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ALMATY UNIVERSITY OF POWER ENGINEERING AND TELECOMMUNICANION

Department of "Computer and infocommunication security

ANTENNA-FEEDER DEVICES AND PROPAGATION OF RADIO WAVES

Lecture notes
for English class students of the speciality
5V071900 – Radio engineering, electronics and telecommunications

Almaty 2016

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The lecture notes corresponds to the program of course and intended as additional literature for the study of discipline "Antenna-feeder devices and propagation of radio waves". In a lecture note physical processes, distribution of radio waves of different ranges in the real terms, methods of calculation of the field tension, are examined in the place of reception, the general questions of theory of antennas, requirement, device, principle of action and basic parameters of different types of transmitter and receiving antennas are examined.

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Lecture 1. Introduction. Technical parameters of antennas

Any transmission line of information (communicational, broadcasting or televisional) contains the radio transmitter and radio receiver devices at the ends provided with antennas. The wrong choice of antennas, their wrong exploitation, can result in violation of radio line work, in spite of application of powerful radio transmitters and sensible receivers. To understand a role and value of antennas and highways, we consider the generalized flow diagram of radio technical apparatus.

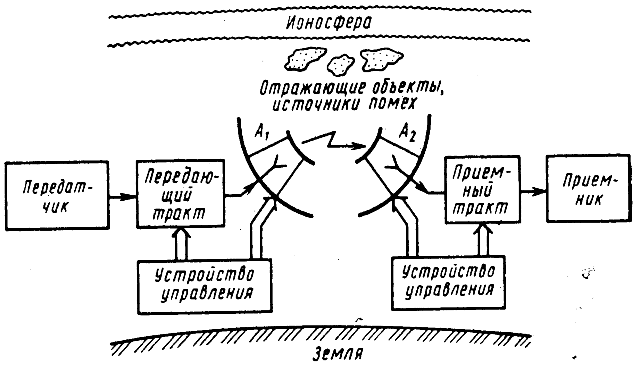


Figure 1 - Flow diagram of radio system

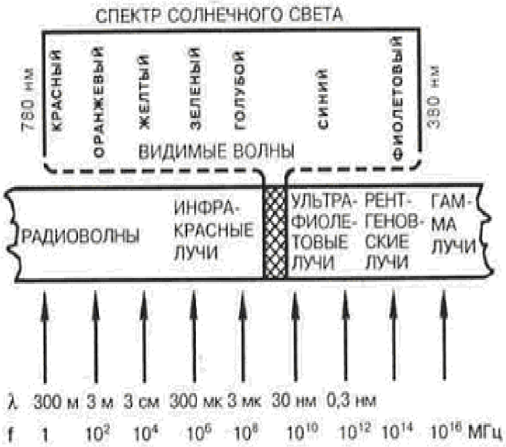


Figure 2 - Flow diagram of electromagnetic wave

Receiving antennas catch and convert energy of electromagnetic waves in high frequency energy entering from feeder (it is ordinary coaxial cable) to the receiver. The quality of receiving signal mostly depends on antenna.

Transmitter antennas will transform and emit the high-frequency energy into electromagnetic waves to surrounding space.

Transmitting and receiving antennas possess property of reciprocity (to convertibility), which means that the same antenna can emit or accept electromagnetic waves, moreover they has identical characteristics (parameters) on both modes.

Transmitter antennas must have additional requirements related to the large powers of high frequency energies, therefore receiving antennas are simpler than transmitter structurally. Antennas of modern radio system should have many requirements and two important of them are given below:

- directivity of an action, distribution of electromagnetic power in space (or reaction on the coming electromagnetic field at radio reception) according to a certain law. In some cases it is desirable to provide uniformity of antenna action on all directions, in other, it is required to concentrate a radiation or to carry out radio receive within a rather narrow angular sector - so-called ray. For forming the narrow ray, the size of antenna must exceed the working wave-length of radio system significantly;
- a radiation or radio receive must be accompanied by the minimum losses of electromagnetic power on heating of conductors and dielectrics of antenna, which means that antenna must have high input-output ratio (IOR). Problem of high IOR achievement is shown up at creation of antennas, where the sizes of that are small in comparison to a wave-length.

The environment (highway) of distribution renders to work of any радиолинии. When distribution takes place in free space, influence consists only in weakening of the field.

In case of the real environments semiconductor properties of ground result in losses of the field energy in Ground. From sphericity of Ground the diffraction occurs. Different sort of unevenness of ground surface disperse and reflect radio waves, changing their polarization, create shading of receiver point.

An atmosphere of Ground is an absorptive heterogeneous environment, therefore the signal may weaken and action trajectory of wave may change.

Upper-airs (ionosphere) contain gas in the ionized condition, so that also has influence on distribution of radio waves.

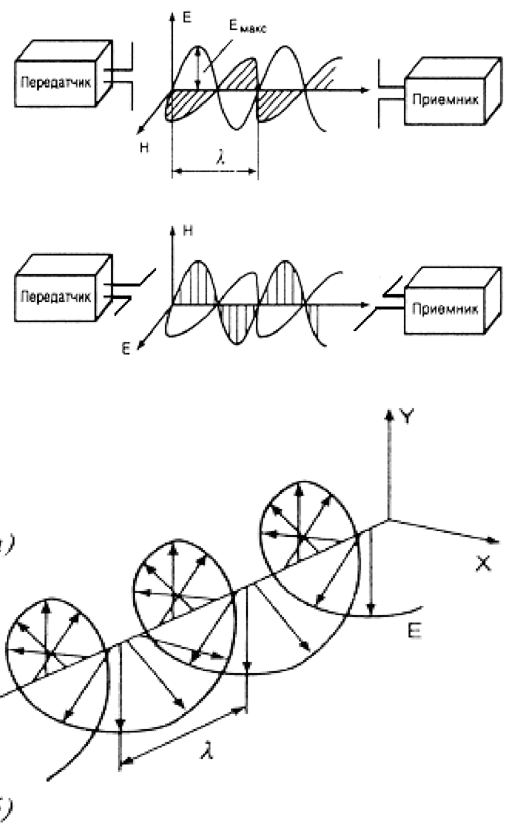
Electromagnetic waves. There is an example of what an electromagnetic wave represents. If on a water smooth surface throw a stone, then the waves will appear on a surface. They move from the source of their origin (indignations) with certain speed of distribution. For electromagnetic waves, indignations are the electric and magnetic fields which move in space. The changing in time electric field causes appearance of variable magnetic-field necessarily, and vice versa. These fields are mutually constrained.

The main source of spectrum of electromagnetic waves is the Sun. Part of spectrum of electromagnetic waves sees the eye of man. This spectrum lies within the limits of 380...780 nm (figure 1). Electromagnetic waves with different length cause feeling of light with the different colouring.

Part of spectrum of electromagnetic waves is used for the aims of radiotelevisional broadcasting and communication.

Table 1 - Distribution of radio spectrum on ranges

Frequencies	Wavelength	Metrical name of range of waves	Name of range of frequencies	Subranges of waves	Contracted notation	
					Russ	Inter
3-30 kHz	100-10 km	Merimetric	Very low	Ultralong waves	ОНЧ	VLF
30-300 kHz	10-1 km	Kilometric	Low	Long waves	НЧ	LF
0.3-3 MHz	1 km-100 m	Hectometric	medium	Medium waves	СЧ	MF
3- 30 MHz	100 -10 m	Decametric	high	Short waves	ВЧ	HF
30-300 MHz	10- 1 m	Metric	Very high	Ultrashort waves	ОВЧ	VHF
0.3- 3 GHz	1 м- 1 dm	Decimetric	Ultrahigh		УВЧ	UHF
3- 30 GHz	10- 1 cm	Centietric	Ultra very high		СВЧ	SHF
30- 300 GHz	10- 1 mm	Millimetric	Enormously high		КВЧ	EHF
300-3000 GHz	1- 0.1 mm	Decimillimetric	Hyperhigh		ГВЧ	GHF
3-$3\times10^{8} THz$	0.1-0.01mm	Millimicrometric	Optical range		ОД	OD



a) vertical polarization; b) horizontal polarization; c- rotational polarization.

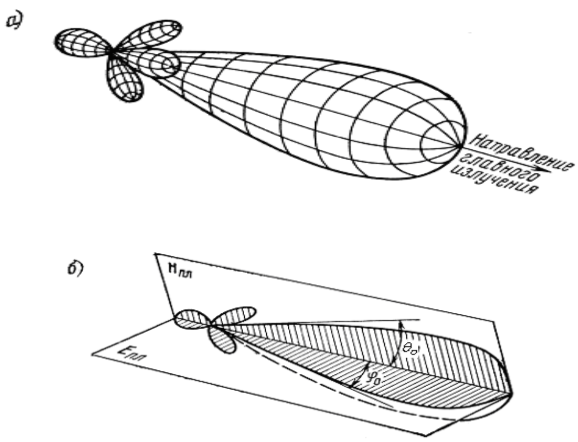
Figure 3 - Is Structure of electromagnetic wave

Technical parameters of antennas.

1. Radiation pattern.

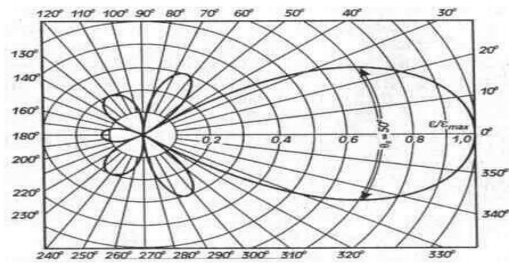
Antennas have property of directivity, which is determined the radiation pattern.

Radiation pattern of f ($f(\theta;\varphi)$) is the graphically presented dependence on the angle of supervision in space (θ and φ) of tension of the electromagnetic field, created by the antenna measured on a large but identical distance from antenna.

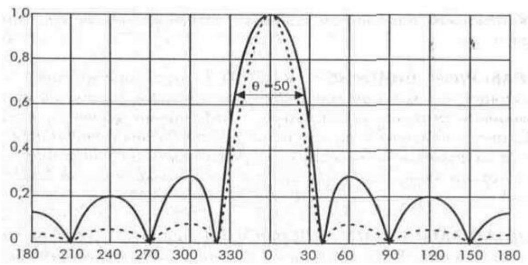


a) spatial; b) spatial, divided by the planes of E and H.

Figure 4 - RP (radiation pattern)



a



b

a) in the polar system of coordinates, b) in rectangular.

Figure 5 - RP (radiation pattern)

2. Coefficient of protective action.

The coefficient of protectivity ($C_{protect}$) of antenna is the ratio of square of the field tension, created by antenna at main direction of E2O to the square of the field tension at opposite direction:

$$K_{защ} = \frac{E^2_{0°}}{E^2_{180°}} = \frac{F^2(0°)}{F^2(180°)}.$$

3. *Level of side lobes.*

$$LoSL = \frac{1}{F(\pi/2) \div F(-\pi/2)} \qquad LoSL = 20\lg\frac{1}{F(\pi/2) \div F(-\pi/2)} \text{ (dB).}$$

4. *Width of main lobe.*

Widths of main lobe on a zero radiation - $2\theta_0$.

Widths of main lobe on a level 0,5 that corresponds maximal power $2\theta_{0,5}$, to the level 0,707 (3 dB) on tension of the field (shown on a figure 5).

5. *Coefficient of the directivity D.*

The coefficient of the directivity D in the given direction the ratio of square of the field tension created by antenna in this (usually main) direction of E_o to the mean (on all directions) value of square of tension of the field of E_{mean}.

$$D = E_0^2/E^2_{cp} \quad D = \Pi_0/\Pi = E_0^2 r^2/30P_\Sigma . \quad E_0^2 = DE^2_{cp} ,$$

which means the numeral value of coefficient of directivity (CoD) shows how many times it is needed to decrease power of radiation, if replace non-directional antenna to directional by remaining the former tension of the field directed at maintenance in main direction

Non-directional (izotropic) is conditionally an antenna which radiate on all directions equally. Practically, those kinds of antennas do not exist, because any real antenna has the directivity properties.

6. Effective, or operating area.

Operating length of transmitting antenna of Lo is the length of emitter with uniform distribution of current that in main direction creates the same tension of the field, as well as the real antenna at identical currents.

$$S_{эфф} = \frac{D\lambda^2}{4\pi} . \quad R_\Sigma = P_\Sigma / I^2_{а.эфф} . \quad \eta_a = \frac{R_\Sigma}{R_\Sigma + R_{пот}} .$$

7. Radiation impedance of antenna.

Radiation impedance of antenna is the coefficient of proportion, relating power of radiation with the square of real value of current in antenna.

8. An output-input ratio of antenna is the ratio of radiated power to the input power.

9. Gain.

Gain *of antenna* (G) is the ratio of density flow of power or square tension of the field, created by antenna in main direction to the flow or square of the field tension, created by standard antenna in main direction at equality input powers

$$G = DE^2_{\text{ср}}/D_{\text{э}}E^2_{\text{э.ср}} = D\,\eta_{\text{а}}/D_{\text{э}}\,\eta_{\text{э}} = D\,\eta_{\text{а}}/D_{\text{э}}.$$

In different frequency ranges use the different types of standard antennas.

1) In the range of LW and MW, as standard, use the short asymmetrical dipole located directly above ideally conducting ground. For such antenna of DЭ=3.

2) In the range of SW, as standard, antenna accept the symmetric half-wave dipole located in free space, for that DЭ = 1,64.

3) In a range over high-frequency (OHF), as standard, accept a non-directional isotropic emitter with DЭ=1.

