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 the matching techniques of transmission lines with an arbitrary load”

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 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 named research of the matching techniques of transmission lines with an arbitrary load.

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)

Approved methodical council of ONAT n.a. A.S. Popov. (Protocol № 3/14 from April 9, 2013)

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CONTENTS

1 LABORATORY WORK
"Research of the matching techniques of transmission lines with an arbitrary load"

1.1 Goal of the work

Research of matching techniques of a load with a waveguide transmission line; acquisition of skills of narrow-band matching of a waveguide with load.

1.2 Key points

It is known that an optimal operating mode of a transmission line is ***traveling waves***, at which efficiency of the transmission line $\eta = 1$ that is achieved with the help of matching of the transmission line with load (for $K_{TW} = 1$). In case the condition $K_{TW} \neq 1$ is not satisfied this operation mode, is provided, by use of ***matching device*** that is placed between the end of a transmission line and load. The matching device consists of elements that have reactive impedances (without ohmic losses) in order to get high efficiency.

More often the so-called ***narrow-band matching*** is used. The traveling waves in this case occurs only on a single frequency. When the frequency of a signal deviates from a central value a mismatch occurs and decrease in K_{TW} is observed. The frequency band for which K_{TW} exceeds certain value $K_{TW\,\min}$ is called a matching frequency band. In case of narrow-band matching the matching frequency band is not controlled. It is defined by verifying calculation or experimentally.

In case of ***broadband matching*** the values of matching elements are defined from a need to achieve the maximum matching frequency band.

In case of narrow-band matching it is enough to compensate a reflection wave from load on the chosen frequency, bringing in an additional reflection wave into a transmission line. For extending of a matching frequency band a usual approach is to reduce the length of matching device and place it as closer to load as possible. Then frequency deviation from the design value will produce the least change of electric lengths in the matching device and the mismatch effect that arises with frequency change will develop more slowly. The narrow-band matching is usually implemented with the help of transformers in the form of pieces of transmission lines with changed wave impedance and also distributed and lumped reactive elements (for example a stubs, diaphragms, pins), which are placed in the particular cross-section of the transmission line.

Stub is a piece of a regular transmission line of the finite length L_S, terminated in a load with impedance $\dot{Z}_L^S$. Then changing the length of the stub L_S one may achieve proper change of input impedance $\dot{Z}_{IN}^S$ of the stub within certain limits. In practice stubs with reactive input impedances have the widest application (they have a short circuit load $\dot{Z}_L^S = 0$ so the stubs are called short-circuited stubs). Input impedance of a short-circuited stub is always reactive and is defined by the following expression

$$\dot{Z}_{IN}^S = iZ_W^S \operatorname{tg}\frac{2\pi L_S}{\lambda_w}, \tag{1.1}$$

where Z_W^S is a wave impedance of a short-circuited stub.

From the expression (1.1) it is clear that a load with any needed reactive impedance may be created by means of a short-circuited stub. For example, if L_S/λ_w changes from 0 to 0.25 the input impedance of a short-circuited stub is inductive and changes from 0 to infinity. If L_S/λ_w changes from 0.25 to 0.5 the input impedance of a short-circuited stub is capacitive and changes from infinity to 0.

Matching by means of lumped reactive element. This method has been developed by V.V. Tatarinov and widely applied in all ranges of wave lengths – from middle waves to millimeter waves.

The method consists in the following. If the transmission line is terminated in a load with an impedance not equal to wave impedance of the line $Z_L \neq Z_W$ then according to wave model there a reflected wave arises in guiding structure. Inclusion of a reactive element with particular impedance before load will provoke a wave reflected from the element. It is possible so to choose the value of a reactance (or admittance) of the element and its position in such a way that the waves reflected from load and reflected from the reactive element, will have equal amplitudes and be in antiphase and consequently will compensate each other (their sum is equal to 0). Thus in the transmission line from the oscillator to point of connection of matching element there will be only a traveling wave.

Equivalent circuits for serial and parallel reactive elements connections are shown in fig. 1.1. For matching of transmission line with load and provisioning of traveling waves in it, in each of the circuits one needs to choose a place of connection of reactive element and its reactance.

Serial compensating reactance (reactive element with reactance ix_{com} (fig. 1.1, a)) should be connected in the cross-section of a line l_{x} where the real part of a total impedance of the line is precisely equal to a transmission line wave impedance. The imaginary part of impedance in this point is the sum of imaginary part of a total impedance of the line and x_{com} and it can be made equal to 0 (achieved by proper selection of the reactance of compensating reactive element). This provides the ideal matching on a chosen frequency.

