MINISTRY EDUCATION AND SCIENCE OF UKRAINE

ODESSE NATIONAL ACADEMY OF TELECOMMUNICATIONS NAMED AFTER O.S. POPOV

Fiber optic communication lines department

Methodical instructions

for laboratory works of discipline

"Directional electric and optic communication systems"

Part I

APPROVED
by the Methodical Council
Protocol № 8 from 11.02.2012 y.

Odessa 2013

УДК 681.778 – 681.069 Plan 2013 y.

Writers: prof. Bondarenko O.V.
doc. Stepanov D.M.
doc. Petrovich V.S.
asp. Bagachuk D.G.

The following methodical instructions is about the first part of the discipline "Directed electric and optic communication systems". Methodical instructions include laboratory works which devoted to the study of transmission parameters of communication lines and interference between them.

APPROVED
At the department session
Protocol № 4
from 18.12.2012 y.

CONTENT

Laboratory work № 1

DIRECT CURRENT CHECK OF CABLE ELECTRIC PARAMETERS

1 PURPOSE OF THE WORK

The purpose of this work is to learn the method of direct current check of the communication cables (CC) electric parameters. Such method is used during cable mounting on cable plants, and in produce of cables.

The main task of the work is acquirement some practical skills in CC measuring, mastering measurement devices used, and introduction with the CC electric parameters rate.

2 MAIN POSITIONS

Electric measurements of cable lines are carried out with the following purposes:

a) taken to exploitation CC electric parameters verification to the standards;

b) exploited cable lines electric parameters verification to the standards and detecting sections which are substandard for the purpose of prevention line from damages;

c) determination of character and cable fault location;

d) quality of repair control.

According to it the CC electric measurements are distinguished:

– acceptance measurements;

– periodic tests (preventive ones);

– measurements to check quality of construction and repair works;

– measurements to determine character and cable fault location.

The following electric parameters can be measured at direct current:

– insulation resistance between conductors and insulation resistance of every conductors relatively to other conductors, connected with the grounded metallic shell, and in cables with plastic shells – to the grounded screen;

– mutual capacitance of circuit and capacitance between a conductor and the ground;

– conductors stub resistance;

– ohmic disbalance of circuit;

– electric strength of insulation.

A direct-current measurement of cable electric parameters is the basic method of determining transmission characteristics normality: an insulation resistance, a mutual capacitance, a stub resistance and an ohmic disbalance.

In this work measurements of cable electric parameters are carried out on the stand of transmission line. Stand’s scheme, types of cables and their lengths are demonstrated in a fig. 2.1.

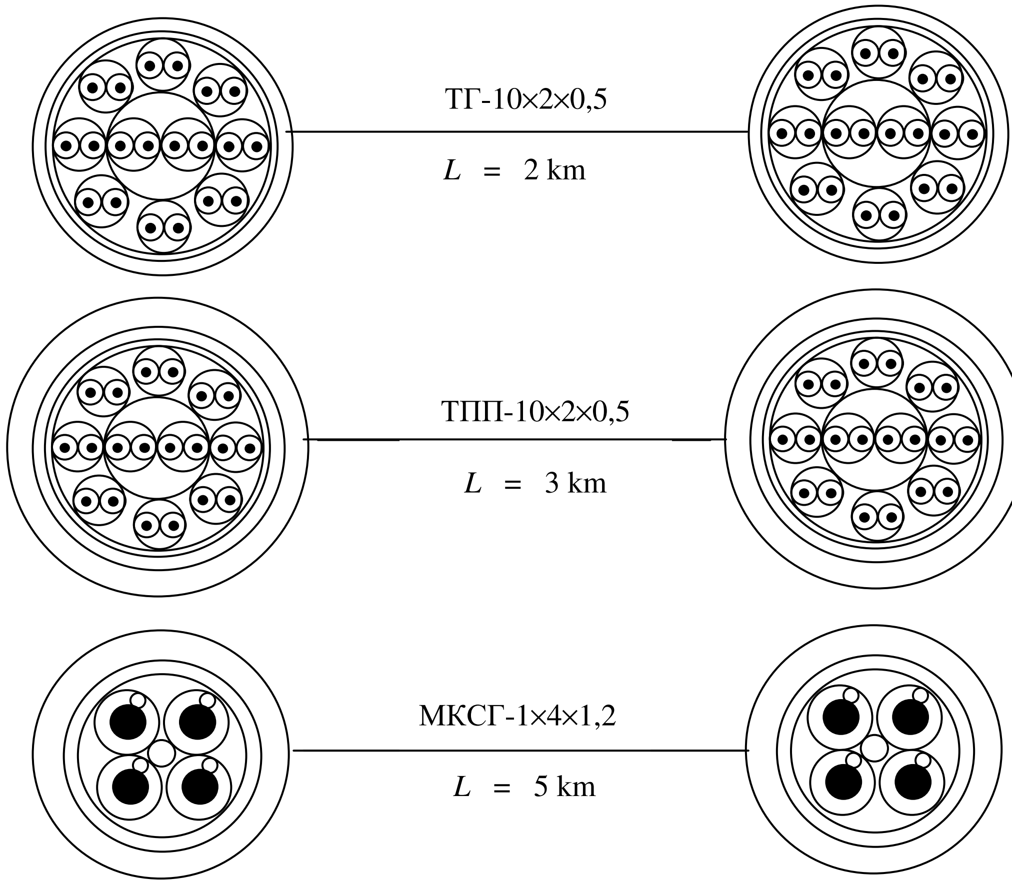


Figure 2.1 – Types and lengths of cables used for measuring

Expected kilometer values of mutual capacitance and conductor's stub resistance are calculated according to the following formula.

A direct current stub resistance of a circuit:

$$R_{sr} = \chi\rho\frac{2000}{S},\ \text{Ohm/km}; \qquad S = \frac{\pi d_0^2}{4},\ \text{mm}^2, \qquad (2.1)$$

here χ – the twisting coefficient, χ = 1,01…1,03;

ρ – specific material resistance which conductors are made of; for copper ρ = 0,0175 Ohm·mm²/m;

d_0 – diameter of conductor without insulation, mm;

S – cross-section area, mm².

A mutual capacitance of a symmetric circuit:

$$C_0 = \chi \cdot \frac{\varepsilon_{eq} \cdot 10^{-6}}{36\ln\left(\frac{2a}{d_0}\psi\right)},\ \text{F/km}, \qquad (2.2)$$

here a – distance between the centers of conductor's pair, mm;

ε_{eq} – equivalent dielectric permittivity of insulation (tab. 2.1);

ψ – correction factor which characterizes closeness of conductors to the earthed shell (tab. 2.2);

d_0 – diameter of conductor with insulation, mm.

Table 2.1 – Values of equivalent insulation dielectric permittivity for different types of insulation

Purpose of cable	Insulation type	ε_{eq}
City network	Air-and-paper Polyethylene Film-pulpe	1,5 ... 1,6 1,9 ... 2,1 1,4…1,5
Interurban networks	Cord-styroflex	1,2 ... 1,3

Table 2.2 – Correction factor dependence on diameters' ratio

d_1/d_0	Value ψ for pair twisted conductors	Value ψ for quad twisted conductors
1,6	0,608	0,588
1,8	0,627	0,611
2,0	0,644	0,619
2,2	0,655	0,630
2,4	0,665	0,647

Calculations of the expected kilometric values of ohmic resistance and capacitance of circuit should be recalculated on the length of observed section and used for setting and working with ПКП-4М device during measuring.

A diameter of an insulated conductor with a solid air-and-paper insulation is determined as a sum of conductor's diameter and a effective thickness of insulation:

$$d_1 = d_0 + 0{,}65 d_0 = 1{,}65 d_0 . \quad (2.3)$$

A diameter of an insulated conductor with a solid polyethylene insulation is determined as a sum of conductor's diameter and a doubled thickness of insulation:

$$d_1 = d_0 + 2\Delta_{ins} , \quad (2.4)$$

here Δ_{ins} – a thickness of insulation, mm.

A diameter of a conductor with an insulated cord is determined as

$$d_1 = d_0 + 2d_c(1-\sigma) + 2\Delta_{ins} , \quad (2.5)$$

here d_c – insulated cord's diameter, mm;

σ – bearing ratio of the cord.

For a cord-styroflex insulation the bearing ratio of cord $\sigma = 0$, and for a paper-cord insulation $\sigma = 0{,}1...0{,}3$.

A diameter d_1 of an insulated conductor in cables of an urban telephone network (UTN) with air-and-paper insulation of conductors is determined taking into account calibration (appendix 9.2).

A distance between the centers of the conductors in a pair for cables with pair twisting $a = d_1$, for cables with quad-type twisting $a = 1{,}41 \cdot d_1$.

Before start of an electric parameters verification of the mounted cable sections, an identification of conductors should be done in order to check the correctness of the mounting. It enables to determine the separating of pairs and provides the symmetric connection of telephone pairs to the line terminal devices.

Measuring of conductor's insulation resistance, mutual and partial capacitance, stub resistance of circuits and resistance of conductor's ohmic disbalance are carried out with ПКП-4М device. A short explanation of its exploitation is given in the description which is placed next to the device.

The results of measuring are converted to kilometric values taking into account temperature coefficient, they are compared to the standards and then there should be made a conclusion concerning operability of cable section measured. It is also necessary to take into account that an insulation resistance decrease with the increase of the line length but a stub resistance and a capacitance increase, i.e. an insulation resistance is inversely proportional to line length, and a stub resistance and a capacitance are directly proportional to it.

A stub resistance calculation at temperature of t = 20° C is obtained from formula:

$$R_{sr\,20} = \frac{R_{sr\,t}}{1+\alpha_R(t-20)}, \quad (2.6)$$

here $R_{sr\,t}$ – a stub resistance at the temperature of $t°\,C$;

α_R – a temperature coefficient of resistance; for copper $\alpha_R = 0{,}004\ldots0{,}0045$.

A cable insulation resistance calculation at temperature of $t = 20$°C can be obtained from formula:

$$R_{ins\,20} = \frac{R_{ins\,t}}{1+\alpha_{Rins}(t-20)}, \quad (2.7)$$

here $R_{ins\,20}$ – an insulation resistance at the temperature of 20° C;

$R_{ins\,t}$ – an insulation resistance at the temperature of t° C;

α_{Rins} – temperature coefficient of an insulation resistance.

For cable paper $\alpha_{Rins} = 0{,}06$; for a polyethylene and styroflex temperature coefficient is $\alpha_{Rins} = 0{,}001$.

Thus the recalculation of parameters given above as a rule should be done for paper-insulated cables. In cables with cord-styroflex and solid polyethylene insulation resistance virtually does not depend on temperature.

Approximate values of soil temperature at a depth of 0,8 meters for the Ukraine are given in tab. 2.3.

Extracts from specification for cables ТГ, ТПП, МКС are shown in appendix 9.2. All of standard values are recalculated on 1 km at temperature of 20° C.

Values of electric parameters of other cables can be taken from reference books.

3 KEY QUESTIONS

3.1 Purpose and elements of urban telephone network cables both low frequency (LF) and high frequency (HF) ranges.

3.2 Purpose, kinds and volume of electric measurements of cables.

3.3 Basic circuits of insulation resistance, capacitance, stub resistance and conductor’s ohmic disbalance measuring by ПКП-4М device.

3.4 Procedure of mutual capacitance and stub resistance of electric circuits calculation.

3.5 Direct current standards of the cable electric parameters.

Table 2.3 – Reference values of temperature of soil for the Ukraine

Month	Temperature of soil (rich black soil), °C	Month	Temperature of soil (rich black soil), °C
January	3,2	July	15,4
February	1,6	August	17,6
March	1,2	September	16,8
April	6,1	October	10,6
May	9,4	November	7,6
June	12,9	December	4,5

4 HOME TASK

As a result of independent preparation to laboratory work with this workbook and recommended literature it is necessary:

4.1 To learn construction of LF cables for urban telephone network (ТГ and ТПП) and HF cables (МКСГ).

4.2 To learn purpose and instructions for ПКП-4М device.

4.3 To calculate the capacitance and the stub resistance values taking into account the length of the cable.

4.4 To prepare the report from tab. 4.1 for noting results of measurements.

4.5 To note down into the tab. 4.1 standards for electric parameters of the corresponding cables.

4.6 To prepare oral answers for key questions.

5 LABORATORY TASK

5.1 Prepare ПКП-4М device for work.

5.2 Verify the direct current cable electric parameters:

– stub resistance R_{sr};

– ohmic disbalance ΔR;

– insulation resistance between conductors and each single conductor to earth: $R_{ins\ \mathrm{ab}}$, $R_{ins\ \mathrm{a}}$, $R_{ins\ \mathrm{b}}$;

– resistance of the shield-earth insulation $R_{ins\ sh}$, in case cable is shielded;

– mutual capacitance C_0 of circuits and capacitance of conductors C_a, C_b to the earth.

5.3 Convert the results of electric parameters measurement to kilometric values taking into account the temperature of soil for stub resistance and insulation resistance (if necessary).

5.4 Compare measured values with the standards of the cable electric parameters and make a conclusion about concerning their accordance with the cable specification.

Table 4.1 – Results of measurements

The measured parameter	For the length L at temperature t° C		Per 1 km at 20° C		Specification information for 1 km at 20° C	Note
	1 pair	2 pair	1 pair	2 pair		
R_{sr}, Ohm						
ΔR, Ohm						
$R_{ins\ ab}$, Ohm						
$R_{ins\ a}$, Ohm						
$R_{ins\ b}$, Ohm						
$R_{ins\ sh}$, Ohm						
C_0, F						
C_a, F						
C_b, F						

6 EQUIPMENT

6.1 Samples of urban telephone network cables

6.2 Stand with cable circuits (ТГ-10×2×0,5 – 2 km; ТПП-10×2×0,5 – 3 km; МКСГ-1×4×1,2 – 5 km).

6.3 ПКП-4М device.

7 CONTENT OF A REPORT

7.1 The expected values calculations of the stub resistance and the mutual capacitance of the corresponding cable.

7.2 Measuring data of the cable electric parameters according to the Table. 4.1.

7.3 Conclusion concerning to serviceability of a given cable section.

8 REFERANCES

8.1 Гроднев И.И. Линии связи / И.И. Гроднев, Н.Д. Курбатов – М.: Связь, 1980. – С. 409 – 414.

8.2 Ионов А.Д. Линии связи / А.Д. Ионов, Б.В. Попов – М.: Радио и связь, 1990. – С. 155 – 158.

9 APPENDIX

9.1 Electrical measurements of urban telephone network transmission lines

9.1.1 Classification of measurements

Electric measurements of UTN transmission lines are executed to determine electric characteristics according to the standards, and also to determine character and point of fault on a line. The electric measurements of UTN lines are executed both at direct and alternating currents. Alternating current measurements are executed after direct current measurements and only in case direct current measurements meet standards. Otherwise measurements at alternating current should be executed after elimination of trouble on the line.

The following measurements at direct and alternating currents are distinguished:

– periodic tests, which are executed during exploitation according to a set plan;

– control tests, which are executed after repair-and-renewal operations;

– measurements to test quality of cables and line equipment, which have entered from a manufacturer, before mounting them on a line;

– measurements to locate point of fault;

– acceptance tests, which are executed at accepting built, reconstructed, fully-repaired lines to exploitation.

Structure and volume of periodic tests, control tests and acceptance tests is defined in proper manuals. All measurements must be executed by devices which had passed the proper state or department verification.

9.1.2 Direct current measurements

Direct current measurements enable to make a conclusion concerning accordance of the most unstable line characteristics with the set norms. They are:

– electric insulation resistance;

– electric stub resistance;

– ohmic disbalance;

– electric capacitance of circuit.

Besides, direct current measurements are widely used for determination of the most widespread damage – an insulation fault.

For a direct current measuring of circuits the purpose-designed portable cable devices have acquired wide use, for instance ПКП-3, ПКП-4 and ПКП-5.

Direct current measurements are worth being executed in the following order: an electric stub resistance, an ohmic disbalance, an electric insulation resistance, an electric capacitanceof circuit.

9.1.3 Stub resistance

A stub resistance (an electric resistance of a two-conductor circuit, $R_{sr} = R_a + R_b$) is usually measure, using the DC bridge with a fixed ratio of branch resistances (fig. 9.1). The resistance of the bridge branches is selected to reduce current in the bridge diagonal in which the indicator is connected and it must equal to zero during measurement. Having balanced the bridge, we can find the value of the stub resistance over the entire length of the circuit.

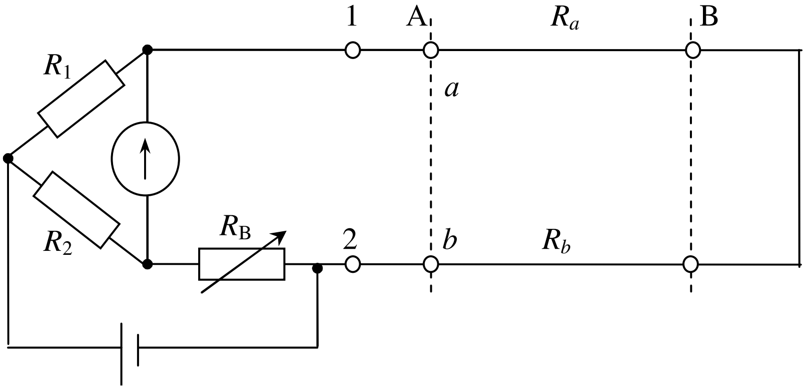


Figure 9.1 – Stub resistance measurement scheme

9.1.4 Ohmic disbalance

An ohmic disbalance (a difference of electric resistances of a circuit conductors at direct current $\Delta R = R_a - R_b$) is measured by a DC bridge (fig. 9.2). The circuit beginning (the end A) is connected to the terminals 1 and 2, and an earthed shell or a shield are connected to the terminal 3. The opposite end of circuit B becomes short-circuited and earthed. A bridge with fixed ratio of branch resistances equal to 1 is used for measuring. If the bridge is balanced $\Delta R = =R_B = R_a - R_b$. The conductor with lower resistance should be connected to the branch, which contains the variable resistor R_B (resistance box). The bridge won't be balanced otherwise, in this case the conductors should be swapped using device switch «Line switching».

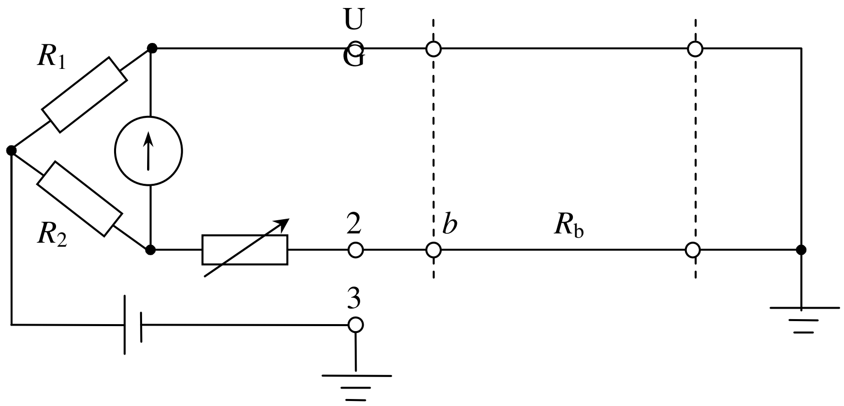


Figure 9.2 – Ohmic disbalance measurement scheme

9.1.5 Electric insulation resistance

An electric insulation resistance is measured between the conductors of cable pair and between each conductor and grounded metallic cover (shield). A measurement can be carried out in different ways, they are method of comparison, bridge method, method of voltmeter-ammeter. In cable devices ПКП-4 and ПКП-5 the scheme of megaohmmeter with direct current amplifier is used. The scheme is one to measure an insulation resistance using voltmeter-ammeter method (fig. 9.3).

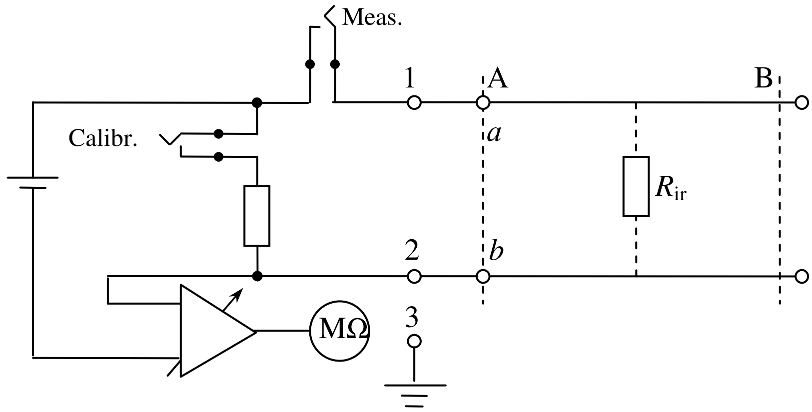


Figure 9.3 – Scheme of electric insulation resistance measurement

Calibration of the device is to be executed before each measurement. After about a minute of the circuit being under tension the mega-ohmmeter's scale shows value of insulation resistance over the entire length of the circuit.

9.1.6 Mutual capacitance

An electric capacitance between conductors and capacitance between each of conductor and earthed metallic covering (shield) is measured by ballistic method or charge-discharge method, or method of comparison. All of the noted methods are direct-current ones. Devices ПКП-4М and ПКП-5 are provided with electric capacitance measurement scheme which use voltmeter-ammeter method at alte-rnating current (fig. 9.4). Before measuring calibration of device is to be executed. The measured value is extended for a capacitance over the entire length of circuit.

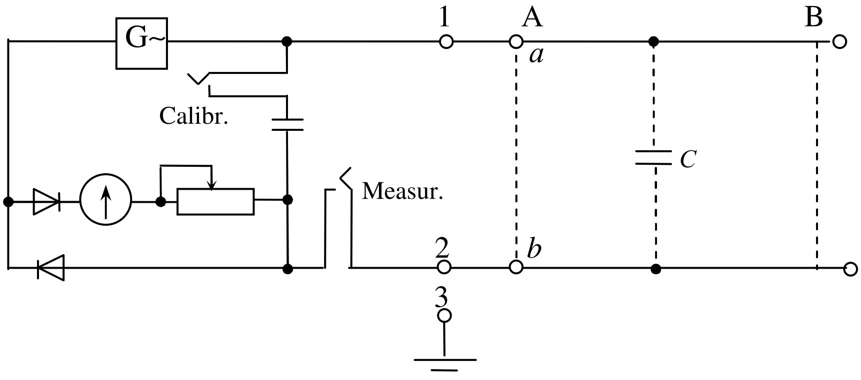


Figure 9.4 – Scheme of electric capacitance measurement

9.2 Structural and electric standards for basic cable types used on UTN

Following basic types of paired cables are used in UTN:

– cables with air-and-paper insulation in metallic water-proof covering (ТГ);

– cables with insulation made of solid polyethylene in a polyethylene water-proof covering (ТПП).

Cables with air-and-paper insulation contain conductors in diameters of 0,4; 0,5; 0,7 mm. The insulation is made mainly of paper strips 0,05 mm thick, which overlaid spirally with an overlap of (20…30) %. Taking into account calibration, the diameter of an insulated conductor is d_1 = 1,0 mm, if the bare conductor diameter equals 0,5 mm.

Cables have pair twisting with a strand pitch of (70...100) mm and a layer twisting of core. Cables are produced both “bare” unarmored ones (ТГ) and cables with different armored coverings (ТБ, ТК). The cables of ТГ type are produced with pair amount from 5 to 1600 pairs, and armored cables contain up to 600 pairs.

ТПП cables with polyethylene cable-core insulation are produced by capacity from 10×2 to 2400×2. Cable leads are made of copper in diameter of 0,32 mm; 0,4 mm and 0,5 mm.

Depending on conductor diameter the insulation of solid polyethylene has thickness of Δ_{ins} = 0,18...0,4 mm for pair twisting and Δ_{ins} = 0,18...0,35 mm for quad twisting. Over the core there is a shield made from aluminum strip which is Δ_s = 0,1…0,2 mm thick.

Under the shield there is the copper tin-plated wire with a diameter of 0,5...0,6 mm; an external plastic jacket of polyethylene is (1,5...4,2) mm thick depending on the capacity of a cable.

Electrical norms, which are measured at direct current and vary depending on type of the cable used in UTN, are given in tab. 9.1. All standards are reduced to the length of 1 km and the temperature of 20°C.

Table 9.1 – Electric norms for ТПП

Parameter	Value	Note
Insulation resistance, Ohm•km	No less than 6500 for 100 % capacity of cable	Specification В 05758730.014-2000
Mutual capacitance, F/km	45,5 ± 5	Single conductor capacitance is not normalized

A standard of screen-earth insulation resistance for jacketed cables of ТПП type, which has protective jacket made of polyethylene, is 5000 MOhm·km.

A stub resistance of conductors, which is reduced to the temperature of 20° C and cable length of 1 km, for cables ТГ and ТПП should be:

– for a conductor with a diameter of 0,4 mm – no more than 296 Ohm/km;

– for a conductor with a diameter of 0,5 mm – no more than 186 Ohm/km;

– for a conductor with a diameter of 0,7 mm – no more than 96 Ohm/km.

A value of ohmic disbalance of conductors for cables ТГ and ТПП should be no more than 1% of conductor stub resistance.

ТГ cables should stand the 500 V of test voltage between conductors during two minutes at alternating current with frequency 50 Hz as well as the same voltage (500 V) between the conductors and leaden water-proof covering. ТПП cables should stand 1000 V between the conductors of a pair during 1 minute.

Balanced cables with a styroflex insulation of conductors (МКС) or with polyethylene one (МКП). Capacity of such cables can be 1×4, 4×4 or 7×4 cables.

These are cables with quad twisting of conductors and layer twisting of the core. Conductors of such cable have diameter of 1,2 mm and they are insulated by varicolored styroflex with diameter of 0,8 mm and by polystyrene strip which is 0,05 mm thick with overlap of (25…30) %. The first pair of every quad contains red (a) and yellow (b) thread, while the second pair contains blue (a) and green (b) one. Inside each quad there is a centering core with a diameter of 1,1 mm. All quads are characterized by interconsistent conductors of twisting which are in the range (125…275) mm. A wrapping for such cables is produced from a cable paper. A moisture-proof envelope can be both made of lead (МКСГ) and from an aluminum (МКСА) or steel (МКСС). An aluminum and steel moisture-proof envelope requires protecting from external influences; therefore cable is covered with polyethylene jacket (МКСАШп, МКССШп). A bituminous adhesive layer spread on the water-proof envelope to prevent the jacket sliding off.

Quad cables can have armor from two steel strips (МКСБ) or steel wires (МКСК).

In case cable-core insulation is polyethylene, a cable is marked as МКП. A thickness of solid polyethylene conductor insulation is Δ_{ins} = 1,1 mm. The moisture-proof envelope of such a cable is a two-layer plastic one.

Electrical norms measured at direct-current for different types HF balanced cables are given in tab. 9.2 (State Standard 52221-74). A factory length for conventional cables МКС is $l_{bl} = 825 \pm 5$ m.

All standards are given for UTN cables without the account of their connection to network terminal equipment. During measurement of cables connected to the terminal equipment (boxes, etc) norms, even insulation resistances, should be calculated taking into account terminal plinths.

Table 9.2 – Electric norms for cables МК, МКС, МКП

Parameter	For paper insulation	For styroflex insulation	For polyethylene insulation
Insulation resistance (MOhm•km) between each conductor and other earthed conductors at temperature t = 20°C is no less than	10 000	10 000	10 000
Mutual capacitance (nF/km) between conductors of the basic circuit and other earthed conductors is no more than	27 ± 1,1	24,5 ± 0,8	34,5 ± 0,5
Resistance of circuit (Ohm/km) with d_0 = 1,2 mm at t = 20°C is no more than	32	32	32
Ohmic disbalance per l_{bl} is no more than	0,2	0,2	0,2
Insulating strength (V) between a cable core and earthed covering or shield is no less than	1800	1800	1800
Electric strength (V) between threads a and b respectively joined to bundles is no less than	1000	1500	1500

Laboratory work № 2

STUDY OF TRANSMISSION PARAMETERS OF CABLE COMMUNICATION LINES

1 PURPOSE OF THE WORK

Learning primary and secondary transmission parameters of circuits, learning methods of parameters calculation and methods of cable transmission primary and secondary parameter measurement.

2 MAIN POSITIONS

A propagation of an electromagnetic field along a circuit is characterized by parameters which include:

– the primary parameters: an active resistance of a circuit *R*, Ohm/km; an inductance of a circuit *L*, H/km; a capacitance of a circuit *C*, F/km; a conductivity of insulation of a circuit *G*, S/km;

– the secondary parameters: an attenuation coefficient α; dB/km; a phase coefficient β, radian; a wave impedance Z_w, Ohm; a wave propagation velocity *V*, m/s.

An attenuation coefficient (kilometric attenuation) of a circuit, α, is a parameter which characterizes power decreasing of a signal, propagating along a line. Its value is equal to signal attenuation (in decibels) per circuit length of 1 km.

A phase coefficient is determined by the alteration of signal phase (current or voltage) when propagated along a line. The phase coefficient numerical value can be determined as a difference of signal phases (in radians) for two points of the circuit separated by 1 km distance.

A wave impedance is resistance to a progressive voltage wave. For a uniform line, where indirect waves are absent, a wave impedance is the same in every point and it is equal to the ratio of voltage to current in any point of the circuit. A wave impedance is a complex quantity; its modulus is equal to a ratio of the voltage amplitude to the current one, and its argument is the voltage and the current phase difference in every point of the circuit.

A propagation velocity (a phase velocity) *V* is a velocity of a monochromatic wave front propagation. It does not exceed the speed of light in free space ($c = 3 \cdot 10^8$ m/s).

All of parameters of transmission have different values at different frequencies. The frequency dependence diagrams of primary and secondary transmission parameters of symmetrical circuits are shown in fig. 2.1.

Among the primary parameters *R* and *G* only cause loss of energy: *R* characterizes thermal loss in conductors and other metallic parts of cables such as shield, coverings, armor, C and *G* characterize loss in conductor insulation.

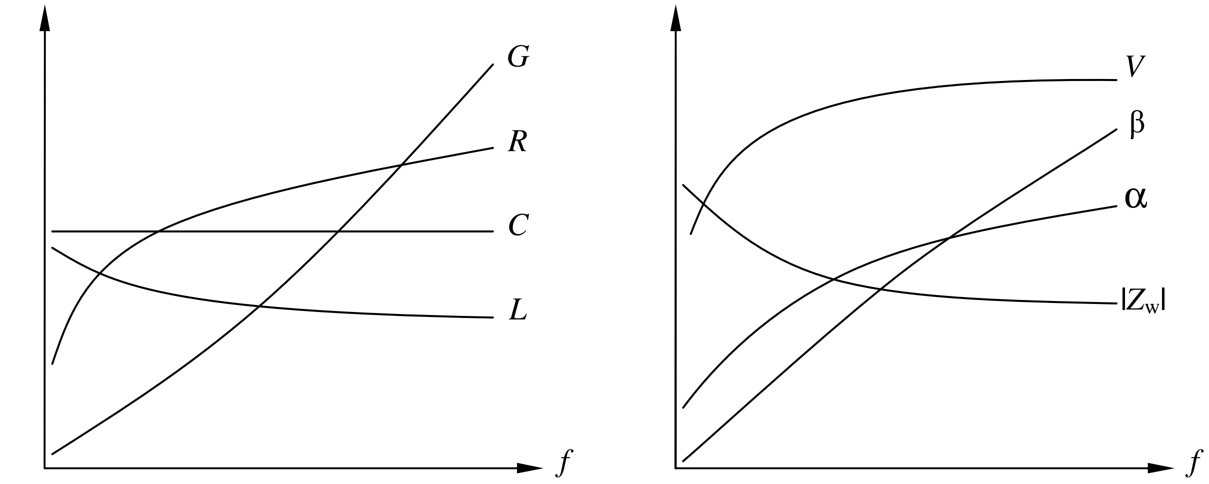


Figure 2.1 – Primary and secondary parameters frequency dependence

The values of primary transmission parameters can be obtained by the direct measurement, where the secondary parameters can be obtained by the indirect measurements only.

While carrying out the measurements on a line, it is necessary to match an oscillator and load impedances with the impedance of line, therefore, as a rule; each measurement should be started with the line impedance determination.

Using device МПП-300 the input parameters of the line can be measured by short-circuit and free-run methods (SCM, FRM) and therefore the secondary transmission parameters α, β, *V*, φ and $|Z_w|$ are determined. In case high-frequency measurements for a long line its impedance can be measured as an input resistance of this line.

An attenuation coefficient α can be also obtained by the method of level difference or comparison method (fig. 2.2).

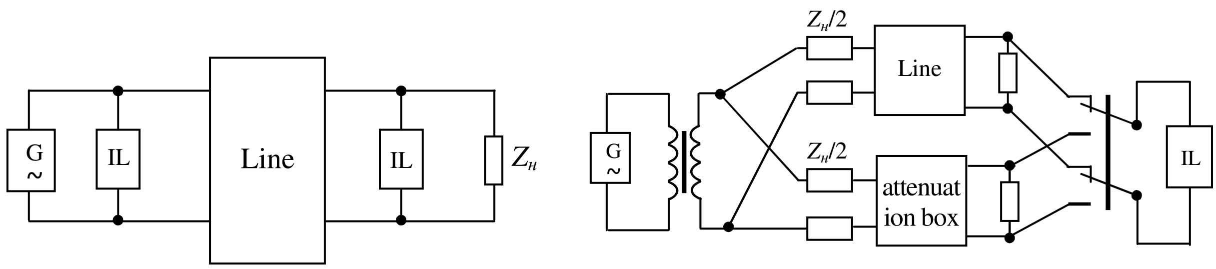


Figure 2.2 – Measuring of fading: by the method of difference of levels and by the method of comparison

A phase coefficient β can be measured by the compensation method in accordance with the chart of fig. 2.3.

Voltages on the output of measured line and attenuation box differ by a phase shift produced by the measured line, because the attenuation box is constructed of active resistances and does not bring in the change of phases in the probed voltage.

A phase difference between voltage on the output of line and the attenuation box can equal zero only if length of a line equals zero or integer number of wave lengths measured frequency. Consequently, for every length of line there is a series of frequencies, for which a phase shift produced a line, is 2πn. These frequencies are named critical. Knowing a length of line and a critical frequency, it is possible to define a phase coefficient for this frequency as $\beta = \frac{2\pi n}{L}, \frac{\text{рад}}{\text{км}}$, here L – length of the probed line. A critical frequency is determined by an indicator (IL, indicator of level) which will show minimum at the counter-opposite connection of coils of differential transformer (DT).

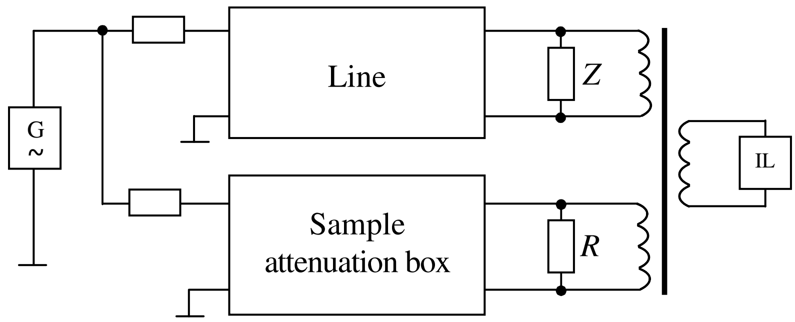


Figure 2.3 – Measuring phase factor by the method of indemnification

The secondary transmission parameters determination for the obtained results of the line input parameters measured in short-circuit and free-run modes can be done according to the proper formula using transmission equations for uniform lines ([1], p. 90):

$$U_i = U_0 \operatorname{ch} \gamma x - I_0 Z_{sim} \operatorname{sh} \gamma x,$$

$$I_i = I_0 \operatorname{ch} \gamma x - \frac{U_0}{Z_{sim}} \operatorname{sh} \gamma x,$$

here $\gamma = \alpha + i\beta$ is a propagation constant;

x – a distance between the beginning of the line and the point being observed;

U_x, I_x – complex voltage and current at the x point;

U_0, I_0 – complex voltage and current at the line's beginning.

Solving the equations given above with respect to U_0 and I_0 at $x = l$, we get

$$U_0 = U_L \operatorname{ch} \gamma L + I_L Z_w \operatorname{sh} \gamma L,$$

$$I_0 = I_L \operatorname{ch} \gamma L - \frac{U_L}{Z_w} \operatorname{sh} \gamma L.$$

It follows from this that

$$Z_{in} = \frac{U_0}{I_0} = \frac{Z_{lr} \operatorname{ch} \gamma L + Z_w \operatorname{sh} \gamma L}{Z_w \operatorname{ch} \gamma L + Z_{lr} \operatorname{sh} \gamma L} \cdot Z_w,$$

here $Z_{lr} = Z_L = \frac{U_L}{I_L}$ is a load resistance (of the receiver).

In case the receiver resistance is equal to zero (SCM, $Z_{lr} = 0$) the input resistance

$$Z_0 \equiv Z_{in0} = Z_w \operatorname{th} \gamma L. \tag{2.1}$$

In case the receiver resistance is infinite (IM, $Z_{l_r} = \infty$)

$$Z_\infty \equiv Z_{in\infty} = \frac{Z_w}{\text{th}\,\gamma L}. \tag{2.2}$$

Thus

$$Z_w = \sqrt{Z_0 \cdot Z_\infty} = |Z_w| \cdot e^{i\varphi_B}. \tag{2.3}$$

Should consider that the short-circuit (SCM) and the free-run (FRM) mode methods are used for short electric circuits only, where $\alpha L \le 4{,}6\,\text{dB}$. For long lines $\alpha L \ge 13$ dB; in this case $\text{ch}\,\gamma L \approx \text{sh}\,\gamma L \approx \frac{e^{\gamma L}}{2}$, and $Z_\text{w} \approx Z_{in}$. Also for lines with attenuation coefficient lying in the range of (4,6…13) dB SCM and FRM methods are not used because attenuation coefficient is determinated with low accuracy.

We designate phase shifts between a voltage and a current at the circuit's beginning as φ_0 and φ_∞ (input impedance argument) for rear end short-circuit and idle running respectively. A value of input admittance $Y_0 = |Y_0| e^{i\varphi_0}$, $Y_\infty = |Y_\infty| e^{i\varphi_\infty}$ for SCM and FRM can be determined from vector diagrams (fig. 2.4).

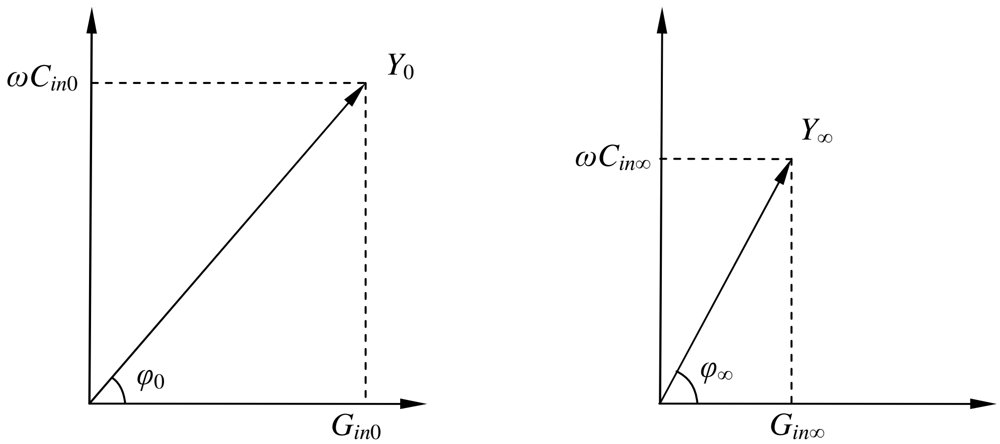


Figure 2.4 – Input admittance vector diagrams in SCM and FRM

From fig. 2.4 it is obvious that

$$|Y_0| = \left|\frac{1}{Z_0}\right| = \frac{G_{in0}}{\cos\varphi_0},\ |Y_\infty| = \left|\frac{1}{Z_\infty}\right| = \frac{G_{in\infty}}{\cos\varphi_\infty}; \tag{2.4}$$

$$\varphi_0 = \text{arctg}\frac{\omega C_{in0}}{G_{in0}},\ \varphi_\infty = \text{arctg}\frac{\omega C_{in\infty}}{G_{in\infty}}. \tag{2.5}$$

It should be noted that usually φ_0 has a negative value (a sign is "minus"), and φ_∞ – positive (a sign is "plus").

