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 characteristics and parameters of electromagnetic wave"

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

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Goal of the methodical instructions is to help students during independent study of 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 consists of two parts: part 1) Measurement of wave length of electromagnetic oscillations in a waveguide, and part 2) Standing wave ratio measurement.

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
"Measurement of wave length of electromagnetic oscillations in a waveguide"

1.1 Goal of the work

Study of design and operation principle of waveguide measuring line; acquisition of skills of measurement of electromagnetic oscillation wave length in a waveguide with the help of waveguide measuring line.

1.2 Key points

There are four types of electromagnetic waves that may propagate in guiding structures depending on the presence of the longitudinal components of electric and magnetic field intensity vectors.

The equations describing complex components of electric and magnetic field intensity vectors in guiding structures, have the following form:

$$\begin{cases} \dot{E}(x, y, z) = E_m(x, y)\exp(-i\beta z); \\ \dot{H}(x, y, z) = H_m(x, y)\exp(-i\beta z). \end{cases} \qquad (1.1)$$

where $E_m(x, y)$, $H_m(x, y)$ are the amplitudes of electric and magnetic field intensity;
$\beta = 2\pi/\lambda_w$ is longitudinal wave number or a phase factor.

Value λ_w is ***wave length of the microwave oscillation in guiding structure*** (waveguide), i.e. distance between two surfaces of equal phases on which phases differ on 2π.

The wave length of the microwave oscillation in a waveguide can be determined experimentally or calculated from expression

$$\lambda_w = \frac{\lambda}{\sqrt{1-(\lambda/\lambda_{cut})^2}}, \qquad (1.2)$$

where $\lambda = v_0/f$ is ***wave length of the microwave oscillation in free space*** with parameters of the medium filling the waveguide or in other words ***wave length of the microwave oscillation formed by the oscillator***;
v_0 is a velocity of light in the medium filling the waveguide;
f is frequency of the microwave oscillation formed by the oscillator;
λ_{cut} is ***cutoff wave length of the microwave oscillation*** in guiding structure.

If the wave length of oscillation in a waveguide λ_w is determined experimentally from the expression (1.2) it is easy to find wave length of the oscillation formed by the oscillator from expression:

$$\lambda = \frac{\lambda_w}{\sqrt{1+\left(\lambda_w/\lambda_{cut}\right)^2}}. \tag{1.3}$$

For the description of an electromagnetic wave in guiding structures a wave model is used in which the existence of two waves in the guiding structure is supposed: incident wave passing from the generator to load and reflected one passing from the load to the generator. The presence of reflected wave leads to the amplitude of a total wave $E_\Sigma(z)$ in each point z along guiding structure changes. The maximum value of the amplitude is observed in those points where the incident and reflected waves are in phase and on the contrary minimums of the amplitude are formed where the incident and reflected waves are in anti phase.

Amplitude of a total wave as functions of the longitudinal coordinate is determined by the following expression:

$$\left|\dot{E}_\Sigma(z)\right| = E_0\sqrt{1+\Gamma_L^2+2\Gamma_L\cos(2\beta z-\varphi_L)}, \tag{1.4}$$

where z is coordinate which is measured from load towards the generator;
E_0 is amplitude of an incident wave;
Γ_L, φ_L are module and argument (phase) of reflection coefficient in a point where the load is connected.

From the expression (1.4) one may conclude that for $\Gamma_L \neq 0$ with change of coordinate z along guiding structure the amplitude of total field intensity $\left|\dot{E}_\Sigma(z)\right|$ also changes: the minimum value is $E_{\min} = E_0(1-\Gamma_L)$ and the maximum value is $E_{\max} = E_0(1+\Gamma_L)$ (fig. 1.1).

Thus coordinates of nodes and loops (for $z \geq 0$) are determined by following expressions:

$$z_{n\min} = \frac{\lambda_w}{4}\left(\frac{\varphi_L}{\pi}+2n-1\right), \quad n=0,1,2,..., \tag{1.5}$$

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

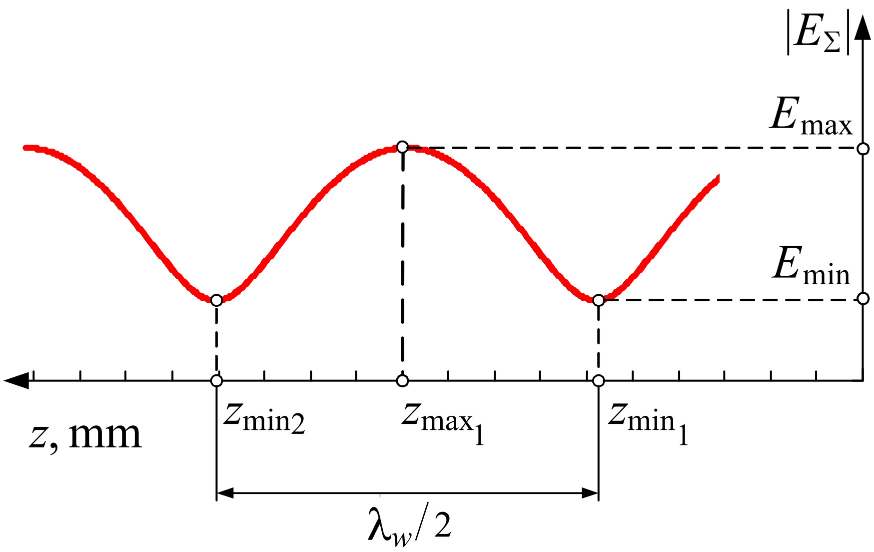


Figure 1.1 – Longitudinal distribution of total field intensity amplitude

From expressions (1.5) and (1.6) one may conclude that the distance between the neighboring minimums (nodes), or maximums (loops) equals $\lambda_w/2$. Thus, after the places of two neighboring nodes (loops) are found it is possible to compute wave length of the microwave oscillation in a waveguide.