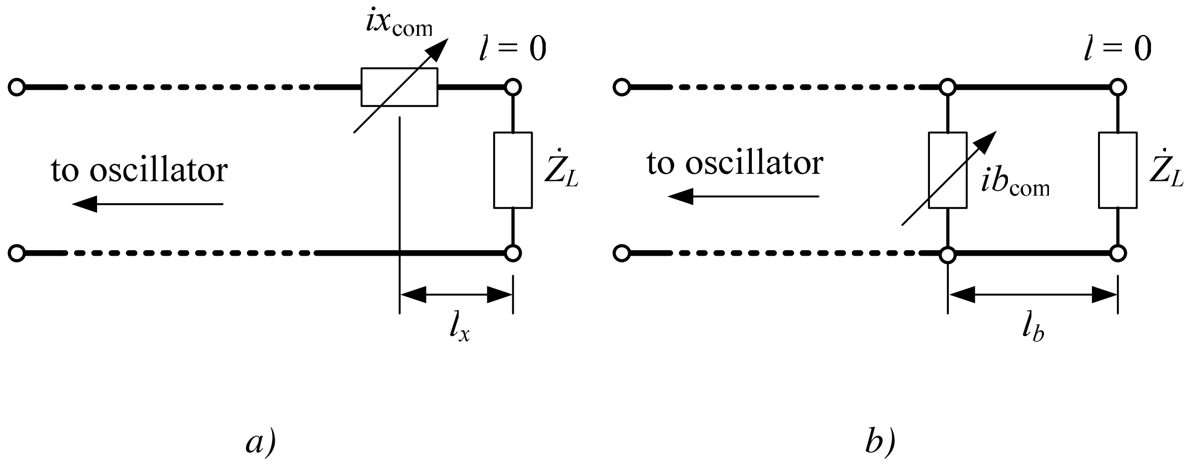

Figure 1.1 – Equivalent circuits:
a) for the serial connection of reactive element;
b) for parallel connection of reactive element

In the second case compensating reactive element with reactive admittance ib_{com} is connected in parallel with the load on distance l_b from it (fig. 1.1, b)) – in the place where the real part of total line admittance is precisely equal to wave admittance of the transmission line. The imaginary part of admittance in this point is the sum of imaginary part of a total admittance of the line and b_{com} can be made equal to 0 (achieved by proper selection of the reactive admittance of compensating reactive element).

Matching by means of quarter wave transformer. This method of the narrow-band matching is based on use of the so-called quarter wave transformer which consists of a piece of regular guiding structure of $\lambda_w/4$ length which is inserted directly between a resistive load R_L and a waveguide with a wave impedance $Z_W \neq R_L$. Wave impedance of transformer Z_{TR} is calculated from

$$Z_{TR} = \sqrt{Z_W R_L}\,. \tag{1.2}$$

Thus on the frequency corresponding to a chosen λ_w reflection from the input of the transformer will be absent. Physically it is explained in the following way: on this frequency there is a compensation of the wave reflected from load by one reflected from the transformer's input.

The quarter wave transformer is widely used for connection of two transmission lines of the same type, but with different wave impedances whose value is defined by the dimensions of transmission lines (fig. 1.2).

For example wave impedances of a two-wire line, a coaxial cable, a rectangular waveguide with a wave of type H_{10} and an asymmetrical strip line (microstrip line) are defined, accordingly, by following expressions:

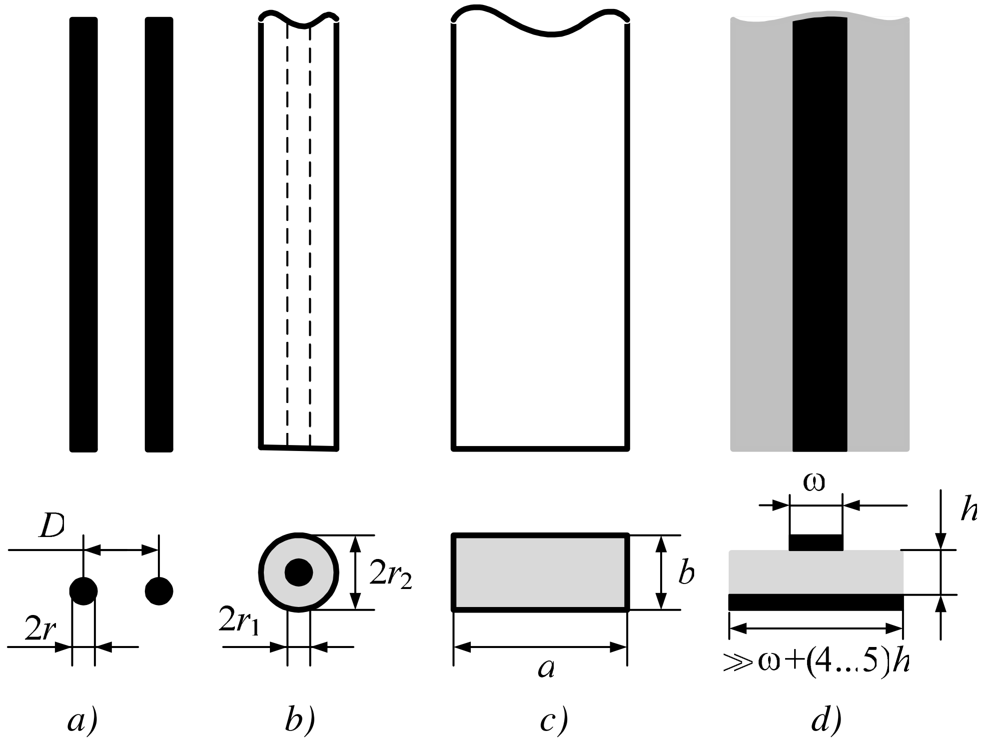

Figure 1.2 – Transmission lines and their dimensions:
a) two-wire line; b) coaxial cable;
c) rectangular waveguide;
d) asymmetrical strip (microstrip) line