As φ_0 and φ_∞ are the arguments of entrance complex conductivities of Y_0, Y_∞, arguments of entrance complex resistances of Z_0, Z_∞ will differ from them only by signs:

$$\varphi_{Z0} = -\varphi_0; \qquad \varphi_{Z\infty} = -\varphi_\infty.$$

Therefore a modulus and an argument of the impedance in accordance with

(2.3) will be

$$|Z_w| = \sqrt{|Z_0| \cdot |Z_\infty|}, \ \varphi_w = -\frac{\varphi_0 + \varphi_\infty}{2}. \tag{2.6}$$

We designate

$$T = |T| e^{i\varphi_T} = \sqrt{\frac{Z_0}{Z_\infty}}. \tag{2.7}$$

here

$$|T| = \sqrt{\frac{|Z_0|}{|Z_\infty|}}, \ \varphi_T = -\frac{\varphi_0 - \varphi_\infty}{2}. \tag{2.8}$$

With (2.1), (2.2) and (2.7) we get:

$$Te^{i\varphi t} = \text{th}\,\gamma L. \tag{2.9}$$

Using an identity $\text{arth}\,x = \frac{1}{2}\ln\frac{1+x}{1-x}$ we can write:

$$2\gamma L = \ln\frac{1+Te^{i\varphi t}}{1-Te^{i\varphi t}}.$$

Hence determining real and imaginary parts, we can get the expressions for α and β:

$$\text{th}\,2\alpha L = \frac{2|T|\cos\varphi_T}{1+|T|^2}, \tag{2.10}$$

$$\text{tg}\,2\beta L = \frac{2|T|\sin\varphi_T}{1-|T|^2}. \tag{2.11}$$

Determination of the secondary transmission parameters using results of measurements of line input admittances G_{in0}, $G_{in\infty}$ and input capacitances C_{in0}, $C_{in\infty}$ in short-circuit and free-run modes is recommended to perform in the sequence given below:

$$\varphi_0 = \pm\text{arctg}\frac{\omega C_{in0}}{G_{in0}}; \tag{2.12}$$

$$\varphi_\infty = \pm\text{arctg}\frac{\omega C_{in\infty}}{G_{in\infty}}; \tag{2.13}$$

$$|Z_{in0}| = \frac{\cos\varphi_0}{G_{in0}}; \tag{2.14}$$

$$|Z_{in\infty}| = \frac{\cos\varphi_\infty}{G_{in\infty}}; \tag{2.15}$$

$$|Z_w| = \sqrt{|Z_{in0}| \cdot |Z_{in\infty}|}; \tag{2.16}$$

$$\varphi_w = -\frac{\varphi_0 + \varphi_\infty}{2}; \tag{2.17}$$

$$|T| = \sqrt{\frac{Z_{in0}}{Z_{in\infty}}}; \tag{2.18}$$

$$\varphi_T = \frac{\varphi_\infty - \varphi_0}{2}; \tag{2.19}$$

$$\alpha = \frac{1}{2L}\text{arth}\frac{2|T|\cos\varphi_T}{1+|T|^2}; \tag{2.20}$$

$$\beta = \frac{1}{2L}\text{arctg}\frac{2|T|\sin\varphi_T}{1-|T|^2}; \tag{2.21}$$

$$V = \frac{\omega}{\beta}. \tag{2.22}$$

The calculated value of β can fall short of certified one at a rate frequency, because of tg 2βL is a periodic function, and not only a single value of β but a range of them satisfies the equation (2.11)

$$\beta = \frac{1}{2L}\text{arctg}\frac{2|T|\sin\varphi_T}{1-|T|^2} + \frac{\pi n}{2L},$$

here n is an integer. Therefore the task reduces to determination of π number multiple to be added to the obtained value. The number n is selected to approximate β to a tabular value.

Having worked out the secondary transmission parameters values it is possible to calculate the primary ones.

A propagation coefficient γ is a complex number and it can be represented as the following expression

$$\gamma = \alpha + i\beta = \sqrt{(R + i\omega L)(G + i\omega C)}.$$

A wave impedance

$$Z_w = \sqrt{\frac{R + i\omega L}{G + i\omega C}}\ .$$

Multiplying γ by Z_w we get the complex circuit impedance:

$$\gamma \cdot Z_w = R + i\omega L = \dot{Z}\ . \qquad (2.23)$$

Dividing γ by Z_w we get the circuit complex conductivity:

$$\frac{\gamma}{Z_w} = G + i\omega C = \dot{Y}\ . \qquad (2.24)$$

Separating, the real and the imaginary parts of $\dot{Z}$ and $\dot{Y}$ and dividing the imaginary components by ω we get the primary transmission parameters R, L, C, G.

3 KEY QUESTIONS

3.1 The primary and secondary transmission parameters, their units of measure, physical interpretation, frequency dependence.

3.2 What does methods of short-circuit and free-run modes consist of for measurement of the secondary transmission parameters?

3.3 When is it possible to use methods of SCM and FRM?

3.4 Sequence of circuit input conductivity and capacitance measurement with МПП-300.

4 HOME TASK

4.1 Learn the following questions:

– electric processes which take place in the symmetrical and coaxial cables;

– frequency dependence of the primary and secondary transmission parameters;

– methods of calculation of the primary and second transmission parameters;
– methods of transmission parameter measurement.

4.2 Prepare the laboratory report and plan of work's implementation according to the sections 5 and 9.

4.3 Prepare to the discussion of key questions.

5 LABORATORY TASK

5.1 Acquaint yourself with equipment on-site and specify your implementation plan with a lecturer.

5.2 Cut the scheme for parameter measurement by the SCM and FRM methods.

5.3 Measure cable input parameters in a short-circuit and an idling modes at the set frequencies. Note down the measured and the calculated values in a tab. 5.1.

Table 5.1 – Measurements table

f, Hz	C_{in0}, F/km	G_{in0}, S/km	φ_0, deg	$C_{in\infty}$, F/km	$G_{in\infty}$, S/km	φ_∞, deg	α, dB/km	β, radian/km	$\lvert Z_w\rvert$, Ohm	φ_w, deg

6 EQIUPMENT

6.1 A model of cable line 0,5 km long, cable ПРППМ-1×2×1,2.

6.2 An input conductivity bridge МПП-300.

6.3 A low-frequency generator Г3-56/1.

6.4 A selective level indicator ИУУ 5–300 kHz.

7 CONTENT OF A REPORT

7.1 Purpose of work.

7.2 Equipment.

7.3 Schemes and results of measurements, calculation results, frequency dependence diagrams of the primary and secondary transmission parameters, based on the measurement results.

7.4 Conclusions.

8 REFARANCES

8.1 Гроднев И.И. Линии связи / И.И. Гроднев, Н.Д. Курбатов. – М.: Связь, 1980. – С. 98 – 116, 120 – 133.

8.2 Гроднев И.И. Линии связи / И.И. Гроднев, С.М. Верник. – М.: Радио и связь, 1988. – С. 120 – 131, 168 – 172.

9 APPENDIX

9.1 Protocol of taking measurements

9.1.1 Check earth connection of the devices. The ground leads of the bridge, the generator and the indicator must be connected to earth.

9.1.2 Assemble the scheme for input admittance G_{in} and capacitance C_{in} in idling and short-circuit modes (fig. 9.1). Connect a generator and indicator to the respective pins of the bridge МПП-300.

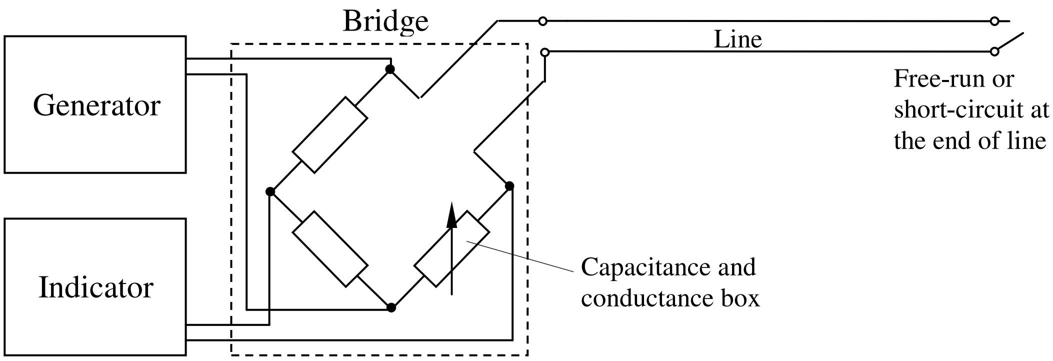


Figure 9.1 – Scheme of measurements

9.1.3 Turn on generator's and indicator's power.

9.1.4 Set necessary frequency using the generator. The output voltage should be no less than 15 V.

9.1.5 Tune ИУУ to generator's frequency. To attain this, keep revolving the frequency-set knob until the pointer swings maximally to the right (it means you have set a frequency which correspond to the maximal level of signal). If the indicator's pointer goes off-scale, you should decrease the sensitivity of the device; if the pointer swing to the left you should increase the sensitivity.

9.1.6 Set the capacitance and the conductance boxes' knobs of МПП to zero position. Set a switch «Кл» on the panel МПП to position which corresponds to the sign of angle φ of the line being measured. If a frequency $f < 90$ kHz, then the sign *of* φ_0 is «plus» in the SC mode and «minus» in the idling one. For a frequency $f > 90$ kHz the signs reverse.

9.1.7 Carry out an initial balancing of the bridge without connecting to the measured line. To attain it keep revolving knobs «Conductance» and «Capacitance» of the initial balancing (on the panel of МПП) alternatively until obtaining the leftmost reading of the indicator's pointer at maximal sensitivity. The initial balancing is to be executed before each measurement.

9.1.8 Connect the beginning of the measured line to respective terminals of the bridge. Set necessary mode (SCM or IM) at the far end of the line. Changing alternatively a conductance and a capacitance of the respective boxes balance the bridge, i.e. obtain the leftmost reading of the indicator's pointer at maximal sensitivity.

9.1.9 Determine the values of input admittance and capacitance of the circuit according to the position of boxes' knobs. Write down the obtained values to the table of measurements.

9.1.10 Without changing generator's frequency, reverse φ sign and repeat measurements beginning from paragraph 9.1.6. For each frequency it is necessary to measure an input admittance and a capacitance of the circuit in a short-circuit and an idling mode.

9.1.11 Measure an input capacitance and an admittance at each frequency in a short-circuit and idle modes.

9.1.12 Determine secondary transmission parameters α, β, $|Z_w|$, φ_w, V of the line according to expressions (2.12) – (2.22). Calculate primary transmission parameters R, L, G, C using (2.23) – (2.24).

9.2 Single-pair cables for rural area network and installation of radio

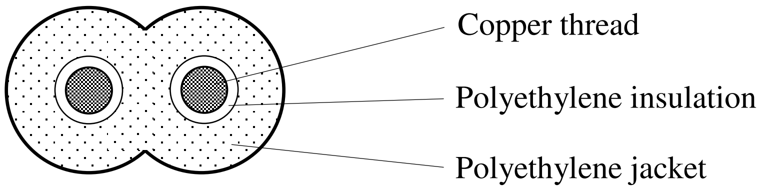


Figure 9.2 – Cross-section of cable ПРППМ-1×2

Exchange cable ПРППМ-1×2 (fig. 9.2) are used for a rural broadcast only. They have copper threads with a diameter of 0,8; 0,9; 1,2 mm. The insulation is made of polyethylene. Over the core jacket of hose lightproof polyethylene is laid. Also cable constructions with polyvinylchloride (PVC) insulation are employed, e.g. single-pair cables with aluminum (ПРППА-1×2) and steel (ПРПЖ-1×2) threads.

Cables with polyethylene insulation are acceptable for operating at temperatures of –40…+50° C. For polyvinylchloride insulation range of negative temperatures reduces to –20° C. Factory length of single-pair cables is 500 m.

Single-pair cable's electrical ratings are given in tab. 9.1.

Table 9.1 – Single-pair cable's electrical ratings

Make of the cable	R, Ohm/km	L, mH/km	C, F/km	α, dB/km	$\lvert Z_w\rvert$, Ohm	U, V	R_{ins}, MOhm·km
ПРППМ-1×2×0,8	72,0	0,7	50	1,24	353	380	6000
ПРППМ-1×2×0,9	56,8	0,7	51	1,0	290	380	6000
ПРППМ-1×2×1,2	32,0	0,7	56	0,83	237	380	6000
ПРПВМ-1×2×1,0	47,8	0,7	114	–	–	360	10
ПРППА-1×2×1,6	29,4	0,7	80	0,65	269	380	6000
ПРПЖ-1×2×1,2	280,0	0,7	56	–	–	500	60

Laboratory work № 3

DETERMINATION OF THE SECONDARY TRANSMISSION PARAMETERS FOR COAXIAL CABLES

1 PURPOSE OF THE WORK

Familiarization with the method of determination of the coaxial cable secondary transmission parameters by the results of wavelength shorting coefficient measurement.

2 MAIN POSITIONS

2.1 Method of secondary transmission parameters determination

A wavelength shorting coefficient is often used in describing electromagnetic energy propagation in radio-frequency cables. The coefficient, ξ, characterizes diminishing of electromagnetic energy propagation velocity in cables compared with the speed of free-space propagation:

$$\xi = \frac{c}{\upsilon}, \tag{2.1}$$

here c – the light speed in free space, which is equal to 300 000 km/s;

υ – a phase velocity of electromagnetic energy propagation in the coaxial pair circuit, km/s.

Every line has a particular propagation velocity of a pulse signal; it is defined by the primary transmission parameters, which depend on type of dielectric, cross-section and material of conductors.

The secondary transmission parameters of coaxial circuit α, β, Z_{sim}, v_{ph} can be expressed through the overall sizes (diameters of inner d and outer D conductors) and insulation parameters (dielectric conductivity ε, dielectric dissipation tg δ).

To estimate secondary parameters' values the pulse method of shorting coefficient determination is often used for coaxial circuits, e.g. applying P5-10 device or it analogue. An accuracy of the secondary parameter determination by the pulse method is mainly defined by accuracy of the shorting coefficient measurement.

To measure the shorting coefficient you need a cable sample which length is approximately equal to one fourth of the wavelength in the cable in accordance with the frequency of the measurement (e.g. if the frequency is 45 MHz then the length of the cable with solid polyethylene insulation is 1,15...1,20 m).

A determination of the transmission parameters of a coax sample at resonance frequency f_r is possible in the order given below.

Knowing the cable length you measure shorting coefficient ξ with the P5-10 device (appendix 9.1).

A resonance frequency f_r is determined from an equation

$$f_r = \frac{3 \cdot 10^8}{\xi \cdot 4l}, \text{ Hz}, \tag{2.2}$$

here l – length of the pattern, m;

ξ – shorting coefficient.

A capacitance of the cable circuit is determined from the expression

$$C = \frac{\xi^2 \cdot 10^{-6}}{18 \ln x}, \text{ F/km,} \qquad (2.3)$$

here $x = \dfrac{D}{d}$ – ratio of coax outer conductor's diameter D to inner conductor's diameter .

Knowing capacitance C or shorting coefficient ξ values a surge impedance of the circuit is evaluated as:

$$|Z_w| = \frac{\xi}{3 \cdot 10^{-4} C} = \frac{60}{\xi} \ln x, \text{ Ohm,} \qquad (2.4)$$

here C – a cable capacitance, nF/km.

An attenuation coefficient for a frequency range of (8…17)·10^6 Hz is determined according to a formula

$$\alpha = 6{,}047 \frac{\xi \sqrt{f}\,(x+1)}{D \ln x} \cdot 10^{-3}, \text{ dB/km,} \qquad (2.5)$$

here f – the calculated frequency, Hz;

D – the core diameter of the outer conductor, mm.

A phase coefficient is determined from an expression

$$\beta = \frac{\omega \xi}{3 \cdot 10^5}, \text{ rad/km,} \qquad (2.6)$$

here $\omega = 2\pi f$, radian per kilometer is a cyclic frequency.

A phase velocity is determined according to a formula

$$v_{ph} = \frac{3 \cdot 10^5}{\xi} = \frac{\omega}{\beta}, \text{ km/s.} \qquad (2.7)$$

To compare the evaluated transmission parameters obtained at temperature of t° C with norms you are to reduce $|Z_w|$, α and β to their values at 20° C. The following equation is used for it

$$N_{20} = \frac{N_t}{1 + \alpha_N (t - 20)}, \qquad (2.8)$$

here N_{20} – a parameter ($|Z_w|$, α, β) reduced to temperature of 20° C;

N_t – the same parameter at temperature of t° C;

α_N is temperature coefficient of the corresponding transmission parameter (relative change of the value at temperature variation of 1 degree centigrade):

$$\alpha_\alpha = (2 \ldots 2{,}6) \cdot 10^{-3}; \qquad \alpha_\beta = (2 \ldots 4) \cdot 10^{-4}; \qquad \alpha_Z = 5 \cdot 10^{-5}.$$

2.2 Attenuation coefficient measurement in coaxial cables

An attenuation coefficient measurement in coaxial circuit can be carried out by a bridge method, a compensation method, a light scattering coefficient method, a voltage-ratio method (a two-voltmeter method) and other ones.

The simplest and most demonstrable method is the two-voltmeter one. It is widely used for work situations.

The circuit of attenuation change measurement is shown in fig. 2.1

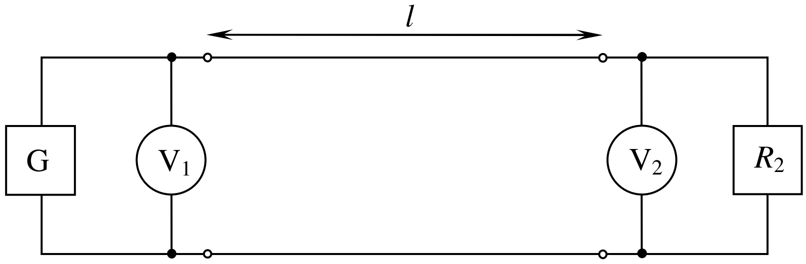


Figure 2.1 – The circuit of attenuation measurement by two-voltmeter method

According to the method a generator *G* is connected to the circuit input, its frequency can be changed gradually in the given range. An output resistance of the generator must be equal to a surge impedance of the measured line. At the circuit's output a variable resistance R_2 is connected, which must be purely active one because a surge impedance of coaxial cable at high frequencies has virtually active character.

Voltmeters V_1 and V_2 are connected to the sending and dead ends of the line in order to measure voltages U_1 and U_2 at these points.

Changing resistance R_2 value it is possible to get R_2 equal to the surge impedance Z_w. In this case the line works in a running-wave mode. R_2 value is selected for the measurement so that slight frequency deviation (±25 %) doesn't cause appreciable deviation of the output voltage U_2 (it must stay stable). If the load resistance R_2 is not matched with the surge impedance Z_w then the frequency deviation will cause voltage U_2 oscillation. In case of complete match ($Z_w = R_2$) due to generator's frequency increase the voltmeter's V_2 reading will decrease a little bit without any periodic oscillations.

On measuring the voltage at the sending and the dead ends of line the attenuation coefficient α can be easily calculated as:

$$\alpha = 20\frac{1000}{l}\lg\frac{U_1}{U_2}, \text{ dB/km}, \qquad (2.9)$$

here *l* – length of the measured cable in meters.

3 KEY QUESTIONS

3.1 Give the definition of the secondary transmission parameters and show their frequency dependences.

3.2 Write down the expression of a wavelength shorting coefficient and give its definition.

3.3 How do you measure a value of shorting coefficient in transmission line?

3.4 What do α, $|Z_w|$, β and υ_{ph} depend on in high-frequency range?

3.5 Analyze the expression according to which measured parameter's values are reduced to for the temperature of 20° C.

3.6 What are temperature coefficients $\alpha_\alpha, \alpha_\beta, \alpha_Z$?

3.7 Principles of transmission line attenuation measurement by the two-voltmeter method.

4 HOME TASK

For self-reading for the laboratory work it is necessary:

4.1 Learn the recommended literature.

4.2 Learn the methodology of a wavelength shorting coefficient measurement in a transmission line (p. 9.1).

4.3 Learn the principles of attenuation measurement according to a two-voltmeter method (p. 2.2).

4.4 Prepare recitations to the key questions.

4.5 Prepare the report.

5 LABORATORY TASK

5.1 Familiarize yourself with the laboratory model.

5.2 Turn on instruments and make them ready to work.

5.3 Measure according to a task a lector has given to you:

– a wavelength shorting coefficient value in a coaxial cable;

– U_1 and U_2 values at four frequencies in the same cable.

5.4 Calculate:

– the secondary transmission parameters according to ξ measured at four frequencies;

– an attenuation coefficient of the cable at the same frequencies using U_1 and U_2 values obtained by two-voltmeter method.

5.5 Chart frequency characteristics of the secondary parameters according to the measurement results.

6 EQUIPMENT

6.1 Models of coaxial cables РК-75, РЖ-58 and РЖ-59 30 m long.

6.2 P5-10 device or its present-day analogue.

6.3 Generators, voltmeters, resistances.

7 CONTENT OF A REPORT

7.1 Results of shorting coefficient measurement for three cable models.

7.2 Results of the secondary transmission parameter calculation at four frequencies and frequency dependence diagrams.

7.3 Results of an attenuation coefficient measurement by a two-voltmeter method for the same cable at the same four frequencies and a frequency dependence diagrams.

7.4 Make the conclusion which includes the analysis of the obtained results.

8 REFERANCES

8.1 Гроднев И.И. Линии связи / И.И. Гроднев, Н.Д. Курбатов. – М.: Связь, 1980. – С. 113 – 115.

8.2 Ефимов И.Е. Радиочастотные линии передачи / И.Е. Ефимов, Г.А. Останькович. – М.: Связь, 1977.

8.3 Измеритель неоднородностей линий Р5-10. Техническое описание и инструкция по эксплуатации, 1980.

9 APPENDIX

9.1 Measurement of wavelength shorting coefficient by P5-10 instrument

An obstacle measuring instrument P5-10 is intended for measuring aerial and cable lines' parameters by a pulse method. A principle of pulse measurements consists of inputting voltage pulses to a line (monitoring pulses) which, while propagating through the line, reflect partially from the impedance obstacles and return to the point of sending.

Monitoring pulses and reflected signals are displayed on CRT screen with timebase of beams. Reflected signals will be time-shifted relative to the monitoring pulse depending on distance to the obstacle, thus a shift value between the reflected signal and the monitoring pulse on display will be proportional to the distance to the obstacle.

Determination of wavelength shorting coefficient is carried out in the following way:

9.1.1 Set the switches to position:

«Shorting» – 1;

«Distance» – 0;

«Set reference» – to the left position.

9.1.2 Choose the measurement range which conforms to the length of cable being measured. For a cable section up to 300 m long the minimal range «0,3 km» must be set.

9.1.3 Connect an interface cable joined with analyzed cable to the «input-output» slot.

9.1.4 Set a reference of distance matching a rising edge of a monitoring pulse with the reading mark of the display with the knob « Уст. отсчёта ».

9.1.5 Set the knob «Расстояние» into a position which corresponds to the determined length of the cable (you should take into account the length of a patch cable for relatively short cables).

9.1.6 Match a rise-up portion of the reflected pulse with the reading point of the display scale by rotating the knob «Shorting» to the right.

9.1.7 Determine a shorting coefficient in the cable by the «Shortening» scale. Accuracy of wavelength shorting coefficient determination is defined by precision of geometrical length determination.

9.2 Cable specification

A radio-frequency exchange coaxial cable РК-75 is used for internal laying in on-air broadcasting systems to transmit signals from a receiving aerial to a TV set in the range of (5…1000) MHz, in cable television systems for a house distribution and an individual connection.

Electrical and structural parameters of cables used in this work to take measurements are given in tab. 9.1.

Table 9.1 – Electrical and structural parameters of coaxial cables РК-75, РЖ-58 and РЖ-59

Make of the cable	Surge impedance, Ohm	Attenuation coefficient, dB/km at frequency of, MHz			Capacitance, nF/km	Diameter of inner conductor, mm	Inner diameter of outer conductor, mm
		10	100	1000			
РК-75	75	27,04	85,6	270,7	67	0,85	4,00
РЖ-58	50	38,67	122,4	387,0	110	0,64	3,00
РЖ-59	75	33,3	105,4	333,3	75	0,64	3,71

Laboratory work № 4

MEASUREMENT AND TESTING TRANSMISSION LINES BY PULSE METHOD

1 PURPOSE OF THE WORK

Learning of pulse method to determine point and nature of line's damage as well as learning of methodology of coax attenuation coefficient determination by the results of wavelength shorting coefficient measurement.

2 MAIN POSITIONS

2.1 Determination of point and nature of transmission lines' damage by pulse method

During the transmission line exploitation because of different causes faults arise, which lead to connection malfunction. Therefore one of the most important task to attain at TL exploitation is a determination of point and nature of damage for the purpose of its instant correction.

Line faults according to their nature are broken into the following categories:

– conductor's break;
– conductor's fault;
– conductors' insulation resistance reduction;
– conductors' connection to the ground.

On revealing faults their nature should be found out, and then the distance to the place of the damage is determined by measuring instruments.

In this work a pulse method is examined to determine a location and nature of TL fault.

A pulse method of TL measurement is based on a phenomenon of electromagnetic pulse reflection at locations of obstacles through the changes in a TL wave impedance. TL obstacles appear as a consequence of its quality or being damaged.

The method is implemented in P5-10 and its analogues and consists of the following: in a TL circuit, for instance in a cable, voltage pulses are transmitted (monitoring pulses), which propagating through the line partially reflect from a wave impedance obstacles and return to the sending end where they are displayed on the CRT screen with a time sweep. Signals which are reflected from obstacles are time-shifted and the size of the shift between the reflected signal and the monitoring pulse on the screen is proportional to the distance to the obstacle.

A measurement by a pulse method allow to get fast and accurate results especially in case of break, short, conductor's connection in multiple-wire systems.

An obstacle is characterized by a reflection coefficient:

$$p = \frac{U_{ref}}{U_{mon}} = \frac{Z - Z_w}{Z + Z_w}, \qquad (2.1)$$

here U_{ref}, U_{mon} – amplitudes of reflected and monitoring pulses;

Z_w – rated value of TL surge impedance;

Z – value of the wave impedance in the place of the obstacle.

A reflected signal's absence on the CRT display indicates obstacles' absence in the line. In this case the reflection coefficient is equal to zero $(p = 0)$ in every point of the line.

If the obstacle is caused by an increase in the wave impedance then the pulse reflected from the obstacle has the same direction with the monitoring one $(p > 0)$. In case of line's break (the extreme case) in the point of break the total reflection without the pulse direction reversion takes place $(p = 1)$.

If the obstacle is caused by decrease in line's impedance then on reflecting the pulse reverses its direction to the opposite one $(p < 0)$. In case of short circuit the fault total reflection of the pulse with reversing direction to the opposite one takes place $(p = -1)$.

It is clear that the reflected signal's amplitude doesn't exceed the monitoring pulse's one therefore a reflection coefficient can only possess the value from –1 to +1.

A distance to the obstacle (short, break, cable insertion, smooth variation of impedance) is determined by a latency time t_{lt} of the reflected signal relative to the leading edge of the monitoring pulse.

Each line has its own propagation velocity of a pulse signal. It is defined by primary transmissions parameters, which depend on a type of dielectric, a cross-section and a material of conductors.

Knowing (or having already measured) pulse propagation velocity υ and having measured latency time t_{lt}, the distance to the obstacle can be determined as:

$$L = \frac{1}{2}\upsilon \cdot t_{lt}. \tag{2.2}$$

Depending on a length of a line being measured and its attenuation, a duration of a monitoring pulse, which is sent to line, can be chosen by use of a switch «Mon. pulse μs».

Use of narrower pulses makes it possible to study a line more accurately; in this case an accuracy of distance measurement is improved (an increase in device's resolution). However it is known that narrow pulses have wide spectrum and attenuate highly during propagation. Therefore narrow pulses are not applicable to study lines with high self-attenuation, because propagating in line they will be received too damped, which may complicate their detection against noise.

Thus decrease in duration of pulses leads to accuracy improvement but it restricts distance. Increasing duration of pulses lowers accuracy of measurement but distance of measurements increases.

Reading the distance is carried out taking into account a velocity of pulse propagation in the line. The propagation velocity is connected with a wavelength shorting coefficient ξ through an expression

$$\xi = \frac{c}{\upsilon}, \tag{2.3}$$

here c – the electromagnetic constant, c = 300 000 km/s;

υ – pulse propagation velocity in line of a certain type, km/s.

You can set the wavelength shorting coefficient by the knob «Shorting».

Taking pulse measurements on lines with unknown shorting coefficient it can approximately be calculated as

$$\xi = \sqrt{\varepsilon}, \tag{2.4}$$

here ε is dielectric constant of conductor's insulation.

2.2 Studying of coaxial cables with unknown length

The mutual capacitance of coax can be written as

$$C = \frac{\varepsilon \cdot 10^{-6}}{18 \ln \frac{D}{d}}, \text{ F/km}, \tag{2.5}$$

here ε – an equivalent dielectric constant of insulation;

D – inner diameter of outer conductor;

d – diameter of inner conductor.

Coaxial cable wave impedance is

$$Z_w = \frac{60}{\sqrt{\varepsilon}} \ln \frac{D}{d}, \text{ Ohm}, \tag{2.6}$$

Considering that shorting coefficient is $\xi = \sqrt{\varepsilon}$ then we get:

$$\xi = \frac{60}{Z_w} \ln \frac{D}{d}. \tag{2.7}$$

Thus to study coax with unknown precise length, we could indirectly determine the shorting coefficient via the formula (2.7) and measure the surge impedance preliminarily.

It is easiest to measure surge impedance of coax by comparison method. To do this the measured cable section is connected to a P5-10 instrument. Variable active load resistance is connected at the end of circuit chain. If the resistance is not matched with the cable surge impedance then the pulse-response characteristic will have a break, which corresponds to a reflection of the pulse from the unmatched load. Therefore to determine a value of the surge impedance of the line being measured it is necessary to choose a load resistance so that the break disappears (or reduces to a minimum); then the required surge impedance will be equal to the value of load resistance. It is worth remembering that in case a load resistance is less than the impedance characteristic's break is directed downwards and in the opposite case – upwards.

Thus, having determined the surge impedance we may evaluate the shorting coefficient for this cable and other parameters as well.

3 KEY QUESTIONS

3.1 What is the principle of line's obstacles determination by using a pulse method?

3.2 How do you determine a distance to the obstacle's location in the transmission line?

3.3 How do you determine a wavelength shorting coefficient's value?

3.4 What quantity characterizes surge impedance's obstacle of transmission line?

3.5 Write down the expressions for reflection and shorting coefficients of electromagnetic wave.

3.6 Give expressions for C, Z_w, υ_{ph} determination using ε.

4 HOME TASK

In process of preparation for the laboratory work it is necessary to:

4.1 Study the recommended literature.

4.2 Familiarize yourself with a pulse method of place and nature of line's fault determination (p. 2.1).

4.3 Learn a methodology of measurement for:

– a distance to an obstacle (a fault) of a transmission line;

– a wavelength shorting coefficient for a line with a known length;

– a surge impedance for transmission line with an unknown length.

4.4 Prepare recitations to key question.

4.5 Prepare the report.

5 LABORATORY TASK

5.1 Familiarize yourself with the laboratory stand.

5.2 Turn on a P5-10 device and set it ready for work.

5.3 Connect the device to an artificial extension line and carry out the following actions:

a) run a pulse-response characteristic of an operable line which includes different obstacles;

b) determine the distance to certain points of transmission line (for aerial lines $\xi = 1.05$);

c) determine locations and nature of line's faults according to the task assigned by instructor.

5.4 Measure a surge impedance of coax' sections according to a comparison method and evaluate the shorting coefficient.

5.5 Having evaluated the shorting coefficient, measure each cable section's length.

6 EQUIPMENT

6.1 Laboratory stands of aerial lines several sections of coaxial cables with different surge impedance values.

6.2 P5-10 device or its modern analogue.

6.3 Resistance set.

7 CONTENT OF A REPORT

7.1 A drawing of pulse-response characteristics of operable and inoperable aerial lines.

7.2 Results of measurements of a distance to certain TL stations and places of faults determined according to the pulse characteristics.

7.3 Results of measurements of a surge impedance Z_{sim} and a length L of the cable sections, determination of a shorting coefficient ξ.

8 REFERANCES

8.1 Гроднев И.И. Линии связи / И.И. Гроднев, Н.Д. Курбатов. – М.: Связь, 1980. – 414 с.

8.2 Ефимов И.Е. Радиочастотные линии передачи / И.Е. Ефимов, Г.А. Останькович. – М.: Связь, 1977. – 251 с.

8.3 Измеритель неоднородностей линий Р5-10. Техническое описание и инструкция по эксплуатации, 1980. – 16 с.

9 APPENDIX

9.1 P5-10 work start

9.1.1 Before turning on the device it is necessary to check that the device is switched to corresponding current and voltage.

9.1.2 Set the knobs to the base point:

«Gain» – to the extreme left position;

«Distance» – 0;

«Set of reading» – to the extreme left position;

«Power» – to the lowest position (turned off).

9.1.3 Check if the device is grounded.

9.1.4 Switch on power by the knob «Power». The indicator will light up on the front panel. In 0.5…2 minutes a sweep trace will appear.

9.1.5 Regulate brightness, focus and position of sweep trace on the display by the knobs «☼», «⊙» and «↕». The sweep trace must be in the center of the screen.

9.2 Getting the device ready for taking measurements

9.2.1 Depending on the measured line's length, the work is carried out in the following ranges which are selected by the switch «Диапазоны км»: 0,3 km; 1 km; 3 km; 10 km; 30 km; 100 km; 300 km.

9.2.2 Set the knob «Зонд. имп. µs» into position:

– «0.05; 0.1; 0.3» (if the length is less than 10 km);

– «0.1; 0.3; 1; 3» (if the length is less than 30 km);

– «1; 3; 10; 30» (if the length if less than 300 km).

9.2.3 Set the knob «Вых. сопр.» according to the value of surge impedance of the line. Approximate values of the output impedance are determined by colored sections on the front panel of the device below the switch «Вых. сопр.». The light section indicates output impedance of (20…100) Ohm; the grey one – (100…250) Ohm; the leaden one – (250…500) Ohm.

9.2.4 Set the switch «Укорочение» into a position that corresponds to the value of shorting coefficient of the line.

9.3 Measurement of the distance to fault location

9.3.1 Connect the device to the line and examine the line pulse characteristic.

9.3.2 Find a point where the curve jumps which corresponds to a reflection from some obstacle (possible fault) in the line, ascertain type of damage. A jump (burst) up conforms to an increase of surge impedance (break), a jump down – a decrease of Z_w (short fault or leakage).

9.3.3 Match the leading front of a monitoring pulse with a mark of scale by the knob «Уст. отсчёта».

9.3.4 Match the beginning of the burst with the reading mark (the mark which was matched with the monitoring pulse) by the switch «Расстояние».

Laboratory work № 5

MEASUREMENT OF THE CAPACITIVE COUPLING COEFFICIENTS AND CAPACITIVE ASYMMETRY AND CHOICE OF THE TRANSPOSITION OPERATORS

1. PURPOSE OF THE WORK

The purpose of this work is the study technique of measuring the primary parameters of the influence between the circuits and the choice of the low-frequency cable transposition operators by measurement results the capacitive coupling coefficients and asymmetry.

The key work goal is acquisition of the practical skills in balancing, studying of the measurement schemes and the equipment which used in this laboratory work.

2. MAIN POSITIONS

2.1. Balancing of the low frequency cables

Influences between lines in low frequency cables are basically by capacitive couplings and partial capacitances asymmetry of the line cores concerning to the ground. First of all the ground asymmetry is affected on the magnitude of external electromagnetic fields influence on the cable line circuits.

The influence magnitude between circuit is affected, besides, by a resistance asymmetry, a work capacitances deviation off a mean value etc.

Values defining a capacitive coupling within a quad are given by the following formulas:

$$k_1 = (C_{13} + C_{24}) - (C_{23} + C_{14});$$
$$k_2 = (C_{13} + C_{14}) - (C_{23} + C_{24}); \qquad (2.1)$$
$$k_3 = (C_{13} + C_{23}) - (C_{14} + C_{24}),$$

here k_1 – a capacitive coupling between main circuits – I/II;

k_2 – a capacitive coupling between the first main circuit and the phantom (artificial) one – I/phant.;

k_3 – a capacitive coupling between the second main circuit and the phantom one – II/phant.;

C_{13}, C_{23}, C_{14}, C_{24} – are partial capacitances among wires (fig. 2.1)

A capacitive asymmetry is given by formulae:

$$e_1 = C_{10} - C_{20};$$
$$e_2 = C_{30} - C_{40}; \qquad (2.2)$$
$$e_3 = (C_{10} + C_{20}) - (C_{30} + C_{40}),$$

here e_1 – is a capacitive asymmetry of the first circuit with respect to the ground I/G;

e_2 – a capacitive asymmetry of the second circuit with respect to the ground – II/G;

e_3 – a capacitive asymmetry of an artificial circuit – A/G;

C_{10}, C_{20}, C_{30}, C_{40} – are partial capacitances between each conductor and the ground respectively.

Besides there are capacitive couplings among artificial circuits of different quads as well – k_4; among main circuits and artificial ones of different quads – k_5, k_6, k_7, k_8; among main circuits of different quads – k_9, k_{10}, k_{11}, k_{12}. They could all be expressed via partial capacitances. Influence parameters values of construction lengths and amplification elements must not exceed certain limits listed in an appendix 9.1.

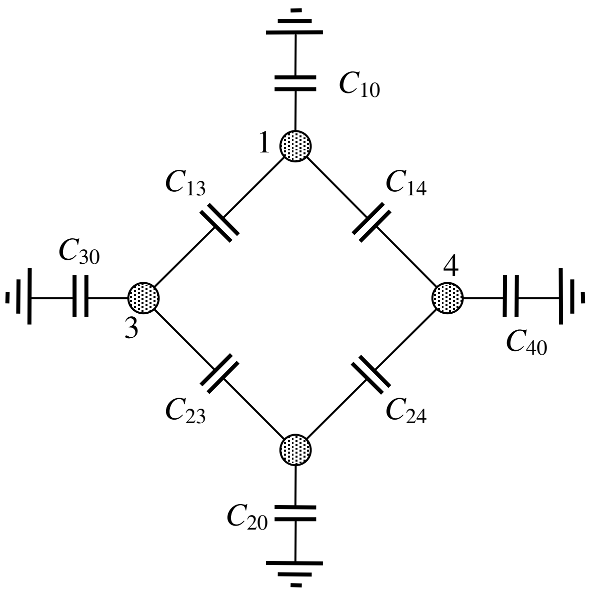


Figure 2.1 – A capacitive couplings and capacitive asymmetry in a quad equivalent circuit

A symmetrizing (balancing) by crossing is coupling and asymmetry compensation of one cable element by another one.

Resulting asymmetries and coupling values are calculated by a coefficients algebraic addition. There are eight diagrams of a pair and symmetrized quad wires crossing (tab. 2.1).

The table lists a change of sing for quad coupling and asymmetry coefficient from side B and a notation for crossing diagrams (operators). The first operator's sign (the left one) indicates how the first pain wires are connected for a given operators the second sign (the middle one) – does how the second pair wires connect and the third one (the right one) – does how quad (an artificial circuit) pairs connect.

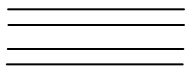
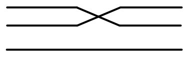
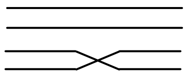
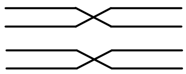
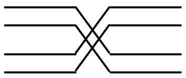
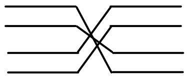
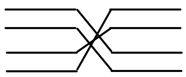
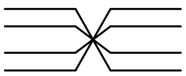
Asymmetry coefficients of two main and two artificial circuits may be lowered in symmetrizing process by crossing for any sign combination for both sides and coupling coefficients may be lowered if "+" and "-" number is odd for both sides of a symmetrizing point. One needs to consider this for an operator choice. To increase a symmetrizing efficiency it is help full to connect with each other quads having the closest values of coupling coefficients by quad mixing. A number of positive and negative sings of coupling coefficients for connected quads has to be odd. A quad mixing is allow within the same layer only and for the same transmission system quads.

A separate record based on a form of a tab. 2.2 is filled for every symmetrizing joint (with an example form filling): quad numbers are written in rows 1 and 14, a sign and a value of measured asymmetry coefficients for a side A and a side B are done in rows 2 and 13, a sign and a value of measured coupling factors for sides A and B correspondingly are done in rows 3 and 12. Coupling factors and asymmetry coefficients values are written in a sequence corresponding to headers of the corresponding lines.

We choose quads to compensate a capacitive coupling after that. We start with the quads that have the highest coupling value.

One finds a quad with the highest capacitive value in the left hand side of the form then one does a quad with the highest capacitive value in the right hand side of the form. We select the quads so that a sum of plus and minus signs for the combined quads coupling coefficients has to be odd. A quad number selected in the right hand side of the form and the corresponding coupling factors and asymmetry coefficients are written in column 5, 6 and 7. We do an analogous procedure consecutively for the other quads moving to lower capacitive coupling (k_1). Then, we select operators in quads to be connected as follows: compare the factors k'_2 and k'_3 in the left hand side of the form with the couplings k''_2 and k''_3 in its right hand side. If $k'_2 \approx k''_2$ and $k'_3 \approx k''_3$ then pairs in a quad are connected directly; if $k'_2 \approx k''_3$ and $k'_3 \approx k''_2$ then pairs in a quad are crossed.

Table 2.1 – Capacitive coupling and asymmetry coefficients addition for quad balance by the transposition

Diagram number	Notation (operator)	Crossing diagram Side A Side B	Sum coefficient value						Type of the transposition circuits
			I/II	I/A	II/A	I/G	II/G	A/G	
			k_1	k_2	k_3	e_1	e_2	e_3	
1	• • •		$k_1'+k_1''$	$k_2'+k_2''$	$k_3'+k_3''$	$e_1'+e_1''$	$e_2'+e_2''$	$e_3'+e_3''$	–
2	X • •		$k_1'-k_1''$	$k_2'-k_2''$	$k_3'+k_3''$	$e_1'-e_1''$	$e_2'+e_2''$	$e_3'+e_3''$	the 1st
3	• X •		$k_1'-k_1''$	$k_2'+k_2''$	$k_3'-k_3''$	$e_1'+e_1''$	$e_2'-e_2''$	$e_3'+e_3''$	the 2nd
4	X X •		$k_1'+k_1''$	$k_2'-k_2''$	$k_3'-k_3''$	$e_1'-e_1''$	$e_2'-e_2''$	$e_3'+e_3''$	the 1st and the 2nd
5	• • X		$k_1'+k_1''$	$k_2'+k_3''$	$k_3'+k_2''$	$e_1'+e_2''$	$e_2'+e_1''$	$e_3'-e_3''$	artif.
6	X • X		$k_1'-k_1''$	$k_2'-k_3''$	$k_3'+k_2''$	$e_1'-e_2''$	$e_2'+e_1''$	$e_3'-e_3''$	the 1st and artif.
7	• X X		$k_1'-k_1''$	$k_2'+k_3''$	$k_3'-k_2''$	$e_1'+e_2''$	$e_2'-e_1''$	$e_3'-e_3''$	the 2nd and artif.
8	X X X		$k_1'+k_1''$	$k_2'-k_3''$	$k_3'-k_2''$	$e_1'-e_2''$	$e_2'-e_1''$	$e_3'-e_3''$	the 1st, the 2nd and artif.