Gain shows how many times it is necessary to decrease the input power to the directed antenna, as compared to standard, so that to the field tension remain same in main direction.

Gain and Directivity express in decibels:

$$G' = 10\lg G,$$

$$D' = 10\lg D.$$

10. The impedance of antenna of W is determined by ratio of voltage to current of input flow wave

$$Ww = Unna/Inna.$$

At consideration of the antennas executed from the system of wires, for the calculation of *Ww*, Ohm, following equation can be applied for the balanced lines:

$$Ww = L1/C1,$$

where L1 and C1 - inductance, Г/м, and a capacity, F/m, accordingly.

Impedance substantially influences on maximal voltage, input resistances and working frequency bands of antennas.

11. Working frequency band Δf *is the area of frequencies* f_{rom} f_{max} *to* f_{min}, *where the all parameters of antenna lies within the given limit.* Usually the borders of working frequency band are determined by parameter that with the change of frequency quicker than other goes out the set limits. The working frequency bandwidth is determined in percentage relatively to the mean of frequency of range

$$\Delta f/f_{\text{ср}} = [2\,(f_{\text{макс}} - f_{\text{мин}})/(f_{\text{макс}} + f_{\text{мин}})]\,100\,\%$$

or by the overlapping coefficient of frequency $fm\max/f_{M}\min$.

Antennas with a value $\Delta f / f_{mean} \langle 10\%$ name *narrow-band*, and at $\Delta f / f_{mean}$ =10 - 60% - broadband. Antennas with the overlapping coefficient of frequency 1,6-5 is called *wide-range*, and at $\Delta f / f_{cp} \rangle$ 5 – allpass.

Control questions.

1 Explain the purpose of transmitting antenna.
2 Explain what is the spatial wave.
3 What type of polarization is created by the antenna from Figure?
4 To what subcarrier applies the wave with the length of 2 m?
5 Explain the purpose of receiving antenna.
6 What is the surface antenna?
7 Define the frequency of electromagnetic wave, if a wave-length is equal 6,8 cm.
8 What is the frequency of a wave with length 1m?
9 What is the similarities and differences of Directivity and Gain?
10 What is the similarities and differences of W and Za?
11 What is the resistance of antenna radiation?
12 How to determine operating length of receiving and transmitting antennas?
13 What is the nature of the reversibility of antennas?

Lecture 2. Dipole

A dipole (figure 1) consists of two identical cylindrical conductors (shoulders), between that a line is included, connecting a dipole with a generator (by a transmitter) or receiver. Dipoles are widely used as independent antenna or as an element of complex antenna in ranges short, meter and decimetric waves.

Radiation area of wire antennas and directivity can be defined, if distribution of currents is known on antenna. Dipoles can be regarded as a detailed two-wire line, open on both ends (figure 2).

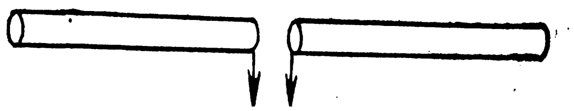
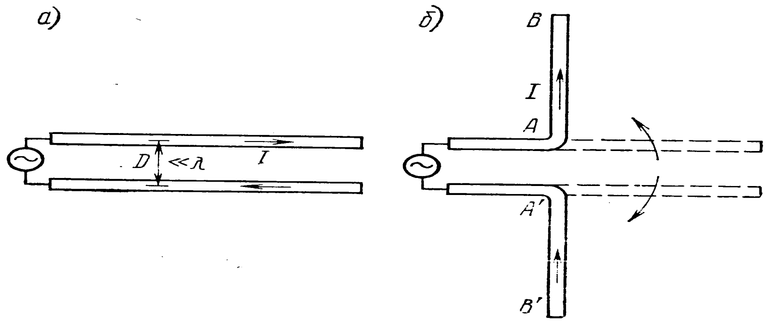


Figure 1 - Dipole

However, in this case, there are also fundamental differences. Line serves only to guide the electromagnetic waves along it and is substantially non-emitting systems, while dipole radiates electromagnetic waves.



a) line; б) dipole.

Figure 2 - Transformation of symmetric line to the dipole

Field of the two-wire line in a fairly remote location is zero, since the field created by each conductor at $D \langle\langle \lambda$, equal in magnitude but oppositely directed mutually. When you deploy a line of conduction currents in the shoulders of the dipole have the same direction and thus produce radiation. The expanded line - dipole - the farther from the beginning (point AA ') and proximity to its ends (point BB') of the conduction currents in the conductors are reduced to zero, moving in displacement currents in the space surrounding the dipole.

Considering that the end of the dipole is open and $I_k = 0$, and $U_c = U_n$, the equations for the voltage and current distribution along the dipole:

$$U_x = U_п \cos kx;$$
$$I_x = I_п \sin kx.$$

,

where $k = 2\pi/\lambda$ - wave-number

The voltage at the ends of the dipole antenna has a maximum value (voltage antinode) and changes along the wires from the end of the vibrator to the power points by the cosine law. The current at the ends of the vibrator is zero (the current node) and varies along the sinusoidal wires. Current position along the nodes dipole coincides with antinodes voltage and current position coincides with the voltage antinodes nodes, i.e. voltage and current are phase shifted by 90 °. At the dipole antenna is installed standing wave mode.

Parameters of dipole :

- LA (lA) = 2L is geometrical length of dipole, where L is length of shoulder;
- L/λ is relative length of dipole;
- $kL = 2\pi L/\lambda$ is electric length of dipole (degrees, rads.).

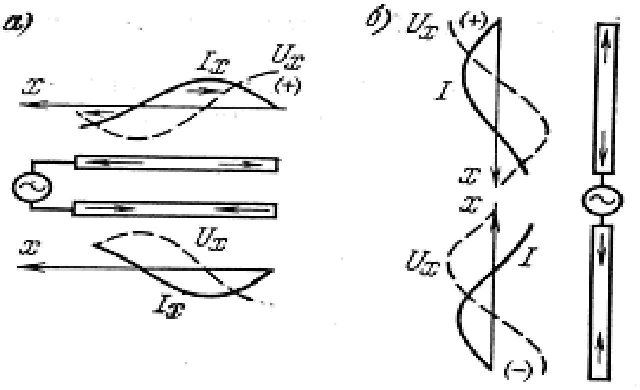
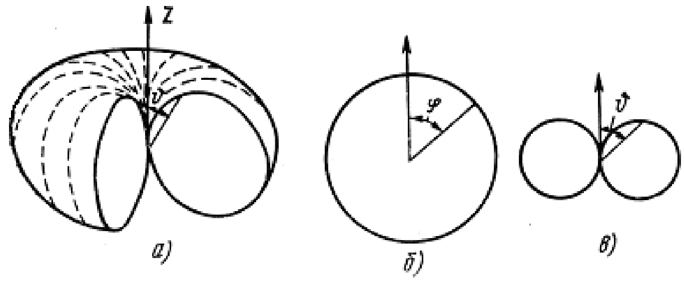
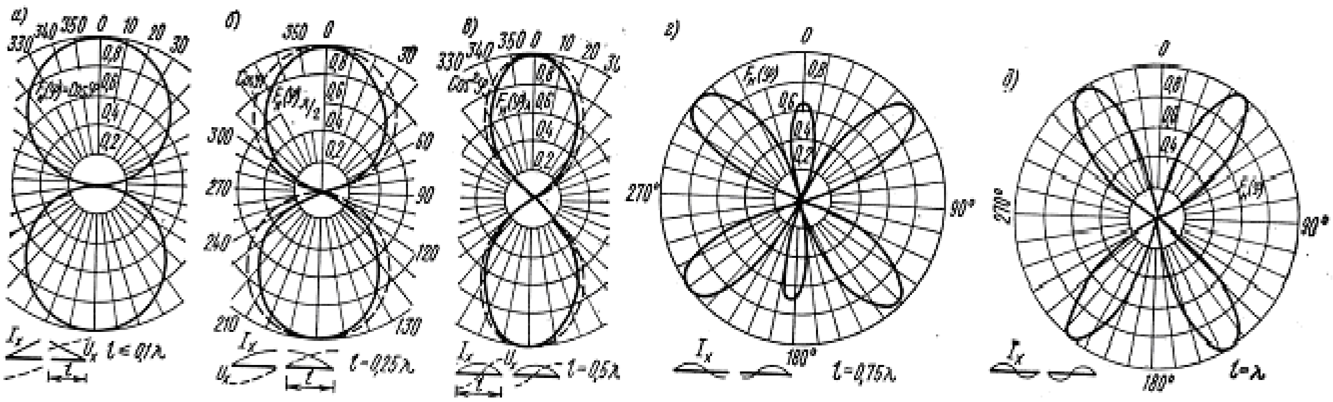


Figure 3 - Distribution of current and voltage



а) spatial; б) in an equatorial plane (H); в) in a meridional plane   (E).
Figure 4 - Radiation pattern of short dipole

The distribution of current and voltage and radiation pattern depends on the relative length dipole:



Short Semiwave Onewave One and a half Two waves wave

Figure 5 - Distribution of current and voltage and radiation pattern of dipole

Directivity.

Directivity of dipole is determined by the equation of

$$D = \frac{60^2 I_п^2}{r^2} F^2(\Delta;\ \varphi)_{макс} \frac{r^2}{30 I_п^2 R_{\Sigma п}},\ \text{или}\ D = \frac{120}{R_{\Sigma п}} F^2(\Delta;\ \varphi)_{макс},$$

where F (Δ,ϕ) max is a maximal value of multiplier of radiation pattern.

Dipole of Hertz and short symmetrical dipole have directivity equal to 1,5.

Directivity of semi-wave dipole is equal to 1,64, one-wave - 2,4.

A maximal value of D =3,1 has a dipole with length of shoulder of L=0,625.

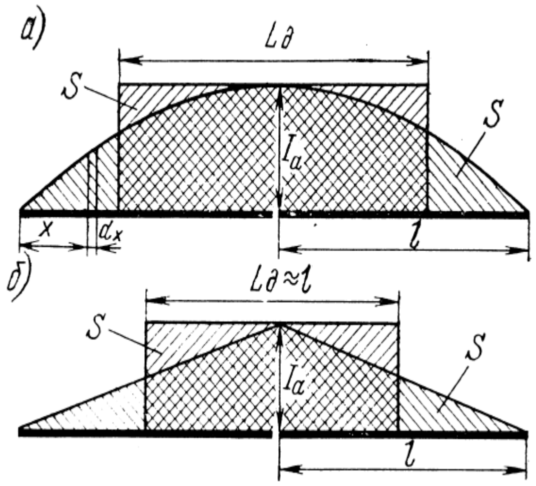
Operating length of symmetric dipole.

Dipole with a sinusoidal current distribution along the length of the antenna is comparable with the equivalent, in which the current remains unchanged in length as a dipole in Hertz, and equal to current at the input of dipole.

Equivalent means the antenna creating equal field strength. Such antennas must have equal areas of currents.

Operating length of the dipole antenna

$$L_д = \frac{2}{k} \operatorname{tg} \frac{kl}{2} .$$



a - general case; б - short dipole.

Figure 6 - Operate length of symmetrical dipole

Operating length of dipole of small sizes is equal to length of one shoulder or half of length of all dipole of *Lд=L.*

Semi-wave dipole is often considered as a standard and by his operating length the parameters of other antennas are expressed. Operating length of semi-wave dipole

$$L_{д\lambda/2} = \lambda/\pi = 4l/\pi \approx 1{,}27l.$$

Radiation resistance of symmetrical dipole R_Σ.

The current of dipole does not remain constant over the length, as in Hertz dipole, but changes. By determining radiation resistance, it is necessary to refer to a specific current, for example, a current at the input current or antinodes. Meaning of dipole radiation resistance relative to the current in the antinode depending on the relative lengths can be determined from the graphs and the simplified formulas given in reference literature.

Note: radiation resistance of semi-wave dipole equals to 73,1 Ohm, and wave dipole – 200 Ohm.

Resistance of radiation and current at antinode allows to define power of radiation $P_{\Sigma} = I_A^2 R_{\Sigma\Pi}$. Power of radiation can be determined also through the resistance of radiation, attributed to the input of antenna:

$$R_{\Sigma a} = R_{\Sigma п}/\sin^2 kl,$$

Impedance of dipole of Ww

There are a few simplified formulas for determination of impedance of dipole of Ww operating at certain conditions; all of them are given at [L 6.4].

A thin dipole (when $r \le 0{,}001\lambda$) has a relatively large impedance about 1000 Ohm. Such dipole is narrow-band and allows tricking into relatively small powers to him. For expansion of working band and possibility to work with large powers apply dipoles with the lowered impedance. For reduction of impedance it is necessary to increase a linear capacity and diminish linear inductance of dipole, that maybe at the increase of his radius. There can be a biconical dipole, i.e. such dipole where every shoulder is executed as a cone. The same properties are possessed by the dipole executed from flat wide metal-plate. Dipoles with the lowered impedance are executed also from the system of the wires located on formative cones or cylinders. Such dipoles are easier than continuous and create the less wind loading on masts.