In practice wave length of the microwave oscillation in a waveguide is measured by means of measuring waveguide line (Appendix A). Measuring waveguide line "P1-28" consists of a piece of a rectangular waveguide with cross-section 23×10 mm with the slot which has been cut in the middle of a wide wall of a waveguide, and a probe consisting of a vertical metal wire, entrained into a waveguide and connected via the tuned in resonator with a detector. The probe is installed on the carriage which allows to move it along a waveguide. The signal induced in a wire is proportional to electric field intensity in the wire location, and after detection it is fed into an indicator circuit. Measuring amplitude of a signal on a detector output for various positions of the probe, it is possible to build dependence of amplitude of a total wave along a waveguide. With the help of the dependency it is possible to define wave length of the microwave oscillation in a waveguide. Changing a depth of a probe wire in measuring line, it is possible to change the magnitude of power taken from a waveguide which is proportional to the amplitude of a signal on a detector output (the detector has a square-law UI curve).

1.3 Description of the laboratory setup

The following equipment is used for measurements in the current work (fig. 1.2 and fig. 1.3) : 1 – microwave generator; 2 – decoupling ferrite isolator; 3 – measuring waveguide line "P1-28" (Appendix A); 4 – short-circuit load

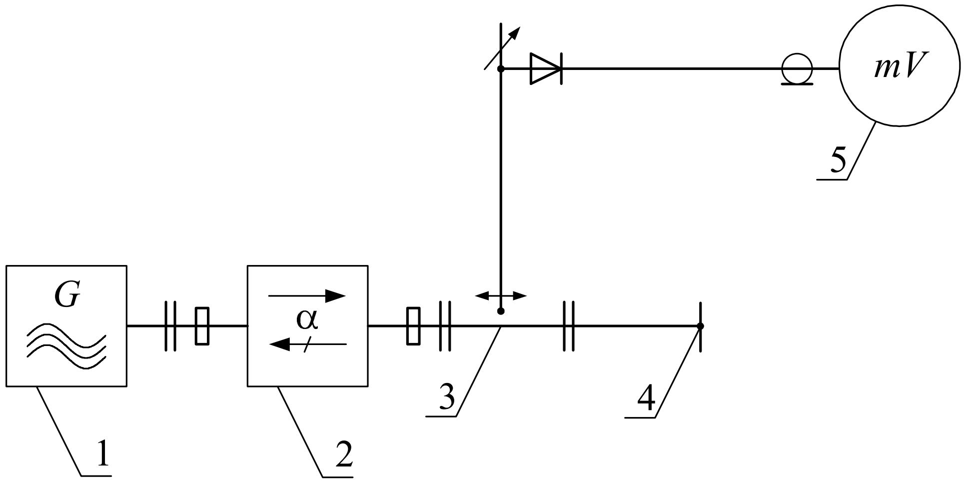


Figure 1.2 – Block diagram of setup for measurement of microwave oscillation wave lengths with the help of short-circuiting fixed load

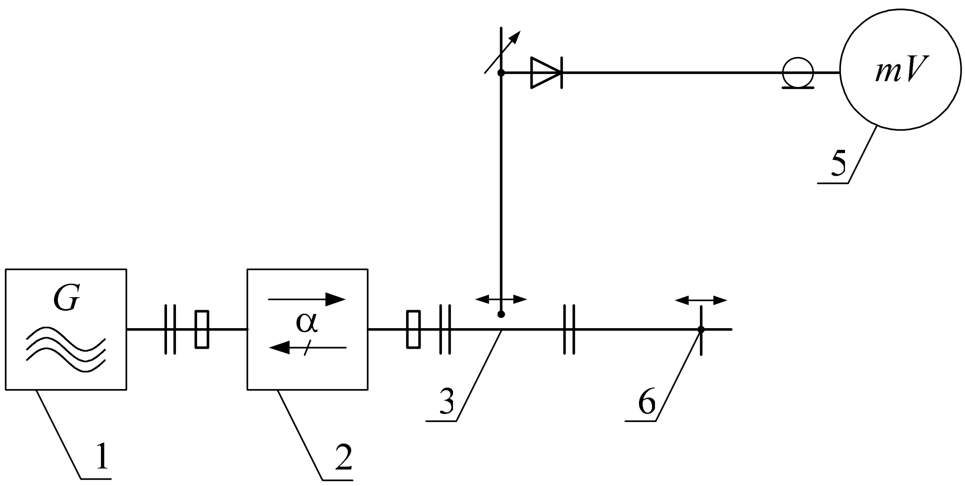


Figure 1.3 – Block diagram of setup for measurement of microwave oscillation wave lengths with the help of short-circuited adjustable piston

(metal plate); 5 – indicating device (measuring low-frequency amplifier); 6 – short circuit load (short-circuited adjustable piston).

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

1.4 Measurement of wave length of electromagnetic wave in a waveguide

Measurement of wave length λ_w of microwave oscillation in a waveguide is possible to be done following the block diagram in fig. 1.2 using one of two alternatives.

Alternative 1 when load 5 is the short-circuiting metal plate connected to a free flange of measuring waveguide line.

In this case algorithm of measurement is the following:

1) by moving of the measuring line probe the co-ordinate of one of the minimums (node) is defined $z_{\min_1}$;

2) also by moving of the measuring line probe the co-ordinate of the next minimum (node) is defined $z_{\min_2}$;

3) the wave length of the microwave oscillation in a waveguide λ_w is computed from expression $\lambda_w = 2\left|z_{\min_2} - z_{\min_1}\right|$.

Alternative 2 when load 6 is the short-circuiting load with the adjustable piston and measuring line probe remains fixed (fig. 1.3). In this case algorithm of measurements is the following:

1) the short-circuiting piston is installed so that the position of the first minimum of the longitudinal field distribution is in the beginning of a track of the probe;

2) on a scale on the short-circuiting load the minimum coordinate is defined $z_{\min_1}$;

3) by moving of the piston of the short-circuiting load one is searching when the minimum of distribution will again be reached. The coordinate $z_{\min_2}$ of the second minimum is read on the scale of short-circuiting load;

4) the wave length of the microwave oscillation in a waveguide λ_w is computed from expression $\lambda_w = 2\left|z_{\min_2} - z_{\min_1}\right|$.