A wire crossing in pairs depends on signs of compensated coupling factors. If the signs are opposite the wires in this pair are connected directly, if the signs are the same the wires are crossed. In case it is impossible to determine a connection type to the coupling factors this is done analogously via asymmetry coefficients.

On selecting an operator, using the tab. 2.1, we compute the symmetrization results and write them in row 8 and 9. On wire connection by a chosen diagram and a symmetrization results calculation we take a control measurement of coupling factors and asymmetry coefficients. A numeration of the pairs and the wires is done along the cable starting from the side A. We write results of a control measurements in rows 10 and 11. Values signs of measurement and calculation results have to be identical.

Table 2.2 – Quad symmetrizing by crossing form

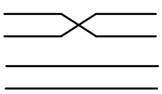
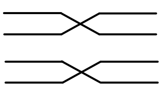
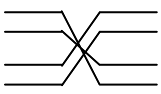
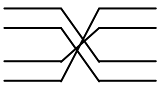
Device ____________________ Cable _________________________

Plant _____________________ Amplification element ___________

Technician ____________________ _______________________________

___________________________ Coil load spacing _________________

Date “___“___________ 20__ year. Crossing box ___________________________

Side A				Side B			Results				Side B		
							Calculated		Measured				
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Quad num.	e_1' e_3' e_2'	k_2' k_1' k_3'	Crossing diagram	k_2'' k_1'' k_3''	e_1'' e_3'' e_2''	Quad num	k_2 k_1 k_3	e_1 e_3 e_2	k_2 k_1 k_3	e_1 e_3 e_2	k_2'' k_1'' k_3''	e_1'' e_3'' e_2''	Quad num
1	–50 –150 0	0 –30 –25		+10 –35 +20	–30 +50 –70	2	–10 +5 –5	–20 –100 –70			+30 –70 0	+10 0 0	1
2	–95 –250 +90	+75 +85 –90		+20 –115 –115	+30 +250 –30	4	+55 –30 +25	–125 0 +120			+10 –35 +20	–30 +50 –70	2
3	–20 –250 +150	–120 –95 –25		+40 –105 –140	–80 –200 +60	3	+20 +10 +15	–80 –50 +70			+40 –105 –140	–80 –200 +60	3
4	+10 –80 +50	+20 –80 +20		+30 –70 0	+10 0 0	1	+20 –10 –10	+10 –80 +40			+20 –115 –115	+30 +250 –30	4
5													5
6													6
7													7

Couplings	Mean	Maximal	Asymmetries	Mean	Maximal
k_1 k_2, k_3			e_1, e_2 e_3		

Note. We could perform a coupling factors and asymmetry coefficients addition in symmetrization crossing process, without the tab. 2.1 by the following rules:

1. All factors are summed (with their signs) for a direct connection of main circuits.

2. If a main circuit is crossed, factors related to this circuit are subtracted.
3. If both main circuits are crossed factors of these circuits are summed.
4. e_3 factors are always summed for direct connection or crossing of main circuits.
5. If an artificial circuit is crossed, k_1' and k_1'', e_3' and e_3'' factors are connected to each other pair wise and factors k_2, k_3 and e_1, e_2 exchange positions i.e. k_2' connects with k_3'', k_3' connects with k_2'', e_1' connects with e_2'', e_2' connects with e_1''. A summation of factor signs is done by main circuit rules (pp. 1, 2, 3) and factors e_3' and e_3'' are always subtracted.

A *capacitor symmetrizing* principle consists of the following: if, for example, a factor $k_1 = (C_{13} + C_{24}) - (C_{14} + C_{23})$ does not equal zero but, e.g., equals +100 pF this implies that a capacitances sum $(C_{13} + C_{24})$ is layer than that of $(C_{14} + C_{23})$ by 100 pF. Obviously, if we connect a 100 pF capacitance capacitor to a lower sum then a factor k_1 will be zero.

To keep factors k_2 and k_3 constant we need to connect an additional capacitance to every capacitor of lower sum. We have to connect 50 pF capacitors between wires ad and be in our example, then $k_1 = 0$, k_2 and k_3 are do not change as both capacitances C_{23} and C_{14} are parts of their corresponding sum (see the formula (2.1)).

Symmetrizing capacitors are produced of different capacitance varying by (5…10) pF. They are connected to wires by attaching individual cable elements in capacitor joints. We select a capacitance of additional capacitors by a tab. 2.3 form with its approximate filling-in. While completing the form, we write measured resulting factor values in rows 3 and 11 based on their signs.

We write fractions of these quantities in rows 4 and 12 then and sum rows. We subtract the smallest sum from the result and, thus, get a symmetrizing capacitors necessary capacitance value that is written in the lowest line.

2.2 Low frequency cable symmetrizing by 1725/S ORION device

A number of devices working as ac bridges are used for LF cable symmetrizing in a tone frequency spectrum by a capacitive asymmetry and capacitive coupling.

A 1725/S ORION device (fig. 2.2) consist of two detachable parts – lower (narrow) one with a power supply connected and upper (wide) one with a capacitive coupling and capacitive asymmetry measure built-in, a quad switch (P_2) and a variable standard capacitance up to 1800 pF to increase a device (P_3) measurement range.

The power supply consists of an 800 Hz transistor generator and an amplifier. There are three КБС (12 V) elements in the power supply box to power the generator.

The coupling measurer is connected to the power supply by two connection socket panels. The generator and the amplifier are connected to each other and are separated from the measuring bridge by a screen.

Table 2.3 – Statement of balancing by capacitors

Device number ___ Plant ___ Measurements taken by ___ ___ Data "___" ___ 200__ year								Cable___ Amplification element___ ___ Coil load spacing___ Oint number___							
The first control measurement result			Fraction of measured value to be written in a blance square	Capacitors capacitance to be connected between wires and the ground				The second control measurement result			Capacitors capacitance to be connected between wires and the ground	The second control measurement result			
Коефіцієнт	Знак	Величина		*1-0*	*2-0*	*3-0*	*4-0*	Factor	Sign	Value		*1-3*	*1-4*	*2-3*	*2-4*
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
e_1	–	125	1, ½, ½	125		63	63	k_1	–	30	½, ½	15			15
	+		1, ½, ½						+		½, ½				
e_2	–		½, ½, 1					k_2	–		½, ½				
	+	120	½, ½, 1	60	60		120		+	55	½, ½			28	28
e_3	–	0	½, ½	0	0			k_3	–		½, ½				
	+		½, ½						+	15	½, ½		8		8
Sum				185	60	63	183	Sum				15	8	28	51
The lowest value is subtracted				60	60	60	60	The lowest value is subtracted				8	8	8	8
Remainder				125	0	3	123	Remainder				7	0	20	43

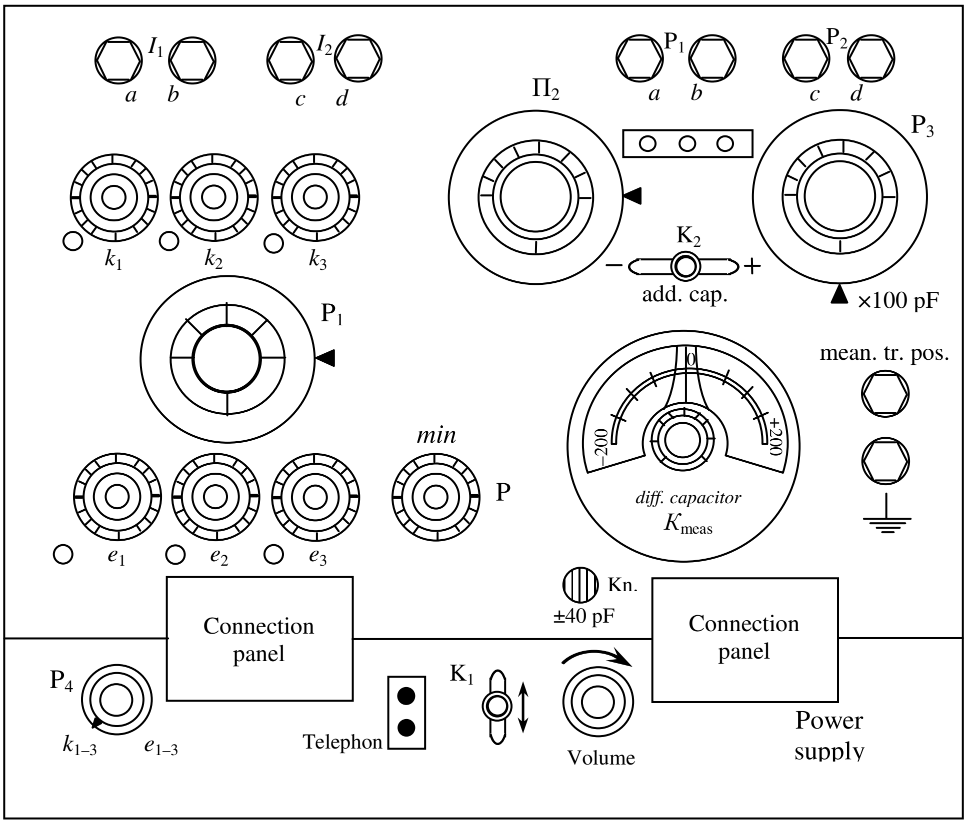


Figure 2.2 – Top view of 1725/S device and its elements positions

Note. The switch P_2 is utilized for measuring coupling factors and asymmetry coefficients between circuits of different quads k_4; k_5 – k_8; k_9 – k_{12}. Measured quad wires during this are connected to the left (I_{1ab}, I_{2cd}) and the right (P_{1ab}, P_{2cd}) device terminals. The switch P_1 has to always be in k_1 position during these measurements.

Measuring circuits for transmission factors k_1, k_2, k_3 and asymmetries e_1, e_2, e_3 measurement are assembled with a small size step switch P_1 as well as the switches P_2 and P_3. The switch P_2 has to stay in a position $I^{k}_{e}{}_{1\text{–}3}$ for the factors k and e measurement between wires and wires with respect to the ground are switched into the bridge branches so that values of measured k and e are directly read by a measuring capacitor position (k_{meas}) on potentials equality at points of a telephone connection (a minimal volume level in a telephone). Quad wires not involved in a measurement are connected to the middle point of a differential transformator for asymmetry measuring e_1, e_2, e_3 for multiquad cables.

2.2.1 A capacitive coupling factor and a capacitive asymmetry measurement device and switch on and tuning.

A device has to be ganged by its “own scale” before starting measurement of coupling factors and asymmetry coefficients, i.e. an asymmetry of measuring circuit itself and a capacitive asymmetry of a cords to be connected to the device have to be equalized. To be this we need:

1. Connect a measuring cord to the left terminals (I_{1ab}, I_{2cd}) following strictly a cord wires colouring (red, write, blue, green), or a terminal numbering (1, 2, 3, 4). The second end of the measuring cord has to be on dielectric, wires have to have no connections with each other and with the ground.

2. Connect a terminal "Земля" to the ground terminal on a measuring stand.

3. Set the switch P_2 in a I^{k}_{e1-3} position.

4. Set the switch k_2 in the middle position, the additional capacitance 200 – 1800 pF (P_3) is disconnected as a result.

5. Set the differential capacitor k_{meas} in a zero position.

6. Set the switch P_1 in a position k_1.

7. Set the switch P_4 in a position $k_{1\text{-}3}$.

8. Connect the telephone to the corresponding terminals.

9. Switch on the power supply by setting k_1 in a "Вкл." position; the volume is adjusted by the volume regulator.

10. If the device is tuned, the volume level of the telephone will be zero or very low.

11. If the device is not tuned the telephone volume will be high. In this case, get a sharp minimum of the telephone volume level on loosening a stop-serew and regulating the tuning capacitor k_1 and the potentiometer P. A capacitor k_1 position need to be fixed by slightly tightening the stop-screw. A tuning accuracy control is done by changing the differential capacitor position by one or two units to the left or to the right from 0, the telephone volume increases sharply after that.

12. One the device tuning for the factor k_1 measurement set the switch P_1 into a position k_2 and get the telephone volume sharp minimum by the alignment capacitor k_2 and the potentiometer P.

13. Tune device for measurement of the k_3 factor analogously.

14. On setting the switch P_4 in the position e_{1-3}, the switch P_1 – sequentially in the positions e_1, e_2, e_3, using for each position the corresponding alignment capacitors e_1, e_2, e_3 and the potentiometer P, tune the device (based on the minimal volume) for all capacitive tuning procedure.

2.2.2 Measurement of capacitive coupling factors and asymmetry coefficients

The measurement of coupling factors and asymmetry coefficients protocol is the following:

1. Connect the second end of the measuring cord from side A to a joint A1 (figure 5.1) so that a sequence of colouring (and numbers) for the wires of the cord and the cable are matched.

2. Setting the switch P_1 into the positions k_1, k_2, k_3 sequentially (P_4 – into the position k_{1-3}), then into the positions e_1, e_2, e_3 (P_4 – into the position e_{1-3}) and utilizing the potentiometer P, measure values for all coupling factors and asymmetry coefficients accounting for their sign with the differential capacitor k_{meas}. Take the measurement at the differential capacitor position at the lowest telephone volume.

3. If measured values of the factors are low we could measure them with higher accuracy by pressing the button Kn. ±40 pF. This way we change a receiving transformator transformation factor, and a differential capacitor measurement limit is set to 40 pF.

4. If a magnitude of the measured factor is higher than ±200 pF then change the switch P_3 position sequentially from 200 to 1800 pF by pressing the key k_2 into a position "+" or "-" (depending on a sign of the measured factor obtained by the differential capacitor measurement) and get the lowest telephone volume. You could get a sharp minimum by an additional tuning of the differential capacitor. Get a value of the measured factor by adding a capacitance reading by the differential capacitor and the capacitance P_3.

For example: P_3 is at the position G, the key k_2 – at the position "+", the differential capacitor is at the position "+30", then the factor value equals +G30. we obtain the same value by setting P_3 into the position 8, the differential capacitor – in the position "-170". Write measured values of the factors k_1, k_2, k_3, e_1, e_2, e_3 with their signs in row 2 and 3 of the tab. 2.2 according tj the protocol of the above row.

5. Connect the measuring cord after that to the colour-corresponding wires of the right cable side (side B), measure the factors k_1, k_2, k_3 end e_1, e_2, e_3 analogously as it was done above and write the results in rows 5 and 6 of the tab. 2.2.

Select a crossing operator at wires for a given quad based on the measured values of all factors, write it in line 4, calculate resulting coupling factors and asymmetry coefficients and write it in rows 8 and 9.

6. Connect quads on the stand in the joint A_1 according to a selected operator and monitor accuracy of the set connection design and of calculation by resulting factors measurement.

You have to connect the cord wires going from the device for the control measurement, on selecting a connection circuit in the joint A_1, based on exact wire colouring for the A side (fig. 2.3).

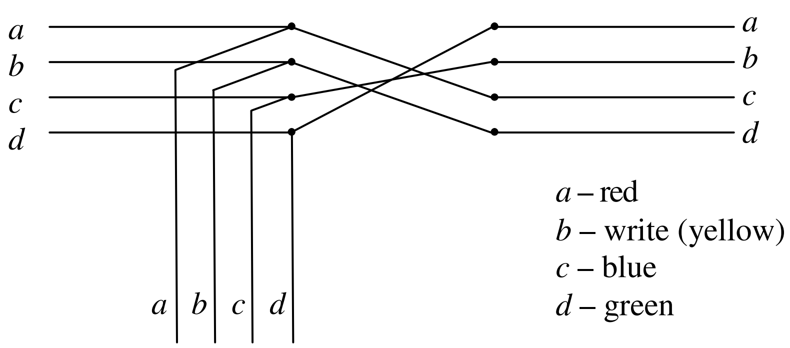


Figure 2.3 – Measuring cord connection to cable wire

7. Write a control measurement data in rows 10 and 11 of the table 2.2 and compare the measurement results with the calculated values in the rows 8 and 9. They have to be identical.

8. Take measurements analogously for the three-point symmetrising diagram. Write, select, set operators and subsequently control at the point A_2, then at the point C.

9. On symmetrising by crossing at the joint C write measured resulting values of coupling factors and asymmetry coefficients for a symmetrisation spacing (a coil load spacing) into the corresponding rows of the form for capacitor cable symmetrising and calculate capacitance values to be connected among wires and

between any wire and the ground to finally get the factors in accordance with the set standards.

10. Select the necessary symmetrising capacitors and connect them to the cable wires based on the calculation data using the capacitor quad symmetrisation form. Match cable wire colouring and numbering, the capacitors and the measuring cord wires' connection exactly.

On capacitors connection, take control measurement of resulting coefficients for a symmetrisation spacing. If the capacitors are selected accurately, the factors have to be equal to zero. If the connected capacitors value differ from the calculated ones the resulting factors may be non zero, however, they must not be higher the set standards for a symmetrisation spacing (appendix 9.1).

3 KEY QUESTIONS

3.1 Types and features of used low frequency cables.

3.2 Electric properties, characteristics and standards of low frequency cables.

3.3 Crossing operators selection rules.

3.4 A capacitive coupling factors and asymmetry coefficients calculation as well as form filling protocol for crossing symmetrization.

3.5 The same for capacitive symmetrization.

3.6 A 1725/S device general work principle and its operation protocol.

3.7 A design and a mounting of a capacitive joint.

4 HOME TASK

4.1 Study the recommended literature.

4.2 Study the design and the operation protocol for the 1725/S device.

4.3 Study a protocol of crossing operators selection by measured capacitive coupling factors and asymmetry coefficients.

4.4 Prepare oral answers to the key questions.

4.5 Prepare the report forms (diagrams, tables) and learn a protocol of using a quad symmetrizing forms by crossing and by capacitors.

5 LABORATORY TASK

5.1 Check wire sequence in quads using the cable line stand.

5.2 Connect the measurement circuit.

5.3 Turn on voltage on instructors permission.

5.4 Symmetrize one quad for a spacing using a three point diagram (figure 5.1). Symmetrize joints A1 and A2 to do this first by crossing only, then – joint C by crossing and by capacitors. *k* and *e* factors have to be within the standard range as a result of symmetrizing. A general protocol of the 1725/S device operation and the form filling protocols for crossing and capacitor symmetrization are in pp. 2.1, 2.2.

5.5 Compare the obtained measurement results with allowed standards for a symmetrizing spacing (*k* and *e*).

6 EQUIPMENT

6.1 Cable line stand (for one symmetrizing spacing).
6.2 1725/S device.
6.3 Symmetrizing capacitor set.

7 CONTENT OF A REPORT

7.1 Measurement circuit.
7.2 Filled-in forms of quad symmetrization results (by crossing and by capacitors).
7.3 Schematic diagram of capacitor connection to quad wires.
7.4 Comparison of obtained results with allowed standards (*k* and *e*) for cable construction lengths and symmetrizing step.

8 REFERANCES

8.1 Гроднев И.И. Линии связи / И.И. Гроднев, Н.Д. Курбатов. – М.: Связь, 1988. – С. 304 – 311.
8.2 Справочник строителя кабельных сооружений связи / Под. ред. Д.А. Барона и др. – М.: Радио и связь, 1988. – С. 555 – 559.

9 APPENDIX

9.1 Low frequency cables electric standards
9.1.1 Allowable capacitive coupling and asymmetry values for construction lengths 230/425 m are listed in a tab. 9.1.
9.1.2 Allowable influence parameter values for symmetrizing spacing of low frequency cables are in a tab. 9.2.
9.1.3 A dc wire resistance asymmetry for cable construction length must not exceed 1% of the pair cord resistance (ΔR_1, ΔR_2).
An artificial circuit resistance asymmetry for a construction length must not exceed 2 % of a pair quad cord resistance (ΔR_3).
A circuit work capacitance deviation for construction length away from its average has to be lower or equal to on average 4 % and 12,5 % maximally.

Table 9.1 – Allowable capacitive coupling factors and asymmetry coefficients value for construction length

Capacitive coupling factor and asymmetry coefficient name	Allowable capacitive coupling factors and asymmetry coefficients value for construction cable length 230/425 m, pF	
	Average	Maximal
k_1	40/55	150/275
k_2, k_3	75/130	375/700
k_4	60/80	225/415
$k_5 - k_{12}$	60/80	225/415
e_1, e_2	150/275	600/1100
e_3	300/555	1200/2200

Table 9.2 – Influence parameter values for symmetrizing section

Name	Allowable value per symmetrizing section		Unit
	Average	Maximal	
k_1	10	20	pF
k_2, k_3	10	20	pF
k_4	30	80	pF
$k_5 - k_8$	20	60	pF
$k_9 - k_{12}$	10	30	pF
e_2, e_3	100/130	300/400	pF
Δr_1, Δr_2	–	0.1	Ohm
Δr_3	–	0.05	Ohm
$\Delta C/C$	–	1.5	%
$\Delta L/L$	–	1.5	%

Note. If a cable element length, l, does not equal a construction length, l, then k and e quantities must not exceed the following values:

a) average values of k_1, $k_4 - k_{12}$ have to be multiplied by $\sqrt{\frac{l}{L}}$;

b) the maximal values of k_1, $k_4 - k_{12}$, as well as average and the maximal values of k_1, $k_4 - k_{12}$, e_1, e_2 and e_3 have to be multiplied by l/L.

9.1.4 Standard values of characteristic resistances for coil loaded circuits at f = 800Hz have to be: for the key circuits – 1500 Ohm, for artificial circuits – 750 Ohm, for radio transmission ones – 500 Ohm (at 5 kHz). An average measured quantity is used as a standard value.

9.1.5 A dc resistance asymmetries for amplification element spacing of main and artificial circuits have to be no higher than $\frac{0,23}{d^2}\sqrt{l}$ Ohm, here l – an amplification element spacing, km; d – a wire diameter, mm.

Laboratory work № 6

STUDYING A CABLE TRANSMISSION LINES CIRCUIT TRANSIENT ATTENUATION

1 PURPOSE OF THE WORK

To get practical skills of a cable inter-circuit transient attenuation measurement and to familiarize yourself with a utilized measurement equipment.

2 MAIN POSITIONS

A high noise protection of circuit lines is one of the key criteria for a long distance cable line reliable transmission.

A transmission quality and distance depend not much on own circuit attenuation rather on mutual influences between adjacent circuits. Electromagnetic waves are the reasons for mutual influences, the former emerge around circuits in electromagnetic wave transmission. We need to take special measures to lower influence between circuits.

A set of measures used in cable mounting to lower mutual influence between circuits is a symmetrization. A cable line symmetrization is done for amplification elements that are finalized symmetrization objects. HF cable symmetrization stages are discussed in [1].

A single quad cable amplification element stand was made in laboratory conditions so that it has three points separated from each other by equal distances and box jacks (BJ). To get higher possible circuit protection within a quad we check crossing diagrams for marked three joints simultaneously based on a circuit protection measurement results at a far end:

– turn on a crossing diagram switch in each joint (an operator switch is connected to the middle joint in this work, we select the crossing diagrams with wires in the outer joints).

– get a device ВИЗ-2Б (or ВИЗ-600) ready and connect a for end protection measurement circuit (fig. 2.1).

– set crossing operators ••• in three joints. Measure and write values A_p 1/2 and A_p 2/1. Then perform selection of the crossing operator combinations based on a measurement protocol (appendix 9.1). We renew the combination of crossing operators for three joints with the highest A_p value after that.

– if a crossing symmetrization does not yield a protection standard (appendix 9.2), we perform a concentrated symmetrization with a counter-coupling circuit (fig. 2.1). We connect the contour with special cords using bars into empty places “Линия 1” and “Линия 2” of the indicator ВИЗ-2Б. Pay attention to the correspondence of numbers and jacks. Set resistances and capacitances of contour to the minimal values. Then we increase the capacitance of one branch gradually, if protection gets higher at the same time, we select a value that provides the highest circuit noise protection.

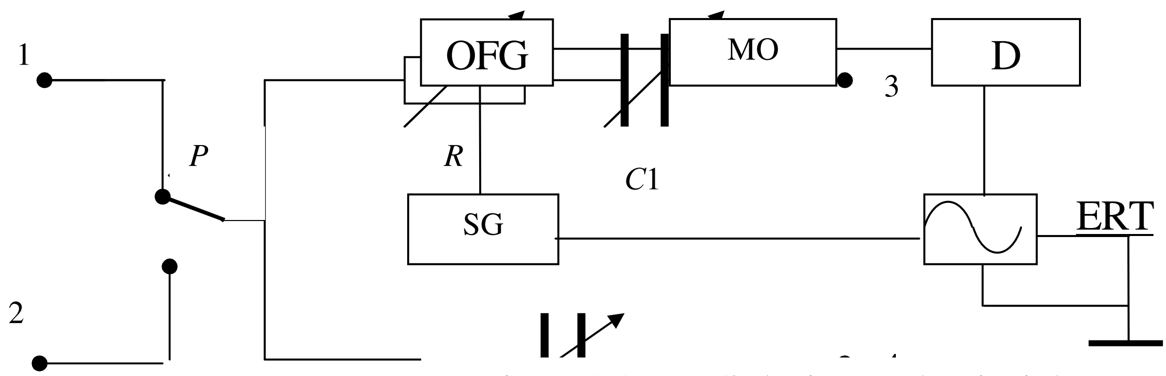


Figure 2.2 – ВИЗ device work principle

Figure 2.1 – Concentrated symmetrization with a counter-coupling circuit

If the protection decreases on increasing the first capacitor capacitance, we set the minimal value of this capacitor and increase the second capacitor capacitance to get the highest protection value. We increase a resistance of a circuit with connected capacitor on capacitance operations. If the protection decreases on the operations above, turn the switch *P* (fig. 2.1) into the other position and repeat the counter-coupling element selection procedure discussed above.

Fixed counter-coupling circuit capacitor capacitance values are read off by capacitor's C_1 and C_2 scales – i.e. using a resistance bank switches position.

We take a control measurement of protection at a far end, a transient attenuation at a close end with an exchange of influencing and influenced circuits (A_{12} and A_{21}) on concentrated symmetrization.

We need to draw a frequency dependence A_p and A_0 in the report protocol.

Take an A_p measurement at intermediate frequencies 50, 100, 150, 200 kHz and write the results into a table (appendix 9.1).

2.1 Key work principles of ВИЗ-2Б device

A panoramic (visual) transient attenuation measurer, ВИЗ, is used for taking a transient attenuation between two circuits for a symmetric cable quickly. We may take measurement of a transient attenuation at a close end and a protection at a far end with it for cable symmetrization in a range up to 300 kHz (ВИЗ-2Б) and up to 600 kHz (ВИЗ-600).

ВИЗ devices are typically utilized for cable lines construction, they may also be used for taking control maintenance measurements.

A work principle of the device is the following (fig. 2.2).

An electronic ray tube (ERT) beam detects a sweep generator (SG) that outputs a voltage linearly dependent on time. The same voltage controls a frequency change of an oscillating frequency generator (OFG). OFG sends constant amplitude but variable frequency oscillations to an input of a measured object (MO) that suppresses different frequency amplitudes in a different degree. If we extract an envelope out of the signal at an output of the MO by a detector D and apply it to vertical plates of an ERT we get a frequency dependence of attenuation of measured element on the screen. However, such an approach of direct attenuation measurement is insufficiently accurate. Therefore we utilize a comparison methodology (fig. 2.3) in ВИЗ-2Б (or ВИЗ-600), i.e. an additional control channel (CC) is set up in the device so that its attenuation may be adjusted to an arbitrary value and could be compared with an attenuation of the MO. To increase a noise protection of a measured signal we use an extra amplitude modulation of the signal. Consequently, a complex signal emerges at the generator output that is designed in a unit separate from an indicator a linear frequency change with a simultaneous 1 kHz sine wave amplitude change then a shat stop and the signal repetition. This complex signal of the generator is transmitted to the influenced circuit 1 input. A receiving unit of the indicator has two channels – measuring and control ones. The control channel “Line 1” is connected either directly to the generator (for tuning and a transient attenuation measurement at a near end – figure 2.4) or to an influencing circuit output (for a protection measurement at a far end – fig. 2.5).

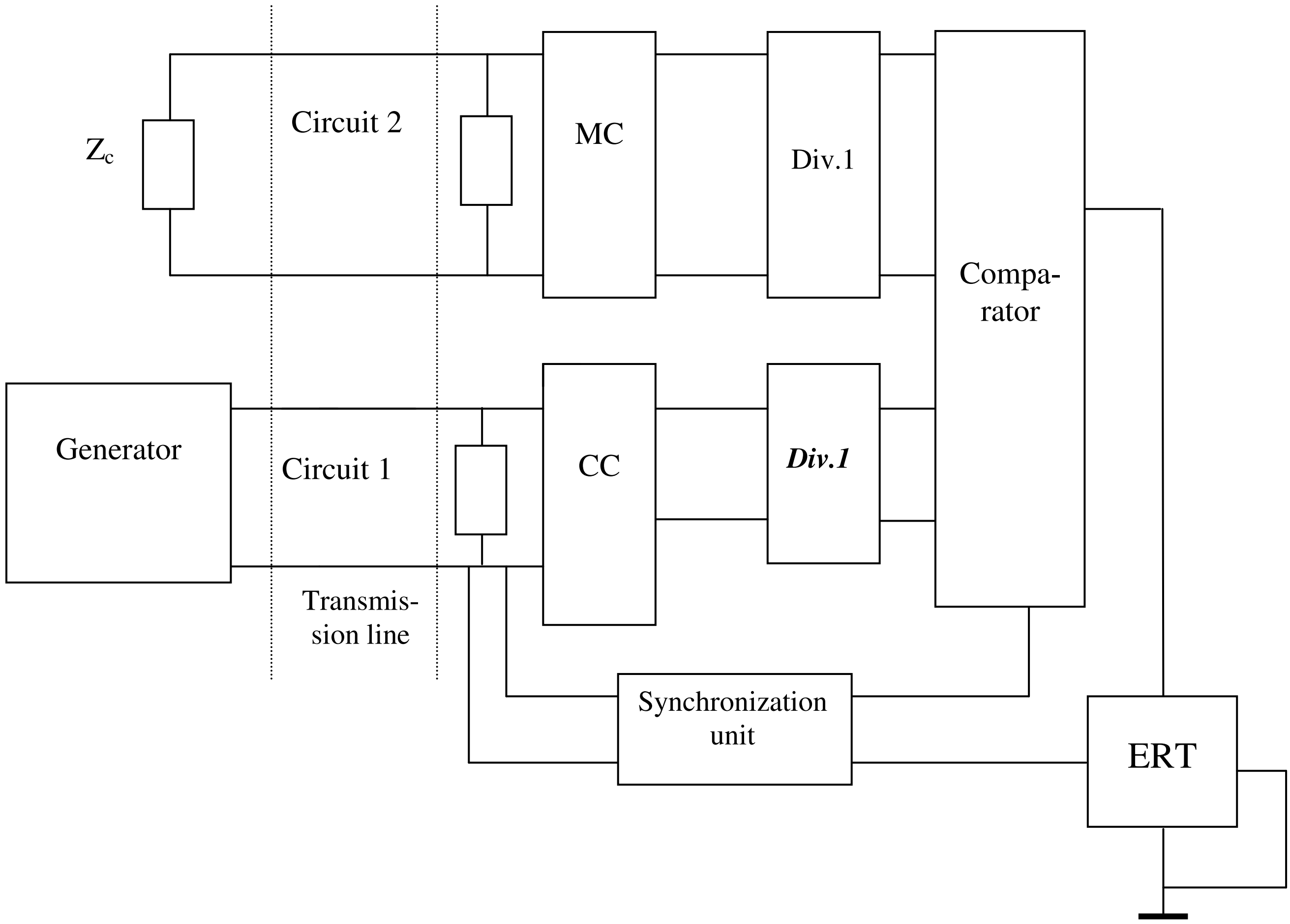


Figure 2.3 – ВИЗ device unit-schematic diagram and its connection for a protection measurement at a far end

The measuring channel “Line 2” is connected either directly to an influenced circuit input (for transient attenuation measurement at a near end – fig. 2.4) or to it output (for a protection measurement at a far end – fig. 2.5).

It is known that as the first approximation a carrying frequency attenuation for amplitude modulated oscillation equals an envelope attenuation of this oscillation.

Therefore, if an oscillation with linearly changing frequencies is modulated by a low frequency oscillation and is transmitted to the MO then an envelope of the low frequency oscillation will correspond to a frequency response of the MO. This oscillation envelope may be transmitted via a narrow band pass filter that will significantly lower noise. A constant component is applied to vertically deflecting plates of the ERT on the second detection of the oscillation. The ERT ray deflects away from its horizontal axis proportionally to a signal or a noise voltage depending which channel is connected to the ERT by a switching unit "Ком.". Thus a distance between two rays will set a signal noise protection at some frequency (fig. 2.6).

A difference of reading for voltage dividers (Div. 1, Div. 2) accounting for level difference read off between the corresponding characteristics points visible on the screen tube determines a magnitude of a transient attenuation.

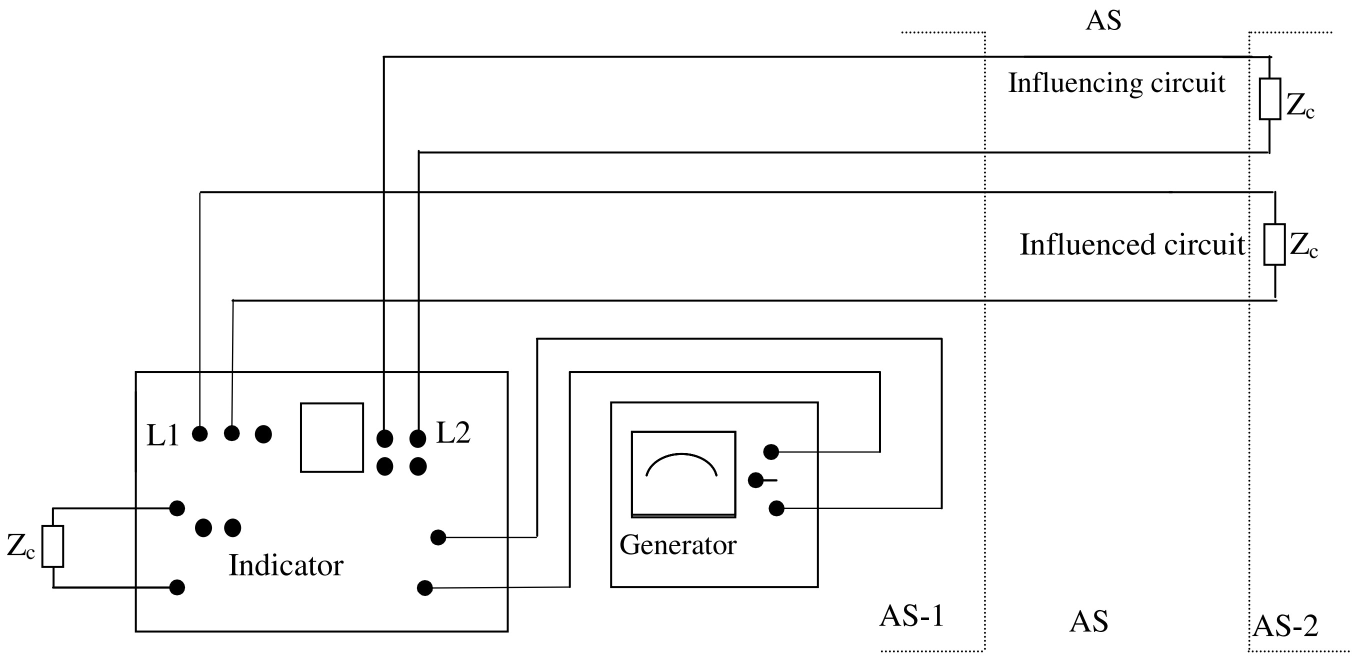


Figure 2.4 – Near-end transient attenuation measurement circuit

If we superimpose the control and the measuring channel curves at a given point the measurement will be more accurate as the transient attenuation value is read using the voltage dividers indicators.

A channel switching synchronization is done by the same synchropulses used for a sweep generator synchronization.

A measurement characteristic turns up fast at a long amplification element measurement, positioning it self at a half of the ERT diameter. To increase a slope of the characteristic we utilize correcting contours.

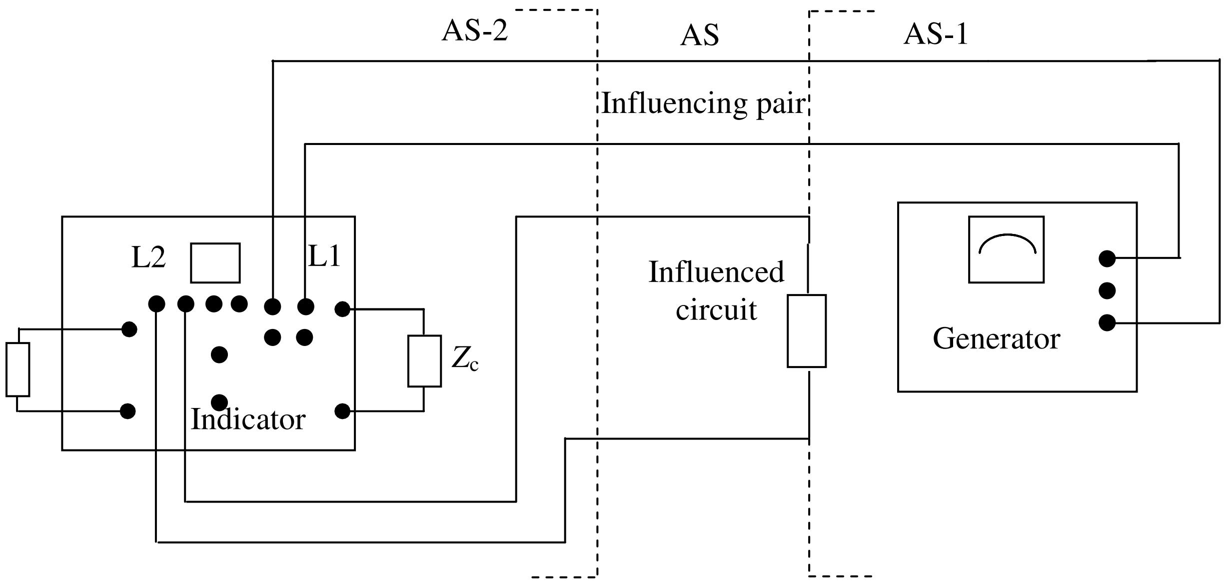


Figure 2.5 – Far-end transient attenuation measurement circuit

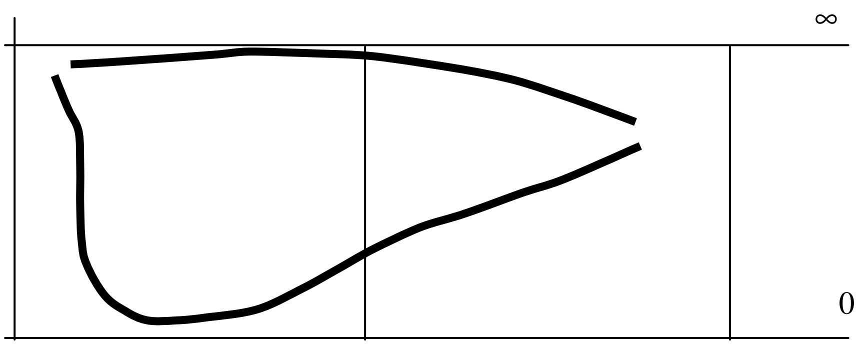


Figure 2.6 – Distance between two rays of signal noise protection at some frequency

The device has two marker units for frequency estimates (frequency scale). A marker unit consists of six resonant contours tuned at frequencies 15, 50, 100, 150, 200 and 250 kHz that are connected in the circuit by a button. On the contour connection pulses (control marks) are observed on a control characteristic corresponding to mentioned frequencies.

2.2 ВИЗ-2Б device operation guide

General information

A panoramic (visual) transient attenuation measurer used fast frequency response of transient attenuation measurement.

Two symmetric cable circuits are considered at both near and far ends.

The device could also be utilized for a transient attenuation measurement between ATL circuits.

Key technical parameters of the device:

- work frequency range of the measurer (12…150) and (15…300) kHz;
- the maximal measurable value of a transient attenuation 139 dB (16 Np);
- attenuation measurement error no more than 1,74 dB (± 0,2 Np);
- the measurer power is supplied by either 220 V and 6.5 V batteries, by 12 V batteries with a ПН-12/220 type voltage transformer utilization or by an ac grid of 110, 127, 220 V with ±10 % allowable deviations;
- design of the measurer is two movable units: the generator and the indicator.

2.3 The device control units

Key units of the generator work control are on its front panel:

2.3.1 power switch with a signal indicator;

2.3.2 range switch;

2.3.3 input level tuner;

2.3.4 box with input jacks in the upper

2.3.5 double toggle switch for turning on the correcting contour in the right part of the generator, side ways;

2.3.6 arrow unit measuring a signal level at the generator output for the middle key switch position that is positioned under the device. We measure filament and plate voltages in side positions of the key switch. The filament voltage is adjusted by a stepwise tuner positioned to the left from the arrow unit.

2.3.7 resistance frequency shift range width tuning knobs us well as frequency sweep tuning ones are placed under the range switch; these knobs are protected by a cover.

There is a tube screen on the indicator front panel in its upper part. Knobs of the ray control (brightness and focus), of sweep frequency and of vertical scale are placed on the same panel.