Entrance resistance of dipole $Za = Ra + \imath Xa$

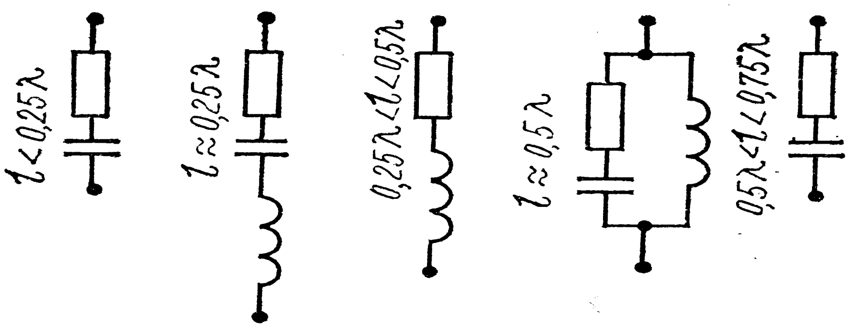


Figure 7 - Equivalent circuit of input resistance of dipole depending on his relative length

Short dipole has a complex input impedance of the capacitive type. The larger value of the reactance of the input impedance, the shorter is a vibrator, the larger its impedance, the smaller the diameter of the vibrator.

A half-wave dipole is resonant as its reactance is zero. Small and pure active input impedance makes it relatively easy to agree on a half-wave dipole with a coaxial line having an impedance of 75 Ohms. Half-wave vibrator is widely used, especially in the meter and decimeter waves, as an independent antenna or as an element of television antennas.

Dipole with length of shoulder $0,25 < L < 0,5\ \lambda$ (electric length $0,5\pi < ka < \pi$) has complex input resistance of inductive character.

One-wave dipole has cleanly pure input resistance and considers as resonant.

For a single symmetric single-wave vibrator R = 200 Ohms. If the vibrator is in the system of radiators or close to the reflector, then by virtue of their mutual influence of the radiation resistance can change substantially. Voltage antinodes and nodes at the current of one-wave dipole are arranged at the output and at the input. Therefore, its input impedance is large, in a thin vibrator Ww = 800-1000 Ohms and Ra = 3200-5000 Ohms. Single-wave dipole is in better agreement with symmetrical lines. Wave dipole antenna is used as an independent, as well as an element of complex antennas for television and sound broadcasting in different wavelengths.

Dipole with a shoulder $0,5 < L < 0,75$ has complex entrance resistance of capacity character. If the size of shoulder lies within the limits of $0,75 < L < 5$, input resistance has inductive character.

Presence of reactive component in the input resistance of dipole hampers the negotiation of him with feeder, therefore in practice aim to use resonant dipoles – one-wave or semi-wave - or to work on frequencies near to resonant.

In most practical calculations use the simplified formulas, they are given in [L 6.4].

Shortening of dipoles/

Phase speed of v in the dipole is less than the speed of distribution of wave in free-space, consequently, wave-length of dipole (to antenna) is less than the length in free space. Therefore the resonant dipoles sizes must be some shorter than $0,5\lambda$ or λ. For the calculation of dipoles *coefficient of wave shortening is applied* –

$$\xi = c/v = \lambda/\lambda_a.$$

Values of coefficient of shortening for semi-wave and one-wave dipoles are given in [L 6.4]. The less the impedance (larger diameter), the larger must be shortening of dipole. Shortening for a wave dipole is required approximately twice much in comparison with shortening for a semi-wave dipole.

Output-input ratio, gain and spectral bandwidth/

For symmetric dipoles with complete length of $2L \geq 0,5\lambda$, resistance of radiation more larger than resistance of losses, therefore their Output-input ratio is 100%.

An amplification of symmetric dipole of non-directional (isotropic) emitter is equal to its gain, for semi-wave dipole it is less than 1,64 times. Spectral bandwidth of antenna is determined by its input resistance. Input resistance of symmetric semi-wave dipole at the small off-tuning near-by resonance of frequency possible to examine as resistance of successive contour. At the small off-tuning the active constituent of Ra changes insignificantly, but a reactive constituent appears *Xa* and a current diminishes in a dipole, if the excitant his electro-motive force (EMF) remains former. By consuming the spectral bandwidth as an area of frequencies, on the borders of that a current diminishes in 0,707 times, then spectral bandwidth of symmetric sem-iwave dipole is

$$2\Delta f \approx {4*73{,}1 f_0} / {\pi W}$$

Control questions.

1 What is the "symmetric dipole"?

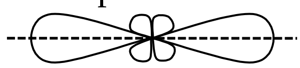
2 Specify correct distribution of current and voltage along symmetric short one, quarter-wave, semi-wave etc. dipole.

3 At what length does a dipole have maximal D?

4 How to increase the gain of dipole?

5 Specify distribution of current and voltage along a dipole with the length of 1,25λ.

6 How to define the proper wave-length of dipole?

7 How to define the relative wave-length of dipole and how its axis is oriented, having indicated radiation pattern of 

8 What is the value of input resistance of semi-wave dipole?

9 How to extend the range of working frequencies of dipole?

10 How to define the proper wave-length of dipole?

11 What is the value of resistance of radiation of semi-wave dipole?

Lecture 3. Asymmetrical vertical dipole. Multidipole antennas

The asymmetrical is a dipole that sizes or forms of its shoulders differ from each other. The asymmetrical vertical grounded dipole is a vertical in relation to ground conductor, to the lower end of that one of clamps of generator is added, and other clamp of generator is added to ground.

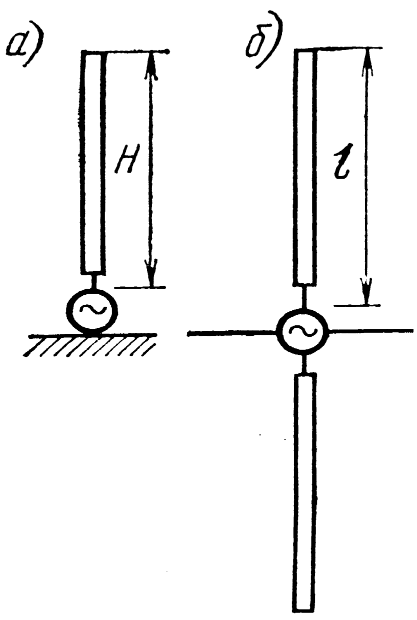


Figure 1 - Asymmetrical (a) and symmetric (b) dipoles

Second shoulder of dipole in this case is a ground. Such dipoles are used as antennas of long, middle and short waves, and also waves of meter range. Asymmetrical dipoles often set on locomotive objects (cars, airplanes, ships). The role of "ground" executes the metallic corps of object to that one of clamps of generator is connected. The asymmetrical dipole located directly above the surface of ideally conducting ground (figure 1a) is analogical to the dipole in free space (figure 1б), because a mirror image executes the functions of the second shoulder at an asymmetrical dipole.

Such presentation allows considerable part of the decisions and conclusions, executed for dipoles, to spread on symmetric antennas. Radiation pattern of vertical dipole in the vertical plane of F (Δ) (E plane) taking into account influence of mirror image is determined also, as for a dipole, in that angle is replaced by angle of Δ .

$$F(\Delta) = \frac{\cos(kl\sin\Delta) - \cos kl}{\cos\Delta},$$

where Δ- is angle between a surface of ground and direction to the supervision.

Radiation pattern of the vertical asymmetrical dipole located above ground, and distribution of current, on a dipole depending on relative length are given in figure 2. It can be noted from the given radiation patterns, that an asymmetrical dipole has a maximal radiation along the surface of ground.

For a short dipole, the radiation pattern in overhead half-space above a surface of ground coincides with the radiation pattern of dipole of Hertz and can be expected on a formula of

$$F(\Delta) = \cos\Delta.$$

On a figure 2 the curve of cos is shown by thin dotted line. Such dipole has a considerable radiation under large angles Δ to horizon. By lengthening of dipole due to narrowing of radiation pattern, intensity of radiation increases along the ground. At length of dipole, greater than 0,5 λ (figure 2. in, г), in the radiation pattern a side lobe appears under a large angle Δ to horizon. The vertical asymmetrical dipole with the length of (in high) $L = (0{,}53 - 0{,}58)\lambda$ is widely applied. This dipole creates a small radiation (less than 15% on the field) under large angles Δ to horizon $\Delta(\text{for}\,\Delta \geq 40°)$ and intensively radiates along the ground ($\Delta = 0$). The radiation pattern of such antenna is shown on the of figure 2в. At weak conductivity, the surface of the ground is considered as a bad screen and considerable part of energy of electromagnetic wave spreading near-by the surface of the ground gets to ground. As a result, the field tension along ground with distance quickly diminishes the field is radiations under some angle to more than along ground appears, and the radiation pattern assumes an air shown on the figure 2a by the thick dotted line.

The worse conductivity of soil and longer distance from antenna, the more considerable weakening of the field along a surface of the ground, and a maximum radiation is observed under a large angle to horizon. The radiation pattern of F(Δ) for the real conductivity of soil are just only for the set distance. In a horizontal plane a vertical dipole radiates evenly on all directions.

Operating length of vertical asymmetrical antenna is half less than dipole. Impedance, resistance of radiation and input resistance of asymmetrical antenna is half less that that with analogical resistance.

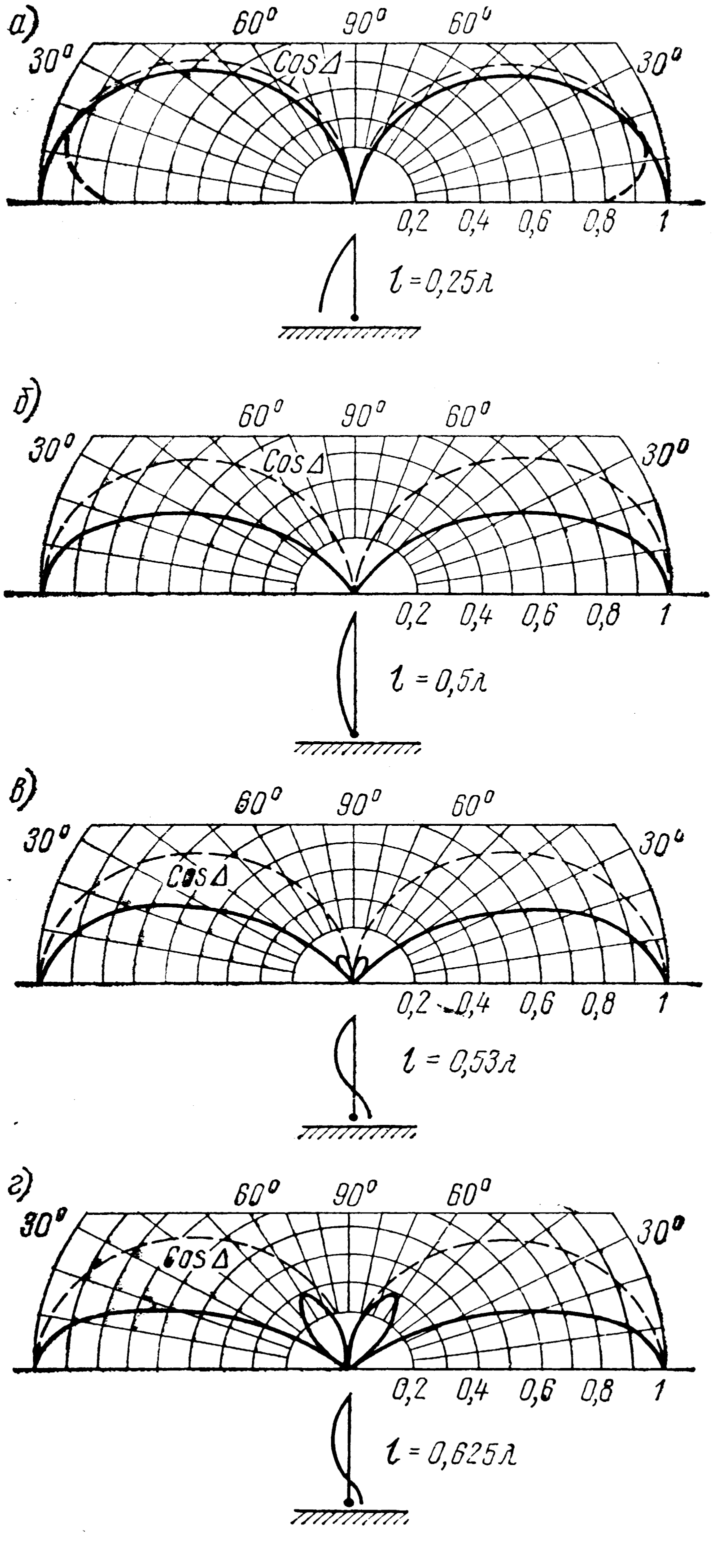


Figure 2 - Radiation pattern of asymmetrical dipole

System from two dipoles.