For the longitudinal field distribution, corresponding to the mixed waves, co-ordinates of minimums (nodes) are hard to define accurately. Then for more exact definition of minimums position and accordingly the wave length of the microwave oscillation in a waveguide λ_w one may use a so called “fork” method (fig. 1.4) that uses those parts of the distribution characteristic with the greatest steepness. For this purpose the probe of a measuring line is installed in a position close to a minimum and the indication of the voltmeter U is read and co-ordinate z^- is also measured, then the probe is moved on the other side from the minimum until the noted indication U is reached and co-ordinate z^+ is read for the position of that point.

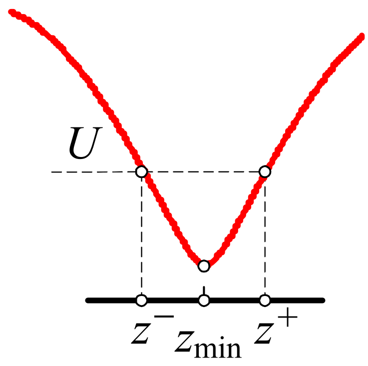


Figure 1.4 – “Fork” method

The minimum position $z_{\min}$ is defined from expression

$$z_{\min} = \frac{z^- + z^+}{2}.$$

1.5 Home task

1) Study theory on the lab work and be ready for discussion of questions.

2) Study the technical specification and the manual of measuring waveguide line “P1-28” (Appendix A).

3) Prepare the report on laboratory work which includes the title page (according to example), the work goal, block diagrams of setups for measurement of wave length of microwave oscillation in a waveguide.

1.6 Laboratory task for experimental research

1) Install the setup and make measurement of wave length of the microwave oscillation in a waveguide with the help of fixed short-circuiting load:

– find positions of two neighboring minimums using two methods: by installing probe in points of minimums of field intensity and “fork” method;

– find wave length of the microwave oscillation in a waveguide using known positions of nodes.

2) Find wave length and frequency of the microwave oscillation formed by the generator. The results should be represented in tab. 1.1.

3) Compare and explain the gained results.

Notice. The wave length of the microwave oscillation formed by the generator λ is calculated from expression (1.3) taking into account $\lambda_{cut} = 2 \cdot 23 = 46$ mm; frequency of the microwave oscillation formed by the generator f is calculated from expression $f = v_0/\lambda$, where $v_0 = 3 \cdot 10^8$ m/s is a velocity of light.

Table 1.1 – Results of experimental researches

Measured parameter	Method of the fixed short-circuiting load	
	Method of installation of a probe in minimum points	"Fork" method
$z_{\min_1}$, mm		
$z_{\min_2}$, mm		
λ_w, mm		
λ, mm		
f, GHz		

1.7 Advanced task (it is carried out facultatively)

4) Install the setup and perform measurement of length of the microwave oscillation in a waveguide by means of the adjustable short-circuiting load:

– find distance between the neighboring minimums, by moving the piston of adjustable short-circuiting load;

– from the results of measurements find wave length of the microwave oscillation in a waveguide.

5) Calculate wave length and frequency of the microwave oscillation formed by the generator. Represent gained results in tab. 1.2.

6) Compare the gained results to results of tab. 1.1 and estimate their accuracy.

Table 1.2 – Results of experimental researches

Measured parameter	Method of the adjustable short-circuiting load	
	Method of installation of a probe in minimum points	"Fork" method
$z_{\min_1}$, mm		
$z_{\min_2}$, mm		
λ_w, mm		
λ, mm		
f, GHz		

1.8 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 (VLS 1) (Appendix B).

The number of team is set by the teacher.

2) Perform measurement of wave length of the microwave oscillation in a waveguide with the help of fixed short-circuiting load:

– find the positions of two neighboring minimums using two methods: by method of installation of a probe in minimum points and “fork” method;

– from the found positions of nodes define wave length of the microwave oscillation in a waveguide.

3) Calculate wave length and frequency of the microwave oscillation formed by the generator. Represent gained results in tab. 1.1.

4) Compare and explain the obtained results.

1.9 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) Block diagrams of setups for measurement of wave length of the microwave oscillation in a waveguide.

4) Results of experimental measurement of the positions of nodes and distances between the neighboring nodes, calculation of wave length of the microwave oscillation in a waveguide, wave lengths and frequencies of the microwave oscillation formed by the generator (tab. 1.1 and tab. 1.2 in case of completing of facultative task).

5) Analysis of the results obtained and conclusions.

1.10 Key questions

1) Explain the design and operation principle of waveguide measuring line.

2) Represent the block diagram of the setup for measurement of wave length of oscillation in a waveguide by means of the fixed short-circuiting load.

3) Represent the block diagram of setup for measurement of wave length of oscillation in a waveguide by means of short-circuiting load with adjustable mobile piston (short-circuiting piston).

4) Explain what the “fork” method of definition of electric field intensity minimum position consists in?

5) How is it possible to measure λ_w with the help waveguide measuring line?

6) What is “wave length of oscillation in a waveguide”?

7) What is “wave length of the microwave oscillation formed by the

generator"?

8) What is "wave length of the microwave oscillation in free space"?

9) How is wave length of the microwave oscillation formed by the generator defined?

10) How do we define frequency of the microwave oscillation formed by the generator?

11) Explain the graph of the longitudinal distribution of electric field intensity amplitude.

2 LABORATORY WORK
"Standing wave ratio measurement"

2.1 Goal of the work

Study of the design and operation principle of waveguide measuring line; mastering the use of waveguide measuring line for standing-wave ratio (SWR) measurement.