$$Z_W = 276\,\lg\frac{D}{r}, \tag{1.3}$$

where D is distance between wires of a two-wire line;
r is radius of wires;

$$Z_W = 60\sqrt{\frac{\mu}{\varepsilon}}\ln\frac{r_2}{r_1}, \tag{1.4}$$

where μ, ε are relative permeability and permittivity of the medium filling space between conductors of a coaxial cable;
r_1 and r_2 are radiuses of internal and external conductors of the cable;

$$Z_W^{H_{10}} = \frac{b}{a}\frac{Z_M}{\sqrt{1-(\lambda/2a)^2}}, \tag{1.5}$$

where a and b are sizes of wide and narrow walls of a waveguide accordingly;

Z_M is wave impedance of the medium filling a waveguide (for an air-filled waveguide the $Z_M = 120\pi \approx 377\ \Omega$),

$$Z_W = \frac{120\pi}{\sqrt{\varepsilon}}\left[\frac{\omega}{h} + \frac{2}{\pi}\ln\left\{17{,}08\left(\frac{\omega}{2h} + 0{,}92\right)\right\}\right]^{-1} \quad \text{for} \quad \frac{\omega}{h} > 2,$$
$$Z_W = \frac{60}{\sqrt{\varepsilon}}\left[\ln\left(\frac{8h}{\omega}\right) + \frac{\omega^2}{32h^2\pi}l\right] \quad \text{for} \quad \frac{\omega}{h} \le 2, \tag{1.6}$$

where ω is width of a strip line;
h is distance between a strip line and a shielding plate;
ε is permittivity of dielectric between a strip line and a shielding plate.

The broadband matching devices are based on step junctions and continuous junctions that are a special guiding structures with a complex form of cross-section. The devices are placed just before the load. The value of a wave impedance of transition (transformer) changes smoothly or stepwise from Z_W to R_L under the special law.

Reactive pins and diaphragms (capacitive and inductive) are more often used in practice for implementation of matching elements in metal waveguides .

The pin which is positioned in parallel to a vector $\vec{E}$ of the basic type of a wave in rectangular waveguide brings in capacitance if its length is less than $\lambda_w/4$.

1.3 Description of the laboratory setup

The following equipment is used for measurements in the current work (fig. 1.3): 1 – microwave generator; 2 – decoupling ferrite isolator; 3 – measuring waveguide line “P1-28” (Appendix A); 4 – detector section with a connecting cable; 5 – directional coupler; 6 – matched load (absorbing waveguide load); 7 – impedance transformer; 8 – waveguide load; 9 – indicating device (measuring low-frequency amplifier).

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.

In the laboratory setup the impedance transformer is used that consists of a piece of a standard waveguide with two connecting flanges with three holes 1..2 mm in diameter located in the middle of wide wall. The holes are separated by the distance $l \approx \lambda_w/4$. Through each of the holes a metal probe (pin) can be injected into a waveguide. The depth of probes can be changed, changing thus amplitude and phase of reflected wave (fig. 1.4).