A power tumble switch with a neon lamp and an after marker toggle switch toggle switch are positioned lower. There are inputs and the voltage dividers' knobs on lower vertical part of the panel – the left knob is for the measuring channel divider channel, the two right ones are for the control channel divider. Six buttons of the marker unit resonant contours are below the dividers. There are terminals for the external generator connection in the lower right corner. The arrow unit measuring plate and filament voltages is positioned between input boxes.

2.4 The device connection and work check protocol

(Done if told by instructor)

2.4.1 Connect power cords to the generator and the indicator, turn on units by power toggle switches, so that the neon lamps are turned on.

2.4.2 Check filament and plate voltages. The filament voltage has to be 6,3V±10%, the plate one has to be 220 V±10%.

2.4.3 A bright line has to appear on the tube screen after 1 – 2 minutes on the switching. We need to set a necessary ray brightness and focus the ray by knobs “Brightness” and “Focus”.

2.4.4 Connect input jades of the generator with input jacks “Generator” on the indicator. Connect a load resistance “ВІЗ-2-170 Ом” to a jack “Line 1”.

2.4.5 Set both control channels dividers to zero and the measuring channel divider to a “+4” position. Two lines have to illuminate on the tube screen after this: one has to coincide with a “∞” scale line, the second one (a control characteristic) – has to go along a line “0 Np”. If this is not the case we adjust first a position of the characteristic going along the line “∞” by a knob “Vertical shift” that is on the right side of the indicator, we tune the control characteristic then so that it goes approximately along the line “0 Np” by a knob “Cont. Scale”.

2.4.6 Check the generator frequency range by pressing the resonant contour buttons "15 kHz" and "150 kHz" on the indicator for the 1st range at the corresponding generator range switch position. Then, on turning the range switch, press buttons "15 kHz" and "250 kHz" for the 2nd range. We would observe pulses at the beginning and the end of characteristic on the control characteristic.

If the range turns out to be frequency shifted or a frequency band does not match the standard, tune ranges by knobs "Ширина" and "Сдвиг" of the generator for the corresponding range. We initially perform tuning by the knob "Ширина" and then by the knob "Сдвиг".

To renew the generator and indicator sweep frequency synchronization set a knob "Част. развертки" of the indicator in the leftmost position. Tune the sweep frequency by the knob "Част. развертки" of the generator until getting a stable synchronization along length on the tube screen around 80...90 mm (with in a vertical mark). Get a sweep line length up to 200 mm by rotating the knob "Част. развертки" of the indicator to the right.

2.4.7 Connect a graduated extender (with an 8,5 Np box) between jacks "Линия 1" and "Линия 2". You need to connect the load resistance "ВИЗ-2-170 м" to a jack "Нагрузка" during this process.

2.4.8 Get a coincidence of characteristics on the tube screens by voltage divider switches. A sum of values of all dividers need to be 8,5 Np ± 0,1 Np. This finishes the measurer work.

2.5 Near end transient attenuation measurement

2.5.1 Disconnect the graduated extender. Connect the jacks "ЛинияI 1" to the influencing circuit input by a cord, connect the jacks "Линия 2" to the influenced circuit. The load resistance, "ВИЗ-2-170 Ом", corresponding to a line wave impedance, has to be connected to the jacks "Нагрузка". Both lines have to be load by resistances corresponding to line resistance at their far end.

2.5.2 Set a necessary frequency range for the measurement at the generator. Disconnect the correcting contour by the toggle switch "Корр. конт". Set power +5 Np at the generator output.

2.5.3 Set the measuring channel divider in a "+4 Np" position. The control characteristic has to coincide with the line "0 Np" (tuning is performed by the knob

"Масш. непрер" and by the knob of the control channel right divider). Set the second divider of the control channel is the position "0".

2.5.4 Check the generator frequency range using markers by pressing buttons, adjust if necessary as discussed in p. 6 of the previous chapter.

2.5.5 Set the signal magnitude so that measured frequency response image is within the screen and does not shift below the line "0 Np", using the measured channel divider switch (the left switch).

2.5.6 Get a coincidence of the attenuation frequency responses by tuning the control channel divider (the middle divider), find the attenuation magnitude by an algebraic summation of readings for all three dividers.

2.6 Far end protection measurement

2.6.1 Connect the output generator jacks to the influencing circuit input. Set a necessary frequency range using a switch $УП_1$ of the generator.

2.6.2 Connect the output of the influencing circuit on $УП_2$ switch with the indicator jacks "Линия 1" and connect the influenced circuit output to the jacks "Линия 2".

2.6.3 Connect the resistance "ВИЗ-2-170 Ом" to the indicator jacks "Генератор" and "Нагрузка". Load the far end of the influencing line and the near end of the influenced circuit by resistance equal to the line ware impedance.

2.6.4 Set power +5 Np at the generator output.

2.6.5 Make sure the control characteristic image is within the screen by the control channel divider tuning. Subsequent steps for protection measurement are done analogously to p.5 and p.6 of the previous chapter.

3 KEY QUESTIONS

3.1 What physical phenomena induce HF cable inter-circuit influence?

3.2 What are near end and far end transient attenuations?

3.3 What is a physical essence of protection?

3.4 How could you distinguish the end *A* from the end *B* of a cable construction length?

3.5 Why do we do crossing of cable circuit?

3.6 Transient attenuation at a near end and protection at a far end standards.

3.7 What is a symmetrization?

3.8 What symmetrization methods do you know?

3.9 Why do you have to interchange circuits that are influencing each other in the process of their symmetrization?

3.10 What measurement methodology is utilized in the ВИЗ-2В device?

3.11 How is a transient attenuation at near end measurement taken?

3.12 How and where could we connect a counter-coupling circuit for an A_p measurement?

3.13 What explains a positive effect of a counter-coupling circuit?

4 HOME TASK

Study using the recommended literature:

4.1 Causes for mutual influence and cable transmission line circuit influence parameters.

4.2 Transient attenuation measurement methods.

4.3 Inter-circuit transient attenuation standards per construction lengths and amplification elements.

4.4 Methods of lowering an inter-circuit attenuation,

4.5 Familiarizing yourself with the ВИЗ-2В work principle and its measurement protocol.

5 LABORATORY TASK

5.1 Study this laboratory work equipment.

5.2 Check and tune, if necessary, the ВИЗ-2В device.

5.3 Connect the far end protection measurement circuit.

5.4 Measure values A_p 1/2 and A_p 2/1 for two different crossing operator combinations in three joints.

5.5 Select the optimal operator combination providing the maximal protection value.

5.6 Draw frequency responses A_p 1/2 and A_p 2/1 before and after crossing.

5.7 If you are unable to get the standard by crossing, symmetrize by an RC contour. Connect the contour In empty box jacks "Линия 1" and "Линия 2" to do this. Determine contour elements and wires they are connected.

5.8 Select appropriate resistors and capacitors, connect them to the middle joint. Check the values A_p 1/2 and A_p 2/1.

5.9 Connect the near end transient attenuation measurement circuit. Measure A_0 for two end points of the amplification element.

5.10 Compare measured A_p and A_0 values with the standards.

5.11 Draw a frequency response, A_0.

6 EQUIPMENT

6.1 ВИЗ device.

6.2 Crossing switch.

6.3 Counter-coupling circuit.

6.4 Load resistances.

6.5 Cable amplification element stand with symmetrization joints marked at the panel front.

7 CONTENT OF A REPORT

7.1 A_p and A_0 measurement circuits.

7.2 A_p measurement form for two different operator combinations.

7.3 Graphs of A_p xa A_0 dependence on frequency.

7.4 Counter-coupling circuit, its connection and its parameter values.

8 REFERANCES

8.1 Гроднев И.И. Линии связи / И.И. Гроднев, С.М. Верник. – М.: Радио и связь, 1988. – 544 с.

8.2 Гроднев И.И. Линейные сооружения связи / Гроднев И.И. – М.: Радио и связь, 1987. – 304 с.

8.3 Инженерно-технический справочник по электросвязи. Кабельные и воздушные линии связи. – М.: Связь, 1966. – 671 с.

9 APPENDIX

Table 9.1 – AC HF symmetric cable electric parameters standards

Number	Name of parameter	Frequency range	Number of combinate	Standard, %		
				100	90	65
1	A far end protection value distribution, dB (Np), no less	12...252 (K60)				
	a) cable of capacity - 4×4	12...108	56	71,22 (8,2)	73,83 (8,5)	78,17 (9,0)
	b) cable of capacity - 7×4		82	72,96 (8,4)	74,70 (8,6)	78,17 (9,0)
	c) cable of capacity- 1×4 (for zonal transmission)		2	75,57 (8,7)		
2	A near end protection distribution, dB (Np), no less	12.. .252 12... 108				
	a) cable of capacity - 4×4		28	59,06	60,08	
	b) cable of capacity - 7×4		91	59,06	60,08	
	c) cable of capacity - 1×4		1	59,06	60,08	

Laboratory work № 7

CABLE PAIRS SELECTION FOR DIGITAL GLAND OF SUBSCRIBER ACCESS NETWORKS

1. PURPOSE OF THE WORK

Explore the use of low-frequency telephone cables of local communication networks to transfer by them of digital streams at speeds of 2,048 Mbit/s and 8,192 Mbit/s.

2. MAIN POSITIONS

2.1 General

The sharp increase in recent years of the communication services number and quality on subscriber access networks has necessitated a rapid increase in capacity of transport networks of UTN and RTN. On these networks, laid electrical and optical cables. Transport network using electrical cables, in most cases implemented by low-frequency cables, such as ТПП. These cables, jumper equipment, control cabinets and terminal boxes are initially developed, produced and operated as a low-frequency equipment. At the same time between the cable lines networks the value of transient attenuation at the near end - A_0 = 70 dB at 1 kHz was provided. The reason of the cable lines capacity increasing on the basis of the cable ТПП is to transfer by them digital streams type $E1$ and $E2$.

Thus, creating a transport network of RTN and STM, the possibility of transferring by the best pairs of cable ТПП of broadband signal with the bitrates 2,048 Mbit/s and 8,192 Mbit/s is used.

Typically, the number of pairs is 10 % of the total number of cable pairs [8.1]. Therefore, the selection of cable pairs and determination of their characteristics is conducted on the basis of their parameters studies.

On the technical condition of the operation cable communication lines of UTN and STM can be divided into three groups:

1. The lines of communication, fully satisfying the technical standards on electrical characteristics.
2. The lines of communication, mostly satisfying TS (too low resistance of the insulation R_{is}; inflated resistive asymmetry R_a, up 2 % at a rate of 0,5 % of loop resistance R_{stl}).
3. Communication lines with significantly low electrical characteristics, that is, the cables are in the pre-emergency and emergency condition.

Only the first two groups of lines on the basis of the cable pairs ТПП can be used for HF transmission of $E1$ and $E2$.

While one or two of digital gland systems are working on a single cable within the permissible length of the line, the significant influence between the circuits cannot be. With a significant increase in the number of circuits of lines used for digital gland within a single cable, the problem of electromagnetic compatibility of these circuits comes to the fore.

The problem reduces to finding the best accommodation options for compacted circuits. The greatest influence on each other have the circuits, glanded of the same type of equipment, with the maximum length of line of. For the lines of transportation networks is usually up to 5 km.

Modern digital gland systems UTN and STM work on the single-cable scheme in two-wire mode. By this transmitting part of the equipment (high level) and the receiving part of the equipment (lower level) are located on one side of the communication line, usually in one ten-pairs elementary beam.

Thus, the main parameter that determines the mutual influence between the circuits on short lines of local networks is a near-end transient attenuation – A_0. There are two "near ends" of such line – on the station side and on the other.

The selection of circuits for gland begins from determining of the required transient attenuations A_0^{nec} and A_l^{nec}. If the system works on the single-cable transmission scheme with counter-transfer modes, the normalized transient attenuation at the near end of the line:

$$A_0^{nec} \geq (24{,}7 + 10\lg N + \alpha l), \tag{2.1}$$

here 24,7 – desired value of protection paths between the DTS level $E1$, dB;

N – number of chains, glanded the DTS;

αl – own circuit attenuation, overlained by the DTS.

For PCM-30 equipment overlapped attenuation $\alpha l = 32$ dB, for PCM-120 – 45 dB [8.1]. If there are two cables between the ATS, DTS operates in coincident mode of transmission. By this normalized transient attenuation of the line at the far end (dB) is determined from the expression:

$$A_l^{nec} \geq 24{,}7 + 10\lg N. \tag{2.2}$$

Since the LF cables of local networks are available in high-capacity (up to 1200 pairs), to solve the problem of circuits selection by direct measurement of transient attenuation between all the circuits is not possible due to the large measurements volume. Thus, when the cable capacity is $M = 100$ pairs, the number of transient attenuation measurements between all the circuits in any combination is $100\cdot(100\text{-}1) \approx \approx 100^2 = 10^4$ measurements. According to these measurements, you must choose a circuit combination, the mutual influences between which satisfy the requirements of the DTS. Due to this, method of pairs' selection used to gland the DTS in the LF cables of UTN should ensure the maximum possible number of pairs with a minimum amount of measurements. Despite the fact that the transient attenuation between the LF cables pairs of UTN at high frequencies is a random quantity, the values of A_0 are grouped depending on the mutual arrangement of circuits in the cable and parameter Q_c characterizing the spatial separation of the circuits. The main factor affecting the transient attenuation in these cables is the spatial separation of the circuits.

The maximum energy of the linear signal spectrum in digital transmission systems is concentrated at frequencies close to half clock frequency of transmission system. Therefore, the normalizing, calculations and measurements of lines electrical characteristics are executed at half clock frequency of a specific DTS.

Measurements of transient attenuations between circuits of the cable line of UTN and RTN are done at a half clock frequency of DTS equipment (for *E*1 – this is 1024 kHz, *E*2 – 4096 kHz). By the results of measurements the average values of transient attenuations and root-mean square deviations are determined for various cases of pairs' location.

Tab. 1 shows the values of transient attenuation at the near end of the cable type ТПП with different core construction (multilayer and beam twisting) at frequencies of 1 MHz and 4 MHz [8.1]. For all influences' cases, the values of A_0 were distributed by normal law.

Table 2.1 – The values of A_0 for different combinations of ТПП cable pairs

№	Mutual influencing pairs placement, μ	Average value $A_0\mu$, at frequency, MHz		RMS deviation σ_μ, dB
		1,024	4,096	
ТПП cables with beam twisting				
1	Inside the elementary beam (EB)	65	56	8,1
2	In the adjacent EB	69	60	7,2
3	After one EB	84	75	6,5
4	After two EB	88	79	5,2
5	In EB of adjacent layers	75	66	7,7
ТПП cables with multilayer twisting				
6	Adjacent in one layer	53	48	4,7
7	After one pair in the layer	65	54	5,5
8	After two pairs in the layer	73	64	7,4
9	After three pairs in the layer	74	65	7,2
10	Adjacent layers	68	59	5,2
11	After one layer	75	64	5,6
Note: μ – pair location variant.				

2.2 Pairs selection methodic

Let's show the pair selection methodic at the example of single-cable transmission. It is carried out in one or two stages.

The first stage of cable selection for the HF gland begins with a determination of required value A_0^{nec} for the lines with length *l* and the number of pairs – N. By this using the expression (3) η_μ is calculated and using the expression (1) – the required value of transient attenuation at the near end.

$$\eta_\mu = (A_0\mu - A_0^{nec}) / \sigma_\mu, \tag{2.3}$$

here $A_0\mu$ – the average value of transient attenuation (tab. 1);

σ_μ – root-mean square deviation of transient deviation for μ-th variant of pairs location.

If parameter η_μ>2…2,5, then the probability that the measured transient attenuation at the near end between the circuits $A_{0\text{meas}}$ is greater than A_0^{nec}, is 0,95... 0,99, i.e. it is close to unit. Hence, it is not necessary to measure A_o and select pairs by this value, since all the pairs in μ-th variant of their positions in the cable will be more likely suitable for DTS. Thus it is necessary to check the number of pairs in the cable *N*μ, which must be greater than or equal to the value of *N*.

If η_μ< 2 and changing the variant of μ location does not allow to increase A_0μ, the second stage of pairs selection is done. At this, A_0 is measured between selected pairs and using this data optimal combination of pairs, at which the number of circuits in the DTS will be maximal, is determined. For this transient attenuation measurements are presented in the form of a chess table (tab. 2.2). Pairs' combinations, for which immunity was less than normal, are marked by a cross. The vertical axis of tab 2.2 depicts number of pairs from the line A side, the horizontal – number of pairs from the line B side. In the example shown in tab. 2.2, the number of pairs is 10. For given in tab. 2 distribution of transient attenuation values η_μ is approximately 0,75.

Search for an optimal circuits combination that are intended for gland by the equipment of DTS, is done using the data in Table 2, starting from the pair with the smallest number of crosses. Denote such pair as m_1. After selecting such pair (m_1 +1) pair is eliminated from further considerations. After the first step of the pairs selection there are only $q_1 = n-(m_1 + 1)$ pairs are rest (where *n* – total number of pairs which the transient attenuation was measured between.

The second and further steps are the selection of pairs using criteria of "crosses" minimum number. Selected pairs are excluded from the further consideration. After the *i*-th step of selection, the number of remaining pairs q_1 is:

$$q_i = n - i - (m_1 + m_2 + \ldots + m_i)$$

Another way to increase the number of gland pairs is to decrease the length of the regeneration section, i.e., αl, which reduces the required value of transient attenuation, and ,hence, increases the parameter η_μ and gland circuits.

2.3 Methods of the noise immunity stock measuring

Stock of noise immunity can be defined for each pair, which is used for the transfer of digital information. For the xDSL line noise immunity stock can be defined: for the required transmission rate, using generalized index that takes into account the properties of the DTS transceiver, the characteristics of the communication cable line (including the presence of heterogeneities), information about the noises spectrum, that are in the transmitted frequencies of DTS.

Table 2.2 – Transient attenuation measurement data, presented in the form of a chess table

Influenced pairs

Influencing pairs	0					5				9
0	■		X		X	X			X	
		■		X		X		X		
	X		■	X	X		X		X	X
		X	X	■		X	X			
	X		X		■		X		X	
5	X	X				■		X	X	X
			X		X		■			X
		X		X		X	X	■		
	X		X		X	X			■	
9			X			X	X			■

There is another approach (discussed earlier), in which the estimation of noise immunity stock depends on the length of the line, attenuation or loop resistance. Reliability of the second method is rather low due to lack of additional information, and errors in the selection of the DTS rate can reach up to 5 times. Such rough estimation methods are meaningless, so we need to develop methods of noise immunity stock measuring at the required transmission speed to increase reliability of established and existing DTSs.

Working attenuation, that determines the form of the signal spectrum at the input of the receiver, increases with frequency increasing. But at the input of the receiver the desired signal is summed with its copies, delayed in time, caused by reflections from the heterogeneities of the line. The spectrum of the useful signal can still have an oscillatory character.

Noise spectrum is also a result of the interaction and summation of several signals, and firstly, of transient noises from DTSs, working at the adjacent pairs.

At the interaction of all these factors, the form of the signal spectrum, resulting from the interaction of the desired signal, its reflections and noises, can be extremely uneven, that reduces the quality and accuracy of the circuit working attenuation and noise immunity measurements at the fixed working frequency.

The minimum value of the noise immunity stock at the transmission frequency bandwidth (dB) can be written as:

$$\Delta R_{\mathrm{xDSL}} = \min_{f=f_0 \div f_1}\left[R(f) - (R_{\min} + \Delta A)\right],$$

here $R(f)$ – frequency response of the line noise immunity, measured as the difference between the spectra of signal and noise. $R_{\min}$ – noise immunity of an ideal receiver (dB), calculated by the Shannon formula.

$$R_{\min} = 10\lg(2^K - 1),$$

here K – the multiplicity of modulation transceiver

$$K = \frac{V}{f_1 + f_0},$$

here V – the required transmission rate.

ΔA – stock of non-ideal receiver, in dB, is determined experimentally, in the range 12 ... 23 dB, and K varies from 2 to 6.

At present time we can recommend the following values of noise immunity stocks $\Delta R_{\min}$ of xDSL lines:

– 6 dB at gland of one-pair cables;

– 12 dB at gland of the pair in the beam;

– 18 dB at gland of the pair in the beam, which has no digital lines, but can contain later.

This is due to the fact, that in the process of increasing the resources of network with xDSL – access, we base on the fact that:

1. Digitalization of any further pair of multi-cable should not lead to a critical reduction in the noise immunity stock of already exploited xDSL-lines.
2. The choice of the normative value for the noise immunity stock of xDSL-lines should consider not only the possible degradation of the cable characteristics, but the further introduction of additional xDSL-lines into the cable.

3. KEY QUESTIONS

3.1. What LF cables of local communication networks are used to gland the equipment of DTS? Construction and labeling of these cables.

3.2. What cable parameters determine the choice of LF cable pairs for local networks to gland?

3.3. What is the methodic of pairs' selection used to gland the DTS?

3.4. At what frequencies is it necessary to perform the measurement of transient attenuation?

3.5. What is the stock of noise immunity?

3.6. What determines the value of the noise immunity stock?

3.7. What equipment is used to gland the LF cables for local networks?

4. HOME TASK

During the self-training to laboratory work it is necessary:

4.1. To study the recommended literature and this guidance.

4.2. To familiarize with the methodology of pairs selection for LF local cable networks.

4.3. To familiarize with the measurement methodology of:

– pair cable working attenuation;

– the level of transient attenuations at the near or the far end.

4.4. Prepare oral answers to key questions.

4.5. Prepare a report form.

5. LABORATORY TASK

5.1. To view the layout of the laboratory work.

5.2. Turn on the device ИПКЛ-15/30 (or its modern equivalent ДЕЛЬТА-ПРО-1.3).

5.3. Connect the device to the line (cable of type ТПП 10×2×0.4).

5.4. Perform a measurement of attenuation of each worker (one) pair at DTS half clock frequency.

5.5. Perform measurement of transient attenuation for given by the teacher pairs at the near and (or) the far end.

5.6. Make a pairs selection for gland by the equipment DTS.

5.7. To determine the stock of noise immunity for the selected circuits.

6. EQUIPMENT

6.1. Communication line based on the ТПП cable 10×2×0,4 (or its layout).

6.2. ИПКЛ-15/30 device (or its modern equivalent).

6.3. Power supply unit of ИПКЛ.

6.4. A set of loads (resistors).

7. CONTENT OF A REPORT

7.1. Scheme of transient effects measurements.

7.2. The results of transient effects measurements for a given pair.

7.3. The results of the working attenuation measurements at the half clock frequency.

7.4. To determine the stock of noise immunity for the selected circuits.

8. REFERANCES

8.1. Гроднев И.И. Линии связи / И.И. Гроднев, Н.Д. Курбатов. – М.: Связь, 1980. – 414 с.

8.2 Парфенов Ю.А. Цифровые сети доступа / Ю.А. Парфенов, Д.Г. Мирошник. – М.: Эко-Трендз, 2005. – 288 с.

9. APPENDIX

9.1. Preparing ИПКЛ-15/30 to work.

9.1.1. Connect the power supply ИПКЛ 12V. Check the grounding of the power supply.

9.1.2. Turn on the device ИПКЛ, including SU and squeeze the button on ИПКЛ shunt. Wrung button corresponds to the sign above the button, the button is pressed – the inscription beneath it.

9.1.3. Check the power supply by pressing the CN.

9.1.4. Measure the attenuation of the working couples:

– switch modes translate into the position of the RE;

– the gearbox to transfer the position corresponding to a selected DTS;

– input pairs attach to the door ИПКЛ, the output of a pair to the entrance ИПКЛ;

– measure operating attenuation.– fig. 9.1.

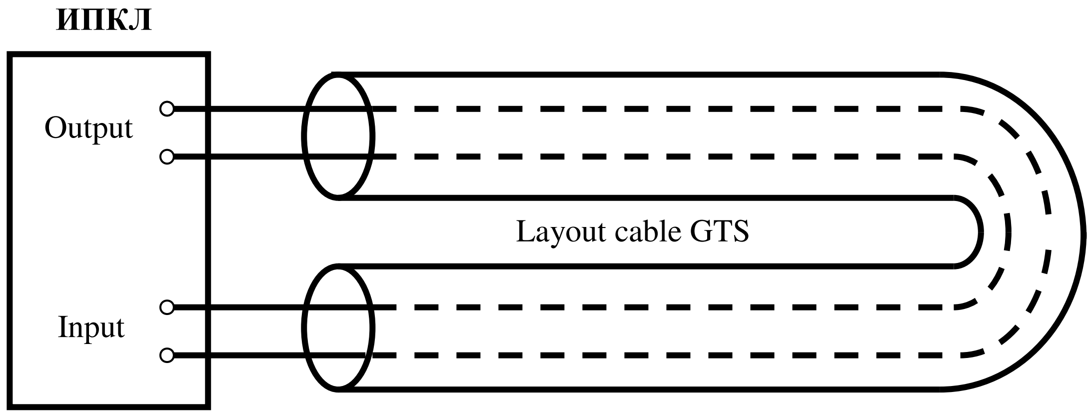


Figure 9.1 – Measurement of the working attenuation

9.1.5 Measurement of crosstalk:

– transfer switch in position MF;

– the gearbox – in the position corresponding to a selected DTS;

– during the measurement of near-end crosstalk ratio began to influence the pair connected to the output ИПКЛ Clem, but the beginning couple, prone to influence – to the input terminals ИПКЛ; to the output of the two circuits connected load of 120 Ohms – fig. 9.2.

– the indicator on the scale of PV is the measured value of the level of crosstalk at the near end.

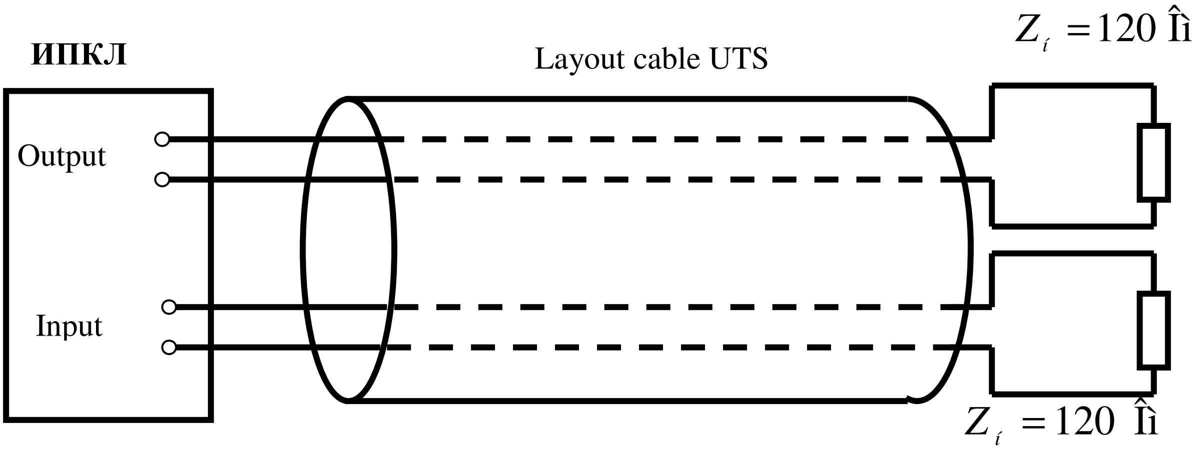


Figure 9.2 – Measurement of the transient attenuation level at the near end

9.1.6. Similarly, measure the crosstalk at the far end of the chain, while only affecting a couple input terminals connected to the "Выход" ИПКЛ and output pairs, subject to influence – to the terminals 'entrance' ИПКЛ. The free ends of both pairs must be loaded on the face value of 120 Ohms of resistance. At the same time on a laboratory prototype, you can use one device ИПКЛ. If the measurements are performed on a real line of communication, in which near and far ends are separated in space, it is necessary to use two different instrument ИПКЛ (fig. 9.3).

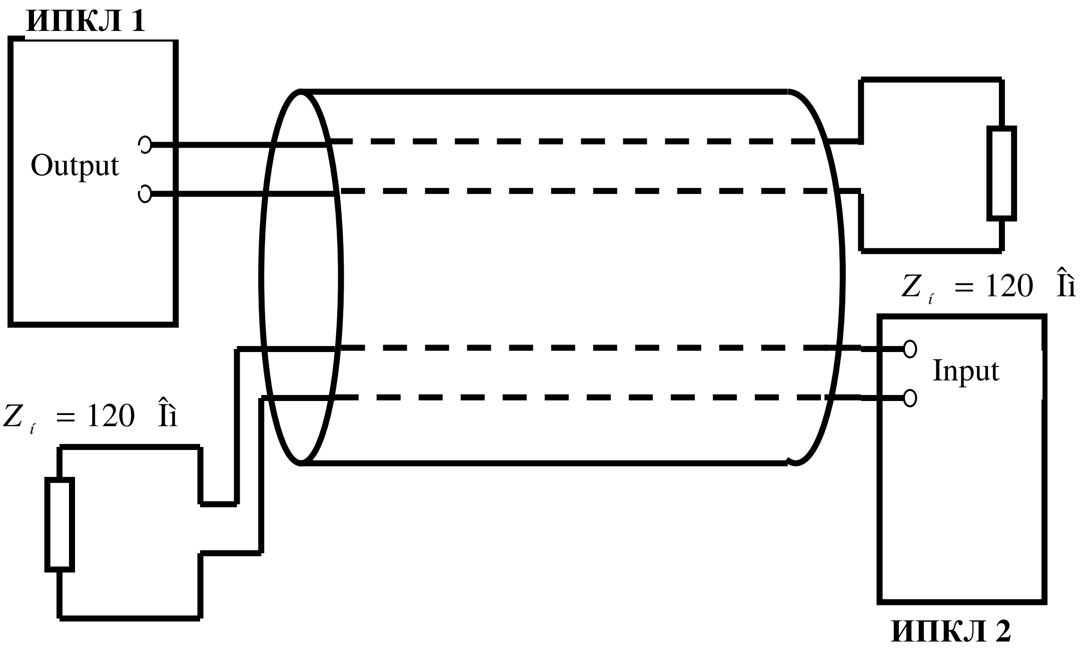


Figure 9.3 – Measurement of the transient attenuation level at far end

Laboratory work № 8

STUDYING PROTECTION CIRCUITS OF TRANSMISSION LINES

1 PURPOSE OF THE WORK

The work purpose is an acquaintance with equipment of protective devices, which are utilized to protect cable and air communication lines (CCL and ACL) against external electromagnetic influences.

2 MAIN POSITIONS

2.1 Purpose and design of the protective equipment

Protection of installations of communication against dangerous action of exceedingly high voltage caused by action of electric transmission lines (ETL), storm phenomena, and also by dangerous currents which arise at contact of communication wires to ETL wires, is carried out by means of rated sportsmen and fuses based on ГОСТ – 35 – 58 and recommendations ITU – T To. 20 in edition 2/2000 „Strength of switching equipment of telecommunication to an exceedingly high voltage and superfluous currents”.

Two and three-electrode rated spark gaps are used for protection against ETL (fig. 2.1). The basic type of rated spark gaps which are used, for example, on ATL are rated spark gaps P-350, two-electrode ones, with voltage of ignition 350 ± 40 V.

A series of spark gaps rated with an air gap of 0,3; 7; 10; 15; 20 mm (fig. 2.2) are utilized in systems of cascade protection for increase in reliability of the circuit.

Coal rated spark gap BP-500 are utilized on communication lines of city telephone networks (CTNs) for protection of the equipment of automatic telephone exchange. Its design represents two coal plates between which there is a mica lining (fig. 2.3).

Vilite spark gap PB – 500 PB – 1000 are used for remote power circuits.

A drainage coil (DC) is utilized in ATL channel multiplexing protection equipment circuits, besides aforementioned devices. A drainage coil consists of two semi-windings which are reeled up on a common core. Each of semi-windings is connected in series with one of rated spark gaps, thus the direction of the coils of the semi-winding should be such that during switching of a rated spark gap the coil has small active resistance only for a category current.

If semi-windings are connected this way, a current flowing via one of the semi-windings at switching any spark gap creates voltage in the second semi-winding due to induction that shortens switching of the second spark gap.

Hence, the drainage coil, not only excludes short circuit for a communication circuit, at a moment of rated spark gap switching, but helps a simultaneity of their switching which excludes possibility of occurrence of undesirable currents, in channel multiplexing equipment. If rated spark gap are connected without a drainage coil a two-wire chain is short circuited at the moment of switching of rated spark gap that causes a distortion in work of a tone telegraph and a photo telegraph.

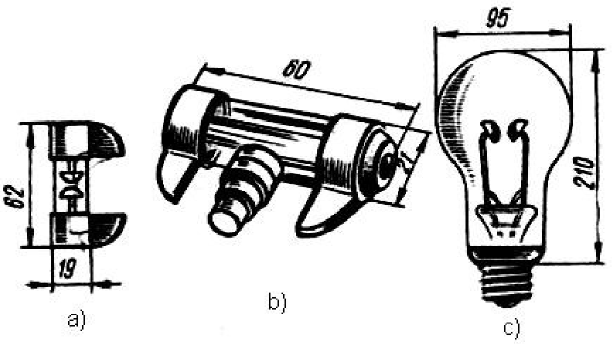


Figure 2.1 – Rated spark gaps: a) two-electrode Р-350; b) three-electrode 3РББ-350; c) two-electrode baric РБ-280

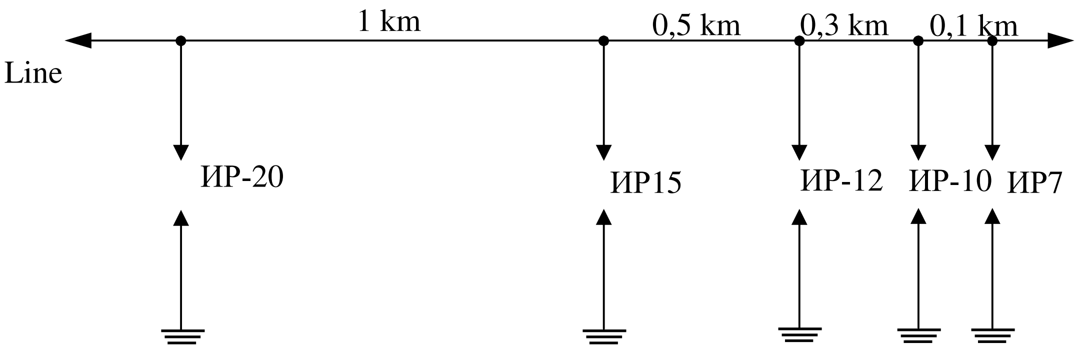


Figure 2.2 – Cascade protection of ACL

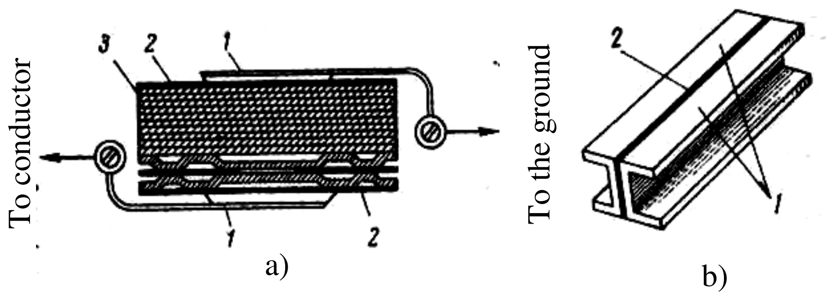


Figure 2.3 – Rated spark gaps: a) vilite one; b) coaling one

Besides, as a result of some resistance difference for chain conductors, and differences of characteristics for rated spark gaps they do not switch on simultaneously. As a result high currents which level potentials and bring distortion to a signal transferred through the equipment connected at the circuit ends and lead to occurrence of acoustic blows.

Locking coils (LC) are used for reduction of mutual influence between an exit and an input of amplifiers of channel multiplexed lines, through third two-wire chains and cable wires and also from external influences.

A locking coil consists of two semi-windings 1-2 and 3-4 which are reeled up on a common core mode from a material with high magnetic permeability. Each semi-winding is connected to one of wires of a two-wire circuit so that magnetic fields of currents with the same directions (noise currents in semi-windings LC) add up and as a result it is possible to receive a big inductive resistance, and magnetic fields of currents with opposite directions (working currents of a signal in semi-windings) have been mutually compensated. That is LC brings considerable losses for noise currents, and it brings low losses for working currents.

Locking coils which are used bring losses for noise currents: at frequency 30 kHz – 8,68 dB (1 Np) at frequency 120 kHz – 190,97 dB (2,3 Np); at frequency 150 kHz– 21,71 dB (2,5 Np). At the same time losses for signal currents (working currents) are no more than 0,18 dB (0,02 Np) at frequencies up to 70 kHz and no more than 0,26 dB (0,03 Np) on frequencies more than 70 kHz. Special matching autotransformers are installed for the matching of characteristic (wave) impedance of circuits of air communication lines with cable inserts in places of their connection.

There is a possibility to match only magnitudes of wave impedance of communication circuits by means of an autotransformer. Therefore in HF spectrum (match over 10 kHz) where wave impedance of circuits of air communication lines and cable inserts has very small phase angle, these circuits are easily matched.

We estimate a level of matching by a reflection factor valve, p, of air or cable communication line:

$$\rho_{ACL} = \frac{Z_{inALC} - Z_{waveALC}}{Z_{in\,ALC} + Z_{waveALC}}; \qquad \rho_{CLC} = \frac{Z_{inCLC} - Z_{waveCLC}}{Z_{inCLC} + Z_{waveCLC}};$$

here Z_{wave} – wave (characteristic) impedance (see tab. 1) ALC or CLC;

Z_{in} – measured values of input impedance for ALC or CLC.

An input impedance of an autotransformer, both from a communication air-line, and from a cable line at corresponding loadings of an opposite side (180 and 550 or 140 and 550 Ohms) provides a reflection factor of no more than 6 % in a range of frequencies 30...160 kHz and no more than 10 % for frequencies lower than 30 kHz. Special autotransformers of type AO-550/140 (for cables of type T3), or AO-550/180 (for cables of type MKC) are used for matching of cable inserts in channel multiplexed circuits.

Fuses are utilized using of an autotransformer for equipment and personnel protection, against dangerous currents on subscriber lines in wire cuts. They could be linear and station ones:

– linear fuses of type CH-1 (spiral with knife contacts) and CK (spiral with cone contacts) are used for 1 A currents;

– station fuses are thermal coils which are mounted on the cross.

Thermal coils are used for 0,25 current (TK-0,25) and 0,3 (TK-0,3). They disconnect an equipment of city telephone exchanges from communication line wires if an electric network voltage drop on the latter is lower than a switch on voltage of mounted rated sportsmen. Thermal coils are reusable fuses (fig. 2.4).

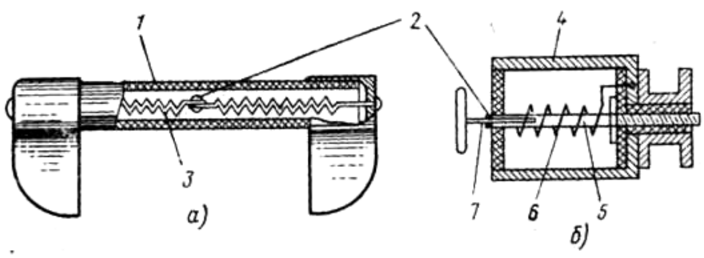


Figure 2.4 – Fuse of type CH (a) and thermal coil (b)

There are several protection circuits depending on a kind of external influence, presence of a remote power and equipment type. A protection circuit for channel multiplexed 150 kHz ACL circuits with cable input is shown on a fig. 2.5 as an example. An electric protection on a cross and on subscriber lines is necessary at an underground lining of a cable on an open district, at a cable suspension bracket on support, and also if mixed communication lines which consist of cable and air communication lines are used. An electric protection of the equipment on a cross is not necessary on completely cabled subscriber lines and on low-frequency connecting lines.

It is necessary to note that due to use of import cross equipment and electronic exchange installation, an electric protection based coal rated sportsmen and thermal coils has to be substituted by more essential protection devices. Two and three electrode tiny miniature gas filled sportsmen with ignition voltage from 90 to 350 V are utilized instead of coal ones. There rated sportsmen have contacts which connect as fusible washers, rings or spring contacts. They provide an emergency shorting of communication wires to the ground.

It is necessary to note also, that electronic and quasi-electronic automatic telephone exchanges are more sensitive to external voltage, in comparison with electromechanical automatic telephone exchanges, therefore the second, additional, degree of protection which is realised directly in the station equipment. Thus as a part of system of switching for protection of the equipment of such automatic telephone exchanges against action of high voltage and exceeding currents the protective equipment is utilized that differs in purpose, technical parameters and design implementation.

The choice of the protective equipment for a specific system of switching is carried out taking into account technical characteristics of the equipment of automatic telephone exchange, subscriber and connecting lines and conditions of operation of the equipment.

So, for example, for protection of a station equipment against action of high voltage which can arise at operation in subscriber and connecting lines protection shops (M3) (fig. 2.6, a) are used.