2.2 Key points

Let's consider a piece of regular ***guiding structure***, or in other words ***transmission line*** in the form of a waveguide, placed between a source of electromagnetic waves (generator) and the terminal (load).

Let dimensions of guiding structure are chosen in such a way that only dominant wave can propagate in it. According to the wave model an inclusion of the load at the end of the line will result in two waves formed in the waveguide. In addition to the incident wave (going from the generator towards the load) the reflected wave is formed that is going backward (from the load towards generator).

For the load description, i.e. for an estimation of its "ability" to absorb power of incident wave or degree of matching of a line with load a complex reflection coefficient or standing wave ratio (traveling wave ratio) is used.

Complex reflection coefficient of electric field is designated with $\dot{\Gamma}_{\mathrm{E}}$ and is determined from expression:

$$\dot{\Gamma}_{\mathrm{E}} = \frac{\dot{E}_{\perp ref}\, e^{-i\beta z}}{\dot{E}_{\perp inc}\, e^{i\beta z}} = \dot{\Gamma}_L\, e^{-i2\beta z}, \quad \dot{\Gamma}_L = \Gamma_L\, e^{i\varphi_L}, \qquad (2.1)$$

where z is longitudinal coordinate of guiding structure which is measured from load that is located at $z = 0$;

$\dot{\Gamma}_L$ is complex reflection coefficient from load;

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

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

λ_w is wave length of the microwave oscillation in guiding structure which is defined by expression (1.2)

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

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

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

f is frequency of the microwave oscillation formed by the generator;

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

The reflection coefficient from load can be computed on the basis of known values of a wave impedance of transmission line Z_W and complex load impedance $\dot{Z}_L = R_L + iX_L$ from following expression:

$$\dot{\Gamma}_L = \Gamma_L e^{i\varphi_L} = \frac{\dot{Z}_L - Z_W}{\dot{Z}_L + Z_W} = \frac{R_L + iX_L - Z_W}{R_L + iX_L + Z_W}. \tag{2.2}$$

The module Γ_L and argument (phase) φ_L of reflection coefficient at a point of load connection are defined from expressions:

$$\Gamma_L = \frac{\left|\dot{Z}_L - Z_W\right|}{\left|\dot{Z}_L + Z_W\right|} = \frac{\sqrt{(R_L - Z_W)^2 + X_L^2}}{\sqrt{(R_L + Z_W)^2 + X_L^2}}; \tag{2.3}$$

$$\varphi_L = \begin{cases} \tan^{-1}\left(\dfrac{X_L}{R_L - Z_W}\right) - \tan^{-1}\left(\dfrac{X_L}{R_L + Z_W}\right), \ for \ R_L \geq Z_W; \\ \pi + \tan^{-1}\left(\dfrac{X_L}{R_L - Z_W}\right) - \tan^{-1}\left(\dfrac{X_L}{R_L + Z_W}\right), \ for \ R_L < Z_W. \end{cases} \tag{2.4}$$

The amplitude of total field intensity in guiding structure changes along the longitudinal axis according to the following law (1.4):

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

where z is longitudinal coordinate of guiding structure which is measured from load towards the generator;

E_0 is amplitude of an incident wave.

From the expression (1.4) one may conclude that for $\rho_L \neq 0$ with change of coordinate z along guiding structure the amplitude of total field intensity $\left|\dot{E}_\Sigma(z)\right|$ also changes, taking the minimum $E_{\min} = E_0(1 - \Gamma_L)$ and maximum $E_{\max} = E_0(1 + \Gamma_L)$ values (fig. 1.1).

Travelling-wave ratio (TWR) is designated as K_{TW} and defined as the relation of the minimum and maximum value of amplitude of field intensity, i.e. from the following expression

$$K_{TW} = \frac{E_{\min}}{E_{\max}}. \qquad (2.5)$$

S*tanding-wave ratio* (SWR) is designated as K_{SW} and defined as the relation of the maximum and minimum value of amplitude of field intensity or as a value reciprocal to travelling-wave ratio, according following expression

$$K_{SW} = \frac{E_{\max}}{E_{\min}} = \frac{1}{K_{TW}}. \qquad (2.6)$$

Due to $E_{\min} = 1 - \Gamma_L$ and $E_{\max} = 1 + \Gamma_L$,

$$K_{TW} = \frac{1-\Gamma_L}{1+\Gamma_L}, \quad K_{SW} = \frac{1+\Gamma_L}{1-\Gamma_L}. \qquad (2.7)$$

From the stated above one can conclude that both K_{SW} and K_{TW} can be defined using the measured values of total field intensity amplitude in node and an in loop. In practice measurement of K_{SW} and K_{TW} is possible to perform by means of a measuring line.

2.3 Description of the laboratory setup

For doing measurements in the laboratory work the following equipment (fig. 2.1 and fig. 2.2) is used: 1 – microwave generator; 2 – decoupling ferrite isolator; 3 – measuring waveguide line "P1-28" (Appendix A); 4 – inductive and capacitor slot loads (inductive and capacitor diaphragms); 5 – display device (measuring low-frequency amplifier); 6 – matched load (absorbing waveguide load).

