E_0 \Gamma_L e^{i\varphi_L} e^{-i\beta z}, \tag{1.2}$$

where Γ_L and φ_L are the module and argument (phase) of reflection coefficient from load.

Traveling waves is a special operation mode of transmission line when the amplitude of a reflected wave is equal to zero. Thus load is ***matched*** with a transmission line, i.e. $\dot{Z}_L$ is purely active and equal to a transmission line wave impedance Z_W, i.e. $\dot{Z}_L = R_L = Z_W$.

S*tanding waves* is an operation mode of transmission line when the amplitude of a reflected wave is equal in to amplitude of an incident wave. It is possible, if load impedance is one of three options: ($\dot{Z}_L = \pm iX_L$ load purely imaginary impedance); ($\dot{Z}_L = 0$ ideal "short circuit"); ($Z_L = \infty$ ideal "idle mode" or open-circuit operation). In all these cases load does not absorb energy, transferred by an incident wave.

In practice the ***mixed waves*** are the most common operation mode when there both incident, and reflected waves are propagating in a transmission line simultaneously, however the amplitude of a reflected wave is less than amplitude of an incident wave. In this case impedance of load $\dot{Z}_L = R_L + iX_L$ has an active component R_L which absorbs a part of energy transferred by incident wave.

It is known that the incident and reflected waves are orthogonal, i.e. the power transferred by an incident wave, does not depend on the presence of reflected wave.

Superposition of incident and reflected waves in a transmission line leads

to an interference, i.e. formation along a transmission line of maximums and minimums of field intensity. Thus the maximum (minimum) value of field is observed at those points where the incident and reflected waves are in a phase (in antiphase).

In a lossless line or when losses in a line are negligible ***amplitude of a total wave*** in each cross-section of a transmission line (the longitudinal distribution of ***amplitude*** of field intensity) is defined from the expression:

$$\left|\dot{E}_{\Sigma}(z)\right| = E_0\sqrt{1+\Gamma_L^2+2\Gamma_L\cos(2\beta z-\varphi_L)}, \tag{1.3}$$

in which module Γ_L and argument (phase) φ_L of reflection coefficient from load is possible to compute from expressions:

$$\Gamma_L = \frac{\left|\dot{Z}_L - Z_W\right|}{\left|\dot{Z}_L + Z_W\right|} = \frac{\sqrt{(R_L - Z_W)^2 + X_L^2}}{\sqrt{(R_L + Z_W)^2 + X_L^2}}; \tag{1.4}$$

$$\varphi_L = \begin{cases} \tan^{-1}\left(\dfrac{X_L}{R_L - Z_W}\right) - \tan^{-1}\left(\dfrac{X_L}{R_L + Z_W}\right), \text{ when } R_L \ge Z_W; \\ \pi + \tan^{-1}\left(\dfrac{X_L}{R_L - Z_W}\right) - \tan^{-1}\left(\dfrac{X_L}{R_L + Z_W}\right), \text{ when } R_L < Z_W. \end{cases} \tag{1.5}$$

Examples of the longitudinal distributions of electric field intensity amplitude in the lossless transmission line for traveling waves ($\Gamma_L = 0$), standing waves ($\Gamma_L = 1$) and mixed waves ($0 < \Gamma_L < 1$) are represented on fig. 1.2. The graphs are plotted with the help of expression (1.3).

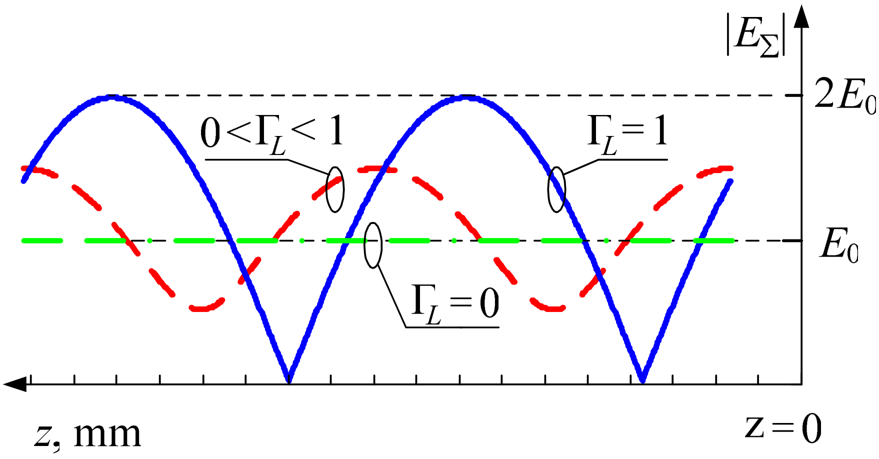

Figure 1.2 – Longitudinal distribution of field intensity amplitude

From the expression (1.3) and fig. 1.2 one may conclude:

a) If $\Gamma_L \neq 0$ (standing and mixed waves) with change of coordinate z along guiding structure, the amplitude of field intensity changes $\left|\dot{E}_\Sigma(z)\right|$, and in points

$$z_{n\,\min} = \frac{\lambda_w}{4}\left(\frac{\varphi_L}{\pi} + 2n - 1\right), \quad n = 0, 1, 2, ... \tag{1.6}$$

$$z_{n\,\max} = \frac{\lambda_w}{4}\left(\frac{\varphi_L}{\pi} + 2(n-1)\right), \quad n = 1, 2, ... \tag{1.7}$$

it takes the minimum $E_{n\,\min}$ and maximum $E_{n\,\max}$ values which are calculated from the following expressions

$$\begin{aligned} E_{n\,\min} &= E_0(1 - \Gamma_L), \\ E_{n\,\max} &= E_0(1 + \Gamma_L). \end{aligned} \tag{1.8}$$

b) Distance between the neighboring minimums (nodes) or maximums (loops) equals $\lambda_w/2$.

c) If $\Gamma_L = 1$ (standing waves) the amplitude field intensity $\left|\dot{E}_\Sigma(z)\right|$ is equal zero in a node and in a loop it is equal the doubled amplitude of an incident wave.

d) If $\Gamma_L = 0$ (traveling waves) the amplitude of field intensity $\left|\dot{E}_\Sigma(z)\right|$ in a transmission line is constant along a waveguide.