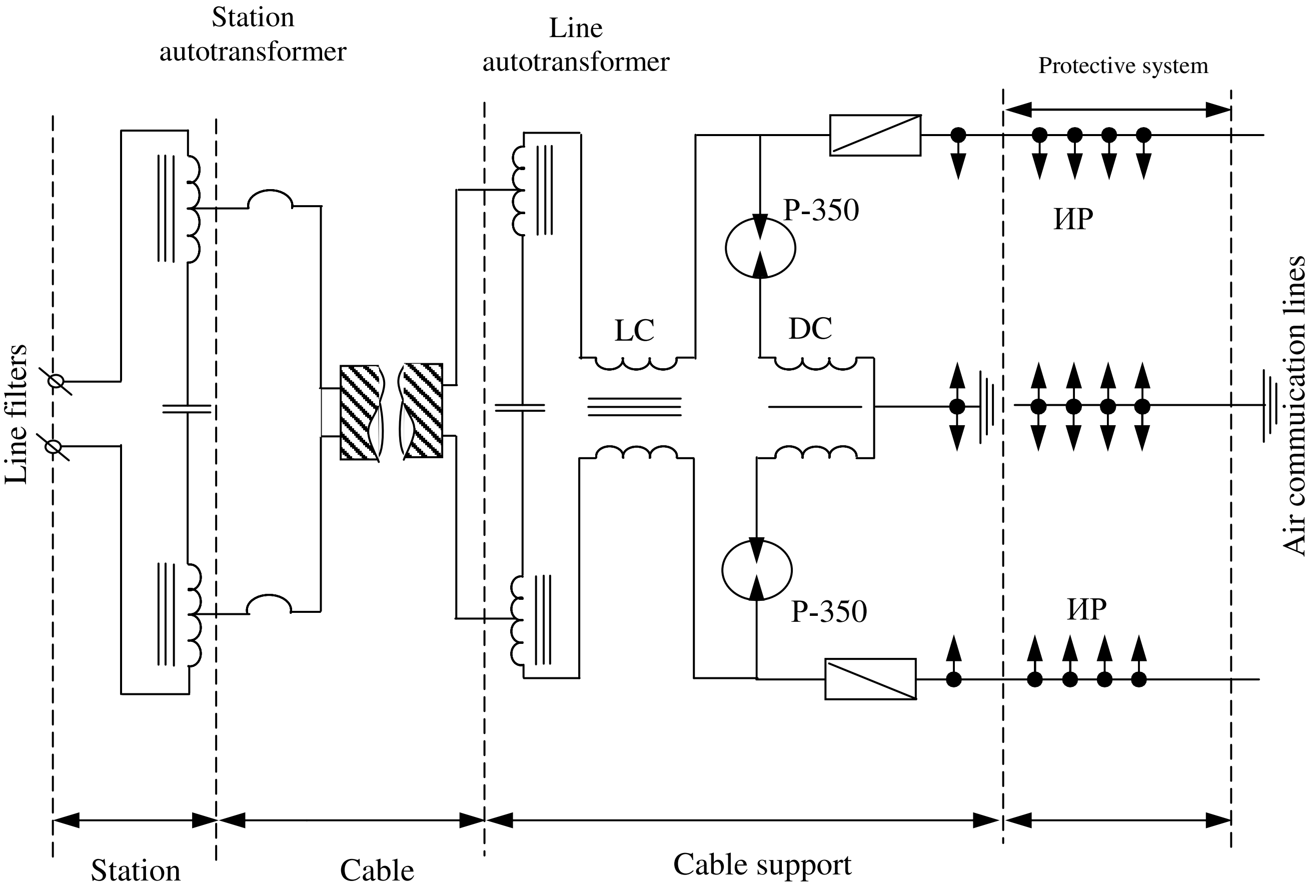


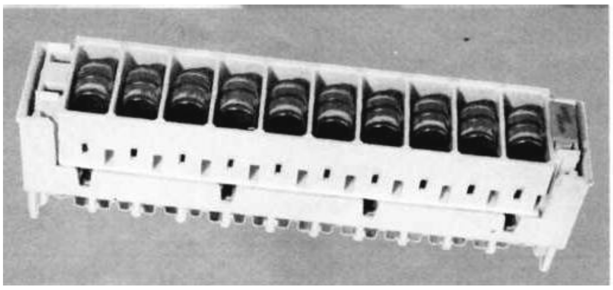
Figure 2.5 – Protection circuit for channel multiplexed ACL circuits with cable input

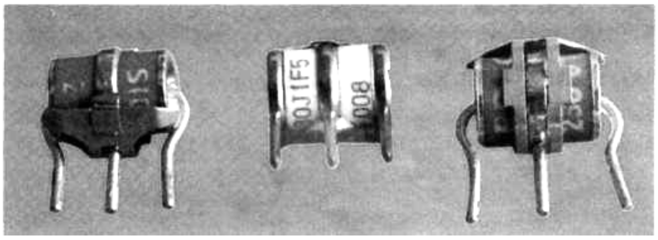
As a protective element in M3 a three-polar are gas discharger used with a thermal closing plate (fig. 2.6, b). Rated spark gap provide the most simple protection against voltage in longitudinal (between wires) and cross-section (between each wire and a frame of a cross) directions and have thermal protection against equipment fire.

A replacement of rated spark gap in M3 is necessary on operation of thermal protection after voltage removal.

Rated sportsmen are mounted in a single case (M3) based on their design the case is set in a switching plinth of a cross equipment, carrying out connection this way: Potential terminals of rated spark gap to all circuits of a plinth; case terminals of all rated spark gap to an assembly collar and a cross frame.

Current protection modules (M3T) are used for protection of station equipment against action of high currents which can arise at operation in subscriber and connecting lines. These modules could be reusable and disposable ones. For example, modules of protection of domestic production M31 – RTS and M31 – PS are devices of reusable use as they are realised on elements of protection which upon termination of action of high currents renew the initial condition. The module of protection M31 – ПР is a device of disposable as how it is realised on protection element (a fusible insert) which upon termination of action of high currents breaks down. A replacement or a repair of such M3T (fig. 2.7) is necessary for subsequent operation of the equipment.





a) general view of M3; b)three-polar gas discharger

Figure 2.6 – Box of protection of the station equipment of automatic telephone exchange against high voltage.

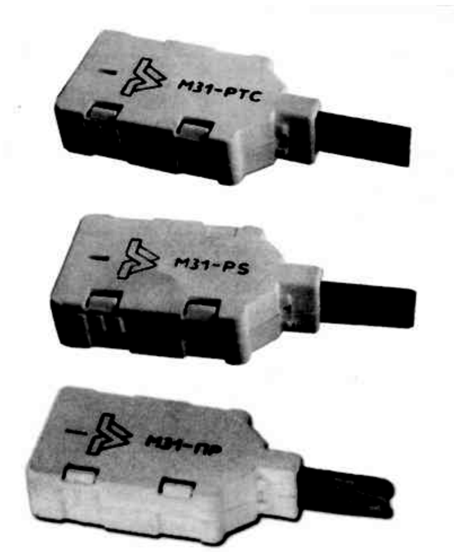


Figure 2.7 – General view of MT3

Design of M3T is realised in a plastic case for connection of one two-wire line of plinths of 2×10 and other plinths on the basis of 2×10. Modules of protection M31-2 Mbit/s or M31-*CLP* are utilized for protection of station equipment against high voltage which can appear at operation in digital connecting lines at action of lightning discharges, influence of ELT, contacts to the industrial electric system voltage 220V 50 Hz.

The following are used as protective elements in the module of protection M31 – 2 Mbit*/s*:

– in a cross-section direction three-polar gas discharger with a thermal closing plate and for reduction of time of operation – varistors;

– in a longitudinal direction for reduction of allowable voltage – voltage limiters.

Design of M3T is realised in a plastic case for connection of one two-wire line of plinths 2x10. They have four potential terminals and one terminal (spring) of grounding. A replacement of M3 is necessary at operation of thermal protection after high voltage elimination.

A feature of modules MZ1 – CLP except protection of station equipment against high voltage is protection of it against high currents too. These modules are utilized on analogue, digital, subscriber and connecting lines as well.

Thermal protection in these modules provides equipment switching-off for a long high voltage line exposure. M31– CLP self reconstructs and the replacement is not necessary on operation of thermal protection after removal of high voltage.

The following is used as protective elements in the protection module:

– Specialised chip *CLP* 200 M for protection against high voltage and high currents;

– RTS thermo-resistors for thermal protection and equipment de-energizing for long line exposure to.

Note:

1. All types of the considered shops and protection modules under electric and operational characteristics meet the requirements of the recommendation ITU – T K.20 in edition 2⁄2000 „Strength of the telecommunication equipment to high voltage and currents”.

2. МЗ units have by rated sportsmen with breakdown voltage 230 V ± 20 % or 300 V ± 20 %, intended for equipment protection, which nominal working voltage does not exceed 170 In and 230 In, accordingly.

3. A nomenclature МЗ of firm KROK – КН (Kharkov state device plant of T.G. Shevchenko) for systems of switching of subscriber and connecting lines of automatic telephone exchange is given in tab. 2.1.

4. A nomenclature МЗТ of the same firm is given in tab. 2.2.

5. Technical characteristics of equipment of protection are given in tab. 2.3.

Table 2.1 – The nomenclature of protection shops

Name	Decimal number	Marking	Type of a plinth for connection	Notes
Protection shop	ЯЕВИ. 301592.008	–	НЗР – 2 × 10 – 004 НОЗ – 2 × 10 – 014 НЗН – 2 × 10 – 020	For 10 rated spark gaps
Protection shop 2 × 10	ЯЕВИ. 301592.018 (1)	2×10 – 18	НЗР – 2 × 10 – 004 НОЗ – 2 × 10 – 014 НЗН – 2 × 10 – 020	For 10 rated spark gaps
Protection shop 2 × 8	ЯЕВИ. 301592.019 (1)	2×10 – 19	НЗР – 2 × 10 – 004 НОЗ – 2 × 10 – 014 НЗН – 2 × 10 – 020	For 8 rated spark gaps
Protection shop 2 × 5 (35)	ЯЕВИ. 301592.019 (1) ЯЕВИ. 301592 (2)	2×5 (3 × 5)–27 2×5 (3 × 5)–27-01	НЗР – 2×5 (3 × 5)–025 NOZ – 2 × 5 (3 × 5)–026	For 5 rated spark gaps
Protection shop 2 × 8 (38)	ЯЕВИ. 301592.030 (1)	2×8 (3×8) – 30	НЗР – 2×5 (3×5)–028 NOZ – 2×5 (3×5)–029	For 8 rated spark gaps

Table 2.2 – The nomenclature of current protection modules

Name	Decimal number	Marking	Protection element
The module of protection М31 – *RTS*	ЯЕВИ.468629.011	М31 – RTS	2 thermo-resistors of RTS 33 Ohm *PLIPS*
The module of protection М31 – *PS*	ЯЕВИ.468629.014	М31 – PS	2 self-restored fusel „Poliswitch”, which self reconstruct TR 250 -120
The module of protection М31 – ПР	ЯЕВИ.468629.017	М31 – ПР	2 quickly operating fusible inserts

Table 2.3 – Technical characteristics of protection equipment

Technical characteristics	Protection shops	Protection modules				
		M31 – PCT	M31 – *PS*	M31 – ПР	M31 – 2 *Mbit/s*	M31 – *CLP*
Number of protected lines	Depending on type 10, 8, 5	1	1	1	1	1
Technical characteristics	Protection shops	Protection modules				
Nominal working voltage, In no more – between A/B – *S* – between *A* – *B*	160 160	200 200	400 400	400 400	160 6	160 160
voltage breakdown, In: between A/B – *S* – between A – B	1800–300 360–600	- -	- -	- -	180– 270 8–12	200–290 -
The maximum working current, mA, is no more	-	90	120	100	200	80
Current protection	Thermal switch	Thermo resistor	Poli-swich	Fusible insert	Thermal closing plate	Chip thermo-resistor
Time of protection: - on voltage switching, s, it is no more - on current, s, it is no more - thermal switch at a current 10A, s, it is no more	$0{,}7\text{x}10^{-6}$ - 5	- 5 (at a current 0,6A) -	- 2 (at a current 1A) -	- 5 (at a current 0,4A) -	$50\text{x}10^{-9}$ - 5	$0{,}6\text{x}10^{-6}$ $0{,}6\text{x}10^{-6}$ -
Resistance of insu-lation MOhm, no more	100	10000	10000	1000	10	10
Resistance brought in Line, Ohm, no more	0	40	12	33	5.5	45
Working temperature, °C	from -40 to +70	from -40 to +70	from -40 to +70	from -40 to +70	from -40 to +70	from -40 to +70
Boundary temperature, °C	from -60 to +80	from -60 to +80	from -60 to +80	from -60 to +80	from -60 to +80	from -60 to +80

2.2 M3 usage – a telecommunication equipment protection devices check tester

M3 – a tester intended for check of working capacity of all nomenclature of devices of protection of system of switching КРОК-КН and devices of protection of other firms which correspond to devices of protection of systems of communications КРОК-КН on the parameters and a design.

Technical characteristics M3 – tester

Checked parameters of devices of protection:

– Breakdown voltage, V	From 20 – 400
– Resistance brought in a line, Ohm	From 0 – 99,9
– Current for operation of protection, mA, up to	170

Number of protection devices connected for check:

– Protection shop on a plinth 2×10	1
– Protection module on one two-wire line of a plinth	2

Check mode of protection devices:

– Automatic at which there is an automatic check of the connected devices of protection;

– Manual, at which check of each subsequent device of protection (a line or protection shop) occurs at the command of an operator.

– The device has a mode of self-checking of its working capacity.

– Device design is table top, 220×220×120 mm dimensions.

– Device has УХЛЧ climatic implementation by ГОСТ 15150.

– Power is an industrial network 220V 50Hz.

2.3 Test of rated spark gaps for their flammability voltage

Determining a voltage at which a discharge begins, is carried out by a device ИР-3. A tester is a converter of low dc voltage into high one with the control voltmeter.

A fuse switch on voltage is defined after rated sportsman connection to corresponding terminals, and pressing buttons "Incl." turn of handles “Регул. напр. грубо”, “Регул. напр. плавно” A gas filled two-electrode rated sportsman Р-350 is considered serviceable if its voltage drop is 350±40 V.

2.4 Determining a performance of a drainage coil

Having chosen a two rated sportsmen Р-350 with the greatest difference of a threshold of ignition connect them in protection circuits. Connect headphones from a side which goes from a station to a line. To disconnect from the circuit the drainage coil by means of a special crosspiece, disconnecting the ground from rated sportsmen. Connect a device ИР-3 in a circuit line „lightning-ground”, to simulate a lightning discharge by the device.

A reduction of level of acoustic blow is noted at subsequent connections of DC in the protection circuit. The same effect can be observed at careful selection of rated sportsmen based on their standard ignition rated voltage.

2.5 Measurement of input resistances for an autotransformer

Measurement of input resistances for an autotransformer is carried out according to circuits on figs. 2.8 and 2.9. The first circuit is a circuit of measurement of input resistance from an air communication line side; the second one is a circuit for of such measurement from a cable communication line side.

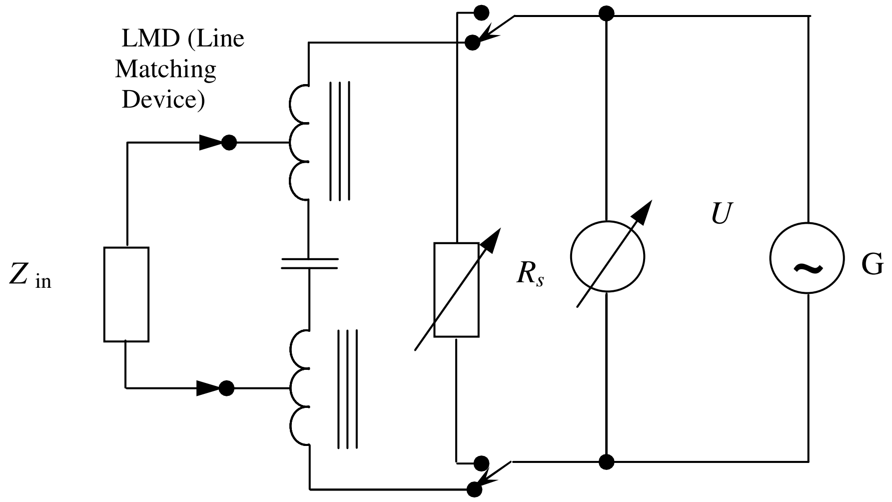


Figure 2.8 – Circuit for measurement of input resistance of an autotransformer from an air communication line side

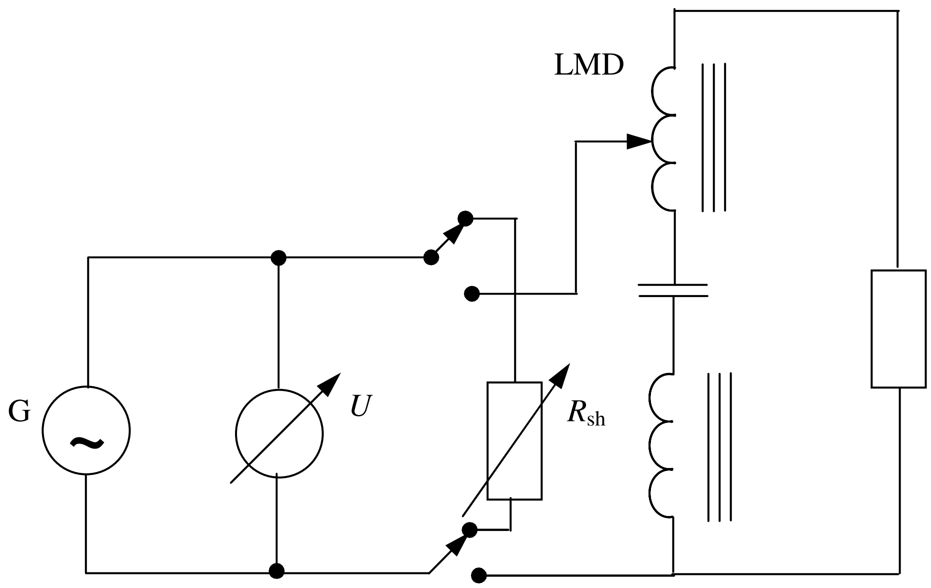


Figure 2.9 – Circuit for measurement of input resistance of an autotransformer from a cable communication line side

Protocol for measurement of input resistance is the following:

2.1 Check and, if necessary, connect devices (the generator, the indicator) to power supplies system.

2.2 Set a given frequency on the generator with an initial level 13,02...17,37 dB (1,5…2 Np). A target resistance of the generator is established equal to 600 Ohm. An input resistance of the indicator is high.

2.3 To connect devices in the circuit to an apparatus which is measured, consistently, first from ACL side, then from a cable insert side, having connected corresponding load on the opposite end of matching device (Z_{inACL} or Z_{inCCL}). Taking average value of wave impedance in a range 30 – 150 kHz to get a sufficient accuracy it is possible to connect resistances $Z_{in\ CCL}$ = 180 Ohm and Z_{inACL} = 540 Ohm in the circuit.

2.4 Set a signal level arrow to any position in the middle of the scale range (range the handle of initial level on the generator).

2.5 Switch the indicator to the shop of resistances then and, rotating the shop handles, achieve the same readings of the indicator (a comparison method).

2.6 Take a measurement of a modulus for input impedance of the autotransformer (Z_{inACL}; Z_{inCCL}) for the corresponding side of its input using handles (knobs) of the resistance shop.

2.6 Calculation of a reflection factor

Use the following formulas for calculation of a reflection factor:

$$p_{\mathrm{ALC}} = \frac{Z_{\mathrm{inACL}} - Z_{wACL}}{Z_{\mathrm{inACL}} + Z_{wACL}}; \qquad p_{\mathrm{CCL}} = \frac{Z_{\mathrm{inCCL}} - Z_{\mathrm{wCCL}}}{Z_{\mathrm{inCCL}} + Z_{\mathrm{wCCL}}}.$$

The autotransformer provides a reflection factor $p \leq 0{,}2$ in the range of frequencies to 30 kHz, and for $p \leq 0{,}1$ for the frequencies up to 150 kHz.

Passport values of wave impedance of ACL and CCL circuits for several frequencies are given in a tab. 2.4.

Table 2.4 – Passport values of wave impedance for ACL and CCL circuits

f, kHz	Z_{wCCL}	Z_{wACL}
30	191	544
60	184	543
120	180	542
150	179	542

2.7 Measurement of attenuation by locking coil

Measurement of losses which are brought by locking coil in a noise circuit is carried out by a methodology of a difference of levels using a circuit on fig. 2.10.

Protocol of carrying out measurement is the following:

1 Check and power the devices (the generator and the indicator).

2 Set a frequency with leaving level 13,02...17,37 dB (1,5...2 Np) on the generator. A target resistance of the generator and input resistance of the indicator should be 600 Ohm.

3 Check the target level of the generator by the indicator direct connection. Tune the devices if needed.

4 Connect the devices to a measured apparatus as shown on fig. 2.10.

5 Take a read out of losses due to LC (α_{cn}) by the methodology of a difference of levels. Measure losses by LC in the signal circuit (α_{cs}) based on the circuit of the fig. 2.11.

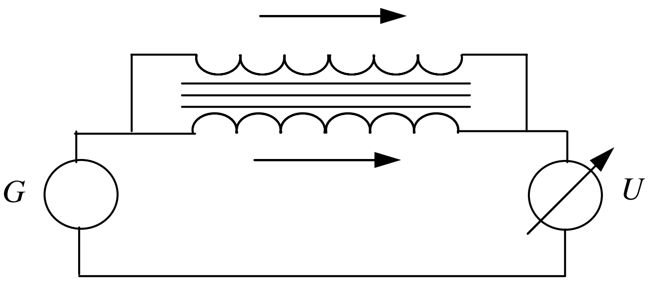


Figure 2.10 – The circuit of measurement for losses by locking coil in a noise circuit

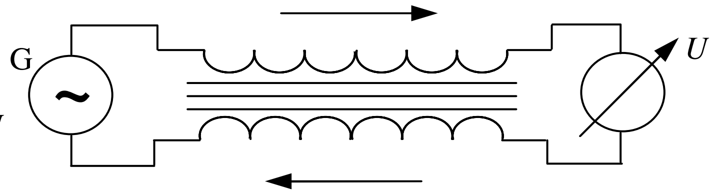


Figure 2.11 – The circuit of measurement for losses by locking coil in a signal circuit

A tab. 2.5 gives passport data for LC losses in noise circuit and signal circuit at different frequencies.

Table 2.5 – Passport data of brought 3K losses in a noise circuit and in a signal circuit for different frequencies

f, kHz	5	10	30	100	120	150
dB α_{cn}, Np	0,87 0,10	2,17 0,25	8,25 0,95	19,10 2,20	20,00 2,30	23,00 2,64
α dB α_{cs} Np	0,09 0,01	0,09 0,01	0,09 0,601	0,26 0,03	0,280 0,032	0,360 0,041

3 KEY QUESTIONS

3.1 Why is a threshold of a fuse of rated spark gap limited from below?
3.2 How do DCs reduce noise in communication channels?
3.3 What is a result of mismatch for cable inserts with communication lines?
3.4 What are LCs used for in ALC protection circuits?
3.5 Principles of work for circuits of air and cable communication lines protection.
3.6 Usage and basic types of rated sportsmen, fuses, M3 and M3T.
3.7 Key functionalities of a device M3 – a tester.

4 HOME TASK

4.1 Using the laboratory work recommended literature and the given guide familiarize yourself with:
– Usage and kinds of protective equipment of communication lines;
– Laboratory work protocol.
4.2 Prepare for discussion of key questions for section three.
4.3 Learn of communication lines protection circuits.
4.4 Prepare the laboratory work blank report form.

5 LABORATORY TASK

5.1 Familiarize with and learn circuits of protection and a design of the protective equipment at inputs of ACL circuits.

5.2 Estimate an overall performance of drainage coils (DC).

5.3 Measure an input impedance of the autotransformer from an ACL and a cable input sides for two frequencies – 30 kHz and 150 kHz. Write the results in a tab. 5.1.

5.4 Calculate a reflection factor for these frequencies. Write the results in a tab. 5.2.

5.5 Measure an attenuation of the locking coil (LC) in a noise circuit and a signal circuit for six frequencies: f = 5; 10; 30; 100; 120; 150 kHz and plot a graph of $\alpha = \varphi$ (f) dependence.

5.6 Measure by means of device M3 – a tester of breakdown voltage of protection shop.

5.7 Measure by means of device M3 – a tester a current of operation of the module of protection.

5.8 to Measure by means of device M3 – a tester of the additional resistance brought in a line by the module of protection.

Table 5.1 – Input resistance for autotransformer measurements data

f, kHz	Z_{in} from ACL side, Ohm	Z_w ACL, Ohm	Z_{in} from CCL side, Ohm	Z_w CCL, Ohm	ρ_{ACL}	ρ_{CCL}	Notes
30		540		180			
150		540		180			

5.9 Write data for measurements of attenuation by locking coil (LC) in a noise circuit (α_{cn}) and in a signal chain (α_{cs}) in a tab. 2.7.

5.10 Estimate data on efficiency of drainage coil usage in protection circuits.

Table 5.2 – Measurements of attenuation by locking coil data

f, kHz	5	10	30	100	120	150	Notes
α_{cn} dB							
α_{cs} dB							

6 EQUIPMENT

6.1 Generator working in a range of (0,3...300) kHz.

6.2 Measuring instrument of level for a signal in a range of (0,3...300) kHz.

6.3 Shop of resistances.

6.4 Load resistors.

6.5 Device M3 – a tester.

6.6 Modules of protection on a current.

6.7 Module of protection M31 – 2 Mbit/s.

6.8 Module of protection M31 – CLP.

7 CONTENT OF A REPORT

7.1 wire communication equipment protection circuit at ACL cable input (as assigned by instructor).

7.2 Basic of measurement circuits.

7.3 The autotransformer line matching device input impedance measurement data and the reflection factor calculation data, the LC attenuation measurement data, measurement with МЗ – a tester (a МЗ breakdown voltage, a МЗТ operation current, a МЗ extra resistance).

8 REFERANCES

8.1 Гроднев И. И. Линии связи / И.И. Гроднев, Н.Д. Курбатов. – М.: Связь, 1980. – С. 307 – 315.

8.2 Строительство кабельных сооружений связи. Справочник / Под редакцией Д.А. Барона и др. – М.: Радио связь, 1988 – С. 620 – 640.

8.3 ITU – T К.20 рекомендации 2/2000 «Стойкость коммутационного оборудования электросвязи к перенапряжениям, избыточным токам».

Laboratory work № 9

STUDYING ETL DANGEROUS MAGNETIC INFLUENCE ON CABLE COMMUNICATION LINES

1 PURPOSE OF THE WORK

A work purpose is acquaintance with methods of calculation and measurement for magnitude of a longitudinal induced EMF in communication cable wires at dangerous magnetic influence of high-voltage electric transmission lines (ETL).

2 MAIN POSITIONS

ETLs and contact circuits of electric railways are classified as high-voltage transmission lines. High-voltage lines which work at alternating current on $f = 50$ Hz have voltage from 3 to 400 kV and higher.

Three-phase ETLs can be symmetric ones, (which have no residual currents and voltage in the ground wire) and asymmetrical ones, (in which the ground is used as one of working wires). The latter have the greatest impact on cable transmission lines.

While discussing impact on a communication circuit we distinguish normal, enforced and emergency operating modes of ETL. The normal mode is a stable line work mode. The compelled mode is a mode at which a line is compelled to work certain time in a mode differing from a normal one, for example, a symmetric line works in an asymmetrical (non-full phase) mode (TWG – two wires – the ground). The emergency mode arises at disruption of ETL normal work, e.g., at break and grounding for one of phase wires. In this case there is a current of short circuit which may exceed a working current by an order of magnitude. At the same time an ETL has dangerous magnetic impact on a cable.

A calculation of ETL dangerous magnetic influence on a communication line (CL) is done at a design stage. Calculated expected values of induced EMF are compared to admissible values and the corresponding actions of protection are chosen. A methodology of calculation for longitudinal induced EMF is called a test methodology. It consists of the following: we short circuit an ETL phase wire to the ground for complicated approach path sequentially, for example, suppose, that at points 0, 1, 2 etc. (fig. 2.1). The elements of the slanted approach path yield parallel ones positioned at a distance:

$$a_{\text{eq}} = \sqrt{a_1 a_2}, \text{ m.} \tag{2.1}$$

We find an induced EMF for elements l_1, l_2... l_n as a mutual inductance factor between the ETL wire and the communication line wire will be different for each element. It depends on a conductivity of soil σ_{soil} and a width of the approach path a_{eq}. The total induced EMF is given by formula

$$\mathring{A}_{\text{ind}} = \omega \sum_{i=1}^{n} I_{sc^з} M_i l_i S_{tot}, \text{V}. \qquad (2.2)$$

here ω – an inducing current circular frequency (f = 50 Hz); I_{sc} – a short circuit current; n – a number of elements for the approach path; M_{i} – a mutual induction factor between the ETL wire and the communication cable wire on the i-th element of approach, is defined by nomogram of M.I. Mikhailov (fig. 2.2); S_{tot} – a total shielding factor

$$S_{tot} = S_c\, S_{wire}, \qquad (2.3)$$

here S_c – a shielding factor by a cable cover; S_{wire} – a shielding factor of the wire suspended on ETL above phase wires.

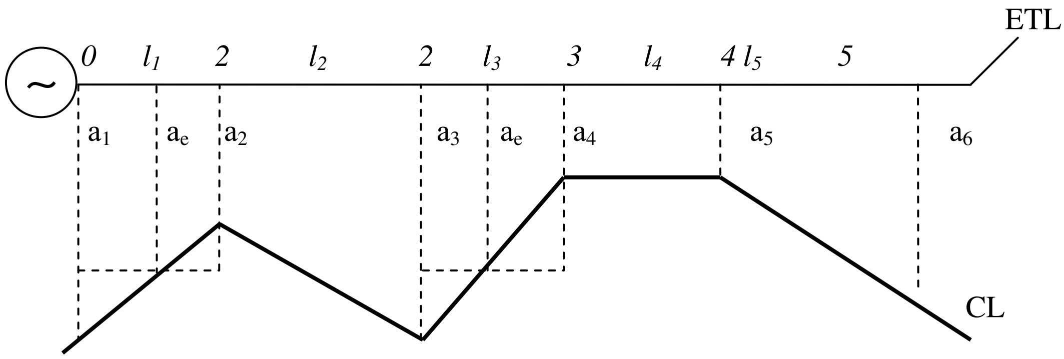


Figure 2.1 – Approach path

Influences at emergency operation may be short-term ones as they disappear with switching off the damaged line. However, for maintenance of safety of service personnel, and also for damage protection of equipment and communication lines standards of allowable magnitudes of dangerous currents and voltage are established. These standards depend on type of communication lines, used system of transmission, a remote power circuit organization, time of ETL shutdown. The EMF is standardized by a galvanically discontinuous circuit element of communication line (i.e. such that does not contain transformers, amplifiers and filters).

Values of allowable EMF in communication wires for symmetric cable lines are given in a tab. 2.1. Protective action factors values for cables depending on a material and size of cross-section section are given in a tab. 2.2.

Table 2.1 – Values of allowable EMF for communication wires

Transmission system	Circuit	TW circuit	Allowable longitudinal EMF, V		Element with standard
			Long term influence	Short-term influence	
К-60П	Symmetric pair	wire – the ground	200	400	Amplification element
		wire –wire	200	530	Regenerating element

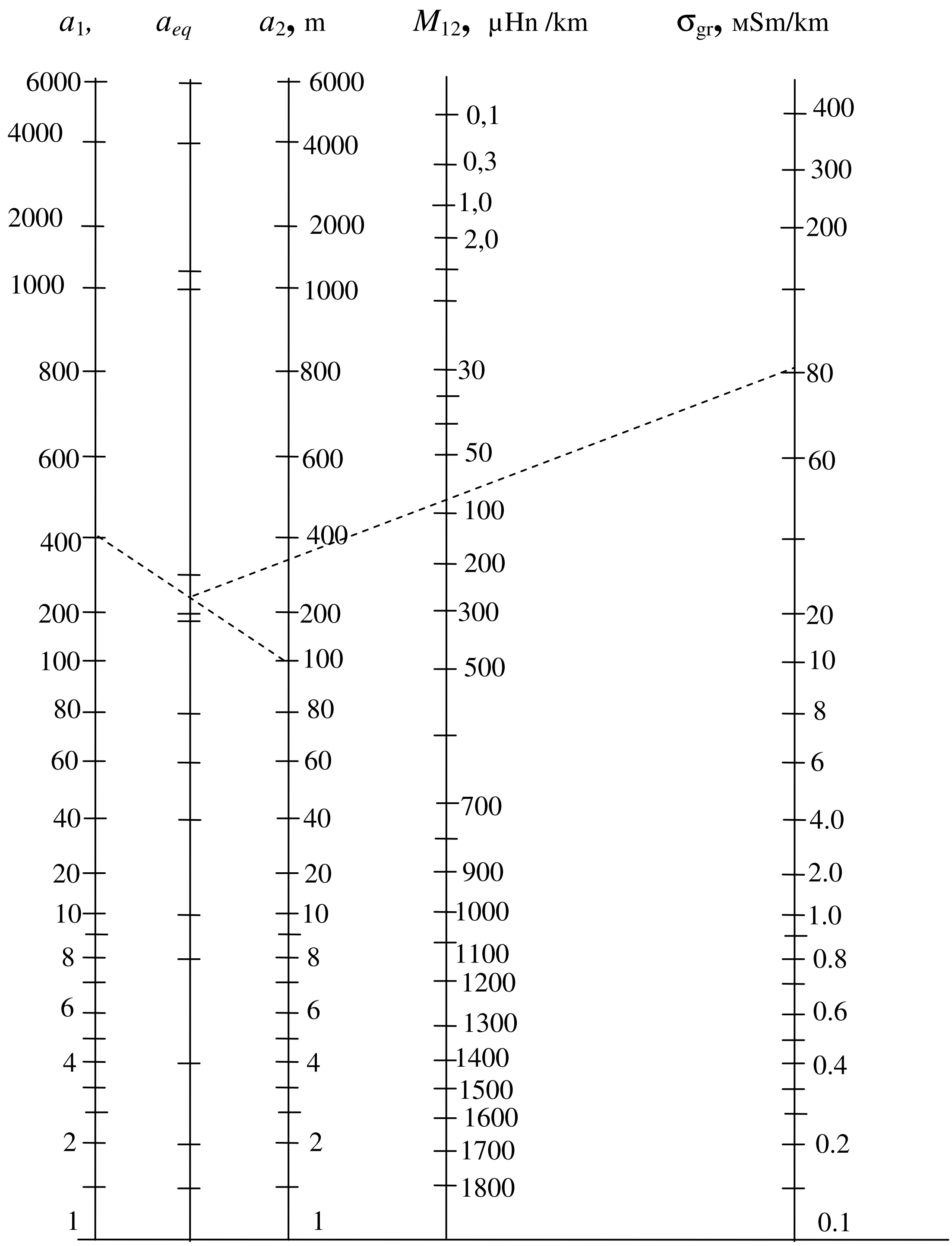


Figure 2.2 – M.I. Mikhailov nomogram

Table 2.2 – Protective action factors values for cables

Cable material	Value of S_{wire} for cables with cross-section section, mm^2	
	50... 100	101... 200
Copper	0,60	0,50
Aluminum	0,65	0,55
Steel	0,95	0,80

If a calculated EMF value exceeds an admissible value, it is necessary to choose protection actions. One of the first and primary actions – the increase of the distance between the CL path and the influencing ETL. It is necessary to calculate a_{cr} – a value of allowable critical approach for this.

If increasing the distance is impossible, electric protection actions need to be used which are divided into actions which are carried out on the ETL, and actions which are carried out on communication lines.

3 KEY QUESTIONS

3.1 What does an EMF induced in cable wires depend on?

3.2 What are the modes of ETL work? Which of them is the most dangerous to a cable communication line?

3.3 Which option of CL circuit grounding at magnetic influence presence is the most dangerous:

– insulated on the ends;

– grounded on the ends;

– grounded from one end?

3.4 What does the M_{12} factor depend on?

3.5 What is a shielding (protective) action factor? What does it depend on? In what ranges does it change?

3.6 What does the methodology of the calculation for longitudinal induced EMF at dangerous influence of ETL on CL consist of and how is it called?

4 HOME TASK

4.1 Using the recommended literature familiarize yourself with the methodology and the protocol of calculation for longitudinal induced EMF in communication cable wires.

4.2 Learn the protection actions for communication cables against ETL dangerous influence.

4.3 Prepare a report form with a table for record of results of calculations and measurements.

4.4 Prepare for discussion of control questions.

5 LABORATORY TASK

5.1 Familiarize with a laboratory work stand (fig. 6.1).

5.2 Connect a circuit of the ETL and the CL approach based on a variant assigned by the instructor.

5.3 Set a short circuit current I_{sc} by the ammeter under instructions of the teacher.

5.4 Calculate a longitudinal resulted EMF in the emergency operation of the ECL for a given scheme of approach as

$$E_{\text{ind}} = \omega \sum_{i=1}^{n} I_{\text{sc}} M_i l_i S_{\text{tot}}$$

Write calculations in the following table (tab. 5.1).

Table 5.1 –longitudinal induced EMF calculation

Point	a_1, m	a_2, m	a_{eq}, m	$M_{12}\cdot 10^{-6}$ H/km	l_i km	$\omega M_{12} l_i$,	$\sum\omega M_i l_i$,	I_{sc}, A	S_{tot}	E_{calc},V	E_{tot}, V
0											
1											
2											

5.5 Measure an induced EMF value at points 0, 1, 2.

5.6 Find the allowable EMF magnitude.

5.7 Plot a graph of $E_{\text{red}} = f\ (l)$ dependence. Put a straight line on the graph corresponding E_{all}.

5.8 Compare $E_{\text{ind.m.}}$ with E_{all} select protection actions.

5.9 Calculate M_{cr} using a formula to find a_{cr}:

$$M_{\text{cr}} = \frac{\mathring{A}_{\text{all}}}{\omega \sum I_{sci} l_i S_{\text{tot}}} \text{H/km.}$$

Using values M_{cr} and σ_{g} by nomogram (see fig. 2.2), define a_{cr}.

5.10 Distance CL away from the ETL by $a > a_{cr}$. Measure total induced EMF (the point 3), compare it with E_{all}. Write conclusions.

6 DESCRIPTION OF THE LABORATORY STAND

A high-voltage transmission line and a cable transmission line of on the basis of symmetric cable МКСБ–4×4×1, 2 (fig. 6.1) are implemented at the laboratory stand. A protective cable made of copper with cross-section section S = 100 mm^2 is suspended on ETL above phase wires. An approach circuit has two slanting sites l_1 = 4 km and l_2 = 8 km.

A failure of ETL has taken place in the point 0. A factor of shielding action of cable МКСБ S_K = 0,41; ρ_{gr} on an approach is line 25 Ohm. A transmission system К-60П with a remote power of amplifiers on system a wire – the ground works on a communication cable МКСБ–4×4×1,2.

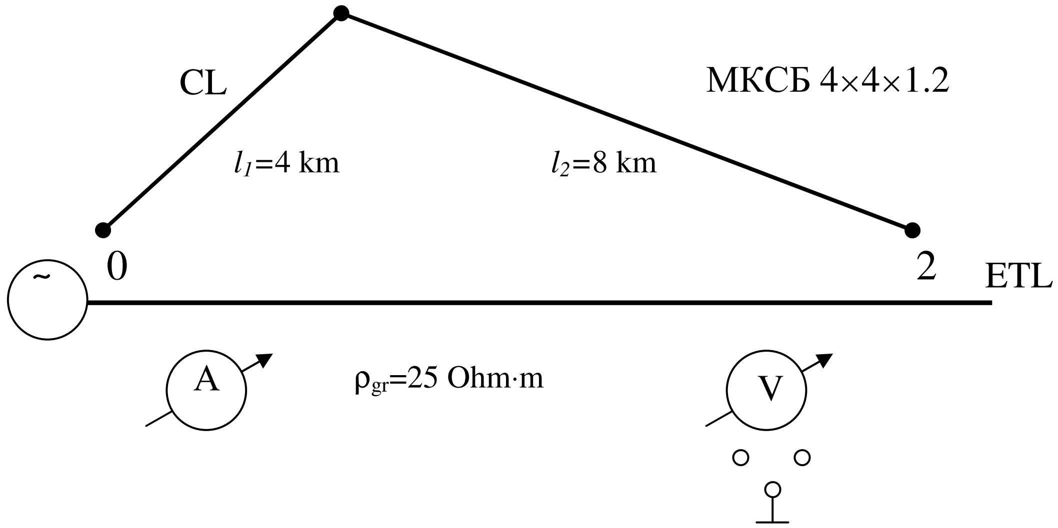


Figure 6.1 – Cable transmission line
on the basis of symmetric cable МКСБ 4×4×1,2

7 CONTENT OF A REPORT

7.1 Name and number of the laboratory work.
7.2 Name of the laboratory and date of performance of the work.
7.3 Purpose of the work.
7.4 Circuit of approach for ETL with CL based on the set variant.
7.5 Table of calculated and measured values E_{ind}.
7.6 Graph of dependence $E_{ind} = f\,(l)$ and comparison with E_{tot}.
7.7 Calculation of a_{cr} and measurement of E_{ind} value after distancing the CL from the ETL.
7.8 Conclusions.

8 REFERANCES

8.1 Гроднев И. И. Линии связи / И.И. Гроднев, С.М. Верник. – М.: Радио и связь, 1988, С. 335-338, 342-343, 346-366.
8.2 Михайлов М.И. Защита кабельных линий связи от влияния внешних электромагнитных полей / М.И. Михайлов, Л.Д. Разумов. – М.: Связь, 1978.
8.3 Правила защиты устройств проводной связи, железнодорожной сигнализации и телемеханики от опасного и мешающего влияния линий электропередач. Ч. 1: Опасные влияния. – М.: Связь, 1969.

Laboratory work № 10

RESEARCH OF PROTECTION METHODS FOR UNDERGROUND LINEAR-CABLE CONSTRUCTIONS AGAINST CORROSION

1 PURPOSE OF THE WORK

Studying a protection methodology for underground linear cable constructions against corrosion.

2 MAIN POSITIONS

2.1 Determining of resistance for 1 m cable

A resistance of a 1 m cable is given by a formula:

$$R = \rho \frac{4}{\pi(d_1^2 - d_2^2)}, \text{Ohm}, \qquad (2.1)$$

here q – a specific resistance of lead $\rho = 0{,}221 \cdot 10^{-6} \frac{Om \cdot mm^2}{m}$;

d_1 – an external diameter of a lead jacket, equal to 16 mm;

d_2 – an internal diameter of a lead jacket, equal to 12,3 mm.