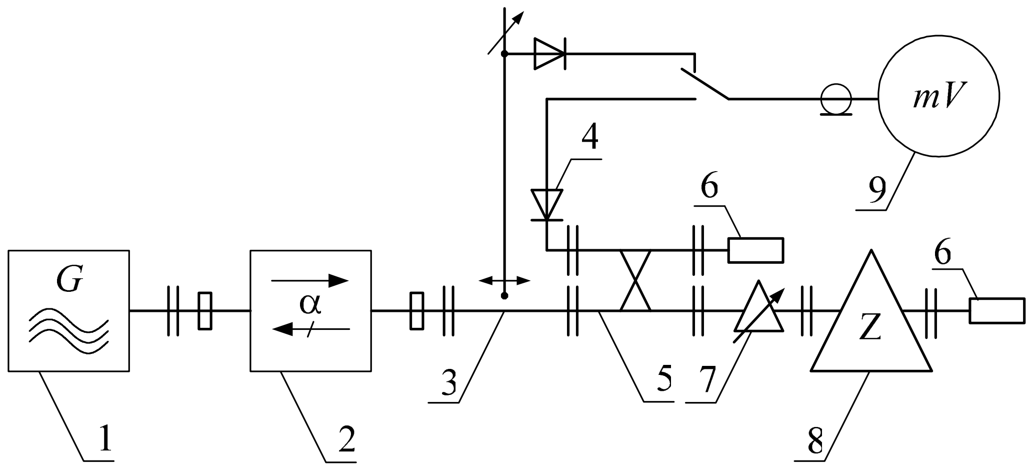

Figure 1.3 – Block diagram of a setup for research of narrow-band matching

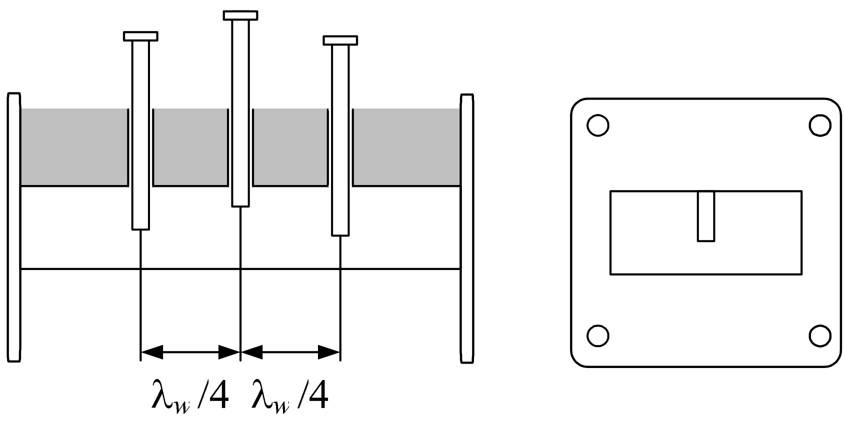

Figure 1.4 – Impedance transformer

Having the transformer between a waveguide and load and setting a particular depth of each probe, it is possible to reach the matching of a waveguide with load. Selection of necessary (optimal) depths of probes is made by serial change of their depth and control of the amplitude of a reflected wave on one of the arms of directional coupler.

1.4 Home task

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

2) Solve a problem. Calculate a wave impedance and parameters of the quarter wave transformer (length, cross-section dimension) for the connection of two rectangular waveguides with air filling which have the following cross-sections: 23×10 mm×mm and $23\times10(n+2)$ mm×mm, where n is the last digit of credit book number. The oscillator, forms the microwave oscillation with frequency of 9 939 MHz.

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

$$23\times10(3+2)=23\times50 \text{ mm}\times\text{mm}.$$

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 the narrow-band matching of waveguide with load.

1.5 Methodical recommendations to home task problem

In order to implement matching of two rectangular waveguides working in dominant wave mode with wave H_{10} and having equal wide walls a but different narrow walls b_1 and b_2, one is recommended to use a quarter wave piece of a rectangular waveguide with the cross-section dimensions a_{TR} and b_{TR} (fig. 1.5). We have $a_{TR}=a$, and value b_{TR} is defined from equality $Z_{W\,TR}^{H_{10}}=\sqrt{Z_{W1}^{H_{10}}\,Z_{W2}^{H_{10}}}$ where correspondent wave impedances $Z_W^{H_{10}}$ are defined from (1.5). As a result $b_{TR}=\sqrt{b_1 b_2}$.

The length of the transformer as one may conclude from its name is equal $\lambda_w/4$, where λ_w is the wave length of the dominant wave H_{10} in waveguide on a chosen frequency (for a chosen wave length λ) is defined from expression

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

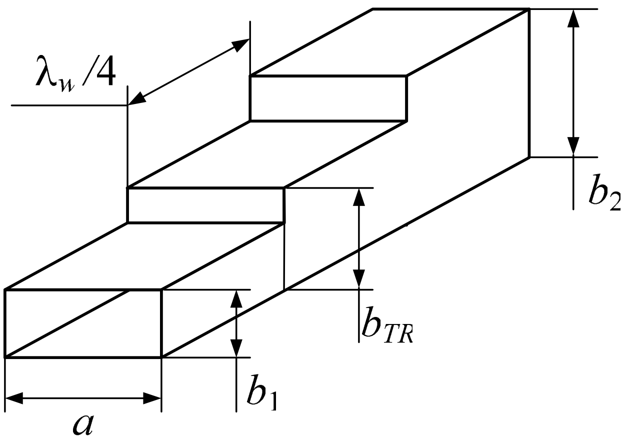

Figure 1.5 – Matching of waveguides with the help of quarter wave transformer

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

v_0 is velocity of light in the medium filling a waveguide (for air-filled waveguide $v_0 = 3\cdot 10^8$ m/s);

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

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

1.6 Laboratory task for experimental research

1) Install the setup for research of the narrow-band matching of waveguide with load (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 capacitive waveguide load $\dot{Z}_C$ (CL – capacitive slot load (fig. 1.7) loaded with an absorbing (matched) waveguide load).

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.