The transmission line operating mode in engineering practice can be characterized either by ***reflection coefficient, traveling-wave ratio*** (TWR) or ***standing-wave ratio*** (SWR).

In a losses transmission line the module of a reflection coefficient Γ_L does not depend on the longitudinal coordinate z, therefore all minimums and maximums of the longitudinal distribution of field intensity amplitude $\left|\dot{E}_\Sigma(z)\right|$ in a line are equal and TWR (SWR) is constant along the line.

Efficiency of power transfer into the load is characterized by ***efficiency*** that is equal to the ratio of the power P_L in the load, to power of the incident wave P_{inc} provided by the generator into transmission line. Reflection of the incident wave from load leads to decrease of power transferred into load $\eta = 1 - \Gamma_L^2$ times and consequently efficiency of the lossless transmission line equals

$$\eta = \frac{P_L}{P_{\text{inc}}} = 1 - \Gamma_L^2 = \frac{4K_{TW}}{(1 + K_{TW})^2}. \qquad (1.9)$$

From a relationship (1.9) one may conclude that optimal conditions for power transfer occur when the load is matched with transmission line, i.e. at $K_{TW} = 1$. Matched transmission line is also optimal from the point of view of achievement of the maximum electric strength. It is necessary to remember that because of increase of field intensity amplitude in a mismatched waveguide there can be an electric breakdown.

In real transmission lines for some reasons (frequency dependence of load impedance, the additional reflections from irregularities) the ideal matching appears unattainable. Therefore in specifications the least accepted value of TWR both for loads and for transmission line as a whole is specified. The usual acceptable value of TWR is not less than 0.7 … 0.8 though there are cases, for example, in transmission lines of receiving antennas of a short-wave range when acceptable value of TWR is decreased to 0.3 … 0.4.

1.3 Description of the laboratory setup

The following equipment is used for measurements in the current work (fig. 1.3 and fig. 1.4): 1 – microwave generator; 2 – decoupling ferrite isolator; 3 – measuring waveguide line “P1-28” (Appendix A); 4 – "short circuit" load – a metal plate; 5 – indicating device (measuring low-frequency amplifier); 6 – inductive slot load and capacitive slot load (inductive and capacitive diaphragms); 7 – matched load (absorbing waveguide load).

Notice. Measuring lines of two neighboring work places are connected to common microwave generator through waveguide tee-joint and ferrite isolators serving for decoupling of measuring sections.

1.4 Home task

1) Study theoretical information and be ready to discuss key questions.

2) Solve a problem. Microwave generator with frequency 9 939 MHz is connected to a rectangular waveguide with cross-section 23×10 mm^2 with air filling. The wave impedance Z_W and wave length λ_w of the dominant wave H_{10} for the set frequency in the guiding structure is equal

$$Z_W = \frac{b}{a} \frac{120\pi}{\sqrt{1 - (\lambda/2a)^2}} \approx 217\ \Omega;$$

$$\lambda_w = \frac{\lambda}{\sqrt{1 - (\lambda/2a)^2}} \approx 40\text{ mm}.$$

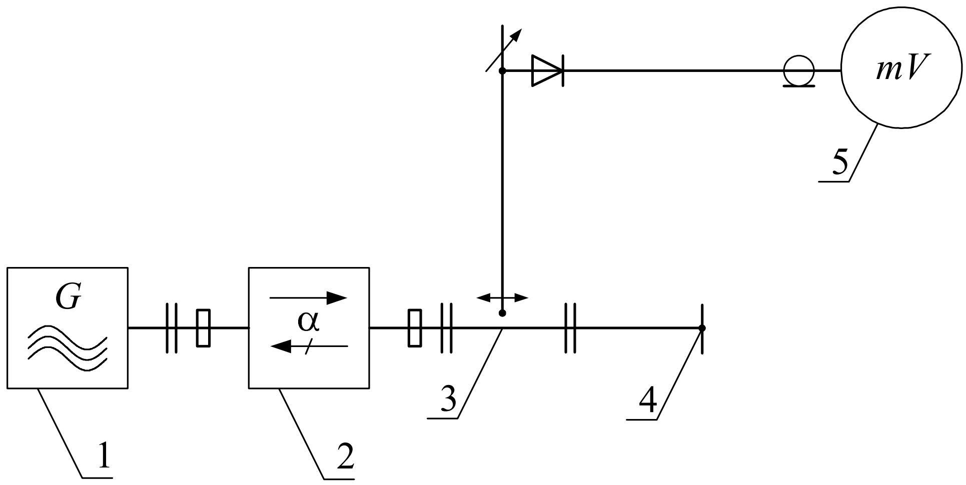

Figure 1.3 – Block diagram of a setup for research of longitudinal distribution of relative field intensity in a transmission line

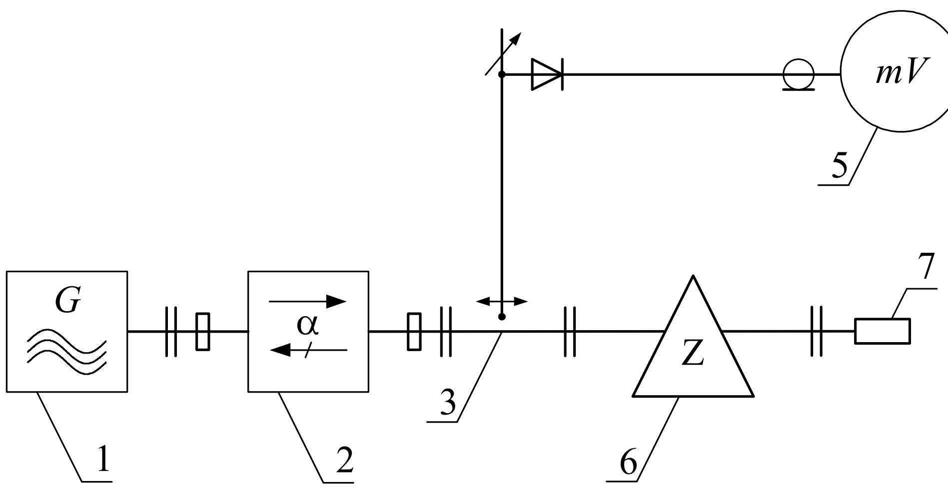

Figure 1.4 – Block diagram of a setup for research of longitudinal distribution of relative field intensity in a transmission line

Calculate and plot a graph of longitudinal distribution of relative field intensity $\left|\dot{E}_{\Sigma}(z)\right|/E_0$ along an ideal rectangular waveguide for following three loads:

a) $\dot{Z}_{L1} = 0\ \Omega$;

b) $\dot{Z}_{L2} = 217\ \Omega$;

c) $\dot{Z}_{L3} = 217 - i30(n-5)\ \Omega$,

where n is the last digit of credit book number.