If we substitute the corresponding values in the formula (2.1), we get a resistance of a 1 m cable which has a environment moisture protection made of. To find a resistance of a 1 m cable which has an environment moisture protection made of other metals, it is necessary to substitute in the formula (2.1) the corresponding values of a specific resistance of a moisture protection covering metal, and the corresponding diameters, d_1 and d_2.

2.2 Determining a direction and a magnitude of a stray current in cable covering by compensation and voltage methods drop. Make measurement for one value of a stray current

2.2.1 Switch on a stray current source on the stand by turning a toggle-switch I_{str} in position "ВКЛ".

2.2.2 Define a direction of stray current I_{str} to connecting a millivoltmeter mV with zero in the center of the scale, to two points of the cable (K_1 and K_2 on fig. 2.1). A distance between these two points is 1m. A scale 75 mV is set on the millivoltmeter. If an arrow of the millivoltmeter moves to the right the stray current has a direction from a point connected to "+", to a point connected to "-" on millivoltmeter.

2.2.3 A magnitude of a stray current is determined by both a method of compensation, and a method of voltage drop. A measurement circuit is shown on a fig. 2.1.

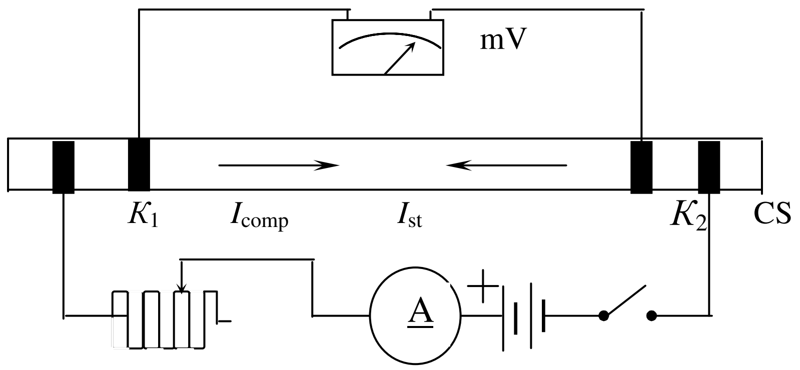


Figure 2.1 – A circuit of measurement by methods of compensation and a voltage drop

2.3 Method of compensation

2.3.1 Assemble a circuit of measurement (fig. 2.1). To do this connect a source of a direct current as noted on the figure. The source of a direct current is connected to the circuit so that a current from the source has a direction opposite to the direction of the stray current.

2.3.2 Using a rheostat change the current from the source of a direct current until a value “0” will be established on the millivoltmeter “75 mV” scale. It will mean that the current from the source of a direct current has completely compensated the magnitude of the stray current.

2.3.3 Determine a valve of a current which will be equal to that of the stray current on a scale of the ammeter set on the stand.

2.4 Method of voltage drop

2.4.1 Using a circuit of fig. 2.1 switch off a source of compensation current. Set the toggle-switch in a position "OFF for this". An arrow of the millivoltmeter will deviate. It will be a value of a voltage drop measured on I_{st} length of a cable with lead moisture protection covering.

2.4.2 Magnitude of a stray current is calculated by a formula

$$I_{st} = \frac{U}{Rl}, A, \tag{2.2}$$

here U – is 1 m voltage drop for a cable with a lead moisture protection covering, V;

R – resistance of a cable of 1 m with a lead covering which is defined by the formula (2.1), Ohm/m;

l – distance between points of the measurement, is equal to 1 m.

2.5 Measurement of cable covering potentials relative to the ground (using a CTN cable stand), plotting of a potential diagram, definition of anode and cathode zones

2.5.1 Draw a schematic of a cable water drain and writ wells numbers.

2.5.2 Measure potentials on a cable covering relative to the ground in each well. Write values of the potentials in a tab. 2.1.

Table 2.1 – Potentials measured on a cable covering relative to the ground

Well number.	1	2	3	4	5	6	7
Potential measured before protection, V							
Potential measured after protection, V							

2.5.3 Determine anode and cathode zones.

2.5.4 Fix a number of a well in which a sign-variable zone was observed, if such zone exists.

2.5.5 Construct a potential diagram before protection.

2.5.6 Determine necessary means of protection against corrosion in specific wells of the cable water drain.

2.5.7 Connect cathode station to a cable in a well with the maximal constant anode zone observed, for protection of the cable water drain and establish in the well the minimal protective potential (-0,3 V) by means of a rheostat *R*.

2.5.8 Connect polarized drainage to a cable in a well with a sign-variable zone (make connections relative to rails of a tram way).

2.5.9 Measure potentials on a cable covering relative to the ground in each well after protection. Write the values of potentials in tab. 2.1.

2.5.10 Plot a potential diagram after protection.

3 KEY QUESTIONS

You need to do the following for laboratory work independent:

3.1 Learn the recommended literature.

3.2 Learn existing means of protection for cables against corrosion.

3.3 Familiarize yourself with methods of measurements on cable transmission lines during the organization of protection means for underground cables against corrosion.

3.4 Learn equipment, devices and apparatuses used in the organization of protection means for underground cables against corrosion?

3.5 Prepare the report form of the laboratory work (schematic diagrams, tables, figures, the sketch of cross-section section of the cable ТГ-50×2×0,5).

3.6 Prepare verbal answers to the following questions:

– types of corrosion and character of its action;

– electric means of protection for cables against corrosion;

– non-electric means of protection for cables against corrosion;

– types of measurements on underground constructions during protection of cables against corrosion;

– equipment, devices and apparatuses, which are utilized in measurement for determining means of protection for linear cable constructions against corrosion.

4 HOME TASK

4.1 Draw the sketch of section of a cable.

4.2 Define a resistance of a cable covering using its geometric dimensions.

4.3 List standards for a protective potential of lead, aluminum, steel.

5 LABORATORY TASK

5.1 Determine a resistance of a cable covering based on its geometrical dimensions.

5.2 Determine a direction of a stray current in a cable covering.

5.3 Determine a valve of a stray current in a cable covering by: a method of compensation: a method of voltage drop.

5.4 Measure potentials of a cable covering relative to the ground (on a cable water drain CTN stand) construct a potential diagram and define anode and cathode zones.

5.5 Establish protection by means of a cathode station (on the stand of CTN cable water drain) and repeat measurement of potentials for a cable covering relative to the ground with the established protection utilizing the cathode station.

5.6 Plot a potential diagram after an establishment of protection. Plot both diagrams on the same graph.

5.7 Establish a protection by means of drainage in sign-variable zones.

5.8 Familiarize yourself with work of cathode station and drainage equipment.

6 EQUIPMENT

6.1 Ammeter.

6.2 Measuring bar with a lead tip.

6.3 Laboratory work stand.

6.4 Cathode station of type КС-400 stand.

6.5 Polarized drainage of type ПГД-200 stand.

7 CONTENT OF A REPORT

7.1 All listed in the item 3.5.

7.2 All listed in the section 4.

7.3 Results of calculations and measurements.

7.4 Potential diagrams before and after protection.

7.5 Schematic diagrams: cathode station, drainage equipment, protection by electrodes.

7.6 Conclusions.

8 REFERANCES

8.1 Гроднев И. И. Линии связи / И.И. Гроднев, Н.Д. Курбатов. – М.: Связь, 1980. – С. 409 – 414.

8.2 Ионов А.Д. Линии связи / А.Д. Ионов, Б.В. Попов. – М.: Радио и связь, 1990. – С. 155 – 158.

9 APPENDIX

9.1 Corrosion of cables and means of protection

9.1.1 Corrosion as a result of stray current

Different kinds of corrosion influence underground linear-cable constructions, including cables. It leads to irreversible consequences. Based on statistical data a damage a underground linear-cable constructions as a result of corrosion takes the first place and is 21,06 % of all types of damages.

One of types of corrosion is that emerging due to a stray current. All types of electric equipment for a direct current, with the ground used as the second return wire, can be sources of corrosion as a result of a stray current. The stray current encounters a metal moisture protection covering of a cable on the way enters into the covering at some point and continues its flow along the metal covering of the cable.

The stray current leaves it in other place of the metal environment, coming back to the return pole of the power supply. Thus on the environment of the cable arise (fig. 9.1):

– cathode zone, in which a potential is below zero;

– anode zone, in which a potential is above zero. The metal moisture protection covering of the cable is damaged as a result of influence of the stray current in this zone.

9.2 Electric means of protection

Today the basic means of protection against corrosion are – electric methods. These methods give an opportunity to form a protective cathode zone on metal moisture protection covering of a cable instead of anode one.

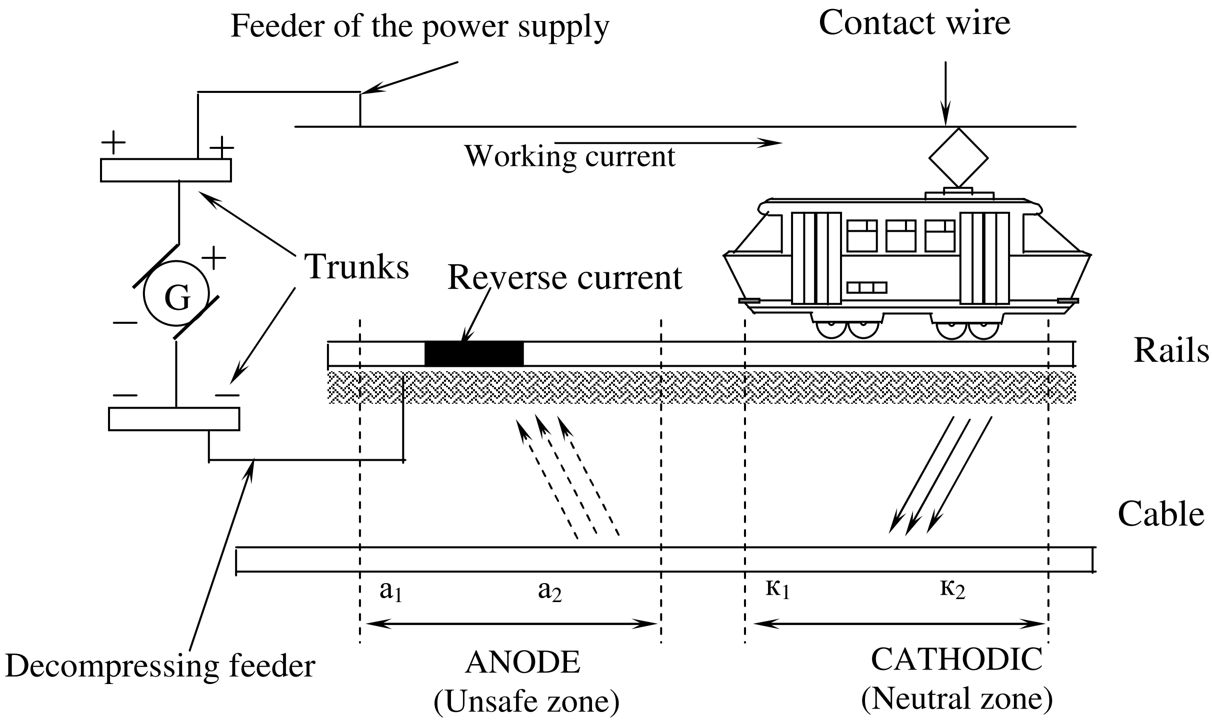


Figure 9.1 – Stray current appears scheme

9.2.1 Protection by means of drainage

A protection by means of drainage assumes directing a stray current from an underground linearly-cable construction which it destroys, to circuits which create this stray current. An electric drainage is connected to a moisture protection covering in the middle of an anode zone, i.e. The highest positive potential relative to the ground is observed here. The stray current by means of a drainage cable is allocated from moisture protection of a cable covering to be protected, to rails of a tram way or to a minus pole of a power supply.

If necessary, drainages are mode with the purpose of formation of a minus potential on moisture protection of several a cable covering along all line of approach with tram ways or an electrified railway. Such drainages are called direct electric drainages. The direct drainage has a bilateral current conductivity; therefore it can be used only in stable anode zones. Namely for this reason the direct drainage is connected together with dispersing feeders.

But there can be zones where potentials on moisture protection of a cable covering periodically change their signs relative to the ground. Such zones are called sign-variable, and it is necessary to connect special drainages in such zones, namely – polarized ones. A polarized the drainage diverts a stray current in one direction only, namely: from a cable to a tram way. This drainage can be connected in sign-variable zones.

A basic circuit for one of types for polarized drainage, ПЭД -58, is represented on fig. 9.2.

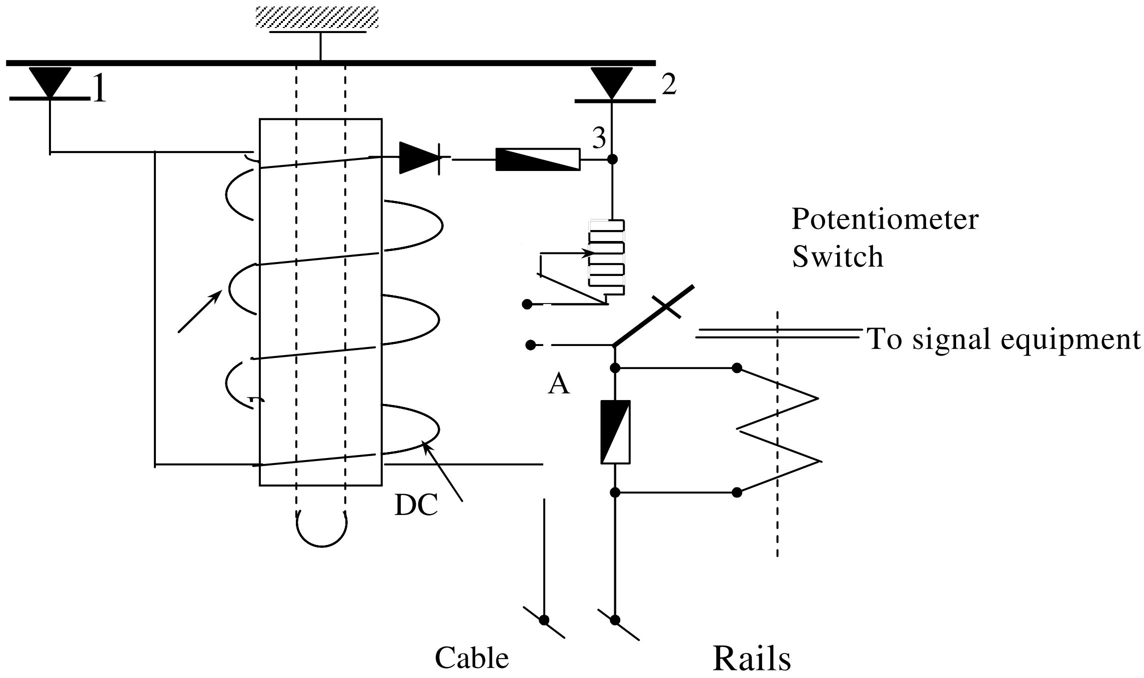


Figure 9.2 – Basic circuit for one of types of polarized drainage ПЭД-58 type

Polarized drainages work in the following way. If a difference of potentials between a protected cable and rails of a tram way will reach value 0,5 V, a current which flows in a circuit of a drainage from a cable circuit through a drainage coil DC, a coil BO, a rectifying device of germanium *D*, a fuse, a potentiometer, a switch, the second fuse to rails of a tram way, will induce drainage relay to switch which will close contacts 1 and 2. The current will flow through the drainage coil, the anchor, the switch, the fuse to rails of a tram way after that. The drainage relay is blocked and will keep the anchor as long as the current flows in this direction. If the rails potential is higher than that of the moisture protection covering of the cable, the current in the circuit of the drainage will change a direction, thus the drainage relay will release the anchor, the contacts 1 and 2 will be opened, the rectifying germanium device will not pass the current in the return direction, i.e. the current from the rails of the tram way to the moisture protection of the cable covering will not flow.

The circuit, ПЭД-58, is assembled in a metal box which can be mounted in a well, on a wall of a house or a ferro-concrete column near to a place of its connection to moisture protection of a cable covering. The unidirectional connection to the cable and rails should be carried out by the cable well insulated from the ground, which its wires parallel connected in points of connection to the device and to the moisture protection cable covering (cables of marks ТГ, ТВ, ТЗБ) and the rails of a tram way.

The basic circuit for a polarized drainage of type ПГД-200 which is included in the laboratory equipment is represented on fig. 9.3. The following is included into a circuit of drainage: a gate, diodes or a polarized relay which has a unidirectional conductivity. Thus the current flows only from a cable covering to a power supply of substation of an electrified railway or a tram way. A drainage equipment has a special relay which is connected in a parallel with a fuse. During a burning of a fuse a relay switches on, it locks a contact group and a signal about damage of a drainage equipment is transmitted on a station or a control item.

Use polarized drainages of type ПГД-200, ПГД-100, ПГД-60 for communication cables which have the maximal current drainage accordingly 200, 100 and 60 A. Maximum admissible voltage is 50, 100 and 150 V accordingly. Values of the maximal drainage current and as much as possible admissible voltage depend on type of diodes which are used in circuits of the drainage equipment.

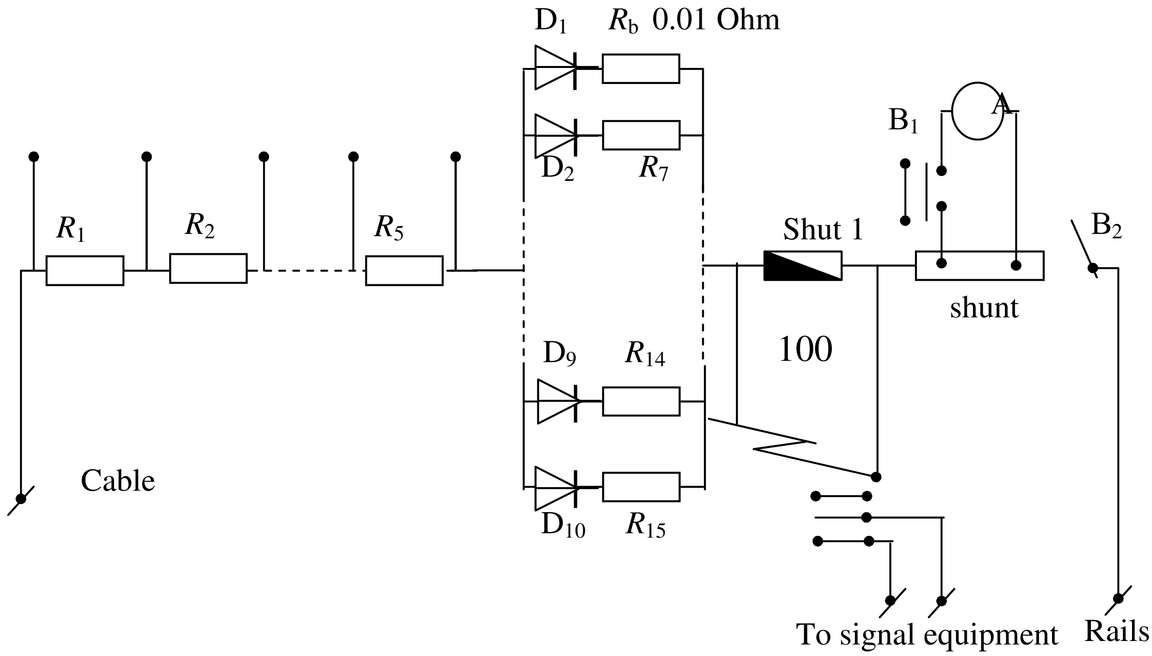


Figure 9.3 – Basic circuit for polarization drainage of ПГД -200 type

9.2.2 Protection by means of cathode equipment

A principle of protection for underground linear-cable constructions by means of cathode equipment consists of compensating a positive potential on a moisture protection cable covering (an anode zone) by a negative potential of a direct current source of, thus the necessary negative potential is created on the covering. The positive terminal of the DC source needs to be grounded.

A cathode equipment contains the following components: cathode stations, a source of electric power supply, control and adjusting devices, grounding and connecting (drainage) cables.

A basic circuit of a cathode station, KC-400, is on fig. 9.4.

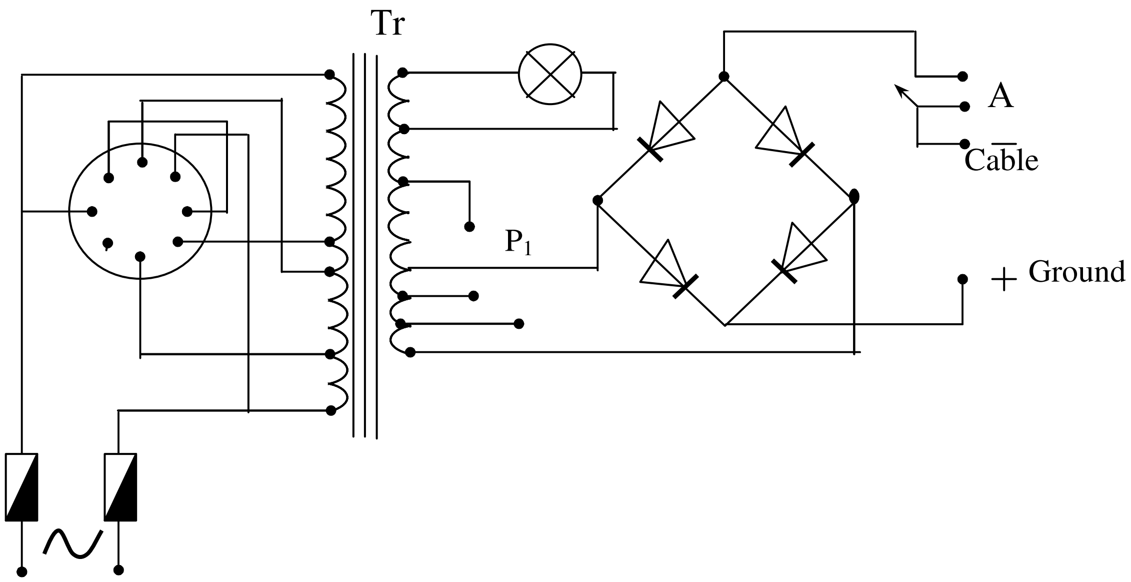


Figure 9.4 – Basic circuit of a cathode station

A rectifying bridge of diodes germanium and silicon is utilized as a source of a direct current. The rectifying bridge transforms an alternating current into a direct one. A power supply in cities is a DC city electric system which has a voltage 220 V. Generators with air engines pray be used in field conditions.

There are different types of cathode stations: КС-400, КСГ-500 and КСГ-1200 which have the maximal power of a direct current 400, 500 and 1200 W corresponding. Two-throe cathode stations per length of an amplifying or regenerating element are usually used to get necessary protection.

Except for this type's КС, there are cathode stations with an automatic control of the top limit of the negative potential over an underground linear-cable construction which is necessary for protecting discussed above. A polarized relay disconnects a power circuit for cathode station if a difference of potentials between a moisture protection covering of a cable and the ground reaches value U_{max} in circuits of such cathode stations. To maintain the necessary protective potential on a cable covering in the corresponding range ($U_{p\min}$-$U_{p\max}$) a more perfect automatic cathode station based on a magnetic amplifier is used.

9.2.3 Electrode protection (protectors)

Inherently an electrode protection is the same, as a protection by a cathode equipment. We use not a collateral source of a direct current, and a current which arises due to a difference of electrochemical potentials during connection of different metals in this case for creation of negative potential on a moisture protection covering of a cable. This current is directed from higher potential to lower. Thereof metal which has smaller potential collapses. Usually for protector electrodes use magnums alloys of ML which consist of magnesium, aluminum and zinc. The electrode represents the cylinder in length of (600...900) mm, diameter (150...240) mm with contact steel cores. We used three types of protectors: ПМ-5У, ПМ-10У and ПМ-20У. For reduction of corrosion of the electrode it place in different fillers (depolarizers).The scheme of protection of an environment of a cable by means of protector's electrodes is represented on fig. 9.5.

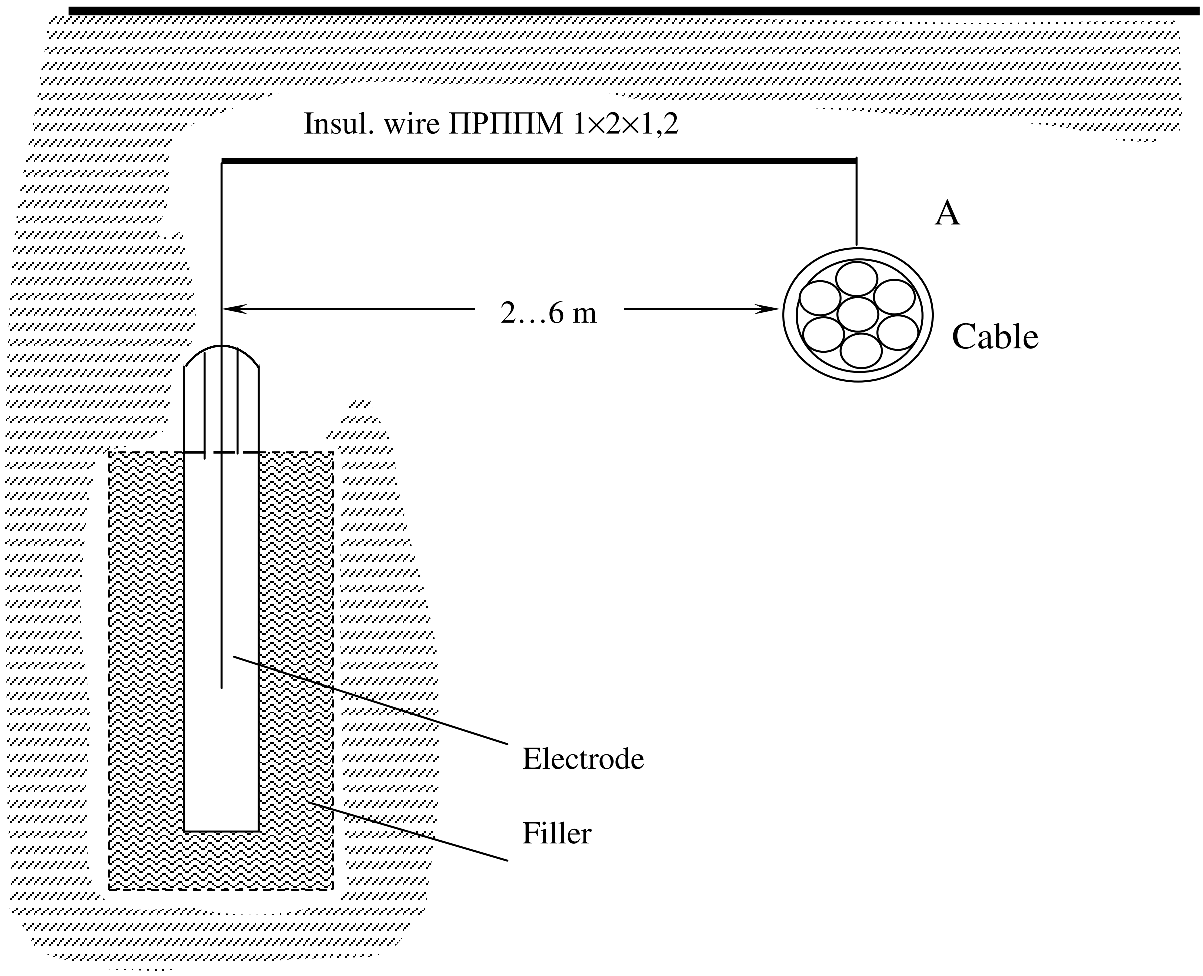


Figure 9.5 – Scheme of protection of a cable covering by means of protector electrodes

A principle of protection by of protectors consists of an anode zone creation on a moisture protection of cable covering as a result of connection by an insulated wire moisture protection covering and the grounded protection electrode which has lower electrochemical potential than a potential of the grounded moisture protection a cable covering. Such electrode becomes an anode, and the current will flow now out of the electrode in to the ground. The electrode will be subject to corrosion, and the cable covering becomes a cathode and, hence, is protected from influence of corrosion in such a way.

Protector electrodes are mainly used for protection against soil corrosion. Two-three of them are set per an amplifying or regenerating element, and also on unattended amplifying and regenerating points. A distance between electrodes and a cable has to be no shorter than (2...6) m, and operation depth (0,6...1,8) m. A protector has to be connected via control-test items (КТІ).

9.3 Not electric means of protection

9.3.1 Use nonmetallic moisture protection of a cable covering.

9.3.2 A waterproof layer of metal moisture protection covering and of armor by plastic compounds, such as polythene, polyvinyl chloride. A combined use of a waterproof covering together with protection by means of protector electrodes and the cathode equipment.

9.3.3 Bitumen covering of a cable.

9.3.4 Use of insulating adapters together with protector electrodes.

9.3.5 Maximum isolation of rails of a tram way and an electrified railway from the ground.

9.3.6 Using a spring suspension of a cable during transportation.

9.3.7 Lining of a cable in poorly aggressive soil.

Laboratory work № 11

STUDYING UNIFORM SOIL SPECIFIC RESISTANCE AND THE GROUND RESISTANCES

1 PURPOSE OF THE WORK

A studying the ground devices equipment used in communications and methodology for finding a uniform soil specific resistance and the ground resistances.

These work materials may be used for the laboratory work, for research and in a diploma project.

2 MAIN POSITIONS

Soil properties, as a current conductor, are parameterized by a soil electric specific resistance value, ρ_{gr} (Ohm·m), that is a resistance of a 1 m^3 of soil if current flows from one side of a soil cube to the other one; it depends on soil structure, its moisture and temperature, a solvable chemical substances presence (acids, buses, rotting products etc).

A definition of soil specific resistance is done to estimate its aggressiveness, a stray current calculation, an estimate of underground cable and other metallic constructions, that are placed in soil, corrosion state.

A soil resistance is one of the key parameters for estimation of cable damage possibility as a result of lightning strike, for finding external electromagnetic fields influence and choice of protection measures for them.

A soil specific resistance is one of parameters determining the ground resistance magnitude for:

– fixed line communication units that work for a circuit that includes the ground;
– lighting roads, dischargers, metal communication devices;
– metal coverings, cable screens and equipment screens.

A soil (ground and earths) is an electric current conductor, that has very large dimensions. It is widely utilized for operation of different electric units.

An electric coupling among parts of electric units and the ground is done by the ground devices. The ground device is a set of the ground units - conductors that are in direct contact with the ground and used for connection of electric device parts with it, and the ground conductors – metal conductors utilized for the electric device parts connection to the ground device.

Grounding of any electric device unit is its non-random connection with the ground device and makes sure a system or its units operate normally in their chosen regime.

Telephone, telegraph and intercity exchanges as well as amplification and regeneration stations and radiotransmission units have special station groundings, key types of these groundings are: working, protective, linear-protective and measuring ones.

Types, a number and value of station ground resistance is set by standard documents subject to an exchange type, an equipment power system, a linear construction type and a schedule of their initial construction at an exchange, a soil specific resistance and other parameter.

2.1 Measuring soil specific resistance by MC-08 device

A measurement circuit is on fig. 2.1. The following conditions have to be satisfied for the measurement:

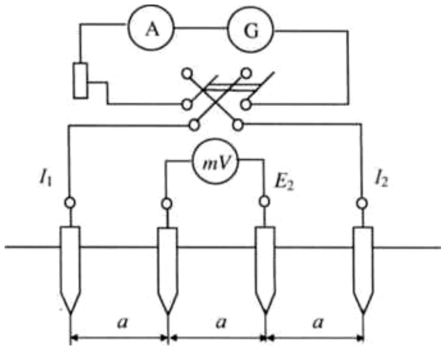


Figure 2.1 – A soil specific resistance measurement by MC-08 device circuit

– a distance between electrodes, *a,* has to be no shorter than double cable depth, *H* (0,8 – 1,2 m): *a*>2*H;*

– a depth of burying for the electrodes in soil, *h,* has to be no shorter than 1/20 of a distance between the electrodes (*h*> *a*/20, here *h* – a depth of burying for the electrodes in soil).

Measurement protocol:

2.1.1. Connect outer electrodes (current ones) to terminals I_1 and I_2 and inner ones (potential ones) – to terminals E_1 and E_2.

2.1.2. Remove a connector between the terminals I_1 and E_1.

2.1.3. Set an arrow of the device on a red mark by a potentiometer in a switch position “Per.” and rotating a knob with an approximate angular velocity 135 rot./min.

2.1.4. On the arrow coincide with the red scale mark, switch the measurement scale limits in one of the following positions: “×1” (at $R \geq 100$ Ohm), “×0,1” (at $R < 100$ Ohm) or “×0,01” (at $R < 10$ Ohm).

2.1.5. Take the measurement and write it, rotating a generator knob with a velocity 135 rot/min accounting for the factor. Calculate the soil specific resistance by a formula:

$$\rho_{gr} = 2\pi R a \quad (2.1)$$

here ρ_{gr} – a calculated value of the soil specific resistance, Ohm·m;

R – the device reading, Ohm;

a – distance between the grounds, m.

Note. You have to repeat the measurement several times for different a values. This will allow to find a soil structure in a measurement region.

Changing a distance between electrodes, i.e. increasing a power and a measuring circuits lengths we may get different ρ_3 values. If these values are approximately equal to each other therefore the soil is uniform at different depths; if the obtained values differ among themselves then an imaginary soil specific resistance value has to be determined by special curves (palettes).

2.2 Measurement the ground resistance by an MC-08 device

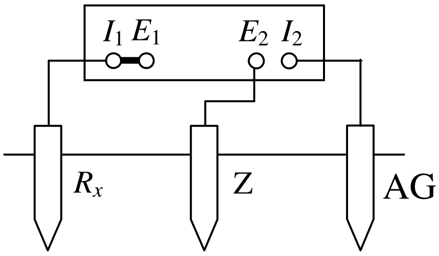


Figure 2.2 – Soil specific resistance measurement circuit by the MC-08 device

We need an auxiliary ground and a probe for the measurement positioned according to a fig. 2.2. The ground R_x to be tested is connected to terminals I_1 and E_1 connected by a wire. The auxiliary ground, AG, and the probe Z, are connected to terminals I_2 and E_2.

We have to do an offset of the probe resistance before the measurement by setting the corresponding switch "Per." Position and positioning the device arrow on the red scale mark with the generator knob rotation at 135 rot/min.

ATTENTION! You cannot rotate the generator knob at the switch position "Per." and disconnected grounds. You have to start the rotation slowly checking the arrow as it will hit a stopper sharply if a potential circuit is broken which may cause the device malfunction.

If you are unable set the red arrow on the red mark at the limiting potentiometer position and you connected the measurement circuit correctly then the probe resistance is higher than 1000 Ohm) that is possible, for example, in a dry sandy soil). You need to lower the probe resistance in this case.

On offsetting the probe resistance turn the switch into the position "×l" i.e. the 1000 Ohm limit and take the measurement by rotating the generator knob at 135 rot/min switch to the scales 100 Ohm (×0,l) and 10 Ohm (×0,0l) sequentially for small arrow deviations.

2.3 Soil specific resistance measurement by the M-416 device

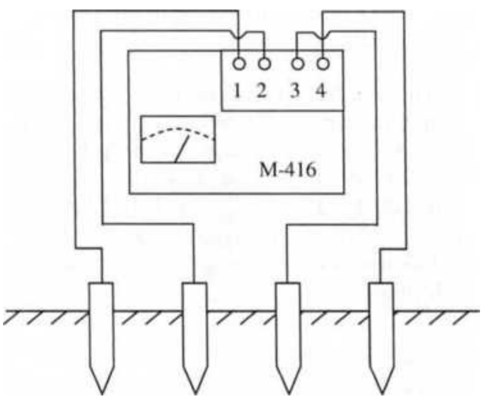


Figure 2.3 – Soil specific resistance measurement circuit by the M-416 device

A measurement circuit is on fig. 2.3.We have to follow conditions discussed in a chapter 1.1 of this guide for this measurement.

Get the device ready before taking the measurement. Turn the switch B_l in a position "Control 5", press a button and set the indicator arrow at zero position by rotating a knob "Reohord". We have to observe the reading 5,0±0,3 Ohm at the potentiometer scale.

Measurement protocol:

2.3.1 Set the switch B_l at the position "×l".

2.3.2 Press the button and get the maximal approach of the indicator arrow to the zero mark on the scale by rotating the knob "Reohord".

2.3.3 The measurement result equals a product of a potentiometer scale reading by a factor corresponding to a position of the switch B_l. If the measured resistance is higher than 10 Ohm then set the switch at a position “×5”, “×20” or “×100” and do steps according to p. 2 and 3.

On taking the device measurement, calculated a soil specific resistance by formula (2.1) accounting for a note discussed in the chapter 2.1.

Use the following formula in exceptional case for a soil specific resistance estimation:

$$\rho_3 = 2{,}73 R_e \frac{h}{lg \frac{4h}{d}}, \qquad (2.2)$$

here R_e – a resistance of electrode of known dimensions (could be found by a measurement with the circuit of the fig. 2.2 using the devices of type MC-08, and M-416 and analogous ones), Ohm;

h – a depth of electrode burying for measurement, m;

d – a diameter of the electrode, m;

ρ_{gr} – a soil specific resistance at a depth of the electrode position, Ohm·m.

2.4 Measuring a ground resistance by the M-416 device

A measured ground, an auxiliary electrode and a probe are connected to the device as on a fig. 2.4,a or 2.4,b. A result of measurement by the circuit of the fig. 2.4,a includes a resistance of wire that connects a clip with R_x. Therefore such connection is utilized if an accurate measurement is not necessary and for measurement of relatively high (higher than 1 Ohm) resistances.

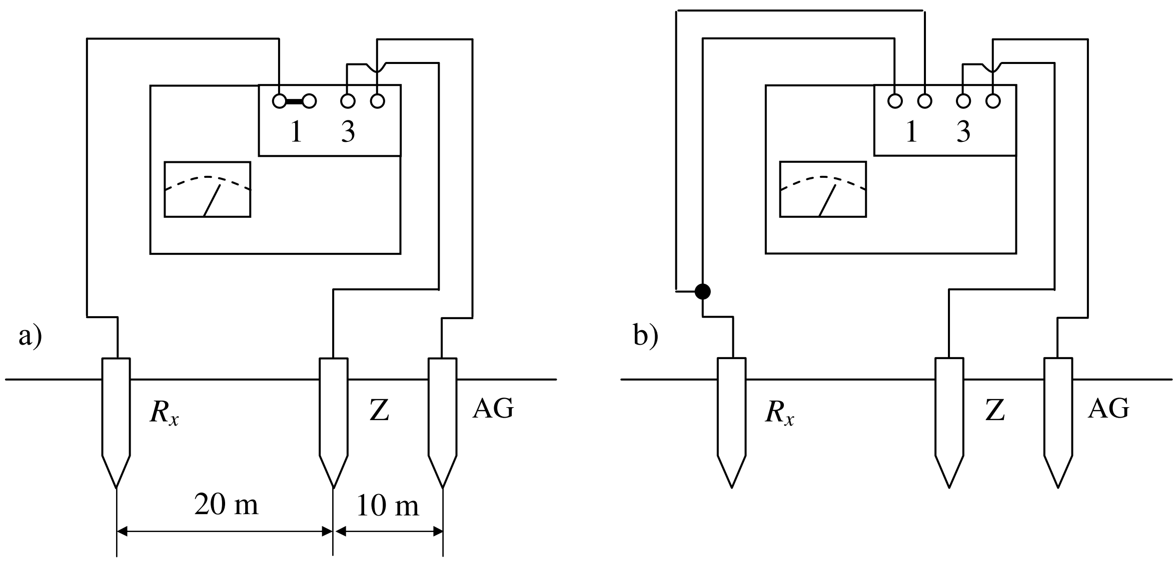


Figure 2.4 – A ground resistance measurement circuit by the M-416 device

A measurement protocol for any circuit is the same as that of for the soil specific resistance measurement (see chapter 2.3).

2.5 Estimation of ground resistance measurement error

Usually we find an error as a percent of a real value for measured quantity (a relative error).

If all measurement conditions are satisfied a relative measurement error is:

$$\delta = \delta_1 + \delta_{meas} \qquad (2.3)$$

here δ – a net relative measurement error;

δ_1 – a 5-percent error due to short distances of measuring electrodes;

δ_{meas} – a relative measurement error due to the ground measurer.

The relative measurement error is:

$$\delta_{meas} = \frac{\pm \Delta R_{gr}}{R_{gr}} \cdot 100, \qquad (2.4)$$

here ΔR_{gr} – the device error (the MC-08 device error is not higher than ±1,5 % of all scale length and that for M-416 is ±5 %);

R_{gr} – is a measured value of the ground resistance.

A measuring electrodes placement on a design map is a key factor for the *R* measurement result and is a key for the measurement. You should use electrode placement circuits as on fig. 2.5, 2.6 for measuring a complex grounds resistance measurement.