Table 1.1 – Results of experimental researches

z, mm														
$U(z)$, mV for $\dot{Z}_{\text{C}}$, CL														
$\lvert\dot{E}_{\Sigma}(z)\rvert/E_0$ for $\dot{Z}_{\text{C}}$, CL														
z, mm														
$U(z)$, mV after matching														
$\lvert\dot{E}_{\Sigma}(z)\rvert/E_0$ after matching														

4) Use the impedance transformer to match the load $\dot{Z}_{\text{C}}$ with the waveguide by setting a particular depth of each probe of impedance transformer. In the best case when a matching is reached the value of reflected wave power in detector section 8 is minimal.

5) Measure the distribution of relative field intensity $U(z)$ along the transmission line after matching.

Results of measurements should be filled in tab. 1.1.

6) 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 $\lvert\dot{E}_{\Sigma}(z)\rvert \approx \sqrt{U(z)}$; $E_0 \approx \left(\sqrt{U_{\text{max}}} + \sqrt{U_{\text{min}}}\right)/2$; $U(z)$ – reading from indicator device in mV; $U_{\text{max}}, U_{\text{min}}$ in mV are the maximum and minimum values from the indicating device.

Normalized results should be presented in tab. 1.1.

7) 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 before and after the matching.

8) On the basis of the plotted dependences define TWR and SWR before and after the matching.

9) Explain the gained results.

1.7 Advanced task (it is carried out facultatively)

10) Measure the distribution of relative field intensity $U(z)$ along the transmission line for waveguide load $\dot{Z}_L$ (IL – inductive slot load (fig. 1.3), covered by the absorbing (matched) waveguide load).

Results of measurements should be filled in tab. 1.2.

Table 1.2 – Results of experimental researches

z, mm														
$U(z)$, mV for $\dot{Z}_L$, IL														
$\lvert\dot{E}_\Sigma(z)\rvert/E_0$ for $\dot{Z}_L$, IL														
z, mm														
$U(z)$, mV after matching														
$\lvert\dot{E}_\Sigma(z)\rvert/E_0$ after matching														

11) 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. 1.2.

12) Use the impedance transformer to match the load $\dot{Z}_L$ with the waveguide by setting a particular depth of each probe of impedance transformer. In the best case when a matching is reached the value of reflected wave power in detector section 8 is minimal.

13) Measure the distribution of relative field intensity $U(z)$ along the transmission line after matching.

Results of measurements should be filled in tab. 1.2.

14) 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. 1.2.

15) 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 before and after the matching.

16) On the basis of the plotted dependences define TWR and SWR before and after the matching.

17) Explain the gained results.

1.8 Laboratory task for virtual setup (Laboratory work is carried out on the personal computer)

1) Start the application «TED_LW_3.exe». Study features of the graphical interface and the way of doing measurements on the virtual laboratory setup (VLS2) (Appendix B).

Team number is set by the teacher.

2) Measure the distribution of relative field intensity $U(z)$ along the transmission line for capacitive waveguide load $\dot{Z}_{\mathrm{C}}$ (CL – capacitive slot load (fig. 2.7) loaded with an absorbing (matched) waveguide load).

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) Use the impedance transformer to match the load $\dot{Z}_{\mathrm{C}}$ with the waveguide by setting a particular depth of each probe of impedance transformer.

5) Measure the distribution of relative field intensity $U(z)$ along the transmission line after matching.

Results of measurements should be filled in tab. 1.1.

6) 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.

7) 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 before and after the matching.

8) On the basis of the plotted dependences define TWR and SWR before and after the matching.

9) Explain the gained 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) Home task problem solved.

4) Block diagrams of setups for research of narrow-band matching of waveguide with load.

5) Results of measurements and normalized values of relative field intensity along the transmission line for different loads (tab. 1.1 and tab. 1.2 in case of completing of facultative task).

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 before and after matching.

7) Results of measurements of SWR and TWR before and after matching.

8) Analysis of the results obtained and conclusions.

1.10 Key questions

1) State an essence of the matching of load with a transmission line.

2) Illustrate a principle of the narrow-band matching with the help of reactive elements.

3) What devices are used as reactive elements in matching devices?

4) What is the difference between the narrow-band and broadband matching of load with a line?

5) Show the circuit of matching device that uses serial compensating reactive element and explain its operation principle.

6) Show the circuit of matching device that uses parallel compensating reactive element and explain its operation principle.

7) State the idea of the matching by means of the quarter wave transformer.

8) How the idea of the matching by V.V.Tatarinov is implemented in a three-stub impedance transformer?

9) In which case the quarter wave transformer is necessary to be inserted directly ahead of a load?

10) Is it possible to use the quarter wave transformer for matching of

complex impedances?

11) What is reactive stub?

12) How the input impedance of a short-circuited stub changes at change of its length?

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.

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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.