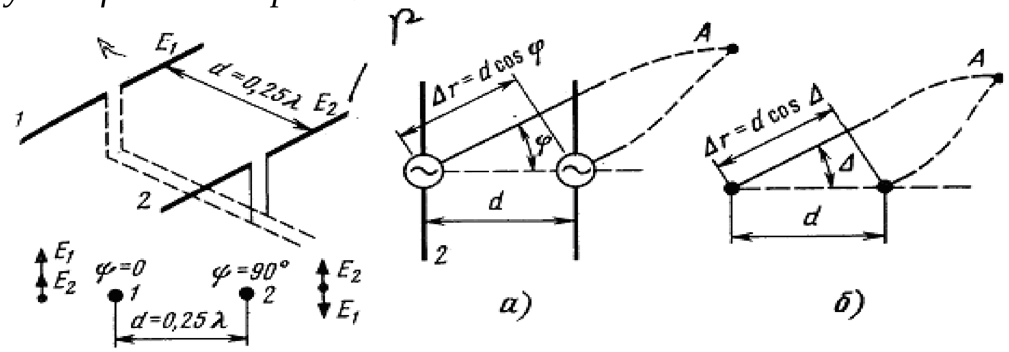


Figure 3 - System from two dipoles

If to make a linear grid from the directed emitters, for example dipoles, then the field of E1, created by every dipole, will be determined by his directed properties $F_1(\varphi)$ and resulting description of orientation

$$F(\varphi) = F_1(\varphi) F_P(\varphi),$$

$$F_p(\varphi) = \sqrt{1 + m^2 + 2m\cos(\Phi - \kappa d\cos\varphi)}$$

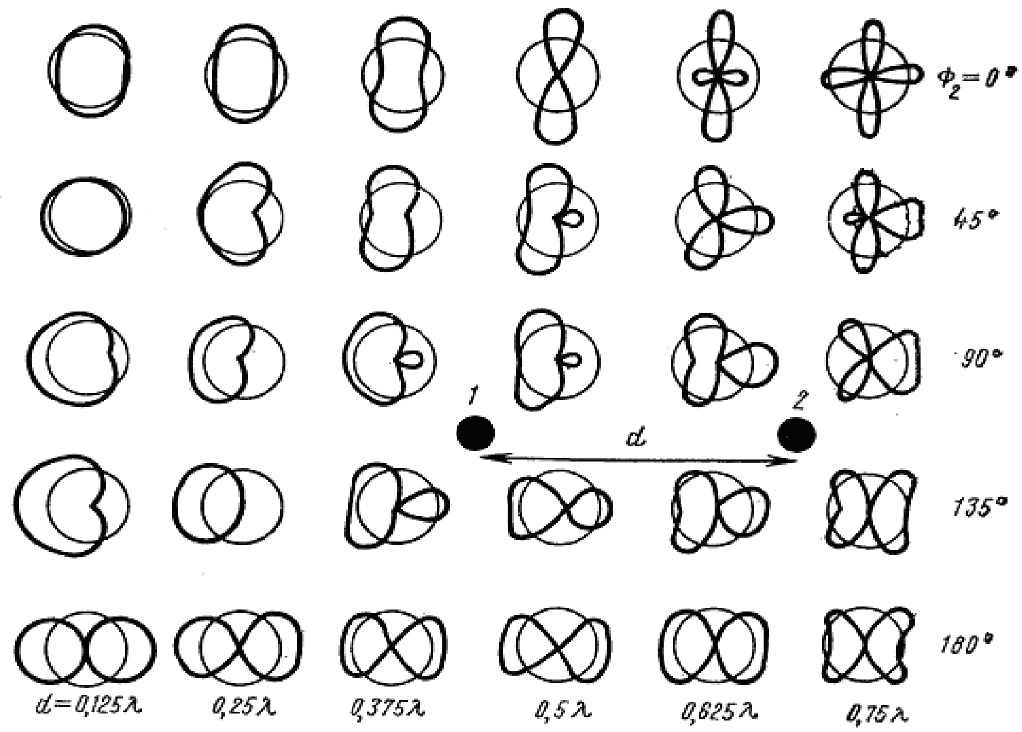
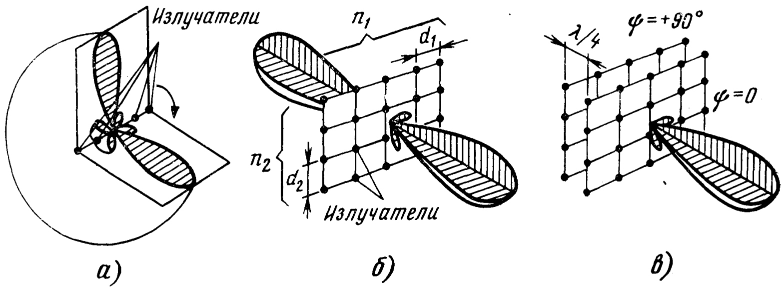


Figure 4 - Radiation pattern of multiplier of the system consisting of two dipoles, with equal amplitudes, but different phases of currents (m=1;) $(F2 \neq F1)$depending on distance between dipoles

Arrays.

For large values of gain and sharply expressed directed properties, antennas as a system of large number of the dipoles named grids *are applied*. Currents in the dipoles of grid can have identical phases. Such grids are called *in-phase antennas. The variably-phase systems* are used also, currents in the dipoles of that have the once-personal phases, conformable to the certain laws. We will consider the linear system from *n* of the non-directional emitters, located on equal distances of *d* from each other, excited by currents equal on amplitude. Such system of dipoles is called equidistant equal amplitude grid.

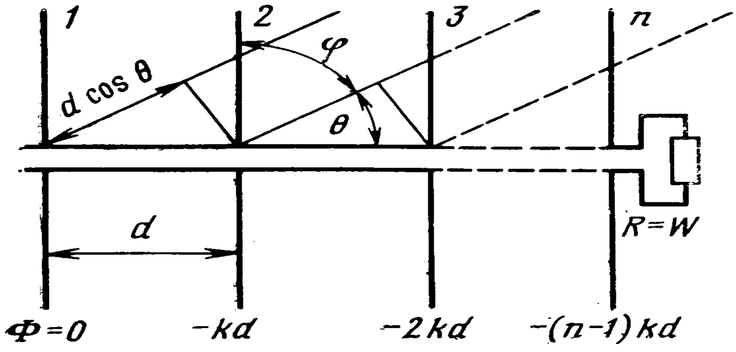
Radiation pattern of in-phase grids from non-directional emitters



а – linear; б – flat; в - flat with a reflector.

Figure 5

For determination of radiation pattern of grid of antenna of progressing wave



$$F_c(\varphi) = \frac{\sin[0{,}5\,n\,(\kappa d \sin\varphi - \Phi)]}{\sin[0{,}5\,(\kappa d \sin\varphi - \Phi)]} = \frac{\sin[0{,}5\,n\,\kappa d\,(\sin\varphi - \xi)]}{\sin[0{,}5\,\kappa d\,(\sin\varphi - \xi)]}\,.$$

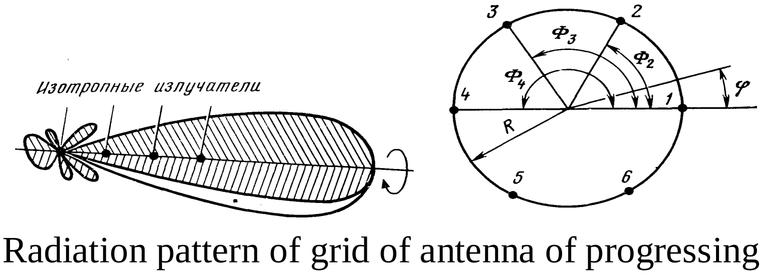


Figure 6 - Radiation pattern of grid of antenna of progressing wave from non-directional emitters and Circular grid

$$\psi = \kappa d \sin \varphi - \Phi;$$

$$F_c(\varphi) = \frac{\sin(0,5\, n\psi)}{\sin(0,5\psi)} = \frac{\sin[0,5\, n\, (\kappa d \sin\varphi - \Phi)]}{\sin[0,5\, (\kappa d \sin\varphi - \Phi)]}.$$

Multiplier of the system (grids) of emitters.

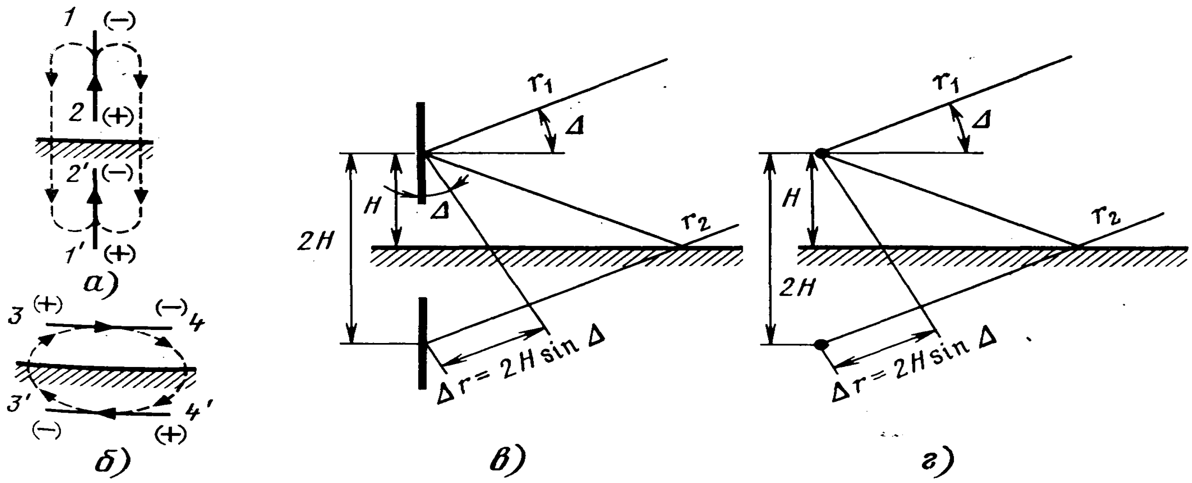
If to make a linear grid from the directed emitters, for example dipoles, then the field of E1, created by every dipole, will be determined by his directed properties $F_1(\varphi)$ and resulting description of orientation.

C o n c l u s i o n. Width of radiation pattern of phase is narrowed with decrease in wavelength, and increasing the number of vibrators increase distance there between. If in in-phase grating reduce the number of vibrators and increase the distance between them so, that the product of *nd* remain constant, the linear dimensions of the antenna, the width of the main lobe would remain unchanged, but the side levels will increase. At $d \le 0,5\lambda$, the side-lobe levels remain unchanged, but the number of vibrators increases and the power system is complicated. Therefore, the distance d between the centers of omnidirectional or half-wave dipoles usually equal to 0.5λ, and the single-wave $-\lambda$. To reduce the side lobe level equidistant grid is applied, at which central vibrators have large currents and the peripheral – equal amplitude or smaller grid, in which the distance between the dipole as their distance from the center of the antenna increases. Application of the law amplitude distribution or placement of dipoles enables to decrease the side-lobe levels to the required values. Given linear dimensions of the antenna with the largest directivity has equal amplitude equidistant grid. Therefore, reducing the side-lobe level is achieved by reducing the directivity or by increasing in size of the antenna.

Influence of the ground on the directed properties of antennas.

Under the influence of the antenna field located directly above the ground, currents are occurred which create the secondary field. The secondary field induces currents in the additional antenna that alter the primary current and charge distribution at the antenna, whereby the input impedance change, and other parameters of the antenna. The resulting field at a great distance from the antenna is the sum of primary and secondary fields. The calculations take into account the influence of the earth by mirror images. Its essence lies in the fact that the resulting field is considered as the sum of E1 direct and reflected waves from the ground E2. Waves reflected from the ground, can be regarded as a wave, creates a mirror image of the antenna.

According the constructions, it is clear that the currents in the vertical dipole and its mirror image coincide at direction and in the horizontal vibrator and its mirror image - comer.



а - vertical dipole and its mirror image; б - horizontal dipole and its mirror image; в - vertical dipole; г - horizontal dipole.

Figure 7 - For determination of multiplier of ground

Radiation pattern in the dipole located above ideally conducting ground. In a point being at long range from a dipole, ray going directly from a dipole, it is possible to consider parallel I shine, reflected ground or mirror image (figure 1, в).

$$F_{в.з}(\Delta) = 2\cos(\kappa H \sin\Delta),$$

where $F_1(\Delta)$- is a multiplier that takes into account the effect of a perfectly conducting ground antenna on the radiation pattern with vertical dipoles.

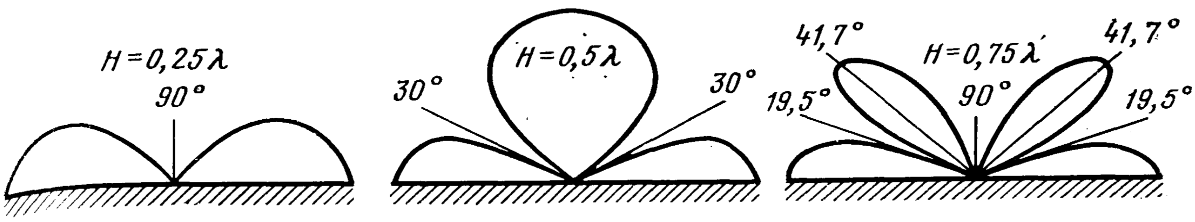


Figure 8 - Multipliers of ground during vertical polarization of wave without the account of the directed properties of dipole

During horizontal polarization of the field

$$F_{г.з}(\Delta) = 2\sin(\kappa H \sin\Delta).$$

Description of orientation of any antenna with horizontal dipoles, located above ground, is determined by the following equation

$$F(\Delta) = F_1(\Delta)\, F_{г.з}(\Delta),$$

where $F_1(\Delta)$- is a multiplier of *radiation pattern* in the vertical plane of the antenna located in free space;

$F_{Г.З}(\Delta)$- it is a multiplier, taking into account influence of ground at horizontal dipoles.

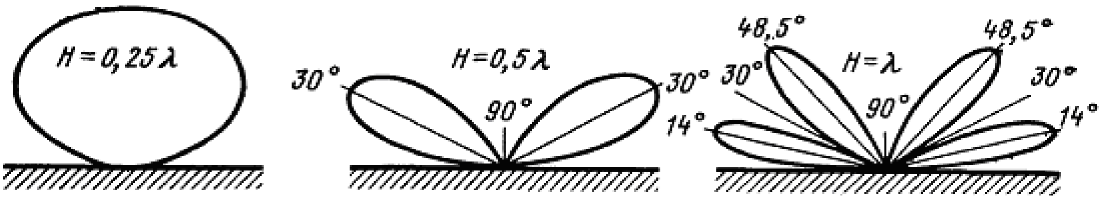


Figure 9 - Radiation pattern of horizontal dipole at the different heights

Conclusion. Antenna with horizontal dipoles along ideally conducting ground does not radiate. A maximum of radiation is directed under some angle to the surface of the ground. The higher H/λ location of antenna, the less corresponding to direction of maximal radiation.