Example of initial data selection. Let the last digit of credit book number is 3, then $n = 3$, and accordingly

$$\dot{Z}_{L3} = 217 - i30(3-5) = 217 + i60\ \Omega,$$

or the last digit of credit book number is 8, then $n = 8$, and accordingly

$$\dot{Z}_{L3} = 217 - i30(8-5) = 217 - i90\ \Omega.$$

3) Prepare the report on laboratory work which includes the title page formatted according to example, the goal of the work, home task solution, block diagrams of setups for research of longitudinal distribution of relative field intensity in a transmission line.

1.5 Methodical recommendations to home task problem

For calculation of longitudinal distribution of relative field intensity $\left|\dot{E}_{\Sigma}(z)\right| / E_0$ along an ideal rectangular waveguide it is possible to use the expression (1.3) in which Γ_L and φ_L are the module and argument (phase) of reflection coefficient from a load in point of connection are defined from correspondent expressions (1.4) and (1.5), and a phase factor or the longitudinal wave number β is defined from expression $\beta = 2\pi/\lambda_w$. The dependences need to be calculated and plotted for z varying from 0 to 60 mm with step not more than 4 mm. For more exact positioning of extreme points (positions of minimum $z_{\min}$ and maximum $z_{\max}$ values of longitudinal distribution of relative field intensity) one may use expressions (1.6) and (1.7) accordingly.

Calculation and plotting of the distributions can be performed by means of specialized programs, for example, MathCAD, MATLAB or other.

1.6 Laboratory task for experimental research

1) Install the setup for research of the longitudinal distribution of relative field intensity in a transmission line (fig. 1.3) and check how well the measuring waveguide line is tuned into resonance.

2) Measure the distribution of relative field intensity $U(z)$ along the transmission line for the following waveguide loads:

– $\dot{Z}_{L1} = 0\ \Omega$, SC – short circuit (fig. 1.3);

– $\dot{Z}_{L2} = Z_W = 217\ \Omega$, ML – absorbing (matched) waveguide load (fig. 1.4 – without load 6);

– $\dot{Z}_{L3}\ \Omega$, OEW – open end of a waveguide (fig. 1.3 – without load 4);

Results of measurements should be filled in tab. 1.1.

Table 1.1 – Results of experimental researches

z, mm															
$U(z)$, mV for $\dot{Z}_{L1} = 0$ Ω, SC															
$\lvert\dot{E}_{\Sigma}(z)\rvert / E_0$ for $\dot{Z}_{L1} = 0$ Ω, SC															
z, mm															
$U(z)$, mV for $\dot{Z}_{L2} = 217$ Ω, ML															
$\lvert\dot{E}_{\Sigma}(z)\rvert / E_0$ for $\dot{Z}_{L2} = 217$ Ω, ML															
z, mm															
$U(z)$, mV for $\dot{Z}_{L3}$ Ω, OEW															
$\lvert\dot{E}_{\Sigma}(z)\rvert / E_0$ for $\dot{Z}_{L3}$ Ω, OEW															

3) Normalize the gained values taking into account the quadric characteristic of the detector. The longitudinal distributions of relative field intensity is thus equal $\lvert\dot{E}_{\Sigma}(z)\rvert / E_0$, where $\lvert\dot{E}_{\Sigma}(z)\rvert \approx \sqrt{U(z)}$; $E_0 \approx \left(\sqrt{U_{\max}} + \sqrt{U_{\min}}\right)/2$; $U(z)$ – reading from indicator device in mV; $U_{\max}, U_{\min}$ in mV are the maximum and minimum values from the indicating device.

Normalized results should be presented in tab. 1.1.

4) Plot in the same coordinate system dependences of the longitudinal distribution of field intensity $\lvert\dot{E}_{\Sigma}(z)\rvert / E_0$ along the rectangular waveguide for all three loads of a waveguide.

5) Define TWR, SWR and the module of a reflection coefficient for all three loads of a waveguide.

6) Explain the gained results.

1.7 Advanced task (it is carried out facultatively)

7) Measure the distribution of relative field intensity $U(z)$ along the transmission line for the following waveguide loads:

– $\dot{Z}_{L1} = 0$ Ω, SC – short circuit (fig. 1.3);

– $\dot{Z}_{L4} = \dot{Z}_C$ Ω, CL – capacitive slot load covered by the absorbing (matched) waveguide load (fig. 1.4).

Results of measurements should be filled in tab. 1.2.

Table 1.2 – Results of experimental researches

z, mm															
$U(z)$, mV for $\dot{Z}_{L1} = 0$ Ω, SC															
$\lvert\dot{E}_{\Sigma}(z)\rvert / E_0$ for $\dot{Z}_{L1} = 0$ Ω, SC															
z, mm															
$U(z)$, mV for $\dot{Z}_{L4} = \dot{Z}_{\text{C}}$ Ω, CL															
$\lvert\dot{E}_{\Sigma}(z)\rvert / E_0$ for $\dot{Z}_{L4} = \dot{Z}_{\text{C}}$ Ω, CL															

8) Normalize the gained values taking into account the quadric characteristic of the detector. The longitudinal distributions of relative field intensity is thus equal $\lvert\dot{E}_{\Sigma}(z)\rvert / E_0$, where $\lvert\dot{E}_{\Sigma}(z)\rvert \approx \sqrt{U(z)}$; $E_0 \approx \left(\sqrt{U_{\max}} + \sqrt{U_{\min}}\right)/2$; $U(z)$ – reading from indicator device in mV; $U_{\max}, U_{\min}$ in mV are the maximum and minimum values from the indicating device.