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

2.4 Measurement of K_{SW} by «maximum – minimum» method

Block diagram of setup for measurement of SWR (TWR) of two-terminal networks is shown in fig. 2.1. Measurement of K_{SW} by «maximum – minimum» method with the use of pointer indicator is done as follows:

– the probe of measuring line is placed to the position corresponding to

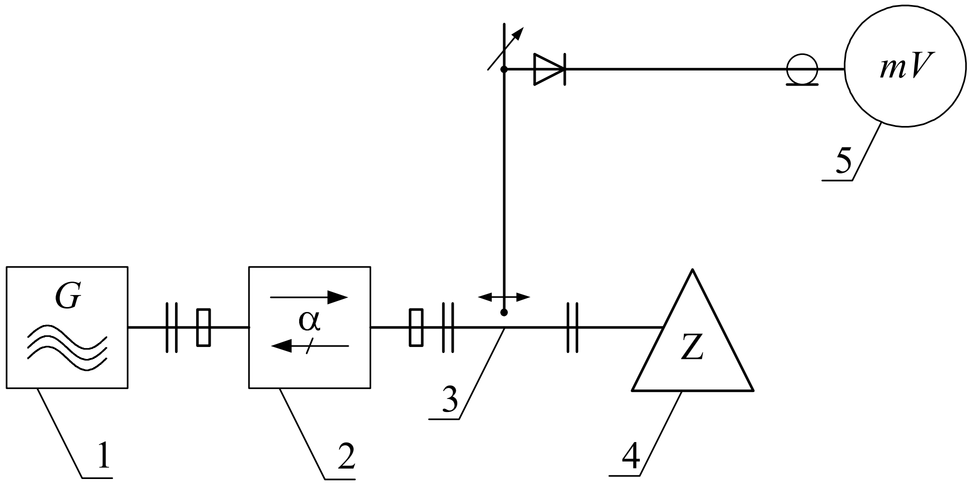


Figure 2.1 – Block diagram of the setup
for measurement of SWR (TWR) of two-terminal networks

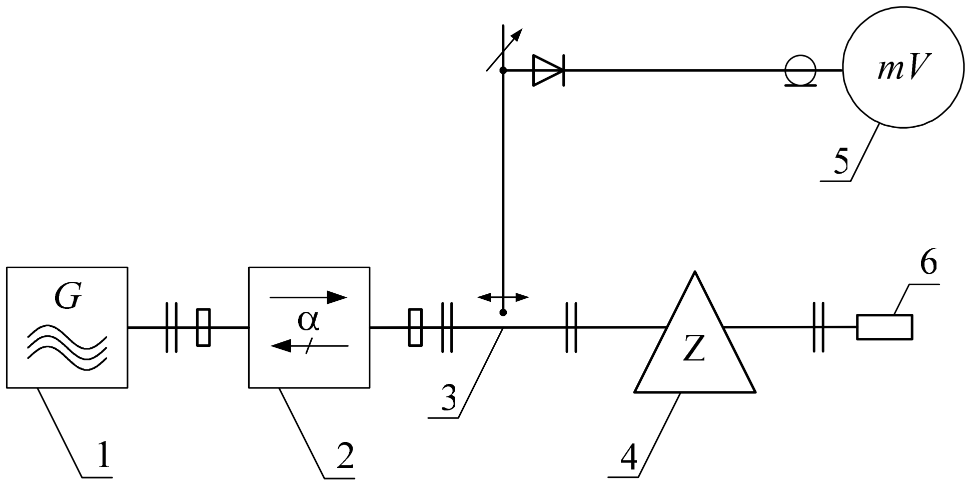


Figure 2.2 – Block diagram of the setup
for measurement of SWR (TWR) of four-terminal networks

the maximum deviation of indicator needle (millivoltmeter), and value $U_{\max}$ is read;

– then the probe is moved into the place corresponding to the minimum deviation of indicator needle (millivoltmeter), and value $U_{\min}$ is read;

– using the found values $U_{\max}$ and $U_{\min}$ taking into account the quadric characteristic of the detector numerical value of SWR is calculated from expression $K_{SW} = \sqrt{U_{\max}/U_{\min}}$.

From the defined value K_{SW} it is possible to define K_{TW} and the module of a reflection coefficient Γ_L from expressions:

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

2.5 Measurement of K_{SW} of four-terminal networks

Measurement of K_{SW} of four-terminal networks is performed in accordance with the block diagram shown in fig. 2.2 also using the «maximum – minimum» method which was presented above.

The main difference of this case from the previous one consists in that the investigated four-terminal network takes place between a measuring line and matched waveguide load.

2.6 Home task

1) Study the theoretical part and be ready for discussion of key questions.

2) Solve a problem. A microwave generator forming oscillation of frequency 9 939 MHz is connected to a rectangular waveguide with the cross-section 23×10 mm^2 with air filling. The wave impedance Z_W of the dominant wave H_{10} on the given frequency (wave length λ) will be equal

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

Calculate values of Γ_L, K_{SW} and K_{TW} for the following four loads of a waveguide:

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

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

c) $\dot{Z}_{L3} = 25(n+1)\ \text{k}\Omega$,

d) $\dot{Z}_{L4} = 217 + i30(n-5)\ \Omega$,

where n is last digit of credit book number.

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

$$\dot{Z}_{L3} = 25(3+1)\cdot 1000 = 100000\ \Omega,$$

$$\dot{Z}_{L4} = 217 + i30(3-5) = 217 - i60\ \Omega,$$

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

$$\dot{Z}_{L3} = 25(8+1)\cdot 1000 = 225000\ \Omega,$$

$$\dot{Z}_{L4} = 217 + i30(8-5) = 217 + i90\ \Omega.$$

Methodical recommendations to the solution of a home task problem. For calculation of Γ_L one may use expression (2.3), and for calculation of K_{SW} and K_{TW} expressions (2.7).

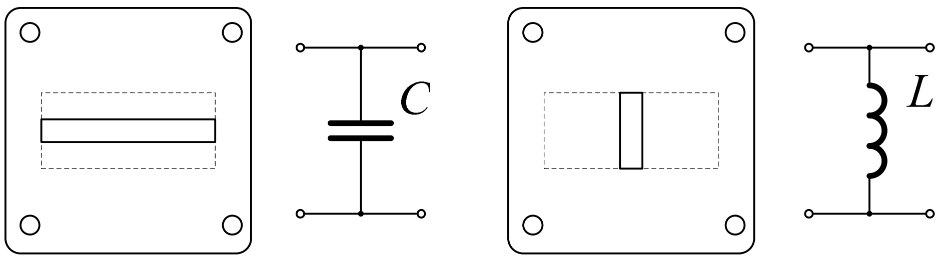
3) Prepare the report on laboratory work which includes the title page composed according to example, work goal, problem solution, block diagrams of setups for measurement of SWR (TWR).