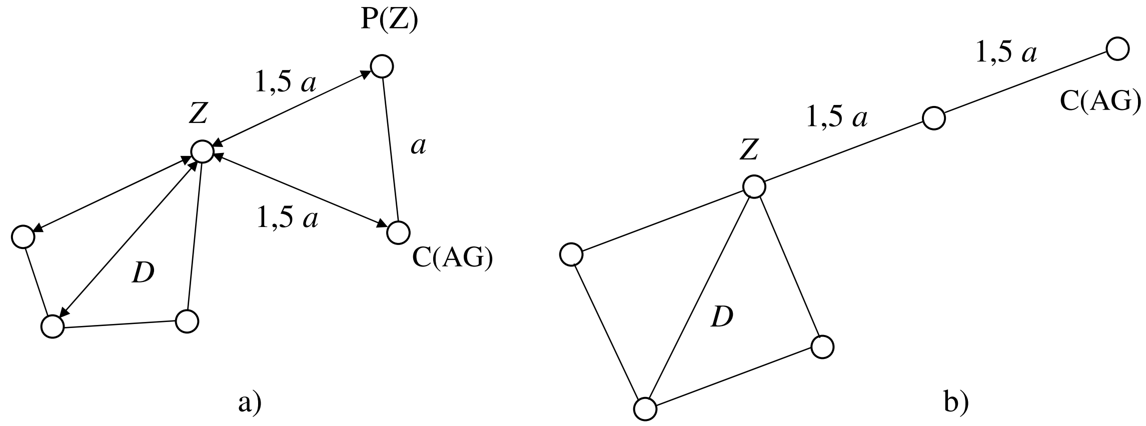


Figure 2.5 – Electrodes placement circuits for complex grounds and single horizontal stripes resistance measurements: a – two-ray, b – single-ray

Let us utilize the following value as *D*: a length of longer diagonal for the grounding nets and the grounds consisting of the grounding nets or a contour and vertical electrodes; a stripe length for the grounds consisting of series positioned vertical electrodes and linked by a horizontal stripe; a stripe length for the grounds as a single horizontal stripe. We choose a size a depending on a size *D* based on the following considerations: *D* > 20 m, a >*D*; 40 m > *D* >10 m; a > 40 m; 10 m > *D*, a ~ 20 m.

We should use electrode placement circuits of the fig. 2.5, a, b for measurement of single vertical grounds resistances and the circuit of the fig. 2.6,c,d for the grounds of lengths more than 6m.A distance *b* should be no shorter than 3*D*, here D – is the vertical ground length.

A relative measurement error due to short electrode distances for the circuits on the fig. 2.5 and 2.6 is no higher than ±5 %.

Measurements of distances between the electrode pairs and any given electrode and the ground have to be taken as accurately as possible by a 10 meter or longer ruler.

In case these conditions are not satisfied additional measurement errors are incurred. A number of prongs in one electrode depends on its required resistance and on a soil surface layer specific resistance. A single prong is enough in most cases for an installation of a potential electrode. We may need three-four or more of connected electrodes for a current electrode installation in dry, sandy or frosty soils. We should hit the prongs into a packed (non-sifted) soil at no less than 0,5 m depth. We moisten by water, soil solution, acid or pack regions of prong positions for high specific resistance soils.

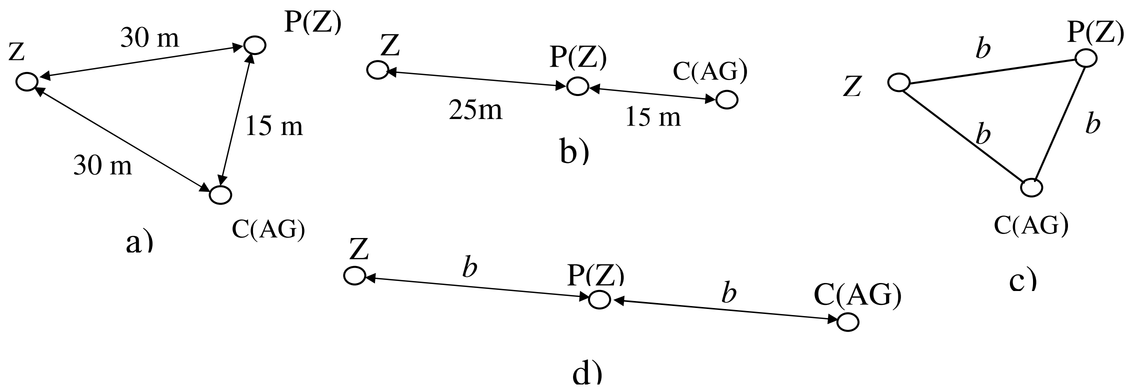


Figure 2.6 – Electrodes placement circuits for single vertical grounds:
a, c - two-ray; b, d – single-ray

2.6 Accounting for soil specific resistance and ground resistance seasonal changes

We measure ρ_{gr} typically at good soil conditions in warm time of the year. However ρ_{gr} for a seasonal changes layer turns out to be maximal in the summer at the highest soil dryness and in the winter at its highest freezing. Namely this maximal calculated value ρ_m is used in design. It is given by a formula:

$$\rho_m = K_i \rho_{gr} \qquad (2.5)$$

here ρ_m – a measured soil specific resistance value;

K_i – a seasonal soil factor, i – a climate zone number.

A ground resistance depends, in its turn, on a seasonal changes layer specific resistance ρ_{gr}. The latter is not constant throughout the year but changes subject to the soil condition.

Both ρ_{gr} and grounds' resistance values are maximal in the summer and in winter. According to standard, the ground (the ground device) resistance must not be higher. To get the maximally possible ground resistance (R_m) over a year one needs to multiply a measured at the current moment value R by a seasonal ground factor K_i'.

Depending on moisture in a seasonal changes layer we use the following factors: K_1, K_1' – a measurement is taken in a wet soil or if a lot of precipitation precedes a measurement moment; K_2, K_2'– for an average soil moisture and a normal precipitation a mount; K_3, K_3'– for dry soil and insignificant rainfall.

Seasonal soil factors and calculated width of seasonal changes layer, h_c, have definite values for every climate zone (tab. 9.1).

Climate zone are classified by average multiyear January temperatures (t° C) the first climate zone are regions with t° C in the boundaries from -14° to -10°, the third one are regions with t° C in the boundaries from -10° to 0°. The middle part of European region for AS is practically the second zone, its northern and southern parts are correspondingly the first and the third zones (the above excludes permanent frost, mountain regions and deserts).

Seasonal factors depend on types and dimensions of the grounds and a horizontal stripes' installation depth. Obviously, surface grounds resistances are subject to seasonal changes in a greater degree than deepened ones.

A single vertical ground seasonal factor values dependence on their length (l) and a distance from a soil surface to the ground highest point (h) and single horizontal stripes of length, l, seasonal factors values, the ground nets of surface, S, and combined grounds consisting of the ground net and series connected n vertical electrodes 5 m length each depending on stripe installation depth h, are in a tab. 9.2.

If a utilized ground parameters do not match ones listed in the tab. 9.2 we use a seasonal factor of the ground with type and dimensions the closest to the tested ground.

2.7 The ground device calculation and its design selection

The ground device resistance value depends on a soil specific resistance and a contact area of the grounds with soil.

Vertical and horizontal electrodes installed at a depth $(0,5\ -\ 1)$ m from an earth surface are utilized as the grounds.

Steel tubes, L-steel and round (rod) steel of length l = (2...10) m are utilized as vertical electrodes. The shortest allowable transverse dimensions are; a diameter d = 6 mm for round electrodes, a shelf size for L-steel b = 4 mm and a steel tube wall width b = 3,5 mm.

We use horizontal stripe grounds of ray circular or contour type as stand, alone grounds or as complex ground elements of horizontal and vertical electrodes. We use a stripe steel with a cross-section no less than 48 mm^2 and a width of 4mm, and a round steel of diameter no less than 10 mm.

The shortest transverse electrode dimensions are set by requirements of stable ground operation at corrosion conditions and may be increased subject to their sufficient mechanical strength at their installation in soil.

Tubular grounds are more widely utilized in practice, their resistance is the following:

$$R_3 = K_i' \frac{\rho_3}{2\pi l}(\ln\frac{2l}{d} + \frac{1}{2}\ln\frac{4l+7h}{l+7h}) \tag{2.6}$$

here h – a distance from an earth surface to a tube upper end, m;

ρ_3 – a soil specific resistance, Ohm-m;

K_i' – a freezing factor, accounting for soil temperature seasonal oscillations, it depends on a climate zone, its numerical value is from 1,15 to 3,8 (tab. 9.2).

R_{gr} – a tubular vertical ground resistance, Ohm;

l – tube length, m;

d – a tube outer diameter, m;

A vertical ground resistance made of L-steel is found using the same formula with the effective diameter d_r = 0,95b, here b –is a width of L-side, m.

A horizontal elongated metal stripe ground resistance installed at a depth, h, m is:

$$R_3 = K_i' \frac{\rho_3}{\pi l}\ln\frac{1,5l}{\sqrt{bh}}, \tag{2.7}$$

here R_3– a stripe ground resistance, Ohm;

l – the ground length, m;

b – a stripe width, m;

h– a stripe installation depth, m;

ρ_3 – a soil specific resistance, Ohm-m;

K_i' – is a soil freezing factor that is assumed to be from 1,8 to 8,0 for different climate zone (tab. 9.2).

Uniform soil vertical and horizontal electrodes resistances are found by formula of a tab. 2.1.

A single ground (a tube, a rod, a stripe, a ring, a plate etc.) may be insufficient in realistic conditions to yet low ground resistance values especially for high specific resistance soils. Therefore we would have to connect several unit grounds in parallel. Such ground device is called a multi electrode one.

We have to consider mutual screening effect i.e. lowering of net ground resistance not directly proportionally to a number of parallel connected grounds but a lightly slower dependence. The closer the grounds are to each other the stronger the screening. The total resistance of parallel connected equal resistance grounds of the grounds

$$R_{tot} = \frac{R}{n\eta_2}, \tag{2.8}$$

here R_{tot} – is a net multi electrode ground resistance, Ohm;

R – a unit ground resistance. Ohm;

n – a number of the grounds;

η_2– a utilization factor that depends on mutual positions and placement (tab. 9.3, 9.5, 9.6).

Table 2.1 – Electrode resistance calculations formulas

Electrode type	Electrode cross-section	
	Round (diameter d)	Bar (width b)
Vertical of length l	$R = K_i' \frac{\rho_3}{2\pi l}(\ln\frac{2l}{d} + \frac{1}{2}\ln\frac{4l+7h}{l+7h})$ Ohm $h \neq 0$	–
Horizontal of length	$R = K_i' \frac{\rho_3}{\pi l}\ln\frac{l}{\sqrt{dh}}$ Ohm $l >> d \quad h >> d$	$R = K_i' \frac{\rho_3}{\pi l}\ln\frac{1,5l}{\sqrt{bh}}$ Ohm $l >> b \quad h >> b$
Horizontal circular diameter D	$R = K_i' \frac{\rho_3}{\pi^2 D}\ln\frac{5D}{\sqrt{dh}}$ Ohm $h \neq 0$	$R = K_i' \frac{\rho_3}{\pi^2 D}\ln\frac{7D}{\sqrt{dh}}$ Ohm $h \neq 0$
Horizontal plate diameter D	$R = K_i' \frac{\rho_3}{4\pi D}(1 - \frac{2}{\pi}\arcsin\frac{D}{3h})$, Ohm $h \neq 0$	$R = K_i' \frac{\rho_3}{4\pi D_e}(1 - \frac{2}{\pi}\arcsin\frac{D_e}{3h})$, here $D_e = 2\sqrt{\frac{S}{\pi}}$, m; S – plate area, m^2

A total resistance of several vertical grounds with the same resistance that are connected in parallel by horizontal grounds (stripes or wires) is:

$$R_{tot} = \frac{R_1 R_2}{\eta_1 R_2 + \eta_2 R_1 n}, \tag{2.9}$$

here R_{tot} – is a net multi electrode ground resistance, Ohm;

R_1 – a horizontal ground resistance (a connecting stripe, a wire or a cord), Ohm;

R_2 – a single vertical ground resistance, Ohm;

n – a number of the grounds;

η_1, η_2 – utilization factors for the connecting wire and the grounds correspondingly (tab. 9.3 – 9.6).

A multiray ground resistance that consists of elongated single grounds positioned radially near earth's surface is:

$$R_3 = K_i' \frac{\rho_3}{\pi n l}\left[\ln\frac{4l}{d} - 1 + N(n)\right], \tag{2.10}$$

here l – a ray length, m;

p – a soil specific resistance, Ohm-m;

d – a wire diameter for the ray wire, m;

n – a number of rays;

$N(n)$ – a function of n (a tab. 2.2).

Table 2.2 – Dependence of N function value on a multielectrode ground ray number

n	2	3	4	6	8	12	100
$N(n)$	0,7	1,53	2,45	4,42	6,5	11,0	116

A protocol for design of the ground device selection is the following.

Find the ground device resistance value (tab. 2.7 – 2.11) according to instructor's assignment based on ГОСТ 464-68. Then select a cost-effective design of the ground device based on calculation with resistance lower or equal to standard one. We may select the ground device design by formulae for different design single electrodes (tab. 2.1) at the same valves of *l*, *b*, *d*, *h* if soils are low specific resistance ones. If soils are high specific ground device resistance standard we select the design using multieleclrode grounds formulae (2.8 – 2.10) at the same valves of *l*, *b*, *d*, *n*, *h*. We should find a connecting stripe or a wire ground resistance valve for R_{tot}, calculations by (2.9) formula using horizontal ray electrode expressions (tab. 2.1)

To connect the grounds we have to utilize a steel stripe of 40×4 mm cross-selection or a steel wire of 4,5 or 6 mm diameter. If R_{tot} calculated is higher than the standard one we have to increase the electrode number or the electrode length and repeat the calculation. An electrode installation depth and an electrode diameter effect in the ground resistance insignificantly in uniform soil therefore we should not change *h* and *d* values for R_{tot} recalculation.

3 KEY QUESTIONS

3.1 Types and purpose of transmissions line grounds

3.2 The ground resistance standards.

3.3 Features of the ground resistance measurement by MC-08 and M-416 devices.

3.4 Design of transmission lines lightning rods and the grounds.

3.5 Features of a uniform soil specific resistance measurement.

3.6 Seasons for taking measurements of soil specific resistance and the ground resistance.

3.7 Utilization factors for horizontal and vertical electrodes. Their dependencies on distance between electrodes and soil conductivity.

4 HOME TASK

4.1 Using the recommended literature for the laboratory work and this guide familiarize yourself with:

– purpose, types and designs of transmission line ground device;

– an operation principle and a usage guide for MC-08 and M-416 devices (chap. 6).

4.2 Learn the ground devices calculation protocol (chap. 2.2).

4.3 Prepare for the key questions of the chap 2.3 discussion.

5 LABORATORY TASK

5.1 Measure a soil specific resistance by the MC-08 and the M-416 devices at different distances between electrodes. Write the measurement results in a tab. 5.1 according to a given form.

Table 5.1 – Soil specific resistance measurement and calculation data

Number of measurement	1	2	3	4	5	6
Distance between the grounds, *a*						
The device reading, R, Ohm						
Soil specific resistance value, ρ_s, Ohm·m						

5.2 Measure resistances of round vertical and horizontal grounds by the MC-08 or the M-416 devices at:

– burying the grounds in soil with different specific resistance value;

– burying the grounds at different depths from a surface of uniform soil;

– different electrode sizes (d and l).

Plot the discussed ground resistances dependence on ρ_s, h, d, l graph based on the measurement data.

5.3 Calculate the ground resistance for verticals, horizontal, ray, horizontal-circular and horizontal-plate electrodes as assigned by an instructor. Set the ground's length constant for this calculation. Find diameters of the ray and the plate electrodes as $D = l/\pi$.

5.4 Calculate the ground device resistance based on instructor's initial data and select the ground device design.

6 EQUIPMENT

We use the device MC-08 or M-416 and a laboratory stand. A simplified circuit of the MC-08 device is on a fig. 6.1. A resistance measurer, MC-08, is utilized for the ground device and soil specific resistances measurements. We may use it for conductor resistance measurements, too. Resistance measurement bands are (0,1 – 100) Ohm.

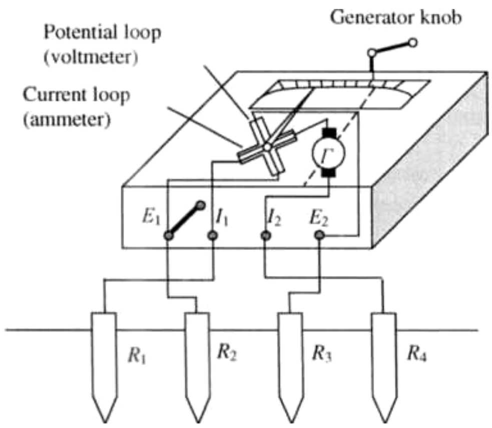


Figure 6.1 – Simplified circuit of MC-08 device

An ammeter-voltmeter method with an auxiliary ground and a potential electrode (a probe), that are distanced at least 20 m from the tested ground, is utilized I the device. The power source is a DC generator mounted in the device that is rotated manually. Two synchronous switches are mounted on a generator rotor (mechanical current transformations), that transform direct current into alternating one, for an outer circuit and back; alternating current is transformed into direct one for an indicator circuit. Therefore, AC flows in the measured ground circuit that excludes eddy currents and electrolysis influence on the measurement results. DC flows in the measuring device circuit permitting a usage of high sensitivity magneto electric radiometer system. An M-416 resistance meter is utilized for the measurements of the ground device resistance, active resistances and a soil specific resistance. Bounds of the measurement are (0,1 – 1000) Ohm.

An operation principle of the device is based on a compensation measurement methodology with an auxiliary ground and potential electrode (probe) usage.

7 CONTENT OF A REPORT

7.1 Basic measurement circuits.

7.2 A soil specific resistance measurement data written in a table.

7.3 A graph of vertical and horizontal grounds resistances dependence on ρ_s, h, d, l based on the measurement data.

7.4 The ground resistance calculation for four different electrode types.

7.5 Calculation confirming the ground device design selection.

8 REFERANCES

8.1. Гроднев И. И. Линии связи / И.И. Гроднев, Н.Д. Курбатов. – М.: Связь, 1980. – С. 314 – 315.

8.2. Справочник строителя кабельных сооружений связи / Под ред. И.С. Равича и др. – М.: Связь. 1977. – С. 626 – 635.

8.3. Руководство по проектированию, строительству и эксплуатации заземлений в установках проводной связи и радиотрансляционных узлов. – М.: Связь, 1971. – С. 88.

9 APPENDIX

9.1 Multielectrode grounds utilization factors

Table 9.1 – Seasonal soil factors and seasonal changes calculated layer width

Climate zone	h_c m	K_1	K_2	K_3
The first	2,2	7,0	4,0	2,7
The second	2,0	5,0	2,7	1,9
The third	1,8	4,0	2,0	1,5

Table 9.2 – Seasonal ground factors

Single vertical grounds						
The ground length l, m	$h = 0{,}7...0{,}8$ m			$h = 0$		
	K'_1	K'_2	K'_3	K'_1	K'_2	K'_3
2,5	2,00	1,75	1,50	3,80	3,00	2,30
3,5	1,60	1,40	1,30	2,10	1,90	1,60
5,0	1,30	1,23	1,15	1,60	1,45	1,30

Complex grounds							
The ground type	The ground dimensions	$h = 0{,}7...0{,}8$ m			$h = 0{,}5$ m		
		K'_1	K'_2	K'_3	K'_1	K'_2	K'_3
Horizontal stripe	$l = 5$ m $l = 20$ m	4,3 3,6	3,6 3,0	2,9 2,5	8,0 6,5	6,2 5,2	4,4 3,8
The grounding net of contour	$S = 400$ sq.m $S = 900$ sq.m $S = 3600$ sq.m	2,6 2,2 1,8	3,3 2,0 1,7	2,0 1,8 1,6	4,6 3,6 3,0	3,8 3,0 2,6	3,2 2,7 2,3
The ground type	The ground dimensions	$h = 0{,}7...0{,}8$ m			$h = 0{,}5$ m		
		K'_1	K'_2	K'_3	K'_1	K'_2	K'_3
The grounding net or a contour with vertical electrodes of l = 5 m	$S = 900$ sq.m $n \geq 10$ units $S = 3600$ sq.m $n \geq 15$ units	1,6 1,5	1,5 1,4	1,4 1,3	2,1 2,0	1,9 1,9	1,8 1,7

9.2. Various type and purpose ground resistance standards

A protection of air transmission line (ATL) poles is implemented by lightning rods installed on input, cable, control and transfer poles as well as ones previously damaged by thunder discharges. The ground resistance values have to meet standards in a tab. 9.7.

We protect linear constructions near an exchange by a cascade protection consisting of spark dischargers connected between the wire and the ground on ATL poles. The ground resistance must not exceed values in a tab. 9.8 in this case.

Table 9.3 – Utilization factors, η_2, for multielectrode grounds (without accounting for a connecting stripe influence) that consist of vertical electrodes

Ratio of distance between tubes to their length a/l	Multielectrode grounds			
	Positioned in series		Positioned along a closed contour	
	Number of tubes(*L*-elements) n	η_2	Number of tubes (*L*-elements) n	η_2
1	2 3 5 10 15	0,84-0,87 0,76-0,80 0,67-0,72 0,56-0,62 0,51-0,56	4 6 10 20 60	0,66-0,72 0,58-0,65 0,52-0,58 0,44-0,50 0,36-0,42

	20	0,47-0,52	100	0,33-0,39
2	2	0,90-0,92	4	0,76-0,80
	3	0,85-0,88	6	0,71-0,75
	5	0,79-0,83	10	0,66-0,71
	10	0,72-0,77	20	0,61-0,66
	15	0,66-0,73	60	0,52-0,58
	20	0,65-0,70	100	0,49-0,55
3	2	0,93-0,95	4	0,84-0,86
	3	0,90-0,92	6	0,78-0,82
	5	0,85-0,88	10	0,74-0,78
	10	0,79-0,83	20	0,68-0,73
	15	0,76-0,80	60	0,62-0,67
	20	0,74-0,79	100	0,59-0,65

Table 9.4 – Utilization factors, η_2, of a connecting stripe for a series of vertical grounds or for their contour position

Ratio of distance between tubes (L- elements) to their length a/l	Number of tubes in a series or a contour						
	4	5	8	10	20	30	50
	Connecting stripe utilization factors for a series lube positioning						
1	0,77	0,74	0,67	0,62	0,42	0,31	0,21
2	0,89	0,86	0,79	0,75	0,56	0,46	0,36
3	0,92	0,90	0,85	0,82	0,68	0,58	0,49
	Connecting stripe utilization factors for a closed contour tube position						
1	0,45	0,40	0,36	0,34	0,27	0,24	0,21
2	0,55	0,48	0,43	0,40	0,32	0,30	0,28
3	0,70	0,64	0,60	0,56	0,45	0,41	0,37

The ground resistance for dischargers in cable cabinets installed for cable inputs has to meet a tab. 9.9 data.

Values of work and protective grounds resistances that are connected to dischargers of cascade protection, ИР-0,2 and ИР-0,3 types according to protection circuits have to be no more than 5 Ohm.

Table 9.5 – Utilization factors, η_2, for a multiray ground that consists of elongated single grounds placed in a radial direction

Ray length, m	Utilization factors for a ray number											
	3				4				6			
	and a ray conductor diameter, cm											
	1	2	3	4	1	2	3	4	1	2	3	4
2,5	0,76	0,74	0,72	0,71	0,63	0,61	0,59	0,58	0,50	0,48	0,46	0,45
5,0	0,78	0,76	0,74	0,73	0,67	0,65	0,63	0,62	0,53	0,51	0,49	0,48
10,0	0,81	0,79	0,77	0,76	0,70	0,69	0,67	0,66	0,57	0,55	0,53	0,51
15,0	0,82	0,80	0,78	0,76	0,72	0,70	0,68	0,66	0,59	0,57	0,55	0,53
30,0	0,84	0,82	0,80	0,78	0,75	0,73	0,71	0,69	0,62	0,60	0,58	0,56

Table 9.6 – Utilization factors, η_2, for multielcctrode grounds consisting of stripe plate grounds that are parallel connected to each other

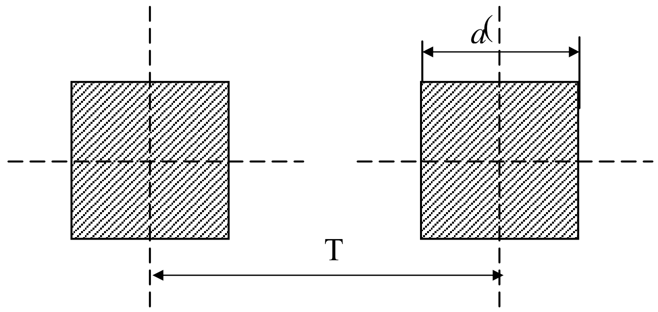
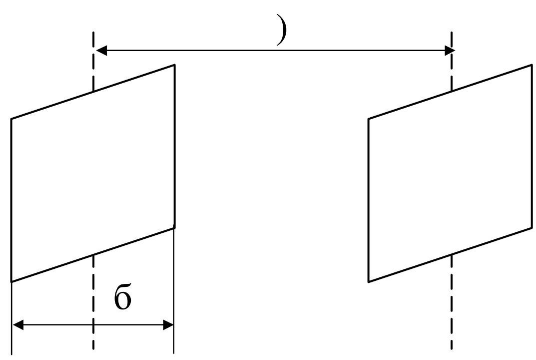
The ground type	n	Value for η_2>2	
		$d = 4a$	$d = 2a$
	2	0,66	0,62
	4	0,52	0,38
	6	0,43	0,30
	8	0,40	0,27
	10	0,39	0,25
	2	0,75	0,67
	4	0,60	0,46
	6	0,55	0,38
	8	0,54	0,35
	10	0,52	0,32

Table 9.7 – The ground resistance values standards

ρ_{gr}, Ohm·m	up 100	101 – 200	201 – 400	401 – 500	501 and more
The ground resistance, Ohm	50	45	65	90	115

Table 9.8 – The ground resistances' values

The ground purpose	Soil specific resistance, Ohm·m			
	up 100	101 – 300	301 – 500	more than 500
For ATL spark dischargers	20	30	35	45
For spark dischargers installed at cable boxes	5	7	9	12
For the grounds A3Y-1 and A3Y-2 connected in UTN and RTN	10	15	18	24

Table 9.9 – The ground resistance values for dischargers in cable cabinets

Soil specific resistance, Ohm-m	At wire number inputted in a cable cabinet			For any sea or river cable wire number
	up 10	11 – 20	21 and more	
	The ground resistance. Ohm			
Up to 100 (black earth, peat, clay, loom)	30	16	13	6
101-300 (sandy loom)	40	20	17	7
301-500 (sand)	50	30	24	10
500 and more (rocky soil)	67	37	30	12

A measuring ground resistance value has to be no more than 100 Ohm.

We assemble two grounds – working and protection (linear protection) ones for NRP that are powered remotely by a "wire-ground" system; their R_{gr} values are in a tab. 9.10.

Table 9.10 – NRP ground resistances values

The ground type	Soil specific resistance, Ohm-m	Resistance standard, Ohm
Working	< 100	10
	≥ 100	30
Protective	< 300	10
	≥ 300	30

9.3 Tube dimensions, used for groundings

We use (25 – 40) mm diameter tubes for soft and average soils, (40 – 60) mm diameter ones for hard soils. The tube length is (1,5 – 3) m. Transverse tube dimensions are in tab. 9.11.

Table 9.11 – Transverse tube dimensions

Inner tube diameter	In inches	¾"	1"	1 ¼ "	1 ½ "	2"
	mm	20	25	32	40	60
Outer tube diameter	mm	26,75	33,5	42,25	48	70

Laboratory work № 12

STUDYING A NON-UNIFORM SOIL SPECIFIC RESISTANCE AND A GROUND RESISTANCE

1 PURPOSE OF THE WORK

Learning multilayer soil specific resistance measurement methods and its calculation. Finding a ground resistance accounting for a realistic geological structure of soil. Materials of this work maybe used for laboratory, research work and in a diploma project.

2 MAIN POSITIONS

It is important to know a specific soil resistance ρ_{gr} (an earth). We need to know a ρ_{gr} value for some tests periodically done on transmission lines. Standards of limit acceptable ground resistance values, for example, are given based on a ρ_{gr} magnitude.

A ρ_{gr} soil electric structure is non-uniform. A ρ_s value changes with as depth does. A standard model for a soil is a hemisphere with horizontal layers so that ρ does not change within each layer. There are two-, three- and multi-layer structures of soil but most typically three-layer ones in realistic conditions. A uniform soil structure is very rare. An electric soil structure is characterized by a number of layers with uniform ρ_{gr}, widths h_i and values ρ_i for each layer (fig. 2.1).

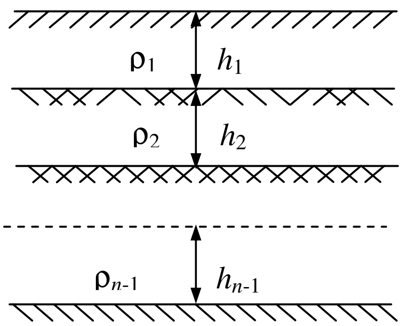


Figure 2.1 – An electric structure of a multilayer soil

Soil layers are media with complex structure. Key soil layer components are inorganic and organic solid particles as well as water. The most typical soils are sand, clay and humus ones; their structure and composition vary significantly among themselves.

Due to high electrolyte ratio of clay and humus soil and their higher moisture capacity than sand, their specific resistance for the same atmospheric conditions is always significantly lower and also more stable. There fore ground elements are positioned typically in these soils.

Not only a soil layer where a ground is but also lower layers influence electric ground parameters.

A soil with a ground is non-uniform in vertical direction due to its geological structure, water composition etc. Besides, a soil temperature, a composition and physical state of soil moisture, a saturation of its different layers change throughout a year with atmospheric conditions change. Therefore a several meter depth soil specific resistance in a so called seasonal changes layer oscillates significantly increasing via a winter earth freezing.

A ground design needs to be implemented taking into account soil non-uniform structure. To do this a specific resistance of different vertical soil layers is found by a vertical electrical probe (VEP) based on direct measurement results [8.1].

2.1 Finding a specific soil resistance by VEP methodology

There is a number of specific soil resistance, measurement methodologies but typically two of them are utilized: an inductive one using an ac and a four electrode methodology using a dc. An inductive methodology measurement is taken either on two single wire (influencing) line and a grid influenced by this line [8.2]. However these inductive measurement, types are cumbersome and inconvenient as they require a (2 – 3) km length influencing line, a generator and specialized measurement devices. The four electrode methodology (the VEP methodology) does not have these drawbacks.

It permits to determine soil electric properties up to large vertical distances with generally good results.

A VEP methodology physical essence is based on a dependence of a vertical soil specific resistance distribution and an electric current point source (in this case – electrodes) potentials distribution over a soil surface. Potentials are induced at different points of a ground surface due to an electric current flow between feeding (current) electrodes A and B (fig. 2.2, a).

A voltage drop, *U*, is induced between the other two ground points where receiving (potential) electrodes M and N are placed, which allows to find ρ_{gr}.

We calculate a measured specific resistance ρ_{gr}:

$$\rho_{gr} = k_d \frac{U}{I} = k_d R_{meas}, \tag{2.1}$$

here ρ_{gr} – a measured specific ground resistance, Ohm·m;

R_{meas} – an apparatus reading, Ohm;

U – a voltage drop measured between the middle electrodes *M* and *N*;

I – a measured current value;

k_d – a device factor dependent on a distance between the electrodes.

A *k* factor value is given by an expression:

$$k_d = \pi \frac{AM \cdot AN}{MN}, \tag{2.2}$$

here *AM*, *AN*, *MN* – are distances between the corresponding electrodes.

The expression (1) yields a true ρ_{gr} value for a uniform soil composition. A result is some conventional quantity for a non-uniform soil, called a conventional specific electric soil resistance (ρ_k). A value ρ_k has a complex dependence on a distance between electrodes, specific conductivities and layer widths within a measured element.

A vertical electric probing is taking a number of measurement, ρ_k, in the same place by a four wire circuit with different distances between feeding electrodes. Different four wire circuits are utilized that vary by distances between electrodes. The most widespread ones are Schlumberger, Wenner and ASEARI (All State Energy and Agriculture Research Institute) circuits [8.1].

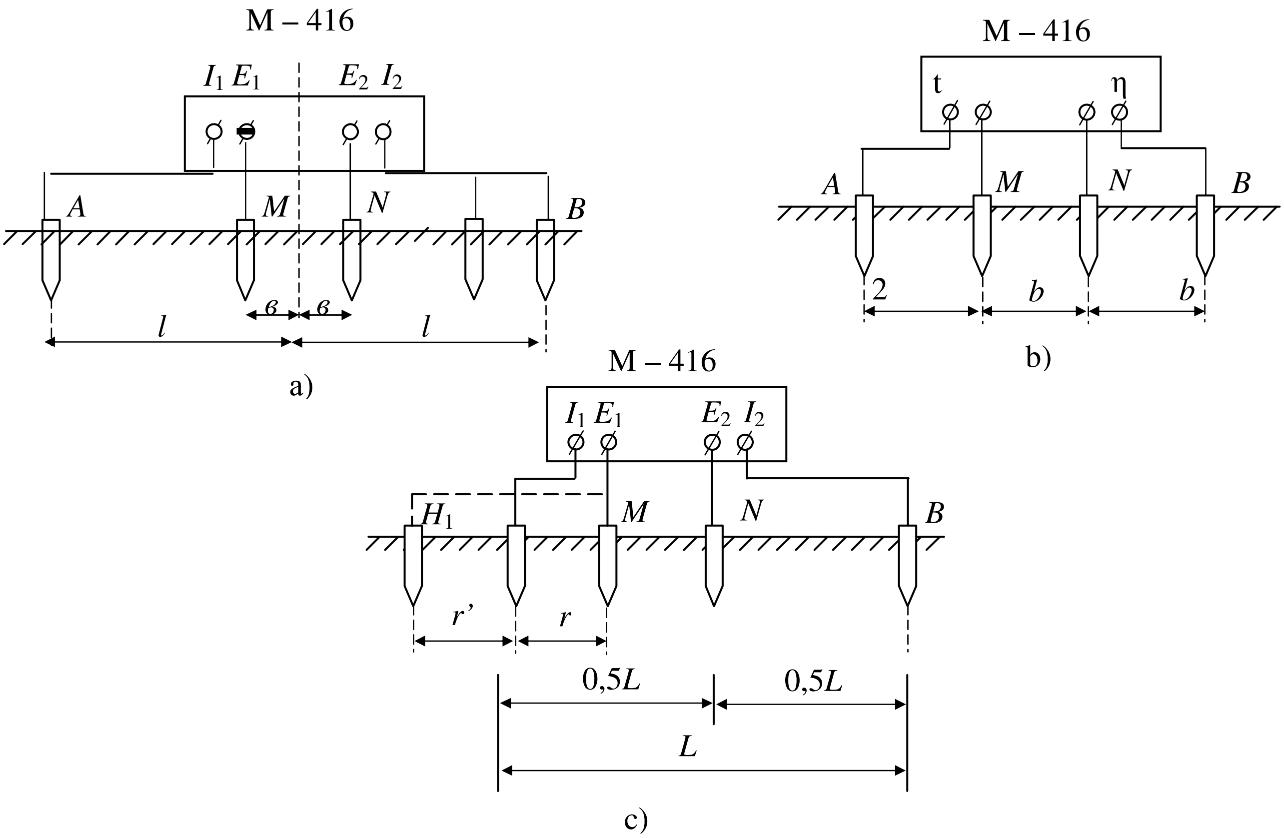


Figure 2.2 – A VEP circuit with M-416 ground measurer:
a – Schlumberger, *b* – Wenner,
c – ASRIERA (All-State Research Institute of Energy and Rural Agriculture)

A distance between receiving electrodes for Schlumberger circuit is definite ($b = MN \le AB/3$), and a measurement is taken by separating feeding electrodes. A device reading decreases significantly faster after each consecutive measurement in Schlumberger circuit than in a work process by Wenner circuit which increases a measurement error. Thus, one to switches to switches to taking measurements by Wenner circuit on reaching a distance between current electrodes *A* and *B* equal to (20 – 50) m therefore, Schlumberger methodology yields high accuracy for a short distance between Schlumberger circuit (see the fig. 2.2, a) is given by a formula (1), with

$$k_d = \frac{\pi(l^2 - b^2)}{4b}, \tag{2.3}$$

here $l = \dfrac{AB}{2}$, $b = \dfrac{MN}{2}$ – are a distances from a symmetry center to a current and a potential electrodes correspondingly, in m.

Each measurement is taken for a different distance between the electrodes and the center of measurement however a distance between the electrodes stays always the same (*AM=MN=MB=b*). *k* is the following for an electrode symmetric setup in Wenner circuit:

$$k_d = 2\pi b. \tag{2.4}$$

A drawback of Wenner circuit is a need to move all four electrodes relative to a measurement center after each measurement.

A single electrode is displaced to the left or to the right of an electrode A in a soil measurement with a practical two-electrode VEP circuit designed by ASEARI (fig. 2.2, c).

Here H_1A may very from 0,5 to 2*L* m range, and a distance *MA* does from 0,5 to 0,4*L*.

The ASEARI circuit is more cost effective. *k* is the following for a movement of an electrode H_1 to the left of an electrode *A* in a ρ_k measurement by ASEARI circuit:

$$k_{\text{left}} = 2\pi r`\left(1 - \frac{r`}{L}\right), \tag{2.5}$$

for a movement of the electrode H_1 to the right of the electrode *A*:

$$k_{\text{right}} = 2\pi r\left(1 - \frac{r}{L - 2r}\right), \tag{2.6}$$

here *r'*, *r*, *L* – are distances, m, represented in the circuit of the figure 2.2,c.

A ρ_{gr} finding is done in two stages:

1) electric measurements are taken at an earth surface and a VEP curve is plotted based on these measurements data;

2) an electric soil composition is found by interpreting (decyphen'ng) a VEP curve: a number of soil layers, with uniform ρ, a width (a thickness) and a value ρ_i for each layer.

To get necessary data set measurements need to be taken for the following distances between electrodes: *A* and *B*: 1,5; 2,1; 3; 4,5; 6; 9; 12; 15; 21; 50; 45; 60; 90; 120; 150; 210; 300; … m for Wenner and Schlumberger circuits usage; *M* and *A*: 0,5; 0,7; 0,9; 1,2; 1,6 m etc for ASEARI circuit utilization.

All external circuit resistances and tuning requirements need to be satisfied in taking VEP with the ground measurer M-416.

2.2 Finding multilayer soil electric parameters

We need to start a VEP results processing right after finishing measurements, as additional or repeating measurements may be required.

The following dependencies are consequence of the performed, ρ_k, calculations:

– for Schlumberger circuit measurements $\rho_k = f(AB/2) = f(l)$,

– for Wenner circuit measurements $\rho_k = f_1(AB/3) = f_1(1{,}5\, b)$,

– for ASEARI circuit measurements $\rho_k = f_2(r)$.

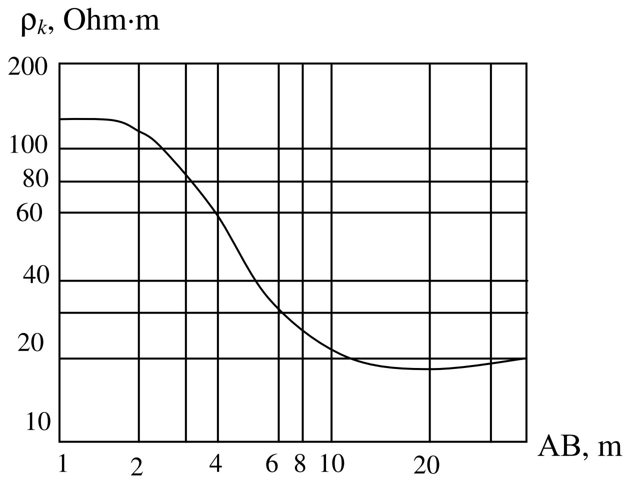


Figure 2.3 – VEP curve

These dependencies are represented graphically for a subsequent processing in rectangular coordinates with a logarithmic scale along each of the axes. Graphs of experimental dependencies $\rho_k = f(l)$; $\rho_k = f_1(1{,}5\ b)$ and $\rho_k = f_2(r)$ are called VEP curves. A bilogarithmic paper with a standard scale (a length of a logarithmic unit equals 6,25 cm) is used. A fig. 2.3 shows an example of plotting an example of a VEP curve.

An interpretation of an obtained experimental VEP curve is done to find an electric soil structure. The VEP curve is compared with a set of theoretical curves for this that are calculated for known electric soil structures. Such curve sets are called templates. There are two-layer, three-layer and other templates. For example, values of ρ_2/ρ_1 and c_3 are listed in a three-layer every template index besides a letter for the template serial type. Digits near each curve denote h_2/h_1 value; e.g., if we consider a palette $A-3/2-\infty$, a curve 2:*A* – is the template serial number, 3/2 – is a ρ_2/ρ_1 ratio, ∞ – is a ρ_{gr} value and 2-is a h_2/h_1 ratio. If a VEP curve coincides with any of the computed curves (e.g. for a two-layer template), may be positioned between two adjacent curves, then we need to assume that a studied soil electric structure is a two-layer one.

A protocol for a VEP curve interpretation is the following.

A tracing paper with a VEP curve on it, coordinate axes and scales is set on a template. The tracing paper is displaced keeping the VEP curve axes and the template parallel until the VEP curve matches any of computed curves or positions between two adjacent curves (fig. 2.4).

Then an x-axis 3 of a template intersection with a vertical axis of VEP curve yields a top layer specific resistance value, ρ_1 and a Y-axis 4 of a template intersection with a horizontal axis of a VEP curve yields a width h_1 of a top layer.

On multiplying by ratio ρ_1/ρ_2 (listed in a chosen template index) we get the second layer specific resistance value.

Then we find second layer depth, h_2, multiplying h_1 by the curve index (given on the tracing paper) and h_3 is assumed to be equal to ∞ for a three-layer soil $h_2 = \infty$ for a two-layer soil.

If a measured curve is not identical to any of template curves and is between adjacent curves then ρ_1, h_1 values are found as discussed above and ρ_2, ρ_{gr} and h_2 values are determined by an interpolation of two adjacent template curves for ŕl and h magnitudes.