Optimal height of antenna with horizontal dipoles

$$H=\lambda/4 \sin \Delta_М.$$

At the heights of radiation pattern in a vertical plane becomes polypetalous.

Flat reflectors.

Flat reflectors are the systems from two dipoles, possessing at certain conditions with one-sided radiations. Such system is simple enough in making, has small windage, but does not allow getting a large protective action and there is narrow banded. To obtain large value of coefficient of protective action in the wide banded frequencies the aperiodic reflectors are applied, made by flat metallic surfaces. Multiplier of aperiodic reflector

$$F_р(\varphi)=2\sin(\kappa d_р \cos\varphi),$$

It is recommended to use reflectors, the edges of which protrude beyond each side edge in the plane E to 0.1λ, at the plane H for 0.25λ. The distance between the vibrator and the reflector is chosen in the range of (0.2 ... 0.35) λ. With the decrease of these distance decreases the resistance of the antenna radiation.

The flat reflectors with large size are executed as grids from wires, metallic bars or planes, located in parallel to the vector of E.

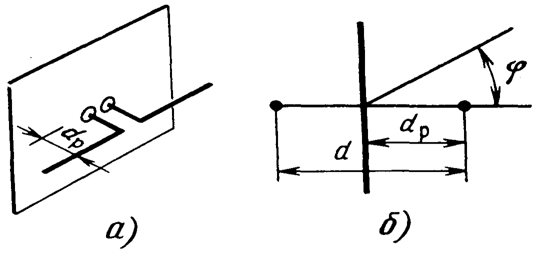


Figure 10 - Aperiodic reflector (a) and to determination of his multiplier (б)

Such reflectors are easier than continuous, but possess the less coefficient of protective action, as part of energy passes through the latticed reflector.

Control questions.

1 Draw the distribution of current and voltage along the monopole.
2 Does affect the ground surface to work of monopole?
3 What are the wave resistance, radiation resistance and input impedance?
4 Explain the working principle of the reflector.
5 Write down the formula of the factor-phase grid.
6 What determines the width of the radiation pattern array?
7 Specify methods for reducing the level of side lobes.
8 Write down the expression for the factor that takes into account the influence of the ground on antenna pattern with horizontal vibrators.
9 What determines the choice of the height of the horizontal suspension of the vibrator?

Lecture 4. Radiation of excitant surfaces

It is hard to implement a dipole system with increasing frequency of the antenna with large directivity. A large number of dipoles and small size greatly complicate the system of power and does not allow obtaining a wide band of operating parts. In the UHF band and shorter wavelengths are widely distributed antennas configured as radiating surfaces - a horn and reflector antennas. Parameters of this type of antennas are determined by the area and shape of the emitting surface (aperture) and by the distribution of amplitudes and phases of the field in the aperture.

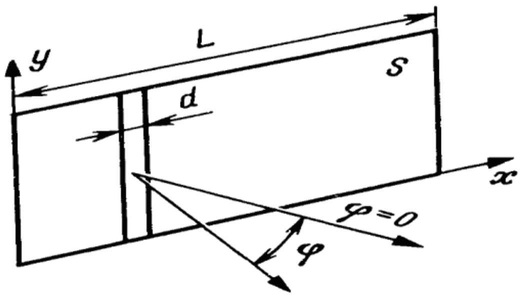


Figure 1 - Determination of the field of radiation of rectangular surface

Let’s consider the radiation of flat surface is rectangular shape, excited at every point of the surface with the field of the same phase and amplitude. To determine radiation pattern of horizontal plate, radiating surface should be taken as a sum of a large number of narrow vertical strips. The vertical dimension (height) of the strip is not affect on the radiation pattern of horizontal plane. In this case, the radiation pattern multiplier is $F(\varphi) = F1(\varphi) * Fс.н.(\varphi)$. Here $F1(\varphi) = 1 + \cos\varphi$ - radiation pattern multiplier’s element radiating surface with the small relative size; $Fс.н.(\varphi)$- the normalized factor system. When amplitudes and phases of the field in the aperture system are equal, normalized factor comes as multiplier-phase grid. In these case the number of bars are more ($n \to \infty$), and their width is small ($d \to 0$). At the same time the sum of all the strips leads to the aperture length, *nd* = *L*. Modifier $0{,}5kd = \pi d / \lambda$ - small, therefore, the denominator can be replaced by a sine function of its argument. Making replacement nd = L, $\sin(0{,}5nkd\sin\varphi) = \sin(0{,}5kL\sin\varphi)$ and $n\sin(0{,}5kd\sin\varphi) \approx 0{,}5kL\sin\varphi$, we obtain:

$$F(\varphi) = \sin(0{,}5kL\sin\varphi) \big/ 0{,}5kL\sin\varphi$$

For antennas with a large aperture ($L \rangle\rangle \lambda$) directional properties $F1(\varphi)$ can be ignored, and considered only the factor of the system. In conclude, the maximum radiation will occur at $\varphi = 0$, when the width of the main lobe of radiation pattern will be the same as for the phase grating. With increasing frequency or size of the radiating surface, the antenna's radiation pattern is narrowed.

In the general case for arbitrary shaped emitting surface with different amplitude and phase distributions of fields on the surface of radiation pattern (RP) is the sum of fields created by the elementary portions of the radiating surface. Modifier radiation pattern (RP), such as a rectangular surface, excited in phase, but the field amplitude, the maximum in the center and decreases to zero at its edges.

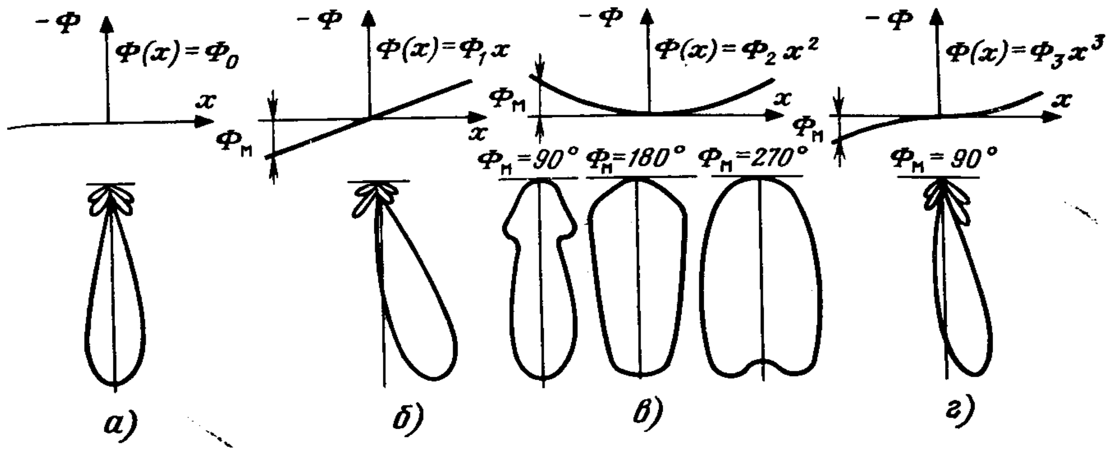


Figure 2 - Influence of phase field distribution in the aperture in the radiation pattern of antenna

The main provisions of the theory of reception.

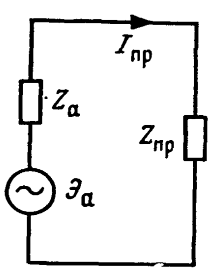


Figure 3 - Receiving antenna as equivalent generator

Furthermore, if the transmission evaluation criterion for antenna is the gain, then the receiver - in some cases, and the directional coefficients of the protective action.

Therefore, some types of antennas that have good range and directional properties, but with a high enough efficiency, use only as a receiver, such as framework, magneto-dielectric, some traveling-wave antenna and others. In the interaction with the electromagnetic wave at the reception antenna induced EMF, which causes the current antenna and receiver connected to it. In this part of the electromagnetic wave energy is absorbed by the antenna. Due to the current absorbed by the antenna energy is partially allocated to the receiver input impedance of the active component, partially re-emitted (due to the antenna radiation resistance) and partially dissipated (as heat) in the loss resistance.

Based on reciprocity receive antenna can be represented as the equivalent generator. The electromotive force equivalent generator (induced in the antenna)

$$Эa = L_Д E F_H(\varphi),$$

where $L_д$ - the current length of the antenna;

$F_н(ф)$ - factor of normalized antenna's radiation pattern.

The current in the receiving antenna, a receiver loaded,

$$Inp = \frac{Эa}{Za + Znp},$$

where *Za* - the input impedance of the antenna;

$Z_{ПР}$ - receiver input impedance.

The current and voltage in the receiver antenna dependent on the aimed properties and orientation of the antenna in space. In professional antenna and receiver devices often work in the agreed conditions, and when Za and $Z_{ПР}$ are the complex conjugate. In this case, the antenna sends a maximum power in the receiver.

Interference mitigation of directional antenna.

Interference with the radio can be external and internal. External interference are electromagnetic radiation of radio stations, various technical devices, atmospheric and space phenomena. Reduction of industrial and natural disturbances made the imposition of the receiving stations a considerable distance from the cities and industrial centers, and the use of directional antennas with high directivity factor and protective action. Domestic disturbance caused by noise input of the receiver circuit, the thermal motion of the electrons in the antenna and feeder. The reception quality is determined by the signal-to-noise ratio: Pc/Pm where Pc - the desired signal power; Pm - total capacity of external noise and internal noise referred to the receiver input.

At decameter ranges and longer wavelengths the main problem is the external interference. In this case, the reduced efficiency of the receiving antenna decreases to the same extent at the input of the receiver signal and interference while maintaining the same signal-to-noise ratio. This makes it possible to use these bands receiving antennas with low efficiency, but with good directional properties. These antennas require less material cost and can operate over a wider frequency range. Reduction of the receiver input signal level in this case can be compensated for by additional gain in the receiver, the cost of creating a much lower value which complex with high efficiency antenna.

At VHF, UHF, SHF ranges, application of antennas with high directivity factor and the protective effect, the level of external noise is much less than internal noise. Under these conditions, to improve the signal-to-noise ratio, it is necessary to increase the efficiency and gain of antenna, and strive to reduce internal noise: noise antenna, feeder and receiver.

If the level of external noise is significantly higher than internal noise and external noise field uniformly comes from all directions, and the direction of arrival of the desired signal coincides with the reign of the main peak of radiation pattern, the use of a directional antenna at a reception in comparison with the non-directional improves the ratio P_c / P_m at D time. In the case of directional external disturbance, coming from the same direction, the receiving antenna, and consequently, its radiation pattern can be oriented so that the direction of the disturbance coincides with the direction of a zero (low) reception, then the signal-noise ratio can be improved more than D times.

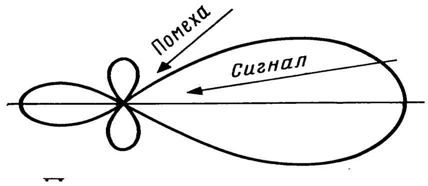


Figure 4 - Interference suppression of the directional antenna

The direction of maximum reception in this case may differ slightly from the direction of arrival of the desired signal.

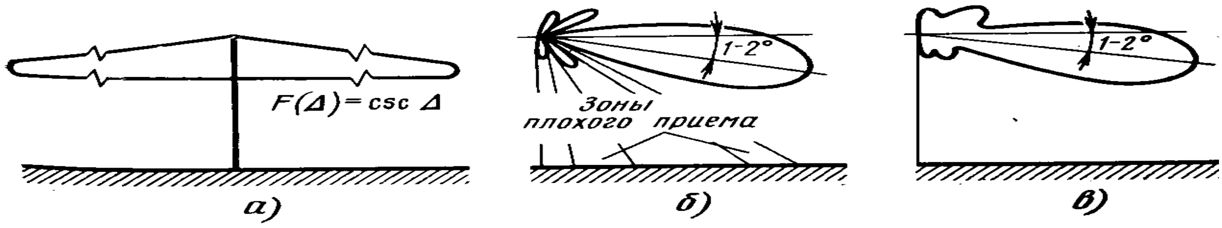
With regard to the relatively short distances in line of sight, such as in the case of radio relay television transmission, transmitting and receiving antennas need to work with the waves of one polarization. If in the process of propagation of the wave passes through the ionosphere or reflected by it, it is possible to change the plane of polarization. For example, if the spatial wavelength in the range decameter waves plane-polarized wave emitted by the transmitting antenna, converted elliptically polarized during the propagation in the ionosphere. In this case, the receiving and transmitting antennas can be mismatched polarization.

Lecture 5. Simple dipole and slotted antennas of USW range

Requirements produced to antennas.

Bands of decametric and metric waves are used for the transmission of television and radio broadcasting, mobile communications, navigation, radar and radio astronomy. An antenna for communication with ground moving objects should preferably have omnidirectional radiation characteristics in the horizontal plane and have a maximum directed along the earth's surface, in the vertical plane. These requirements are satisfied antenna with vertical dipoles. When mounted on the same support multiple antennas need to be positioned so as to loosen the mutual influence. For this antenna are arranged so that their axes coincide vibrator or vibrators located on different sides of the metal support. To reduce the number of antenna sizes produced commercially operate their broadband, allowing work on any one channel range. To increase the range of a transmitting television antennas mounted on towers or masts guyed height of 180 ... 350 m and more. To reduce interference between transmitters operating in the same frequency channel, the antenna used with mutually perpendicular dipoles, wavelength used both horizontal and vertical polarizations.