2.7 Laboratory task for experimental research

1) Install the setup for measurement of SWR in a waveguide and tune measuring waveguide line after the maximum depth of a probe is set.

2) Measure the maximum $U_{\max}$ and minimum $U_{\min}$ values of field intensity relative amplitude for three kinds of loads: the open end of a waveguide, inductive and capacitor slots.

Appearance and equivalent circuit designs of inductive and capacitor diaphragms are shown in fig. 2.3.



a) *b)*

Figure 2.3 – Appearance and the equivalent circuit design:
a) – capacitive; *b*) – inductive diaphragm

3) From the measured values of $U_{\max}$ and $U_{\min}$ find SWR, TWR and the module of reflection coefficient Γ_L. The obtained results represent in tab. 2.1.

4) Compare and explain the obtained results.

Table 2.1 – Results of experimental researches

Measured parameters	Load “Open end of a waveguide”	Load “Inductive diaphragm”	Load “Capacitive diaphragm”
Maximum depth of the probe			
U_{max} , mV			
U_{min} , mV			
K_{SW}			
K_{TW}			
Γ_L			

2.8 Advanced task (it is carried out facultatively)

5) Reduce the depth of the probe of the measuring line so that indicator reading in the loop decreased approximately ten times (in comparison with indications at a maximum depth of a probe) and tune the measuring waveguide line.

6) Measure the maximum U_{max} and minimum U_{min} values of field intensity relative amplitude for the same three kinds of loads: the open end of a waveguide, inductive and capacitor slots (inductive and capacitor diaphragms).

7) From the measured values of U_{max} and U_{min} find SWR, TWR and the module of reflection coefficient Γ_L. The obtained results represent in tab. 2.2.

Table 2.2 – Results of experimental researches

Measured parameters	Load “Open end of a waveguide”	Load “Inductive diaphragm”	Load “Capacitive diaphragm”
Reduced depth of the probe			
U_{max} , mV			
U_{min} , mV			
K_{SW}			
K_{TW}			
Γ_L			

8) Compare and explain the obtained results taking into account their accuracy (for various depth of the probe).

2.9 Laboratory task for virtual setup (Laboratory work is carried out 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 (VLS 1) (Appendix B).

The number of team is set by the teacher.

2) Measure maximum $U_{\max}$ and minimum $U_{\min}$ values of field intensity relative amplitude for three loads of a waveguide: the open end of a waveguide, inductive and capacitor slots.

3) From the measured values of $U_{\max}$ and $U_{\min}$ find SWR, TWR and the module of reflection coefficient Γ_L. The obtained results represent in tab. 2.1.

4) Compare and explain the obtained results.

2.10 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) Solution of home task problems

4) Block diagrams of setups for measurement of SWR (TWR).

5) Results of experimental measurement of SWR and calculations of TWR and the module of reflection coefficient Γ_L for all loads (tab. 2.1 and tab. 2.2 in case the facultative task was completed).

5) Analysis of the results obtained and conclusions.

2.11 Key questions

1) Explain the design and operation principle of waveguide measuring line.

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

3) What are the limits of reflection coefficient module change, of TWR and SWR?

4) Write down the expressions connecting the module of reflection coefficient with SWR and TWR.

5) Write down the expression connecting the value of reflection coefficient with load impedance.

6) Draw the block diagram of the setup for measurement of SWR (TWR) in a waveguide.

7) Explain how waveguide measuring line is used to define K_{SW}?

8) Why accuracy of K_{SW} measurement changes at a change of the depth of the probe in measuring line?

3 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.

4 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.

3) Черенков В.С. Технічна електродинаміка: конспект лекцій / В.С. Черенков, А.М. Іваницький. – Одеса: Вид-во ОНАЗ ім. О.С. Попова, 2004. – 156 с.

4) Пименов Ю.В. Техническая электродинамика: учеб. пособ. для вузов./ Пименов Ю.В., Вольман В.И., Муравев А.Д.; под ред. Ю.В. Пименова. – М.: Радио и связь, 2002. – 536 с.

5) Черенков В.С. Электродинамика информационных систем: учеб. пособ. / Черенков В.С., Драганов В.М., Соломко А.В. – Одесса: Изд-во УГАС им. А.С. Попова, 1997. – 90 с.

6) Черенков В.С. Електродинаміка інформаційних систем: навч. посіб. / Черенков В.С., Драганов В.М., Соломко О.В. – Одеса: Вид-во УДАЗ ім. О.С. Попова, 1995. – 94 с.

7) Иваницкий А.М. Техническая электродинамика: метод. руководство к практическим занятиям и самостоятельной работе. – Одесса: Изд-во ОНАС им. А.С. Попова, 2003. – 22 с.

8) Драганов В.М. Электродинамика и распространение радиоволн: метод. руководство к лабораторному практикуму / В.М. Драганов, В.С. Черенков. – Одесса: Изд-во УГАС им.А.С. Попова, 2002. – 52 с.

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.