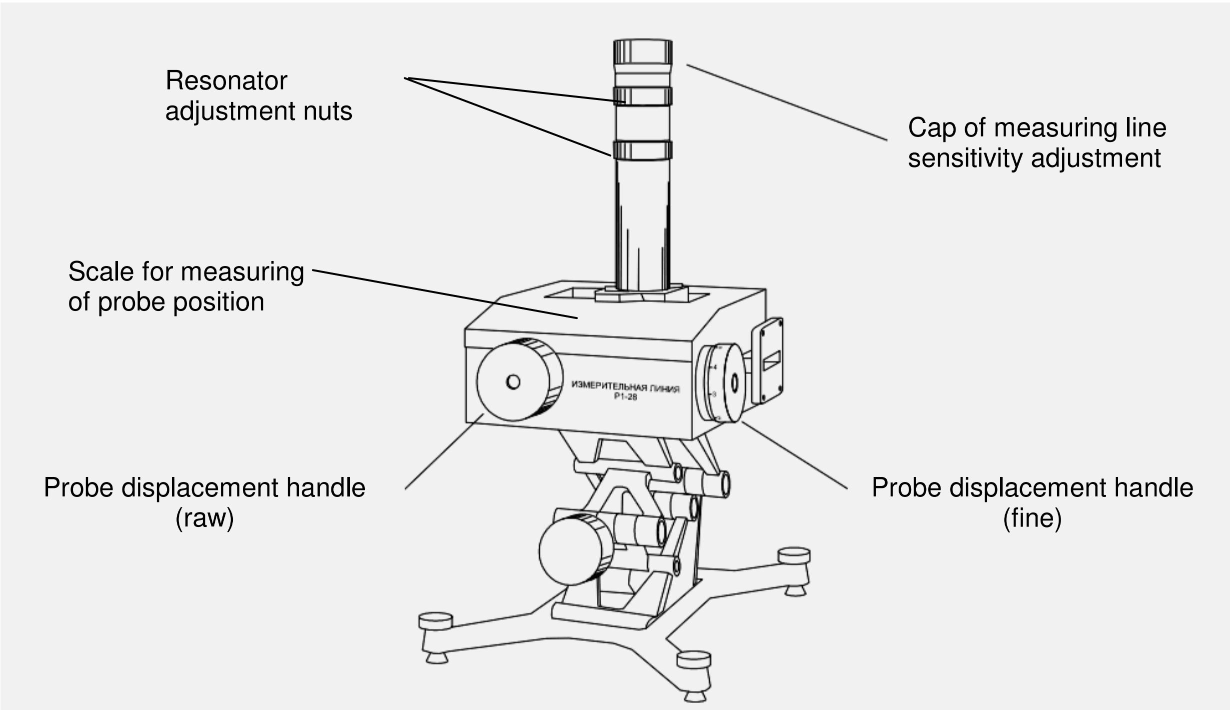
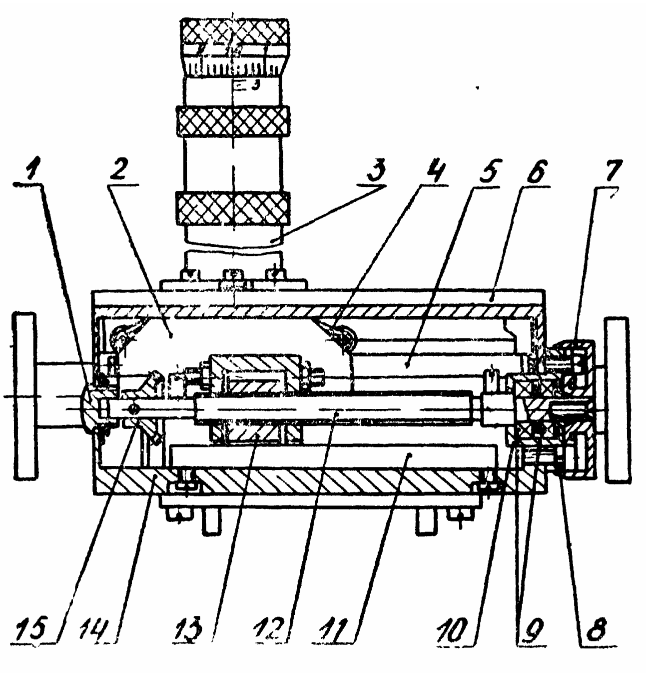


Figure A.1 – General view and arrangement of the basic controls of measuring waveguide line “P1-28”