Normalized results should be presented in tab. 1.2.

9) Plot in the same coordinate system dependences of the longitudinal distribution of field intensity $\lvert\dot{E}_{\Sigma}(z)\rvert / E_0$ along the rectangular waveguide for both loads of a waveguide.

10) Using the gained results calculate complex impedance $\dot{Z}_{\text{C}}$ of capacitive slot load.

1.8 Methodical recommendations to calculation of complex impedance of load

On the basis of experimental researches results a complex impedance $\dot{Z}_{\text{C}}$ of the load is possible to be defined from expression

$$\dot{Z}_C = Z_W \frac{1+\Gamma_L e^{i\varphi_L}}{1-\Gamma_L e^{i\varphi_L}} =$$

$$= Z_W \left[\frac{1-\Gamma_L^2}{1+\Gamma_L^2 - 2\Gamma_L \cos\varphi_L} + i \frac{2\Gamma_L \sin\varphi_L}{1+\Gamma_L^2 - 2\Gamma_L \cos\varphi_L} \right],$$

where Z_W is a wave impedance of the dominant wave mode in the transmission line;

Γ_L, φ_L are the module and argument (phase) of a reflection coefficient from load.

These two parameters are calculated from expressions:

$$\Gamma_L = \frac{K_{SW} - 1}{K_{SW} + 1},$$

where $K_{SW} = \sqrt{U_{\max}/U_{\min}}$; and $U_{\max}$ and $U_{\min}$ are maximum and minimum values of relative field intensity (fig. 1.5). They are defined from tab. 1.2;

$$\varphi_L = 2\beta\Delta z^{\min} - \pi = \pi\left(\frac{4\Delta z^{\min}}{\lambda_w} - 1\right),$$

where $\beta = 2\pi/\lambda_w$ is phase factor or the longitudinal wave number;

λ_w is wave length of the microwave oscillation in guiding structure;

$\Delta z^{\min}$ is the minimum distance between two points $z_{\min}^{SC}$ and $z_{\min}^{CL}$ (fig. 1.5), measured from $z_{\min}^{SC}$ towards the microwave generator; values $z_{\min}^{SC}$ and $z_{\min}^{CL}$ are defined from tab. 1.2.

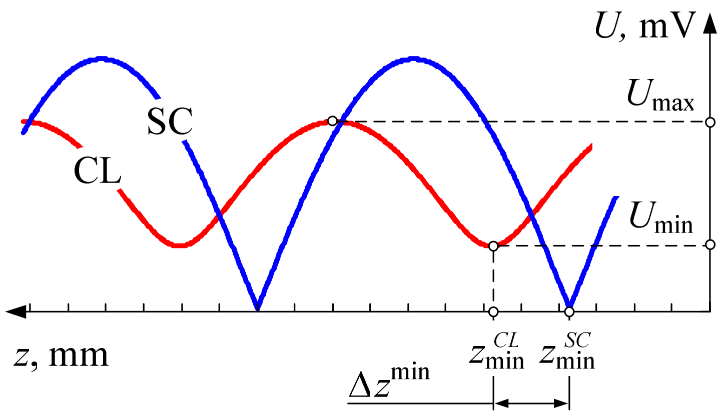

Figure 1.5 – Calculation of load complex impedance

Taking into account that guiding structure in the form of a rectangular waveguide with cross-section 23×10 mm^2 with air filling is used and it is excited by oscillator forming microwave oscillations with frequency 9 939 MHz, the wave resistance Z_W and wave length λ_w of the dominant wave mode H_{10} will be equal: $Z_W \approx 217\ \Omega$; $\lambda_w \approx 40$ mm.

1.9 Laboratory task for virtual setup (Laboratory work is performed on the personal computer)

1) Start the application «TED_LW_1_and_2.exe». Study features of the graphical interface and the way of doing measurements on the virtual laboratory setup (VLS1) (Appendix B).

Team number is set by the teacher.

2) Measure the distribution of relative field intensity $U(z)$ along the transmission line for the following waveguide loads:

– $\dot{Z}_{L1} = 0$ Ω, SC – short circuit (fig. 1.3);

– $\dot{Z}_{L2} = Z_W = 217$ Ω, ML – absorbing (matched) waveguide load (fig. 1.4 – without load 6);

– $\dot{Z}_{L3}$ Ω, OEW – open end of a waveguide (fig. 1.3 – without load 4);

Results of measurements should be filled in tab. 1.1.

3) Normalize the gained values taking into account the quadric characteristic of the detector. The longitudinal distributions of relative field intensity is thus equal $\left|\dot{E}_{\Sigma}(z)\right|/E_0$, where $\left|\dot{E}_{\Sigma}(z)\right| \approx \sqrt{U(z)}$; $E_0 \approx \left(\sqrt{U_{\max}} + \sqrt{U_{\min}}\right)/2$; $U(z)$ – reading from indicator device in mV; $U_{\max}$, $U_{\min}$ in mV are the maximum and minimum values from the indicating device.

Normalized results should be presented in tab. 1.1.

4) Plot in the same coordinate system dependences of the longitudinal distribution of field intensity $\left|\dot{E}_{\Sigma}(z)\right|/E_0$ along the rectangular waveguide for all three loads of a waveguide.

5) Define TWR, SWR and the module of a reflection coefficient for all three loads of a waveguide.

6) Explain the gained results.

1.10 Contents of the report

Report on laboratory work should contain the following points (Appendix C).

1) Title page according to example.

2) Laboratory work goal.

3) Home task problem solved.

4) Block diagrams of setups for research of the longitudinal distribution of relative field intensity in a transmission line.

5) Results of measurements of relative field intensity along a transmission line for various loads (tab.1.1, and also tab. 1.2 and results of calculation of a complex impedance of load $\dot{Z}_{\mathrm{C}}$ in cases the facultative task was completed).