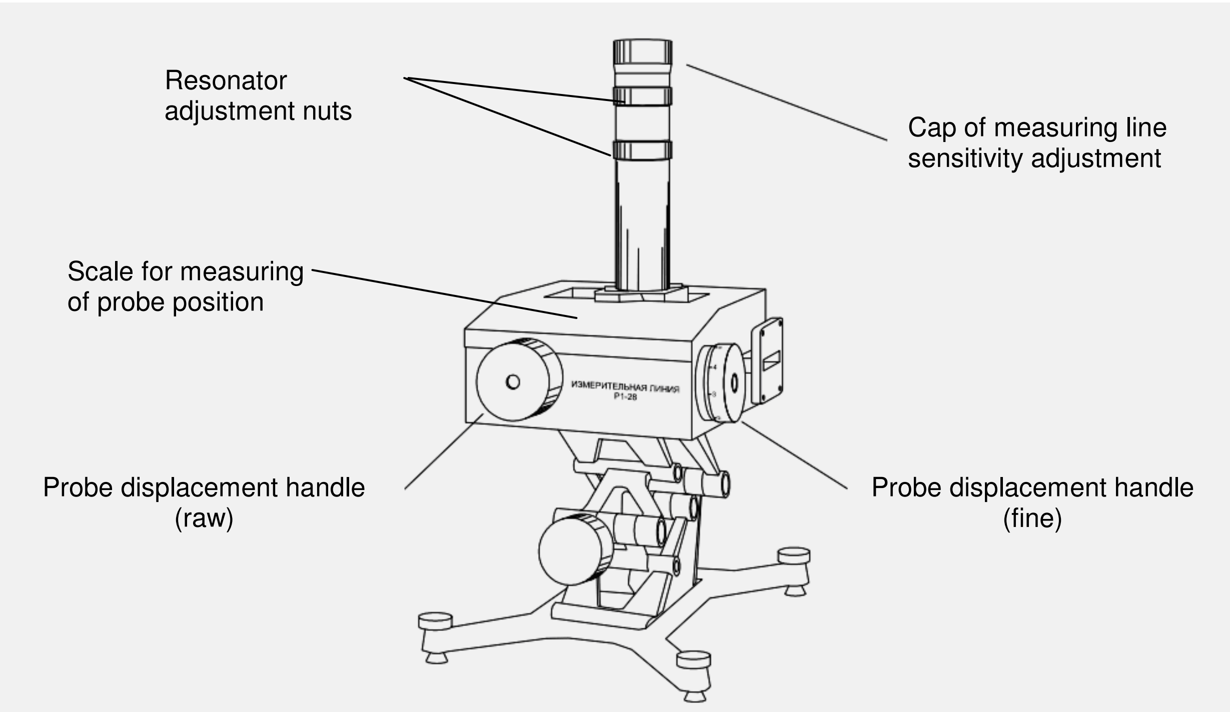
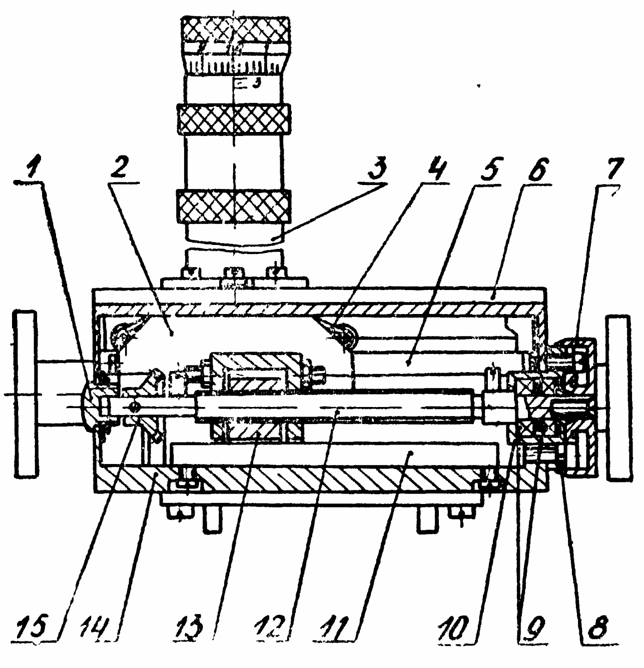


Figure A.1 – General view and arrangement of the basic controls of measuring waveguide line “P1-28”

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

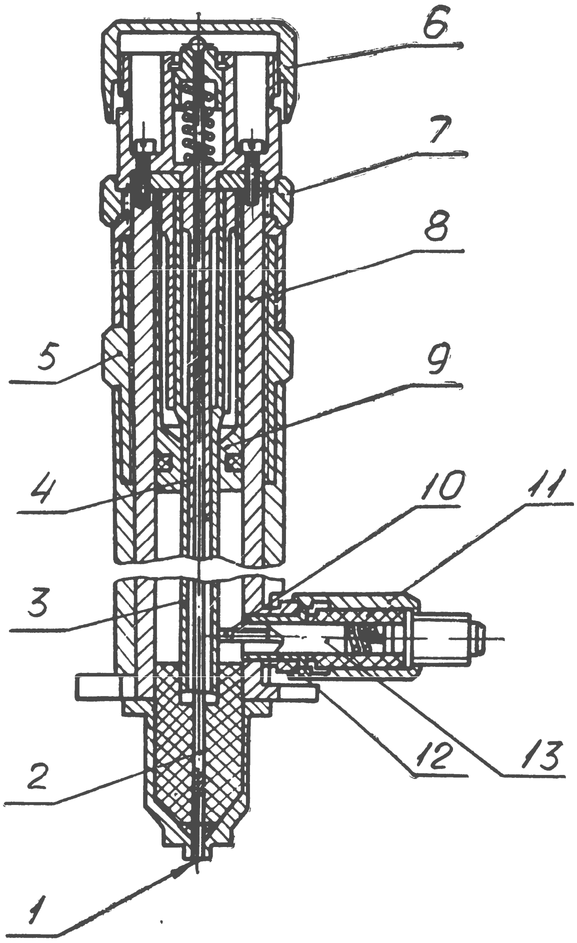
The principle of operation of the line is based on examination of electromagnetic wave field distribution by means of a probe passed through a slot into the interior of the waveguide. The probe is connected to tunable measuring probe head. The head is placed on the chariot that can be moved along the 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: 1) Examination of characteristics and parameters of electromagnetic waves (Part 1. Measurement of wave length of electromagnetic oscillation in a wave guide. Part 2. Measurement of standing wave ratio).