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

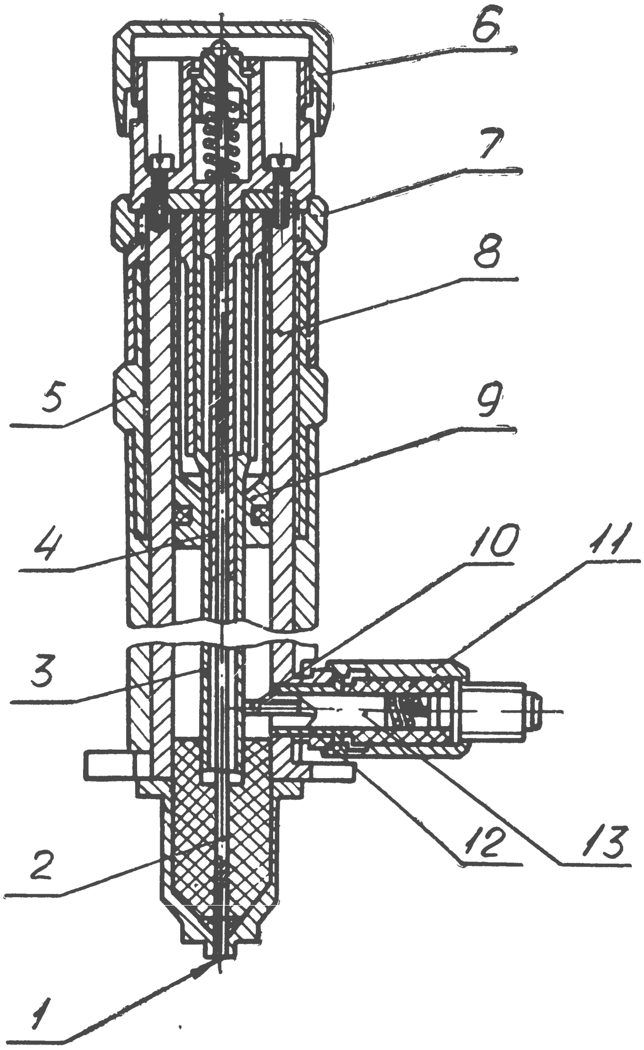
The principle of operation of the line is based on examination of electromagnetic wave field distribution by means of a probe passed through a slot into the interior of the waveguide. The probe is connected to tunable measuring probe head. The head is placed on the chariot that can be moved along the 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 matching of load with a transmission line. Front panel of the virtual laboratory setup is depicted in fig. B.1 (VLS2). With the help of VLS2 the laboratory research of the matching techniques of an arbitrary load with transmission line is possible to be carried out.

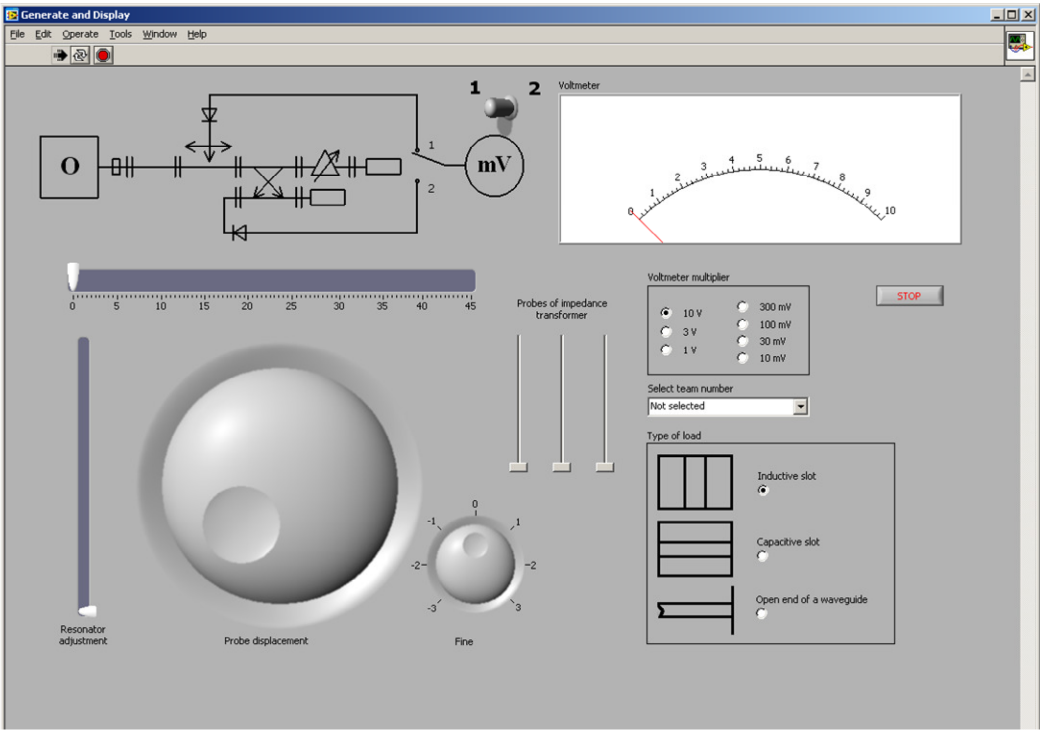


Figure B.1 – Front panel of VLS2

There are 12 main blocks on the front panel of VLS2 shown in fig. B.2.

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

1 – start and stop block of VLS2 (for stopping of VLS2 button STOP of block 12 can also be used);

2 – the diagram of laboratory setup (is presented for the help only);

3 – the indicator of the needle voltmeter connected to the detector of the probe head of measuring waveguide line (when switch 5 is set in position 1) or to detecting section on the output of directional coupler (when switch 5 is set in position 2);

4 – switch of voltmeter scale limits;

5 – switch-selector of detector sections;

6 – block of team number selection;

7 – block of load selection;

8 – block of impedance transformer based on reactive elements (metal rodes are used as reactive elements in the transformer);

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

10 – block of adjustment of the probe head resonator;

11 – 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);

12 – the stop button of VLS2.