6) Graphs of the longitudinal distribution of relative field intensity $\left|\dot{E}_{\Sigma}(z)\right|/E_0$ from co-ordinate along the transmission line for different types of load.

7) Analysis of the results obtained and conclusions.

1.11 Key questions

1) Describe the parameters of different operation modes of transmission line: traveling waves, standing waves and mixed waves.

2) Give definition of a reflection coefficient, TWR and SWR.

3) Write down the expressions showing the relation between reflection coefficient with traveling wave ratio, with standing wave ratio and impedance of load.

4) What does the efficiency of power transfer into load depends on?

5) Draw the block diagram of a setup for research of the longitudinal distribution of relative field intensity in a transmission line, explain the operation of setup and the roles of all elements.

2 GENERAL REQUIREMENTS TO THE IMPLEMENTATION OF LABORATORY WORK

Contents of the lab work has to be pre-studied on the basis of methodical instructions with the involvement of theoretical material from the lecture course, relevant literature (Appendix C).

Laboratory work is done by groups consisting of 2 students, each performing individual assignments. A report is prepared and defended by each student individually. Input data for the research assignments are chosen by each student in accordance with the next to last (m) and the last (n) digits of the student's credit book.

3 RECOMMENDED LITERATURE

1) Rajeev Bansal Fundamentals of Engineering Electromagnetics. – Taylor& Francis Groop, 2006. – 394 s.

2) Черенков В.С. Техническая электродинамика: конспект лекций / В.С. Черенков, А.М. Иваницкий. – Одесса: Изд-во ОНАС им. А.С. Попова, 2006. – 160 с.

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Appendix A
Short technical specification
and manual of measuring waveguide line “P1-28”

The measuring waveguide line “P1-28” is intended for measuring of parameters of electromagnetic waves in the devices based on wave-guide lines with a cross-section 23×10 mm. The line can be used for measuring of module and phase of reflection coefficient of two-terminal networks and quadripoles, measuring of wave length in a wave guide, measurings of small attenuation of waveguide quadripoles.

The general view of measuring waveguide lines “P1-28” with the basic controls is shown in fig. A.1.

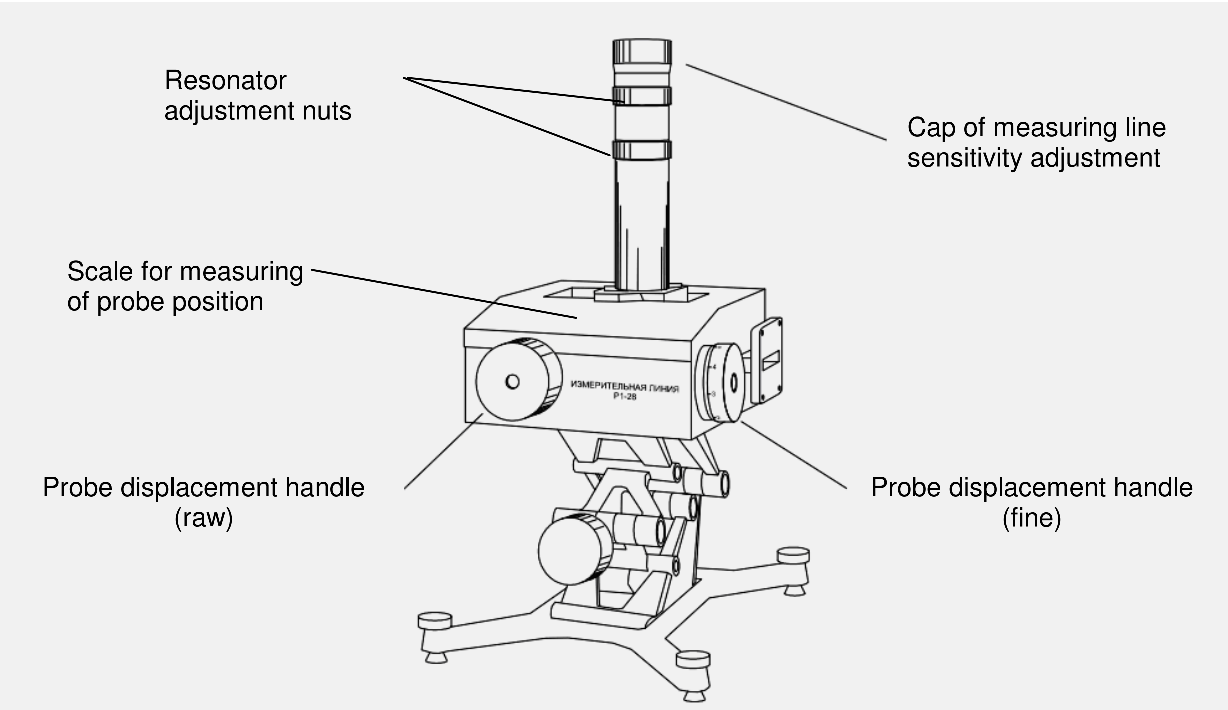
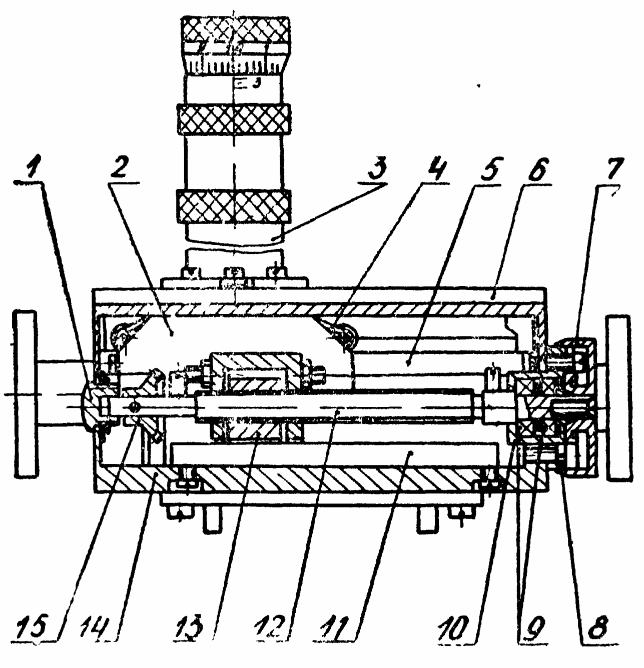


Figure A.1 – General view and arrangement of the basic controls of measuring waveguide line “P1-28”

Measuring waveguide line “P1-28” consists of a piece of rectangular wave guide with the narrow slot which has been cut in the middle of and along the wide wall of the wave guide and a mobile chariot, consisting of a vertical probe which is connected to detecting section via tunable resonator.