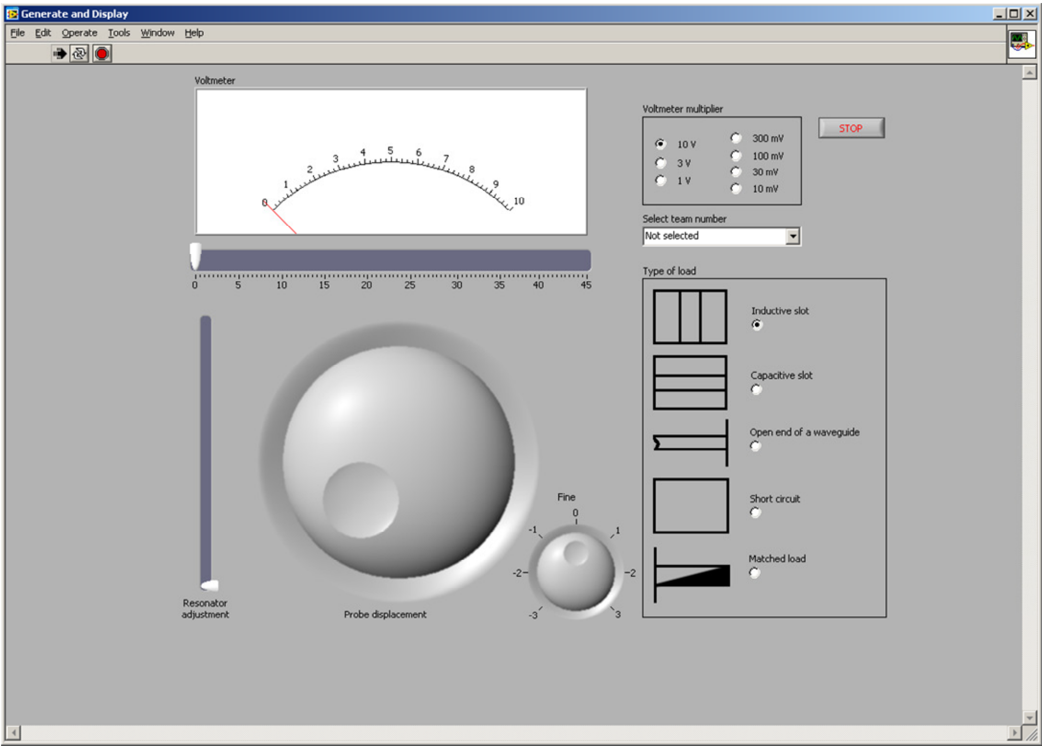


Figure B.1 – Front panel of VLS1

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;

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.

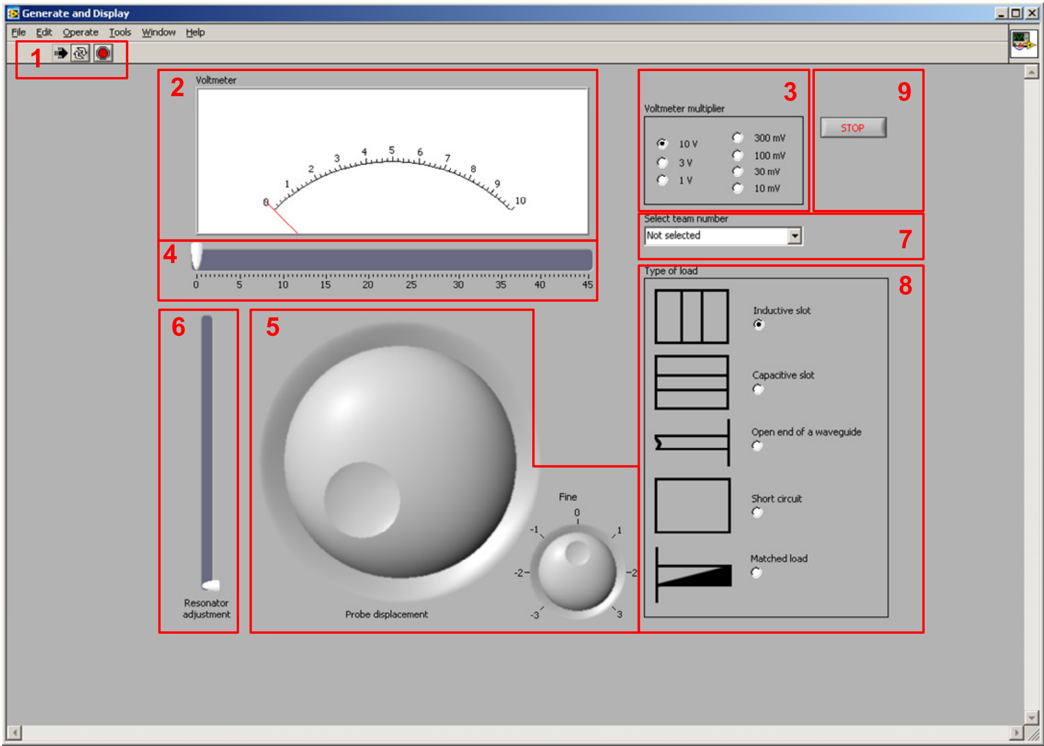


Figure B.2 – Main blocks of the front panel of VLS1

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.

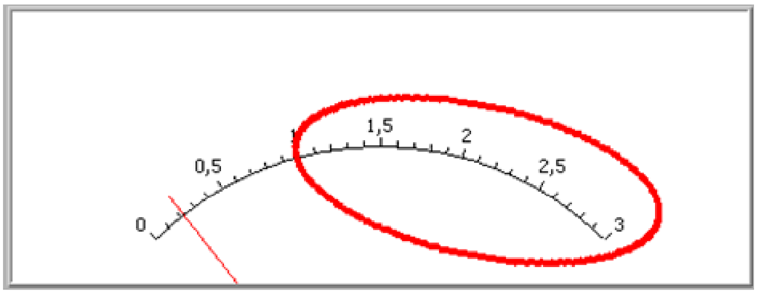


Figure B.4 – Operation area of voltmeter scale

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.