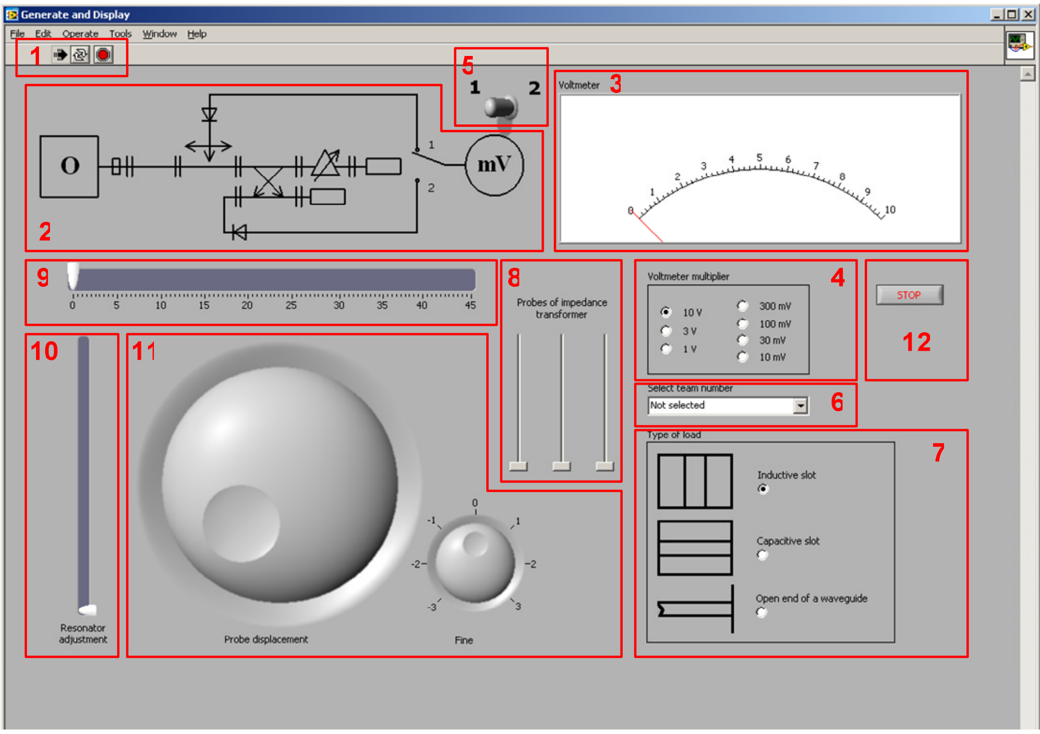


Figure B.2 – Main blocks of front panel of VLS2

Performance of measurements on VLS2. The measurements on the VLS2 are made identically to how they are made with the help of real devices.

The short instruction explaining peculiarities of VLS2 operation and basic differences in operation of VLS2 from real laboratory setup are the following:

1) Start VLS2 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 VLS2. 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 VLS2 for each team. If the team number is not selected, VLS1 ***is NOT in a working state***.

3) Set all probes of impedance transformer 8 in the upper position. It guarantees absence of influence of probes on the process of primary measurements with the help waveguide measuring line.

4) Set switch 5 in position 1 (detector section of waveguide measuring line).

5) 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 7 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.***

6) Choose and connect the needed load in block 7.

7) By moving the probe of measuring waveguide line with the help of handles in block 11, make the measurements SWR (TWR) before matching. Put the readings into the table. The reading of the probe voltage is done from the scale of voltmeter (block 3).

8) Set switch 5 in a position 2 (detector section on the output of directional coupler).

9) Changing the depth of transformer probes one by one, achieve the minimal possible signal on the output of directional coupler. In other words, ***it is necessary to achieve the minimal voltage on the voltmeter*** (during measurements on the current step it is necessary to switch in appropriate way the limits of voltmeter scale – block 4).

10) Again set the switch 5 in position 1 and once again measure SWR (TWR) in a line after matching.

11) If necessary iterate points 6 – 10 the needed number of times.

12) When the labwork is completed press stop button of VLS2 in block 1 or block 12.

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.

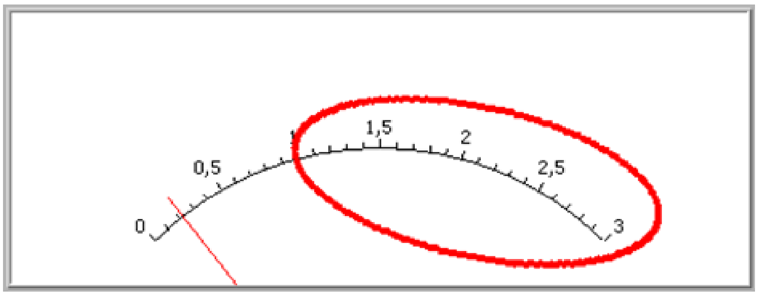


Figure B.4 – Operation area of voltmeter scale

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.