The wave guide is built in the case in the form of a cast detail. The chariot is U-shaped supporting arm sweeping a brass plate which simultaneously is the guiding structure for the chariot. The construction of the chariot displacement mechanism is shown in fig. A.2.



1 – bracket;
2 – chariot;
3 – probe head;
4 – flat spring;
5 – plate;
6 – cap;
7 – graduated collar of displacement mechanism;
8 – fastening screw of the displacement mechanism;
9 – ball-bearings;
10 – plug;
11 – guiding;
12 – screw of displacement mechanism;
13 – nut of displacement mechanism;
14 – case;
15 – conical wheel

Figure A.2 – Construction of the chariot displacement mechanism

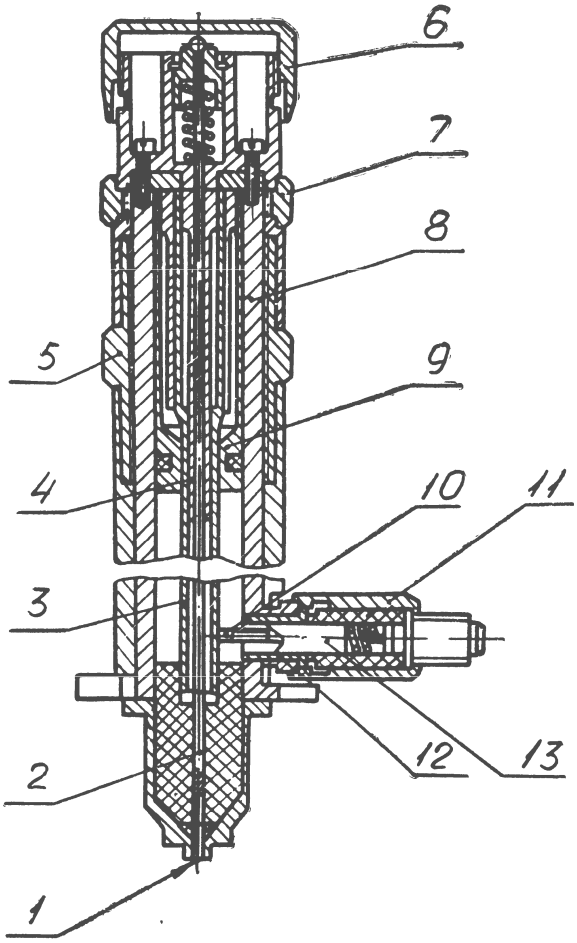
The principle of operation of the line is based on examination of electromagnetic wave field distribution by means of a probe passed through a slot into the interior of the waveguide. The probe is connected to tunable measuring probe head. The head is placed on the chariot that can be moved along the waveguide.

The probe provides a loose coupling with electric field in the waveguide. The induced current is proportional to electric field intensity in the place where probe is located. After detection by the detector, the signal is measured by an indicator.

Adjustment of the probe measuring head for the peak sensitivity allows to compensate reactive component of probe conductivity, influencing the field shape in the waveguide, and thus reduce error of measurements, simultaneously raising the total sensitivity of a line. By moving the probe along the line allows to find positions of maximums and minimums of field intensity in the line and their relative levels.

Measuring waveguide line is used as a part of a laboratory model, therefore it is constantly connected by one hand to the generator through decoupling ferrite isolator.

Chariot displacement is performed by rotation of the screw of the mechanism with a step of a screw line equal 1 mm. The construction of the probe head is shown in fig. A.3.



1 – probe;
2 – dowel;
3 – medial tube;
4 – internal piston;
5 – nut of external piston;
6 – graduated collar of probe depth;
7 – nut of internal piston;
8 – external pipe;
9 – external piston;
10 – contact;
11 – nut;
12 – isolating tube;
13 – detector

Figure A.3 – Construction of probe head

Operating procedure of measuring waveguide line

1) Connect the examinee waveguide device or load to the free flange of the line.

2) Connect signal cable from the measuring low-frequency amplifier to the connector of a low-frequency socket of probe head.

3) Switch on the generator and set the necessary depth of the probe. The peak depth of the probe should not exceed 1.6 mm.

4) Proceeding from the maximum reading of the indicator tune the probe contour into resonance using the upper adjusting nut of probe head, then by means of the lower nut perform the fine tuning of the probe detecting contour into resonance. Try repeating adjustment of contours in order to get the maximum of reading on the indicator.

5) One may consider line operation to be normal if the maximums observed along a line, differ no more than 4%.

Appendix B
Description of virtual laboratory setup

Introduction. The virtual laboratory setups (VLS) are created in the graphic programming environment of LabVIEW – Laboratory Virtual Instrument Engineering Workbench (LabVIEW2009/LabVIEW2010) and is intended for examination of the basic processes in a microwave lines, methods of measuring of their parameters and characteristics. Developed VLS are programs which by means of graphical user interfaces allow simulation of operation with real devices of laboratory installation.

The virtual laboratory setup for examination of basic processes in a microwave path. Front panel of the virtual laboratory setup is depicted in fig. B.1 (VLS1). With the help of VLS1 the following laboratory researches are possible to be carried out: “Research of operating modes of waveguide transmission lines”.