Directional characteristics of transmitting television antennas in the horizontal plane in most cases must be non-directional. In the vertical plane of the antenna should create a uniform field strength at small and at large distances, should have a directional radiation pattern chart describes the functions $F(\Delta) = \csc\Delta$. The construction of the antenna with a radiation pattern presents some difficulties. In practice multistory used with narrow antenna diagram in the vertical direction plane narrowing main lobe 2 ... 4° while the maximum radiation direction of inclination of 1 ... 20 from the horizontal to the earth's surface. Antennas with narrow directional patterns are the multi-lobe with several lines of deep minima, which are formed due to a poor reception area. To exclude these zones field strength minima shall not be less than 0.1 times the field strength of the main peak. To eliminate the harmful influence of echo on the work feeder television broadcasting and stereophonic sound, coefficient of traveling wave in the feeder must be large enough - at least 0.85. Highly placed the antenna exposed to more wind and ice load, as well as the effects of lightning. To improve the reliability and lightning vibrators antennas must be carried out with direct hard ground, provided with a warm-up device for removing ice or fairing, closing vibrators from external influences.

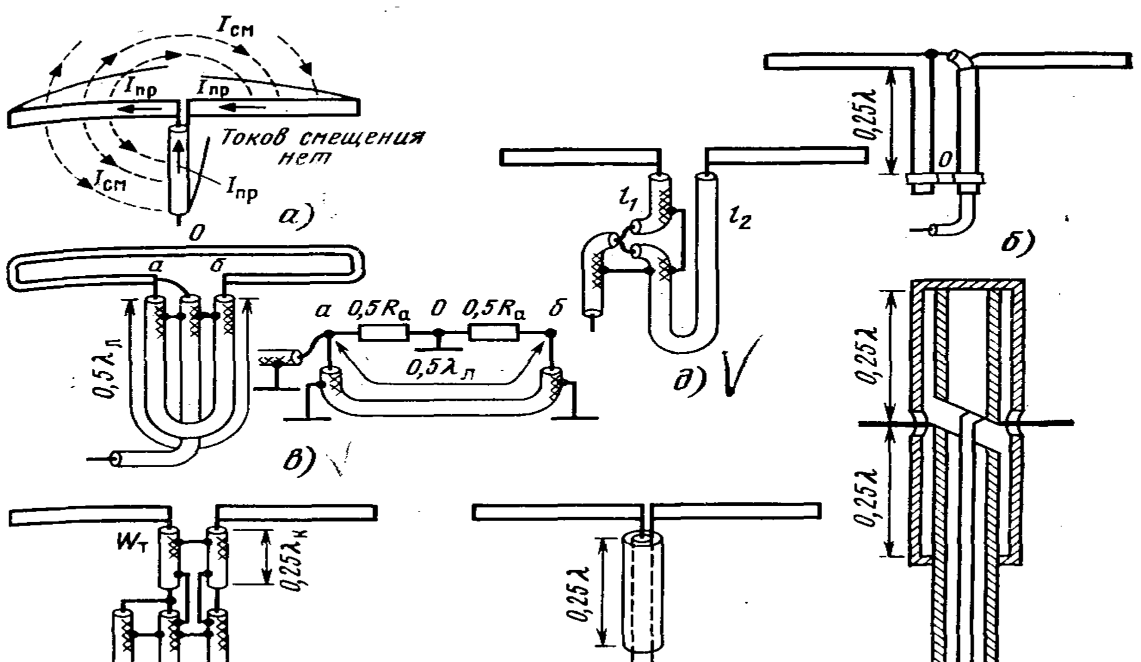


а – csc type; б - with deep minimums; в - the blurred minimums.

Figure 1 - The diagrams in the vertical plane of transmitting television antennas

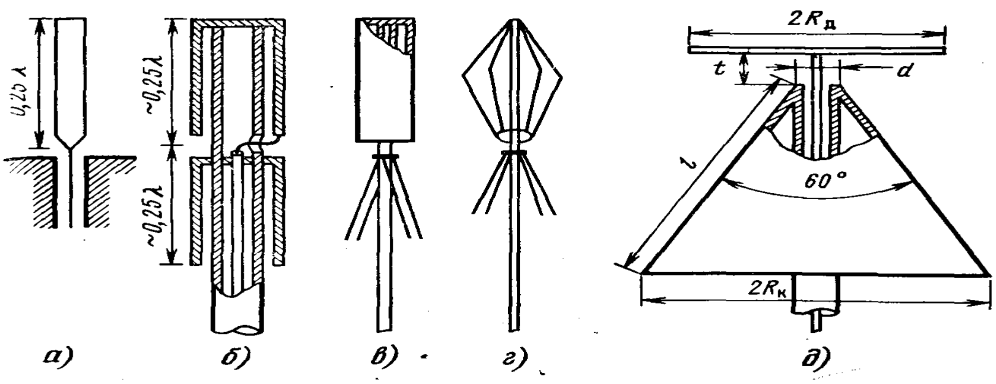
Balancing units.

The asymmetry of the vibrator current. By asymmetric unbalanced antenna feeder can be connected directly: the central conductor of the vibrator, and the external grounding, the counterweight or the body, if the input impedance of the antenna is equal to the characteristic impedance of the feeder. Otherwise, between the antenna and feeder matching transformer is applied. Direct connection to a coaxial feeder dipoles, as shown in figure 2, without balancing unit causes differences between the current amplitudes in the shoulders and the vibrator gives rise to current on the surface of the outer conductor of the feeder. The asymmetry in the currents caused by the shoulders of the vibrator in that between the shoulders and connected to the center conductor of the coaxial feeder and its outer conductor formed bias currents. The second arm of the vibrator has the potential of the outer conductor of the feeder, there is no potential difference and bias currents are not formed. The asymmetry of the currents in the vibrator few distorts its radiation pattern. More significantly affected by the currents on the external conductor of the coaxial feeder. The result of their action is the effect of the antenna feeder. These currents are at work on the transfer of horizontal vibrator create parasitic radiation field with vertical polarization. In the case of horizontal receiving antennas due to the asymmetry is received the vertical field interference.



а – direct connecting of line to the dipole; б – prefix; в – loop; г, д – U-knee, е – cup ; ж – widely stripe.

Figure 2 - Balancing units



a – pin; b - coaxial; c – in the lower shoulders from the wires; g - both shoulders from the wires or tubes; d – disco-cone.

Figure 3 - Vertical vibrators

Lecture 6. Symmetric single (linear) and loopback vibrators

A loopback vibrator offered by Pistolkorski can be considered as two half-wave in-phase vibrators, located on a small distance ($D\langle\langle\lambda$) from each other connected at the ends. Feed point's *ae* vibrator is the symmetric system. In the most remote from the points of feed, for vibrator *c* the system affects short circuited and current antinodes appear here. As moving far from point *c* to the input of antenna, the amplitude of current decreases and at points b and d, situated at distance of 0,25 λ from point *c*, the nodes of current appear. Further, after the points of *b* and *d*, currents change the direction on reverse, but their amplitudes as far as approaching to the points *a* and *e* increase. Segments of vibrator of *ba* and *de* accordingly in points *b* and *d* of relatively overhead segment of *bcd* is unfolded to meet each other, consequently, currents in both vibrators 1 and 2 have one direction. A location of current antinode and voltage node at a point *c* allows to fasten a vibrator in this point to the metallic arrow without isolators ensuring reliable lightning protection.

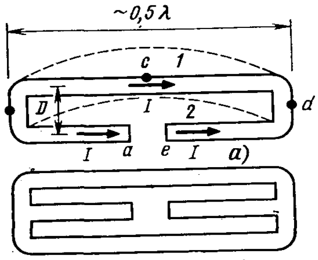
At equality of tube diameters of vibrator, the currents in them will be equal. Radiation area formed by a total current of 2I. Power of radiation of loopback vibrator $P_\Sigma = (2I)^2 R_{\Sigma\Pi}$. Input power $P = (2I)^2 R_a$. By solving these equations together in a relation to *Ra* and supposing $P_\Sigma = P$, we determine input resistance of loopback vibrator of Ra = 300 Ohm.

Input resistance of loopback vibrator can be changed by varying correlation of diameters of vibrator tubes. By changing the ratio of diameter of upper vibrator (1) to lower (2) from 0,5 to 2, input resistance of loopback vibrator changes from 220 to 380 Ohm.

Loopback and symmetric half-wave vibrators have approximately identical directivity, radiation pattern and gain. The location plane of tubes in the vibrator has not significant influence on his parameters. To obtain higher input resistance of antenna two loopback vibrators are applied, consisting of three half-wave in-phase vibrators. Input resistance of such vibrator is approximately equal to 9 $R_{\Sigma\Pi}$.

Wave channel. As directed antennas, wave channels are commonly used. This antenna consists of vibrator *B,* reflector *A* and a few directors B, G and *D*. For simplification of construction in this antenna reflector and directing elements executed by secondary – without feed. Secondary vibrators in this case become excited by the field of primary vibrator of *Б*. Let's consider the system consisting of primary vibrator 1 and secondary 2. Let's assume that the current I1 will generate in a vibrator by a 1. In a vibrator, as well as in the close loop with small losses, the mode of standing wave is set, whereby voltage falls behind the current I1 approximately by the angle of 90°. Voltage of U1 will create field of E1 near the vibrator *1* with the same on phase. This field, reaching the vibrator 2 (E12) will fall behind on a phase by the angle of kd=90° and will point in a vibrator *1 electromotive force 2* EMF Э2. We will take a secondary vibrator 2 some longer than 0,5A,. The reactance of such vibrator has inductive character (kl2>90°), and the current of I2, conditioned by electromotive force *EMF Э2*, will fall behind from on a phase by the angle of 90°

In turn, the current of I2 will create at a vibrator 2 the field of E2, which falls behind at the current on a phase by the angle of 90°. As the fields of E12 and E2 antipodal, resulting field behind a secondary vibrator 2 is weak. E2 field of vibrator 2, reaching the vibrator 1(E21), will fall behind on a phase by the angle of 90°. b will coincide with the field of E1. In direction from a vibrator 2 to the vibrator 1 and further, fields will be folded. Secondary vibrator with the length of 2l2>0,5, behaves as a reflector.

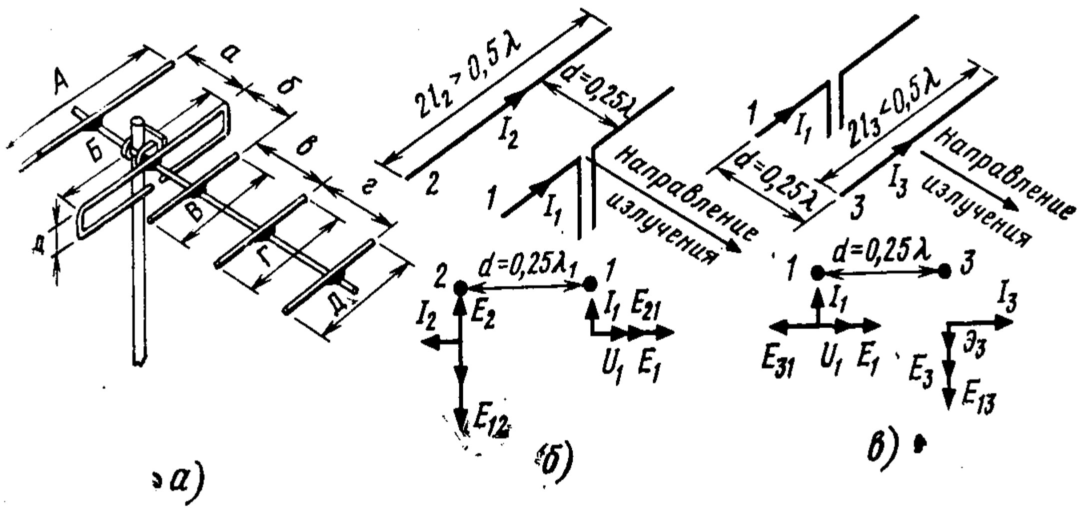


one-a – one loop ; б – two loopback.

Figure 1 - Loopback vibrators

If secondary vibrator is shorter than 0,5 (fig. 11.6, в), then its active resistance has capacity character and current of I3 0 electromotive force of E3 passes ahead on a phase by the angle of 90°. A maximum of radiation is directed toward a secondary vibrator 3, and the field behind a primary vibrator gets weak. Such secondary vibrator (2l3<0,5) is called *director*.