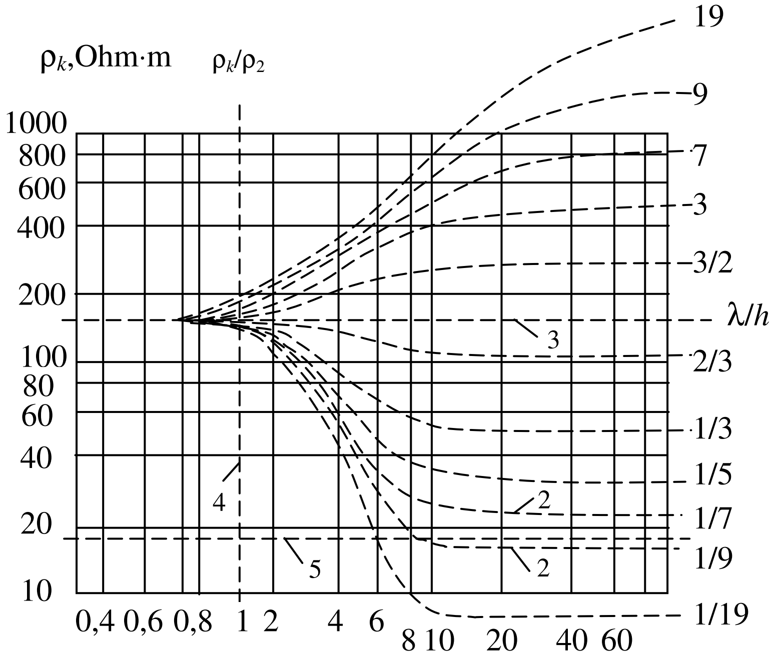


Figure 2.4 – Finding soil parameters by VEP curves with templates for a two-layer electric structure: 1 – VEP curve, 2 – templates, 3 – x-axis, 4 – y-template axis, 5 – asymptotic

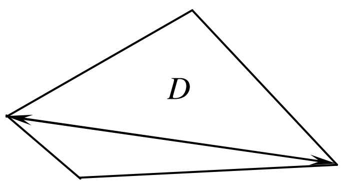


Figure 2.5 – A complex multi-electrode ground electrode placement schematic diagram

A vertical electric probing is taken until a necessary probing depth, H, is reached, a sharp VEP curve is obtained and a device works at its limit.

Approximately,

$$H = \frac{1}{3} AB . \qquad (2.7)$$

A necessary probing vertical distance approximately equals 1,5D (fig. 2.5), here D – is a ground contour great diagonal.

2.3 Multilayer soil resistance calculation

A soil is multilayered in reality; however, we may assume that it is a two-layer structure for practical calculation. To do this the second soil layer and lower ones are reduced to an equivalent layer by a formula (9) and a methodology for consecutive reduction of two lower realistic layers to a uniform equivalent one, and then of the this equivalent one and the next realistic one to a new equivalent one etc. If a soil in a ground positioning region has apparently a two layer structure or reduced to a two layer structure with the equivalent second layer then we need to utilize an effective specific resistance and use formulae in tab. 2.1 for a uniform soil for a ground resistance calculation.

Note. The following notation is used in tab. 2.1 formula: ρ_S – a soil specific resistance, Ohm·m; l – a ground length, m; d – a tube outer diameter, m; b – a L steel ground side width, m; D_1 – a circular ground diameter, m; h_1 – the first layer depth, m; ρ_i – the i-th layer specific resistance, Ohm·m; k – a non-uniformity factor, $k = (\rho_2 - \rho_1)/(\rho_2 + \rho_1)$.

Graphs of soil effective specific resistance values are represented on a fig. 2.6 for tubular grounds and on fig. 2.7 and 2.8 for horizontal grounds at different values of ρ_1/ρ_2 and $k = (\rho_2 - \rho_1)/(\rho_1 + \rho_2)$.

A work with grounds in layered soils implies that the higher a soil conductivity where a ground is positioned the better it functions. Ground efficiency with its correct positioning may be increased by factor of 3 – 5 or greater. Very long tubes should be utilized if lower layer conductivity is 3 – 10 times higher than that of an upper one, so that one such tube may be more effective than a number of shorter length tubes.

Table 2.1 – Ground resistance finding calculation formula

Electrode type	Depth	Electrode cross-section: circular (diameter, d)	Electrode cross-section: rectangular (width, b)
Vertical of length l in a uniform soil	$h = 0$	$R = \frac{\rho_{gr}}{2\pi l} \ln \frac{4l}{d}$, Ohm	–
	$h \neq 0$	$R = \frac{\rho_{gr}}{2\pi l}\left(\ln\frac{2l}{d} + \frac{1}{2}\ln\frac{4l+7h}{l+7h}\right)$, Ohm	–
Horizontal rod of length l in a uniform soil	$h = 0$	$R = \frac{\rho_{gr}}{\pi l} \ln \frac{2l}{d}$, Ohm	$R = \frac{\rho_{gr}}{\pi l} \ln \frac{4l}{b}$, Ohm
	$h \neq 0$	$R = \frac{\rho_{gr}}{\pi l} \ln \frac{l}{\sqrt{dh}}$, Ohm	$R = \frac{\rho_{gr}}{\pi l} \ln \frac{1{,}5l}{\sqrt{bh}}$, Ohm
Horizontal circular of diameter D_1 in a uniform soil	$h \neq 0$	$R = \frac{\rho_{gr}}{\pi^2 D_1} \ln \frac{5D_1}{\sqrt{dh}}$, Ohm	$R = \frac{\rho_{gr}}{\pi^2 D_1} \ln \frac{7D_1}{\sqrt{bh}}$, Ohm
Vertical of length l in a two-layer soil	$h = 0$	$R = \frac{\rho_1}{2\pi l} \cdot \frac{1+k}{1+k\left(\frac{2h_1}{l} - 1\right)} \cdot \left[\ln\frac{4l}{d} + \sum_{n=1}^{\infty} k^n \ln\frac{l + 2h_1 n}{l + 2h_1(n-1)}\right]$, Ohm	–

It makes sense to use subsurface (from 5 to 10m) and deep (over 10 m) grounds that yields to a significant cost, labor and materials savings.

A key factor for stripe grounds is a stripe laying depth. One short stripe with its conductivity may be equivalent to a 4 times longer stripe for the corresponding laying depth.

A deep single rod ground resistance starting on a soil surface for its two layer structure is given by the formula in the tab. 2.1, for oriented calculation by an expression

$$R_{gr}=\frac{1}{2\pi\left[\frac{h_1}{\rho_1}+(l-h_1)\frac{1}{\rho_2}\right]}\ln\frac{4l}{d}, \qquad (2.8)$$

here R_{gr} – is a ground resistance, Ohm;

ρ_1, ρ_2 – are specific resistances of upper and lower layers respectively, Ohm·m;

h_1 – is upper layer depth, m; l – a ground length, m; d – a ground diameter, m.

The formula (8) works well if $l/n \geq 1{,}5$.

$1-\frac{\rho_1}{\rho_2}=\frac{1}{100}$ for k = 0,98;

$2-\frac{\rho_1}{\rho_2}=\frac{1}{10}$ for k = 0,818;

$3-\frac{\rho_1}{\rho_2}=\frac{1}{10}$ for k = 0,667;

$4-\frac{\rho_1}{\rho_2}=\frac{1}{5}$ for k = 0,667;

$5-\frac{\rho_1}{\rho_2}=\frac{1}{3}$ for k = 0,500;

$6-\frac{\rho_1}{\rho_2}=\frac{1}{2}$ for k = 0,333;

$7-\frac{\rho_1}{\rho_2}=1$ for k = 0;

$8-\frac{\rho_1}{\rho_2}=2$ for k = -0,333;

$9-\frac{\rho_1}{\rho_2}=3$ for k = -0,500;

$10-\frac{\rho_1}{\rho_2}=5$ for k = -0,667;

$11-\frac{\rho_1}{\rho_2}=10$ for k = -0,818;

$12-\frac{\rho_1}{\rho_2}=100$ for k = -0,98.

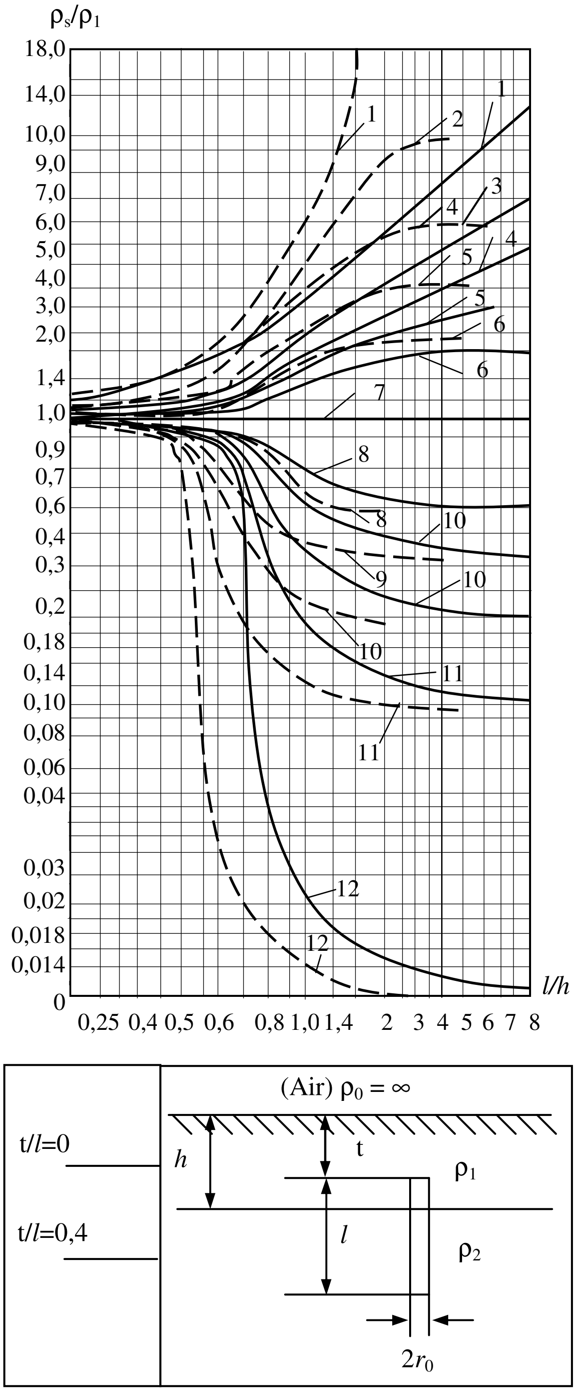
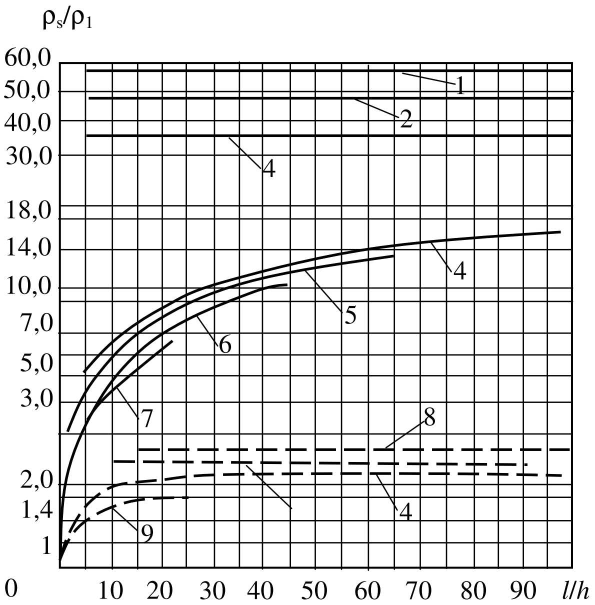


Figure 2.6 – Graph of change acting soil resistivity for tubular grounding

3 KEY QUESTIONS

3.1 A physical essence of a soil vertical electric probing methodology.
3.2 VEP measurements schematic diagrams.
3.3 A VEP curve interpretation protocol.
3.4 An effective specific resistance of soil finding methodology.
3.5 A subsurface grounds calculation protocol.
3.6 A multilayer soil deep ground calculation methodology.



ρ_1/ρ_2	*K*	Notat.
1/3	0,500	– – –
1/100	0,980	——

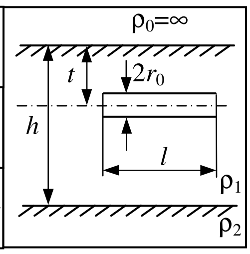
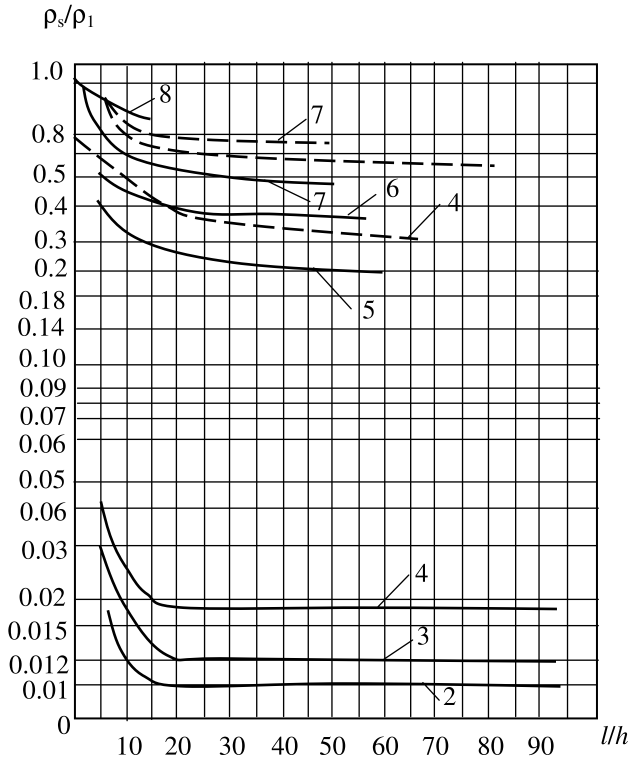


Figure 2.7 – An effective soil specific resistance values graph for horizontal grounds at different *t/h* ratios and *k>0*:
1 - *t/h* = 2; 2 - *t/h* = 1,5;
3 - *t/h* = 1,1; 4 - *t/ h* = 1;
5 - *t/ h* = 0,8; 6 - *t/ h* = 0,4;
7 - *t/ h* = 0,2; 8 - *t/ h* ≥1,5;
9 - *t/ h* ≤0,4.



ρ_1/ρ_2	K	Notat.
3	-0,5	– – –
10	0,98	——

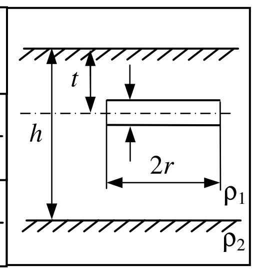


Figure 2.8 – An effective soil specific resistance values graph for horizontal grounds at different *t/h* ratios and *k<0*:
2 - *t/h* ≥ 1,5; 3 - *t/h* = 1,1;
4 - *t/h* = 1,0; 5 - *t/ h* = 0,9;
6 - *t/ h* = 0,8; 7 - *t/ h* = 0,4;
8 - *t/ h* = 0,05.

4 HOME TASK

4.1 Familiarize yourself with, using the literature recommended for the laboratory work and this guide:

– ground devices designs in transmission lines;

– a M-416 device work principle and operations manual.

4.2 Learn:

– a ρ_k measurement and a VEP curve interpretation protocol;

– a multilayer soil ground devices calculation protocol.

4.3 Prepare for a chapter 3 key questions discussion.

5 LABORATORY TASK

5.1 Measure a conditional soil specific resistance with a M-416 device. A soil specific resistance measurement is taken based on any schematic diagrams of the fig. 2.2.

A protocol of the measurement is the following:

1) set a switch B1 to an “×1” position;

2) press the button and get the maximal approach of an indicator arrow to zero by rotating the “Реохорд” knob.

3) a measurement result equals a product of a potentiometer scale reading by a multiplier. If a measured resistance turns out to be higher than 10 Ohm set the switch to an “×5” or an “×100” and do the steps of the first and the second subsections. Results of measurements have written in tab. 5.1.

5.2. Determine by a measured value ρ_k the electrical structure of the earth, using templates.

5.3. Based on initial data given by the teacher, to calculate the grounding resistance in two-layer or *n*-layers of land for:

a) deep grounding;

b) deep single-electrode grounding.

Table 5.1 – Soil VEP results by Wenner, Schlumberger circuits

AB, m	1,5	3,0	6,0	12	15	21	30	45	60	90	120	150	210	300
MN, m	0,50	0,50	1,50	1,50	4.00	4.00	10	10	20	20	40	40	70	70
b, m		0,25	0,75	0,75	2.00	2.00		5.00		10		20		35
l, m		1,50	3,00	6,00	10.50	10.50		22.50		45		75		150
R_{meas}, m														
ρ_k, m														

5.4. Based on the calculations select a design grounding device.

5.5. Investigating the dependence R_{gr} of horizontal or vertical grounding of acting specific ground resistance, to construct graphs.

5.6. Investigating R_{gr} of deep grounding depending on ρ_1, ρ_2, l, h_1 and d, build the graphs $R_{gr} = f\,(\rho_1, \rho_2, l, h_1, d)$.

6 EQUIPMENT

An M-416 device and a laboratory stand are used in the laboratory work. The M-416 ground resistance measurer is utilized to measure a soil specific resistance and a ground devices resistance. A measurement range (0,1 – 1000)Ohm.

7 CONTENT OF A REPORT

7.1 Basic measurement circuits.

7.2 ρ_k measurement data (see the tab. 5.1).

7.3 Data based on a soil electric structure in a measurement region.

7.4 Ground device calculation.

7.5 Graphs plotted by the studying results of p. 5.5 and p. 5.6 for the methodological guide.

8 REFERANCES

8.1 Руководство по проектированию, строительству и эксплуатации заземленный в установках проводной связи и радиотрансляционных узлов. – М.: Связь, 1971.

8.2 Михайлов М.И. Электромагнитные влияния на сооружения связи / Михайлов М.И., Разумов Л.Д., Соколов С. А. – М.: Связь, 1979.

9 APPENDIX

9.1 Seasonal soil and grounds factors

As mentioned in the chapter 2, we need to design ground devices accounting for a soil non-uniformities. If VEP measurement results with seasonal changes layer taken into account yield more than two soil layers we need to apply a methodology of their reduction to a two-layer electric soil model according to p. 2.3 by this formula:

$$\rho_e = \frac{1 + 4\,\tau\cos\alpha + \tau^2\left(4 - 2\cos 2\alpha\right) + 4\,\tau^3\cos\alpha + \tau^4}{\sigma_{\hat{a}}\left(1 - 2\tau^2\cos 2\alpha + \tau^4\right)},$$

here $\tau = N\,e^{-\sqrt{2}\,m_u h_u}$; $N = \dfrac{1 - \sqrt{\dfrac{\sigma_l}{\sigma_n}}}{1 + \sqrt{\dfrac{\sigma_l}{\sigma_n}}}$; $m = \sqrt{\omega\mu_a\sigma_n}$; σ_l; σ_{top} – specific conductance of lower and upper soil layers correspondingly, Sm/m;

μ_a – a soil magnetic permeability, equals $4\pi \cdot 10^{-7}$ H/m as the first approximation;

h_u – an upper soil layer depth, m; α – an angle equals $\frac{180}{\pi}\sqrt{2}\,m_{top}\cdot h_{top}$, radian.

If we find final calculated parameters of a two-layer electric soil model we need to choose the maximal possible value of ρ soil because of its seasonal changes. Therefore if VEP is taken not in a calculated but the most difficult time of a year, we need to reduce a measured ρ for a seasonal changes layer (a thickness h_c) to a calculated value $\rho_{1m} = K_i\rho_{1\text{meas}}$, here K_i – a soil seasonal factor. K_i and h_c quantities depend on a climate zone for which a ground device is designed. There are three climate zones in CIS countries area that correspond to northern, middle-latitude and southern regions of European part of the former USSR (tab. 9.1).

Table 9.1 – Seasonal soil factors and calculated seasonal changes layer width

Climate zone	h_c, m	K_1	K_2	K_3
The first	2,2	7,0	4,0	2,7
The second	2,0	5,0	2,7	1,9
The third	1,8	4,0	2,0	1,5

A calculated value for soil specific resistance in lower (the second equivalent) layer is set to be equal to ρ_e. A ground resistance R_{gr} is measured in the lowest soil conductivity times of the year: in winter at the highest level of its freezing and in summer at the highest dryness. It is not allowed to take measurements in wet weather of right after a rain season. A ground device resistance must not exceed the standard value for any time of the year based on requirements [8.1]. To obtain the minimally possible during a year ground resistance we should multiply a currently measured R_{gr} value by a seasonal ground factor K_i'. Depending on soil moisture we choose factors K_1', K_2' and K_3' in a seasonal changes layer if we take measurements in wet, medium moisture and dry soil correspondingly (tab. 9.2).

Table 9.2 – Seasonal ground factors

Vertical grounds						
Ground length, l, m	h= 0,7…0,8 m			h = 0		
	K_1'	K_2'	K_3'	K_1'	K_2'	K_3'
2,5	2,00	1,75	1,50	3,80	3,00	2,30
3,5	1,60	1,40	1,30	2,10	1,90	1,60
5,0	1,30	1,23	1,15	1,60	1,45	1,30
Horizontal grounds						
Ground length, l, m	h= 0,7…0,8 m			h = 0,5 m		
	K_1'	K_2'	K_3'	K_1'	K_2'	K_3'
5,0	4,3	3,6	2,9	8,0	6,2	4,4
20,0	3,6	3,0	2,5	6,5	5,2	3,8

Russian-English technical dictionary

Абонентская линия – **central office line, exchange line, individual line, subscriber's line**;
Абонентская проводка – **house cable, internal cable**;
Абонентский кабель – **service cable, subscriber's cable**;
АТС – **automatic exchange, dial telephone switching system**;
Автотрансформатор – **matching network**;
Активное сопротивление – **effective resistance, resistance**;
Анодный потенциал кабельной оболочки – **anode conditions**;
Аппаратура ВЧ уплотнения – **carrier channalising equipment**;
Аргумент импеданса – **impedance angle**;
Асимметрия – **unbalance**;
Барабан для кабеля – **hunk of cable**;
Бесспаечное соединение – **solder less connection**;
Биметаллический провод – **bimetallic conductor, composite wire**;
Битум – **bitumen**;
Ближний конец телефонной цепи – **near end**;
Блок канализации – **conduit**;
Блок-схема – **block-diagram**;
Блуждающие токи – **circulating currents, stray currents**;
Бокс – **box**;
Броневая лента кабеля – **armoring tape**;
Бронепроволока – **armoring wire**;
Бронированный кабель – **armored cable**;
Броня кабеля – **armor**;
Бумажная гильза – **paper sleeve**;
Бумажная трубка – **paper tube**;
Бумажно-кордельный кабель парной скрутки – **paper-cord unit twin cable**;
Бумажно-кордельный кабель четверочной скрутки – **paper-quad cable**;
Бухта кабеля – **coil of cable**;
В оболочке – **clad**;
Введение в эксплуатацию – **bringing into service**;
Водно-кабельная стойка – **cable terminating bay**;
Ведомость – **bill, form, list**;
Величина – **size**;
Вибрация – **chatter, flutter**;
Виниловая оболочка – **vinyl jacket**;
Включить линию шлейфом – **loop a line**;
Влагоизолирующий слой – **damp course**;
Влагостойкий – **damp-proof**;
Влияние соседних проводов – **proximity effect**;
Внешнее поле – **external field, applied field**;
Внутренний проводник коаксиального кабеля – **inner conductor of coaxial cable**;
Воздушная изоляция – **air insulation**;
Воздушная линия – **air line, open-wire circuit, pole line, overhead line**;
Воздушный кабель – **overground cable**;
Волновое сопротивление – **characteristic impedance, line characteristic**;
Восстановить цепь – **restore circuit**;
Входное сопротивление линии – **sending-end impedance**;
Входной колодец – **intake chamber**;
ВЧ симметричный кабель – **carrier cable**;

Генератор качающейся частоты – **sweep generator, oscillator**;
Глубина проникновения тока в массу проводника – **penetration of current**;
Гололёд – **slut**;
Голый провод – **line wire**;
Городская телефонная станция – **local central office, local exchange**;
Городской телефонный кабель – **exchange cable**;
Гост – **all-union state standard**;
Группирование – **bunching**;
Дальний конец телефонной цепи – **distant end**;
Диаграмма – **chart**;
Диаметр провода – **conductor weight**;
Диэлектрическая проницаемость – **capacitive, dielectric constant**;
Ёмкость – **capacitance**;
Ёмкостная связь – **capacitive coupling**;
Ёмкостное симметрирование – **capacitance buiding out**;
Ёмкость на единицу длины – **capacitance per unit length**;
Жила – **heart**;
Жила кабеля – **wire**;
Заземление – **ground bed**;
Заземление брони – **bounding**;
Заземление на линии – **line-to-ground**;
Заземление оболочки – **bounding**;
Замыкание на землю – **ground fault**;
Замыкание на корпус – **fault to frame**;
Замыкать накоротко – **short circuit**;
Запас – **margin**;
Запаянный конец – **sealed end**;
Заполнитель – **filler**;
Защита – **protection, guard**;
Защита от грозовых разрядов – **lightning protection**;
Защитная цепь – **guard circuit**;
Защитное действие – **screening effect**;
Знак “Опасно для жизни” – **danger sign**;
Измерение – **metering, test**;
Измеритель переходного затухания – **crosstalk meter**;
Измеритель полного сопротивления – **impedometer**;
Измеритель уровня – **level measuring set**;
Измерительная аппаратура – **metering equipment**;
Изолятор – **insulator**;
Индикатор мощности – **power-level indicator**;
Инженер – **engineer**;
Инструкция – **technical manual**;
Инструкция по ликвидации аварий – **emergency operating order**;
Инструкция по обслуживанию – **maintenance instruction**;
Интенсивность коррозии – **corrosion efficiency**;
Испытание кабеля на пробой – **break test of cable, disruptive test**;
Кабель – **cable**;
Кабельная канализация – **culvert, line of ducts**;
Кабельная коробка – **conduit box**, **connecting box, splice box, test box**;
Кабельный барабан – **cable drum**;
Катодная защита оболочки кабеля – **cathodic protection with a sacrificial anode**;
Катодный потенциал оболочки кабеля – **cathodic condition, negative condition**;
Коаксиальный кабель – **coaxial cable**;
Коррозия – **corrosion, rust**;
Коррозия под действием блуждающих токов – **stray current corrosion**;

Коэффициент защитного действия – **reduction factor**;
Коэффициент неоднородности – **regularity return coefficient**;
Коэффициент передачи – **transfer constant**;
Коэффициент распространения – **propagation constant**;
Коэффициент связи – **coupling factor**;
Коэффициент скрутки – **lay ratio**;
Линейный трансформатор – **insulating transformer**;
Линейный трансформатор со средней точкой – **simplex coil**;
Линия электропередачи – **electric line, power line**;
Люк – **manhole, eruption, engorgement**;
Магистральная линия – **long-haul line**;
Магистральный кабель – **long-haul cable**;
Марка кабеля – **cable makeup**;
Молниеотвод – **arrester, conductor, discharge rod, lightning protector**;
Монтаж – **arrangement, assemblage, erection, jointing up, mounting, wiring**;
Монтаж кабельных муфт – **splice**;
Муфта – **coupling, joint, lead sleeve, sleeve, socket**;
Наведённая помеха – **induced noise**;
Наводка – **pickup**;
Напряжение между проводами – **transverse voltage**;
Напряжение между фазой и нейтралью – **star voltage**;
Напряжение на зажимах – **terminal voltage**;
Напряжение, опасное для жизни – **dangerous pressure**;
Нагрузка – **leading, traffic**;
Нагрузочное сопротивление кабеля – **terminal resistance**;
Напряжение электрода – **electrode voltage**;
Напряжённость – **strength**;
Напряжённость магнитного поля – **magnetic field intensity**;
Напряжённость электрического поля – **electric field intensity**;
Несоответствие – **mismatch**;
Номинальный срок службы – **standard lifetime**;
Норма – **standard**;
Оболочка – **case, coating, cover, envelope, lapping, packing**;
Образец – **essay, prototype, standard**;
Обрыв – **breaking-down**;
Обрыв цепи – **discontinuity, open circuit**;
Обрыв провода – **abruption of wire, break**;
Обслуживание – **attendance, service**;
Обслуживаемый усилительный пункт – **attended repeated station**;
Общий – **common**;
Округлять – **round off**;
Омическое сопротивление – **real resistance**;
Определение – **definition**;
Опыт – **trial**;
Ошибка – **error**;
Параллельный – **parallel**;
Парная скрутка – **pairing**;
Парный кабель – **paired cable, twin cable, twin ax cable**;
Перенапряжение – **excess voltage, overrating voltage**;
Перенапряжение от молнии – **lightning surge**;
Переходное затухание на дальнем конце – **far-end crosstalk attenuation**;
Переходное сопротивление – **brush resistance**;
Поверхностный эффект – **skin effect**;
Повив кабеля – **layer**;

Полиэтилен – **polythene, polyethylene**;
Постоянная распространения – **propagation coefficient**;
Потери – **congestion, loss**;
Потери в линии – **line loss**;
Почва – **ground**;
Правила технической эксплуатации – **engineering instructions**;
Правила эксплуатации линии – **line rules**;
Проводимость изоляции – **shunt conductance**;
Проект – **design, device**;
Проектирование – **laying out**;
Прокладка кабеля – **cable laying, cable work**;
Работа – **work, marking, operation**, **performance, service, working**;
Работа на линии – **line work**;
Разветвительная муфта – **multiple cable joint, splitter box**;
Разрядник для защиты от перенапряжения – **surge arrester**;
Разрядник – **arrester, discharge switch, excess voltage preventer**;
Расчёт – **account, design, estimate**;
Симметрирование кабеля – **balancing**;
Скрещивание цепей – **crossing**;
Сопротивление шлейфа – **go-and-return resistance**;
Срок действия – **duration of validity, period of validity**;
Срок службы – **useful life**;
Стальная бронелента – **iron armoring;**
Стержень – **bar, web**;
Стержень молниеотвода – **lightning rod**;
Стержневой молниеотвод – **rod lightning arrester**;
Строительная длина кабеля – **factor length of cable, shipping length**;
Строительная площадка – **construction site**;
Строительство – **construction**;
Схема – **assembly drawing, circuit, device, layout, network, project, setup**;
Схема кабельных соединений – **cable diagram**;
Схема распределения кабелей – **cable layout**;
Схема связи – **coupling network**;
Схема сети – **exchange area layout**;
Таблица – **chart**;
Технические нормы – **technical standards**;
Технические требования – **Specification**;
Ток – **current**;
Ток в земле – **ground current**;
Ток в свинцовой оболочке – **sheath current**;
Ток коррозии – **corrosion current**;
Токи помех – **extraneous currents**;
Ток потерь – **stray currents**;
Точечное скрещивание – **transposition by crossing**;
Трансформатор с выводом от средней точки – **centre-tapped transformer, phantom coil**;
Трасса – **main route, run, treak**;
Трос – **cable, rope stand cable, stranded conductor, stranded wire, wire cable, wire rope**;
Трос для подвески кабеля – **messenger strand, bearer cable, wire strand**;
Трос для протягивания кабеля – **drowing in wire**;
Угольный разрядник – **carbon protector**;
Удар – **blow, bump, percussion**;
Удар молнии – **bolt**;
Удельное сопротивление – **specific resistance**;
Уплотнение – **channelizing**;

Уплотнённая цепь – **composite circuit, superimposed line**;
Уровень на входе – **input level**;
Уровень на выходе – **output level**;
Уровень передачи/приёма – **send/receive level, transmission level**;
Уровень помех – **interference level**;
Участок – **cut, route portion**;
Участок канализации – **conduit section**;
Фазовая скорость – **phase velocity**;
Физическая цепь – **metallic circuit**;
Характеристическое сопротивление линии – **line characteristic resistance, line constant**;
Холостой ход – **light running**;
Цепь – **catena, circuit, long-distance circuit, line**;
Цепь в четвёрке звёздной скрутки – **star circuit**;
Частотная характеристика – **frequency amplitude characteristic, frequency response characteristic, response characteristic**;
Частотная характеристика затухания – **attenuation frequency characteristic**;
Частотное уплотнение – **channeling, frequency multiplex**;
Четвёрка – **quad**;
Четвёрка с жилами, скрученными звездой – **spiral quad, star quad**;
Чулок для протягивания кабеля в каналах канализации – **cable grip, single-ended cable grip, splite cable grip**;
Шаг пупинизации – **coil spacing, H-spacing, lead coil spacing**;
Шаг скрещивания – **subdivision transposition**;
Шайба – **burr, spacer, wafer**;
Шахта – **vault**;
Шлейф – **circuit, loop circuit, tail**;
Штепсель – **plug, pag**;
Шум – **electrical noise, rattling, rushing sound**;
Экран – **blind, screen**;
Экранированная пара – **screening pair, shielded pair, screened pair**;
Экранированный провод – **screening wire, shielded wire**;
Экранирующий эффект – **screening effect**;
Экранная оплешка – **braid shielding**;
Эксплуатация – **operation, service, working**;
Эксплуатационный срок службы – **operating life, service life**;
Электрическая длина – **electrical length**;
Электрическая ёмкость – **permittance**;
Электрическая защита от коррозии – **electric protection**;
Электрическая индукция – **electric induction**;
Электрическая связь – **conductive coupling**;
Электрический дренаж – **electric drainage**;
Электромагнитный экран – **electromagnetic screen**;
Электропитание – **electric power supply, power feeding**;
Электрохимическая коррозия – **electrochemical corrosion**;
Эмпирическая формула – **cut-and-try formula**;
Эффект близости – **proximity effect**;
Эффект скрещивания – **shadow effect**.

English-Russian technical dictionary

tube – экран кабеля;
transmission line (TL) – линия передачи;
measuring device (instrument) – измерительный прибор;
communication cable – кабель связи;
rate – норма (величина);
substandard – с отклонением от нормы;
acceptance measurements – приёмо-сдаточные измерения;
repeatable measurements – периодические (профилактические) измерения;
construction and repair works – строительных и ремонтных работы;
insulation resistance – сопротивление изоляции;
mutual capacitance – рабочая емкость цепи;
stub resistance (loop resistance) – сопротивление шлейфа;
ohmic disbalance – омическая асимметрия;
electric strength of insulation – электрическая прочность изоляции;
lay ratio – коэффициент укрутки;
specific resistance – удельное сопротивление;
bare conductor – неизолированный проводник;
cross-section area – площадь поперечного сечения;
dielectric permeability – диэлектрическая проницаемость;
correction index – поправочный коэффициент;
pure resistance, ohmic resistance – активное сопротивление;
shunt conductance (= leakance) – проводимость изоляции;
bearing ratio – коэффициент смятия;
pair – пара (жил);
pair twisting – парная скрутка (жил);
star-type twisting – звездная скрутка (жил);
terminal device – оконечное устройство;
partial capacitance – частичная ёмкость;
temperature coefficient – температурный коэффициент;
operability – пригодность к эксплуатации;
directly proportional to smth – прямо пропорциональный чему-либо;
inversely proportional to smth – обратно пропорциональный чему-либо;
basic circuit – принципиальная схема;
urban telephone network – городская телефонная сеть;
serviceability – пригодность к эксплуатации;
alternating current – переменный ток;
periodic tests – плановые измерения;
control instrumentation – контрольные измерения;
repair-and-renewal operations – ремонтно-восстановительные работы;
acceptance tests – приемо-сдаточные измерения;
insulation fault – повреждение (пробой) изоляции;
bridge branch - плечо моста;
variable resistor – переменный резистор;
under tension – под напряжением (в т.ч. электрическ.);
electric wire-to-wire capacitance – электрическая емкость между проводами

ground capacitance – ёмкость на землю;
equal-deflection method (comparison method) – метод сравнений;
paired cable – кабель парной скрутки;
moisture-proof – влагостойкий;
overlap – наложение, перекрытие;
lead – шаг спирали;
layer – повив кабеля;
armored cable – бронированный кабель;
cable-core insulation – изоляция жил кабеля;
lead of a cable - токопроводящая жила кабеля;
tin-coated – луженый;
electrical ratings – расчетные электр. характеристики, требования к электр. характеристикам;
normalize – нормировать, стандартизировать;
stand the test – выдерживать испытание;
symmetrical cable (balanced cable) – симметричный кабель;
cable quad – четверка жил кабеля (звезд. скрутка);
styroflex – кордель полистирольный, кордельно-полистирольный;
wrapping – поясная изоляция кабеля;
cable paper – кабельная бумага;
bituminous – битумный;
bitumen – битум;
adhesive – клейкий;
wire armoring – бронирование кабеля круглой проволокой;
State Standard – ГОСТ;
factory length – строительная длина;
conventional – стандартный (серийный);
cable core – пучок жил кабеля (тлф); также –сердечник кабеля;
cable transmission parameters – параметры передачи кабеля;
attenuation coefficient (attenuation factor, attenuation ratio etc.) – коэффициент затухания;
phase(-change) coefficient – коэффициент фазы;
surge impedance (wave impedance, line characteristic impedance) – волновое сопротивление линии передачи;
propagation velocity – скорость распространения;
damping – затухание;
signal power – мощность сигнала;
numerical value – численное значение;
progressive wave – бегущая волна;
voltage wave – волна напряжения;
uniform line (homogeneous line) – однородная линия;
indirect wave (reflected wave) – отраженная волна;
monochromatic wave (simple harmonic wave) – монохроматическая волна;
wave front – фронт волны;
electromagnetic constant (velocity of light in free space) – скорость света в вакууме;
frequency dependence – частотная зависимость;
bilateral circuit - симметричная цепь;
thermal loss - тепловые потери;
indirect measurement – косвенные измерения;
match – согласовывать (напр. нагрузку с линией);
oscillator (generator) – генератор;
input parameters – входные параметры;
short-circuit method – метод короткого замыкания;
long line (long-distance transmission line) – длинная линия;
idling mode – режим холостого хода;

transmission equation – уравнение передачи;
propagation constant – постоянная распространения;
phase shift (phase angle, phase-shift angle) – угол сдвига фаз;
far end – дальний конец линии;
sending end – начало линии (передающая сторона);
input admittance – входная полная проводимость;
identity – тождество;
imaginary part – мнимая часть (компл. числа);
real part – действительная часть (компл. числа);
certified value - паспортное значение;
design power – расчетная мощность;
tabulated value (tabular value) - табличное значение;
measuring unit (measurement unit) – единица измерения;
coaxial cable (coax) – коаксиальный кабель;
on-site – на рабочем месте;
cut – собирать схему;
low-frequency generator – генератор низкой частоты;
selective level indicator – избирательный индикатор уровня;
lead (pin) – электр. контакт, разъем;
capacitance box – магазин ємкостей;
tune to frequency – настраиваться на частоту;
pointer – стрелка (на измерительной шкале);
knob – ручка (кнопка на приборе);
sensitivity – чувствительность;
zero position – исходное положение;
alternately – попеременно, поочередно;
terminal – клемма;
rural area network – сельская связь;
installation of radio – радиофикация;
exchange cable (subscriber's cable) – абонентский кабель;
hose – шланговый;
lightproof (light-tight) – светоустойчивый;
wavelength shorting coefficient – коэффициент укорочения длины волны;
radio-frequency cable – радиочастотный кабель;
impulse signal (pulsed signal) – импульсный сигнал;
overall size – габаритный размер;
inner/outer conductor – внутренний/внешний проводник (коаксиального кабеля);
dielectric dissipation – тангенс угла потерь (диэлектрика);
pulse method – импульсный метод;
resonance frequency (resonant frequency) - резонансная частота;
frequency span – диапазон частот;
temperature coefficient – температурный коэффициент;
degree centigrade – градус Цельсия;
bridge method – мостовой метод;
compensation method – компенсационный метод;
light scattering coefficient – коэффициент рассеивания;
voltage-ratio method – метод отношения напряжений;
running-wave mode (traveling wave mode) – режим бегущей волны;
to stay put – оставаться неизменным;
stable – неизменный, постоянный;
chart – строить график;
obstacle – неоднородность (в линии передачи);
aerial line – воздушная линия;
input – подавать на вход;
time(-base) sweep, timebase – временная развертка;
patch cable (interface cable) – соединительный кабель;

reference – начало отсчета;
rise-up portion – передний фронт (импульса);
technical features – технические характеристики;
receiving aerial (pickup antenna) – приемная антенна;
malfunction – сбой в работе;
fault location (point of fault) – место повреждения;
multiconduct , multiple-wire, multiwirе – многопроводный;
reflection coefficient (reflectance factor, reflection factor) – коэффициент отражения;
nominal value (rated value) – номинальное значение;
polarity – полярность;
limiting case (extreme case) – предельный случай;
total reflection – полное отражение;
pulse direction – полярность импульса;
cable insertion – кабельная вставка;
tapering (smooth variation) - плавное изменение (параметра);
latency time - время запаздывания;
resolution capability (resolution) – разрешающая способность;
spectrum – спектр;
decision – распознавание;
against the smth – на фоне чего-либо;
resistive impedance (active resistance, ohmic resistance, pure resistance etc.) – активное сопротивление;
pulse(-response) characteristic, impulse response, pulse response – импульсная характеристика;
dummy – макет;
artificial extension line – искусственная линия;
nonfault (operable, faultless) – исправный;
regenerating station – регенерационный пункт;
resistance set – набор сопротивлений;
makeready – приводить в готовность к работе;
glow – светиться;
sweep trace – линия развёртки;
longitudinal resistance – продольное сопротивление;
leak (leakage) – утечка;
ground fault – короткое замыкание на землю;
modulus of a complex number – модуль комплексного числа;
argument of a complex number – аргумент комплексного числа
strand pitch – шаг скрутки;
wire covering – изоляция провода;
conductance bridge – измерительный мост проводимостей;
structure chart (block diagram) – структурная схема;
service instruction (working instruction) – правила эксплуатации;
deceleration – замедление;
uniformity tester – измеритель неоднородности;
scale mark – отметка на шкале;
reading mark – отсчетная риска.