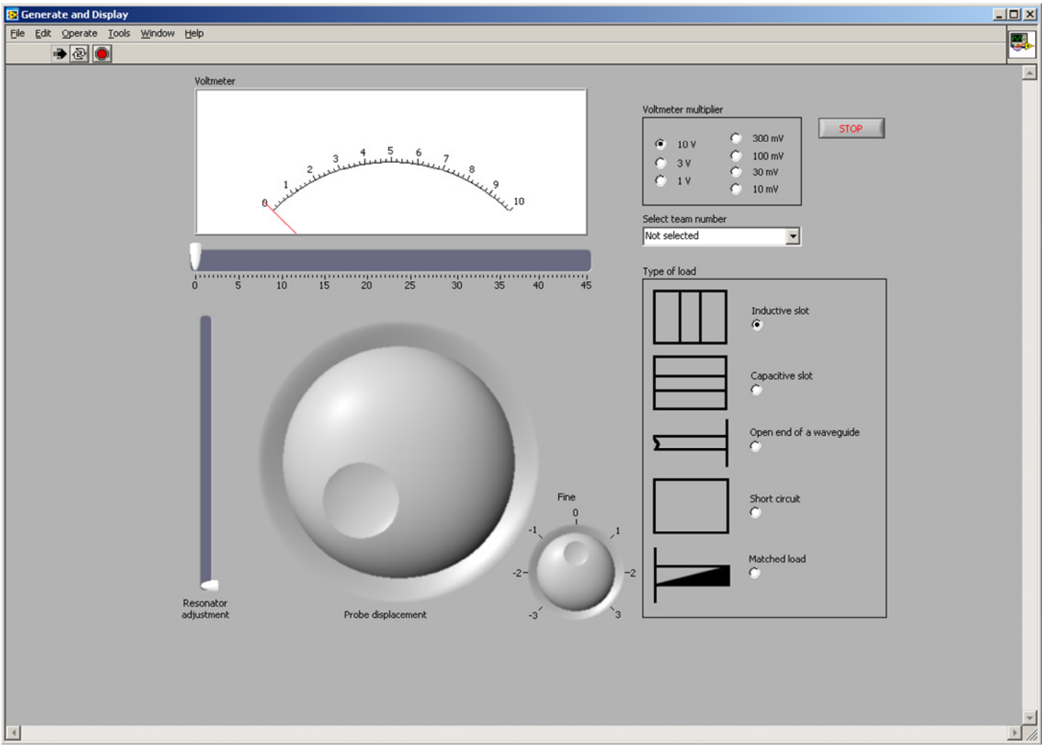


Figure B.1 – Front panel of VLS1

There are 9 main blocks on the front panel of VLS1 shown in fig. B.2.

The blocks on the front panel of VLS 1 have the following names:

1 – start and stop block of VLS1 (for stopping of VLS 1 button STOP of block 9 can also be used);

2 – indicator of a needle voltmeter connected to detecting section of the probe head;

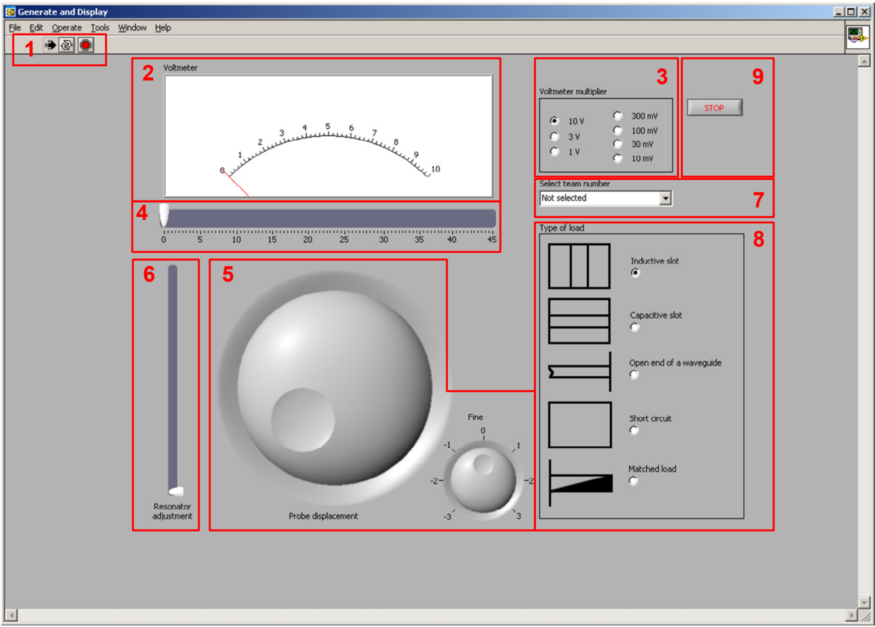


Figure B.2 – Main blocks of the front panel of VLS1

3 – switch of voltmeter scale limits;

4 – scale of waveguide measuring line which is used to measure the position of the probe head;

5 – handles of the displacement mechanism moving the probe along the waveguide measuring line (the large handle is raw and the small handle is fine adjustment);

6 – block of adjustment of the probe head resonator;

7 – block of team number selection;

8 – block of load selection.

Performance of measurements on VLS1. The measurements on the VLS1 are made identically to how they are made with the help of real devices.

The short instruction explaining peculiarities of VLS1 operation and basic differences in operation of VLS1 from real laboratory setup are the following:

1) Start VLS1 by pressing button start (it is marked with a right arrow) in block 1 (fig. B.3). After that the red stop button becomes active and can be used for stopping of VLS1. The button of cyclic run of the program (marked by two arrows) ***is not used***.

a) b)

Figure B.3 – Start and stop block of VLS:
a) – panel of stopped VLS; b) – panel of started VLS

2) From the list of drop-down menu of block 7 select the number of a team specified by the teacher. The team number defines individual options of VLS1

for each team. If the team number is not selected, VLS1 ***is NOT in a working state***.

3) By means of handle of block 6 tune the resonator of waveguide measuring line into resonance. For this purpose it is necessary to apply the matched load from block 8 and by moving the handle of the resonator upwards and downwards achieve the peak indication of the voltmeter (there probably may be a necessity to change the limit of scale on the voltmeter in order to get the needle of the voltmeter within the limits of measuring scale). Resonator tuning is performed ***once before the beginning of measurements.***

4) Choose and connect the needed load in block 8.