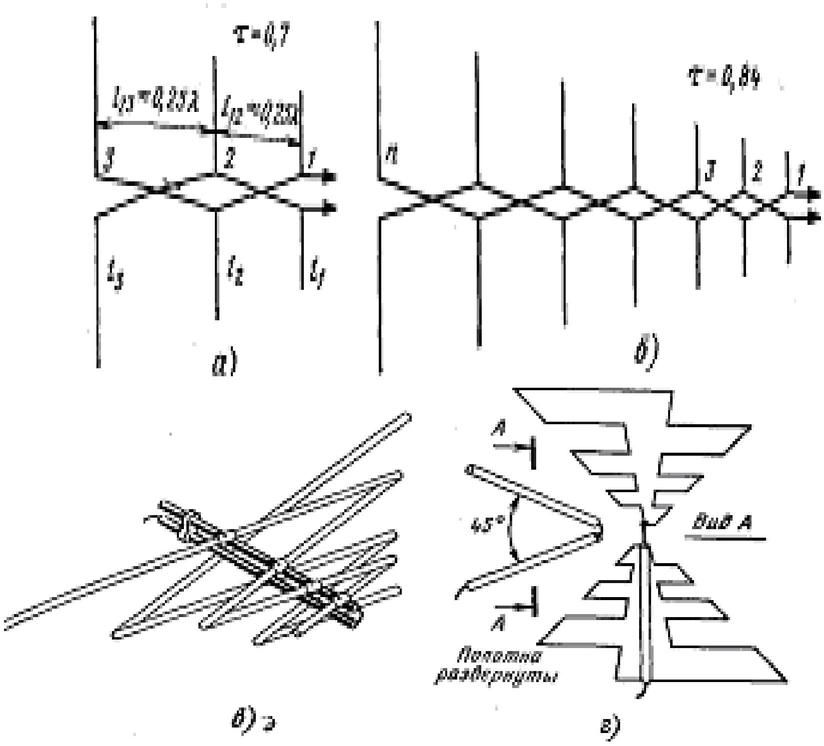
In antenna "wave channel" length of reflector is chosen equal to (0,5... 0,53) λ, and distance between a reflector and primary vibrator is (0,15 ... 0,25) λ . Lengths of directors are chosen equal to; (0,4... 0,45) λ, and distances between a vibrator and nearest to him director, and also between directors are (0,1... 0,34) λ.



a) and – five element;
б) vibrator with a secondary reflector;
в) vibrator with a secondary director.

Figure 2 - Wave channel

With reduction of distances between vibrators, a current increases at secondary vibrators, but input resistance of primary vibrator decreases significantly. For the facilitation of matching with feeder and from structural considerations, it is agreed to apply a loopback vibrator as a primary vibrator. "wave channel" antenna is narrow-banded, because with the change of frequency input resistances change substantially, and consequently, amplitudes and phases of currents change in secondary vibrators. six-, seven elemental antennas have a bandwidth of 10 ... 15% from a mean of frequency. At the increase the number of elements in antenna to ten bandwidth narrows to 5%. A number of elements in antenna is the complete number of primary and secondary vibrators. It is possible to extend the bandwidth by changing the sizes and mutual location of vibrators, by decreasing the directivity of antenna. The calculation of radiation pattern of antenna can be implemented by (8.16), whereas d is the *average* distance between nearby vibrators. The coefficient of wave shortening is determined from (8.20) or accepted by equal to unit, the directivity is determined by (8.21).

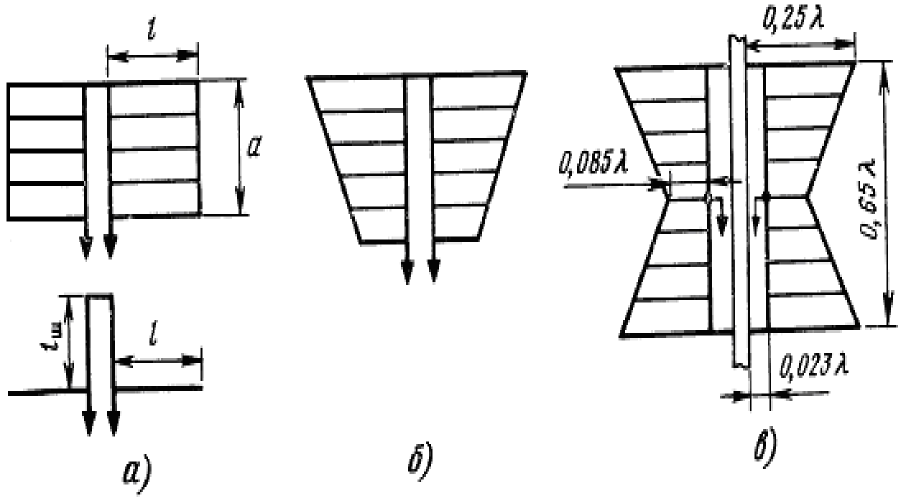


а - active area; б, в - flat; г - spatial by reflector, в - vibrator with a secondary director.

Figure 3 - Logotype periodic of antenna

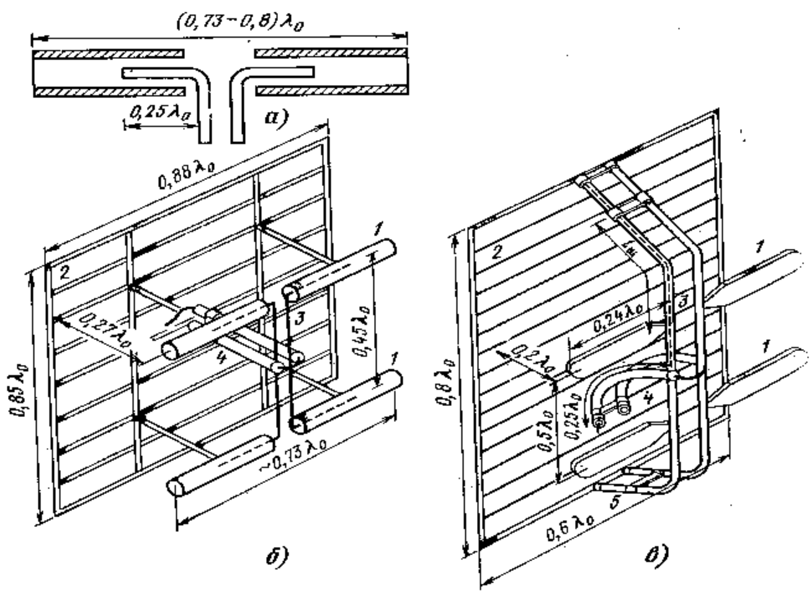
Transmitting televisional antennas.

Multi-vibrator antennas are mainly applied for the transmission of the televisional broadcasting. Vibrators of such antennas must be broadbanded. Extending the bandwidth is possible by applying of vibrators with a small impedance and use the input impedance with the schemes of compensated reactive components. On the very first televisional stations the vibrators of B.V. Broude were applied, which is the flat vibrator combined with a short-circuited shunt. The vibrator of B.V. Broude and its equivalent scheme is given in a figure 4. The reactive components of input resistances of vibrator and shunt have different signs and compensated partly. The presence of a zero potential allows the point of short circuit of shunt to fasten a vibrator to support in this point without insulators. It simplifies a lightning guard.



а - Broude; *б* - trapezoidal; *в* -X-shaped.

Figure 4 - Flat vibrators



а- wave vibrator; *б* - panel with cylindrical one-wave vibrators; *в*- panel with flat semi-wave vibrators.

Figure 5 - Panel antennas

Currents in the vibrator of Broude are excited by the currents of different amplitudes. It is explained that as far as advancement on a shunt voltage from a maximal value at points of feed falls to the zero in the point of short circuit. It is possible to equalize the currents in conductors, by executing the shoulders of vibrator in form a trapezoid. In order to satisfy this purpose, at the points located nearer to short circuit, the length of horizontal conductors is taken by resonant, i.e. close to the value of $l \approx 0{,}25\lambda$, and conductors located closer to the points of feed are shorten. With shortening of the vibrator, a reactive component appears and its input resistance increases. X-shaped vibrators are widely spread which combines in itself two flat vibrators. A feed is tricked into to the middle of vibrator, in a that place, where a short horizontal conductor is located. Input resistance of vibrator is equal to 150 Ohm (for a 75 Ohm on a shoulder), *bandwidth* $f_{M\max}/f_{\min} = 1{,}4$.

Symmetric wave vibrators ($2l \approx \lambda$) with cylindrical form are applied at transmitter antennas, executed from pipes with a diameter of approximately 0,02λ. Fastening of wave vibrators to the aperiodic reflector are implemented at the point of a zero potential, located at the centers of shoulders of vibrator, with the help of "metallic insulators" - pipe length, approximately equal to 0,25λ. Input resistance of one-wave vibrator, with a small mismatching, changes like resistance of parallel contour, which has capacitive character at $\omega \rangle \omega_O$ and inductive character at $\omega \langle \omega_O$. For expansion of bandwidth of one-wave vibrator, the sequentially-open loops are added between every its shoulder and symmetric line, arranging them into a vibrator. Lengths of loops equals 0,25λ mean.

Symmetric one-wave vibrator has relatively large input resistance (250 ... 500 Ohm). It is structurally comfortable to create a block-panel from two (or a few) vibrators with an aperiodic reflector. On a figure 6 the *panel of antenna,* consisting of two one-wave vibrators with *1* cylindrical form, located above an aperiodic reflector *2*, is shown, having a trellis-work. Vibrators are shortened (§ 7.7) and connected between them with symmetric line *3*, to the center of that a coordinating device *4* is connected. A panel has an asymmetrical coaxial input resistance 75 Ohm. A transition from a coaxial line to symmetric is implemented by means of coordinating prefixes with the length of 0,25λ. The selection of impedance of line is provide a matching.

On a figure 6, panel from two semi-wave vibrators *1* is given, which is executed from the steel zincked stripes by the section of 10x60 мм^2 for work in IV TV range. The initial areas of vibrators for the best matching are executed as a cone, the ends of vibrators are rounded. Symmetric two wire line *3* executed from pipes by a diameter 20 ... 35 mm and long, to the equal middle wave-length of range, reserved on ends. Distance between vibrators is taken by equal to 0,5λ. Matching is implemented by selecting of distances from vibrators to the shortly closing bridges *5*.

Horizontal symmetric or X-shaped vibrators in a horizontal plane have a radiation pattern in form of eight. For forming of non-directional radiation pattern, the systems from two vibrators are applied, which is located perpendicular to each other, or from several panels forming an annular lattice. At the so-called *turnstile antenna*, two symmetric loopback or X-shaped vibrators are situated perpendicular to each other and the shoulders of nearby vibrators feed with a change on a phase on 90° (variably-phase feed).

Such antennas are executed with relatively small gain - 10 dB. For its increase, it is necessary to increase the number of floors in antenna.

Spiral antennas.

The satellite systems use waves which are elliptic, close to circular polarization. The waves of such polarization allow to obtain spiral antennas. Spiral antenna consists of metallic conductor, convolute on formative cylinder or cone in the spiral located above a flat screen so, that the axis of spiral is perpendicular to the plane of screen. In a microwave range, a screen with the diameter of (0,6... 1λ) is executed as an entire grid, in the ranges of decimetric and metric waves from a metallic grid.

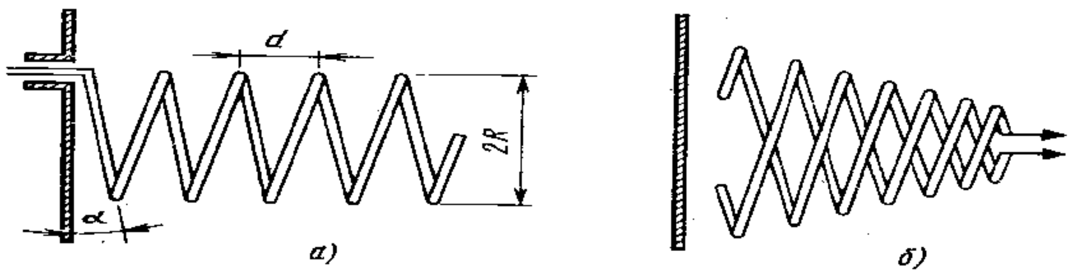


Figure 6 - Spiral antennas: cylindrical single-thread; conical double-thread

Coaxial feeder is supplied into the spiral usually not on an axial line, but on formative and connect directly to the first coil.

At the diameter of spiral, less than 0,18λ, antenna works as flagpole with small resistance of radiation. At the diameter of spiral, greater than 0,45λ, radiation pattern of antenna is divided by half in relation to an axis. At the diameter of spiral (0,25... 0,45λ), antenna creates a maximal radiation along an axis to direction of current motion. Spiral antennas of axial radiation are mainly used. In spiral antenna with length of coil, approximately equal to wave-length (l= λ), and at the number of coils more than three the mode of progressing wave is set.

While the traveling wave of current is passing through the spiral, the elliptic (near to circular) polarized wave is created. Phase speed of wave of current along a wire appears there is some less speed of wave free-space, in consequence, every subsequent coil has a some late phase of current. It allows to examine a spiral as antenna of progressing wave.

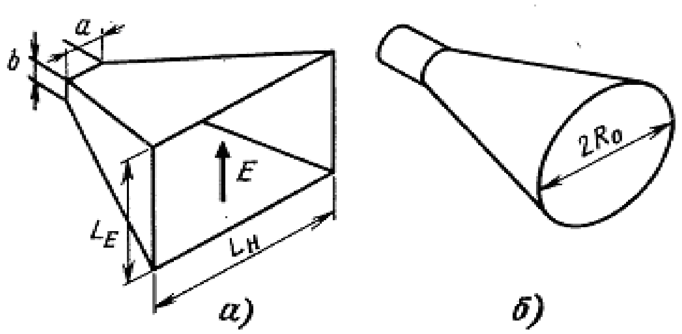
Control questions.

1. Explain the feature of televisional transmitter antennas.
2. Explain the feature of the design and operation of Broude vibrators
3. For what purpose is a vibrator executed by V-shaped?
4. Explain the feature of design and operation of panel antennas.
5. Explain the feature of design and operation of spiral antennas.
6. Why the turnstile antenna has a circular radiation pattern?

Lecture 7. Megaphone Antennas And Irradiators

One of the simplest antennas is an open end of waveguide. The small (in relation to a wave-length) sizes of section of open end of waveguide form the wide radiation pattern. Phase speed of wave in a waveguide considerably differs from speed of wave free-space. It results in the considerable reflection of energy from an open end and subzero output-input ratio in a waveguide. For narrowing of radiation pattern and improvement of matching it is necessary fluently to increase the section of waveguide, to pass to the megaphone.