5) By moving the probe of measuring waveguide line with the help of handles in block 5, make the measurements of necessary quantities. The position of the probe is read from the scale of block 4 and voltage on the probe is read from voltmeter scale (block 2).

6) If necessary iterate instructions 4-5 the needed number of times.

7) Press stop button of VLS1 in block 1 or block 9.

Operation of virtual voltmeter completely corresponds to operation of real device (measuring low-frequency amplifier). Measurements are read out from a device scale. It is necessary to remember that during the process of measurements the voltmeter needle should be in ***upper two thirds of device scale***, as is shown in fig. B.4.

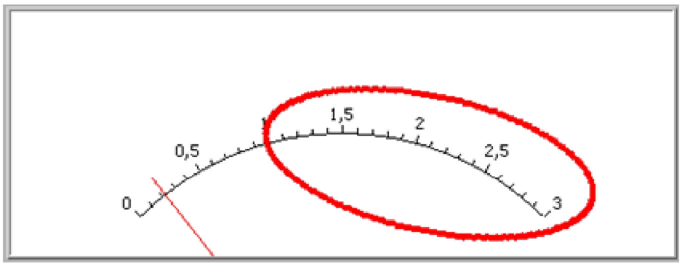


Figure B.4 – Operation area of voltmeter scale

If the needle of the device is below operation area it is necessary to lower a voltmeter factor on the block 3 until the needle enters into operation area. If the needle is in an extreme right position it is necessary to raise value of voltmeter scale limit in the block 3 until the needle enters into operation area. If no manipulations at switching scale limits can get the needle into operation area value of measured voltage is outside the working range of the voltmeter. If the needle is below the operation area, it is possible to take a reading of the estimate value of voltage.

After setting the necessary voltmeter scale limit, it is necessary to read the value of voltage from device scale bearing in mind the set scale limit. The scale limit specifies, the voltage value corresponding to an extreme right position of the needle. For convenience the device scale changes calibration depending on the value of scale limit which was set.

Appendix C
Extract from regulations about organization and procedure of laboratory works in ONAT n.a. A.S. Popov

Laboratory work is a kind of lesson that involves a student performing experimental or modeling tests on his own under supervision of the teacher with the aim of practical proof of certain theoretical statements from the subject, student also acquires practical skills of working with laboratory equipment, computers, measuring devices, methodic of experimental tests in a certain field.

During the labwork student have to learn how to compare theoretical knowledge with experimental results, how to study experimentally processes and phenomena, gain ability to critically analyze results, master special skills of technical operation.

The content, quantity and topics of laboratory works are regulated by the subject program and teaching plans.

Teacher estimates each labwork that is performed by a student.

Final marks that student gains for the labworks are then taken into consideration when the term credit takes place for the certain subject.

Students are allowed to take term exam on a certain subject after he/she has completed all the laboratory works included into the course by the term teaching plan.

Organizational support of laboratory work consists of guidance documents for students, list of laboratory work, hardware-software of work places, laboratory journal of current students work.

Methodical documents for students include handbook, some individual tasks (computational, graphical, algorithmic, circuit), slides, diagrams, handouts, posters and other.

Methodical recommendations for lab works is the basic training document that organizes and directs **an active independent work of the student** in all phases of laboratory work.

Laboratory studies include ongoing monitoring of how well students are prepared for a particular laboratory work, performing of the task corresponding to the topic of the work, composing of individual reports on the labworks and its defense.

Laboratory classes take place in specially equipped laboratories.

The report on specific laboratory work is issued in separate notebook for laboratory work and practical training in this discipline.

This notebook must be proposed to examiner for the check.

On the cover of the notebook there should be the inscription:

Reports of laboratory works on subject_________________________ student of group_______________________ (surname and initials)

Performing of laboratory work consists of three steps:

1) performing of homework,

2) performing of laboratory tasks;

3) preparation of individual report and its defense.

Performing of homework

Homework is contained in the laboratory work methodical recommendations. It may be supplemented or changed by a teacher.

When doing homework for each of a laboratory work student must prepare a form report in workbook first (*experiment diagrams, list of equipment, expressions for doing calculations, preparatory plots and calculations, estimates on the correspondences under research, algorithms and programs, tables for data, etc*).

Student who came to a labwork without report prepared is considered to be not ready to do the labwork.

Performing of laboratory tasks

To perform laboratory tasks the student must bring the results of homework in the workbook, methodical recommendations and if necessary textbook or other literature.

Students independently perform laboratory experiment at their work places and record all intermediate and final results in the form of calculations, tables, graphs, diagrams in the workbook (*notes should also include individual conclusions on the result of the laboratory task completion. The conclusion is the most responsible part of the report because it reveals student's proper thoughts and the level of student's intellect*).

Preparation of individual report

All records in the report are done in ink or pen of dark color.

Figures (diagrams, graphs, charts, etc.) are done in pencil, ink or pen of dark color by hand. Students may use drawing supplies.

Tables of experimental data should be created by following a number of general rules:

– the table should be given the name of the experiment;

– columns should be rectangular (diagonal distribution of table columns is not allowed);

– the values written in each column (row) of the table have to be accurately described and the units for the values must be provided;

– the quantity unit must be separated by a comma from numerical value of the quantity; each value should be rounded following the common rules and should end with a digit in the same position that is the last in the absolute measurement error;

– if during the measurement the obtained values are integer after the decimal point there must be written as many zeros as many decimal places are there in the absolute measurement error.

The graphs formatting should follow the following basic rules:

– the title of the experiment should be placed under each graph;

– the scales must meet the range and accuracy of the measured value;

– obtained in the experiment points should be clearly marked on the graph with the labels such as large dots, crosses, squares, triangles, etc.;

– the figures with multiple graphs should have the parameters indicated for each graph;

– the names of physical quantities and scales should be indicated on the axes.

In accordance with the results of individual interviews with students and judging from the quality analysis of the report a teacher evaluates student's work and puts the mark in the student's report and in special journal.

Each student must complete all lab work listed in the plan. In some cases, the teacher may assign the student an additional meeting in the lab in order to complete or repeat the experiment or for more in-depth study of the material.