Megaphone antenna is a waveguide with a fluently changing section. At expansion of narrow wall of waveguide a megaphone is called E- *sectoral*, at expansion wide is a H- *sectoral.* If at a waveguide both sizes change fluently, a megaphone is called pyramidal. A round waveguide at the smooth increase of section forms a conical megaphone. The waves of the same type become in a megaphone excited, what in a waveguide. However a flat wavefront in a waveguide in transition in a megaphone grows into spherical (in pyramidal and conical) or cylindrical (in sectoral). A spherical wave in a megaphone creates the field in its aperture, different from in-phase with quadratic phase distortions. If at optimal megaphone, remaining his length unchanged, to increase the sizes of aperture, then the directivity of antenna due to large phase distortions in aperture will diminish.



a - pyramidal; б – conical.
Figure 1- Megaphones

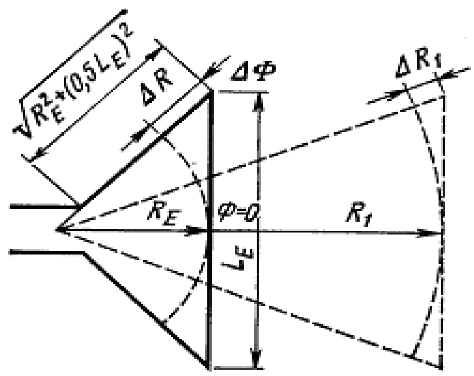


Figure 2- Determination of length of megaphone

To obtain large values of directivity, it is necessary to increase the sizes of aperture, here length of megaphone must increase proportionally to the square of increase of linear sizes of aperture, and length of megaphone appears beyond measure large. Therefore, megaphone antennas with the directivity more than 25 ...30dB does not apply. At small directivity a megaphone is structurally simple and is often used as irradiators of mirror antennas. A megaphone possesses a high protective action due to the small flow currents on his shadow (external) surfaces and well concerted with a waveguide in the wide range of frequencies. Range properties of megaphone on a matching are limited to mainly the waveguide. During work as an irradiator of reflex antennas a megaphone often must work as waves with two mutually by perpendicular polarizations and to provide the identical width of radiation pattern in the planes of E and H for every polarization. A pyramidal megaphone satisfies these requirements with a square aperture into that the metal-plate are located.

7.1 Mirror antennas

Mirror or reflex antennas consist of irradiator and reflector.

Reflector - the paraboloid of rotation reflects falling on his aperture parallel rays in one point named focus. An aperture - is the part of plane, limited with the edge of paraboloid of rotation.

An irradiator - is antenna with the wide radiation pattern.

A plane form the outward edges of reflector is the aperture of antenna.

Axis-symmetrical antenna has aperture in a circle form.

Antennas with the large directivity have sizes of aperture >> than wavelength.

The paraboloid of rotation, that is used as a reflector of antenna, appears the rotation of flat parabola about its axis.

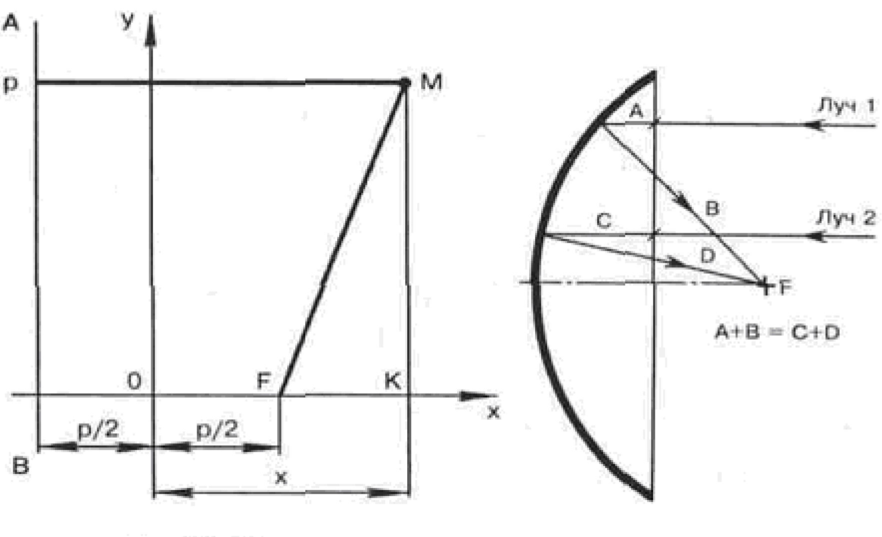


Figure 3

The canonical equation of a paraboloid of revolution at rectangular coordinates:

$$X^2 + Y^2 = 4/Z \ .$$

Parallel axes of paraboloid, the rays (radio waves) from a companion, reflected from an aperture to focus, pass identical (focal) distance. The reflected signals of both rays pass identical distance to focus of F. It means that distance is A+B=C+D. All rays that is radiated by transmitter antenna of companion, and to that the mirror of paraboloid is sent, are concentrated by identical in-phases in focus of F.

If in focus of mirror to place an irradiator creating a spherical wave, then a plane of aperture of reflector will be the plane of identical phases. As a result a spherical wave will be transformed in flat, and wide radiation pattern - in narrow.

The choice of parameter of parabola determines the depth of paraboloid, distance between a top and focus.

A mirror is called *short-focused*, when corner of aperture $2\psi_O \rangle \pi$ here $R_O \rangle 2f$ (deep mirror)

Long-focused - $2\psi_O \langle \pi$ and $R_O \langle 2f$ (shallow mirror).

With the increase of radius of aperture and reduction of the λ, radiation pattern narrows.

An irradiator must:

- to possess an one-sided in the direction of reflector orientation;
- to provide necessary peak distribution of the field in aperture;
- to have the steady phase center combined with focus of mirror;
- to create the small shading of aperture;
- to have the required operating bandwidth.

As irradiators any poorly directed antennas can be used:

1) Semi-wave vibrators with contra-reflectors as a bar or with disk simple, create the small shading, but narrow-banded. Used in the range of decimeter of waves.

2) Megaphone irradiators are broad-banded, but they shade aperture of antenna more. Megaphone irradiators are used on frequencies from 600 MHz and higher.

3) Spiral irradiators allow to get waves with elliptic polarization.

The field, created by an irradiator, must be on possibility even on aperture of reflector and quickly to fall after his limits.

1) At short-focus antennas almost all energy of irradiator gets on a reflector, but distribution of the field is uneven, that lowers the coefficient of the radiated surface (STACKS).

2) At long-focused antennas the field on aperture is smooth, but much energy disperses.

Parabolic antennas are divided by two basic classes: symmetric parabolic reflector and asymmetric. The first type of antennas is called straight focal, second - offset.

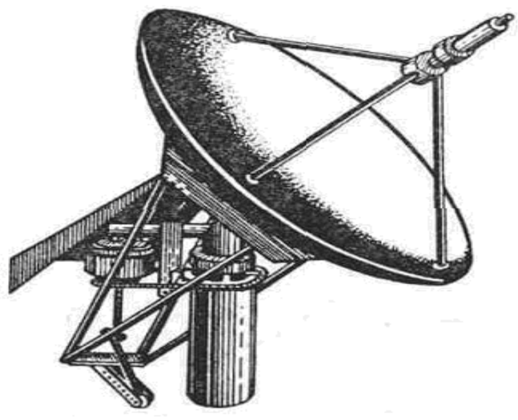


Figure 4 – Axis-symmetrical parabolic antenna

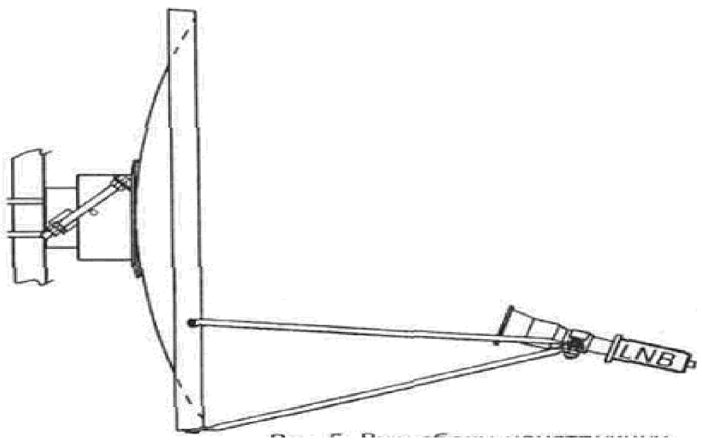


Figure 5 - Is offset parabolic antenna

Offset antennas expedient to use, if for the steady reception of the programs of the chosen companion the size of antenna is needed a to 1,5 m, because with the increase of general area of antenna the effect of shading of mirror becomes less considerable.

The diagram of orientation of antenna characterizes dependence of amplitude of tension of electric-field of E, created in some point, from direction on this point. Thus distance from antenna till this point stays permanent.

Control questions.

1 Explain the requirements for the antennas of radio-relay lines (RRL).

2 How affects the phase distortion on the radiation pattern of antenna?

3 How affects the phase distribution and the field on aperture on the radiation pattern of antenna?

4 What are the advantages and disadvantages of megaphone antennas?

5 For what purpose are used megaphones with the ribs inside?

6 What determines the width of radiation pattern in the plane E?

7 What determines the width of radiation pattern in the H plane?

8 How to obtain the radiation pattern with the same width in fields of H and E?

9 What are the sectorial, pyramidal, conical megaphone antennas?

10 What determines the range of properties of the megaphone antennas?

11 Which of the patterns has a parabolic antenna?

12 Why the parabolic antennas are mostly used in the radio-relay link (RRL) communication?

13 Which of the paraboloid antennas are long-focused?

14 Why is a paraboloid antenna in some cases perform mesh design?

15 Which of the paraboloid antennas are short-focused?

16 Which of the paraboloids is axis-non-symmetrical?

Lecture 8. Electromagnetic fields and waves

1. Brief description of lecture.

In the electromagnetic field electric and magnetic components are closely linked to each other. This connection between electric and magnetic fields was discovered at the beginning of XIX century by Oersted and Faraday. Experiments showed that the at near-by running charges (near-by the conductor with a current) magnetic-field occurs which causes the appearance of electric-field. Before the works of Maxwell (1864), it was supposed that the magnetic field appears only near-by running charges. Maxwell showed in theory, that the magnetic field appears at any change of electric-field, particularly when changes are not related to the running charges. According to the theory of Maxwell, the change of electric-field can be considered as the special form of current-bias current. Bias current flows in space, where the electric field changes. So, at a charge or discharge of capacitor the bias current appears in space between its lining. Thus the presence of substance is not obligatory between the lining. In powerful radio transmitters vacuum capacitors are applied, bias current flows even in a vacuum.

Using the concept of bias current and generalizing the known experimentally established laws of electromagnetism, Maxwell created the theory of the electromagnetic field. According to this theory, the electromagnetic field spreads in waves. Light, as Maxwell showed, is also electromagnetic wave. Theory of the electromagnetic field was confirmed by the experiments of Hertz and P.N. Lebedov. Radio, invented by A.S. Popov, is also one of confirmations of validity of theory of the electromagnetic field.

Spreading in different environments, radio waves generally cause the bias currents and currents of conductivity in these environments. The features of distribution of radio waves depend on the values of density of these currents. From the theory of electric chains there is a density of current of conductivity:

$$\delta_{\text{пр}} = \sigma E,$$

where σ - is permittivity.

We will find expression for the density of bias current. We will consider the current of mixing between facing of flat condenser.

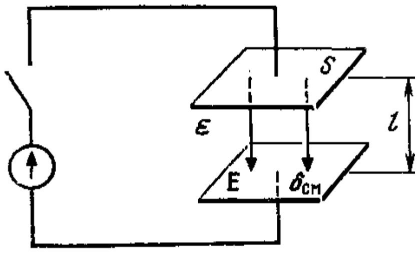


Figure 1 - Origin of bias between facing of condenser at his charge

Capacity of capacitor

$$C = \varepsilon S / l ,$$

where ε - is an inductivity of environment between facing;

S - is an area of plate; l - is distance between them.

In the homogeneous field voltage between facing of capacitor of U_c = E l. Current flowing through a capacitor

$$i = C\frac{dU_c}{dt} = \varepsilon\frac{S}{l}\frac{d(El)}{dt} = \varepsilon S\frac{dE}{dt}.$$

density of bias current

$$\delta_{CM} = \frac{i}{S} = \varepsilon\frac{dE}{dt}$$

$$\delta_{CM} = \varepsilon\frac{d\mathbf{E}}{dt}.$$

Value of εE is the vector of electric bias of **D**. Using the vector of **D,** following equation is obtained

$$\delta_{CM} = dD/dt.$$

Any vibrating electric charge is the source of the alternating electromagnetic field, radiating in surrounding space. Radiation of electromagnetic field with charge is possible to explain as follows. We will consider two conducting spheres being in the distance L, from each other. Such system is called an electric dipole. While launching the generator, spheres charge and discharge. The current of charge and discharge of capacity formed by spheres flow through the wire of L. Capacity of spheres larger than capacity of segments *ab* and *cd* of wires L, therefore it is possible to scorn bias current between the segments of wire. It can be considered that the current of conductivity, flowing through the wire L, is closed through the bias current, which flows in space between spheres. In this case amplitude of current along the wire of L remains permanent. Such electric dipole is called the dipole of Hertz.

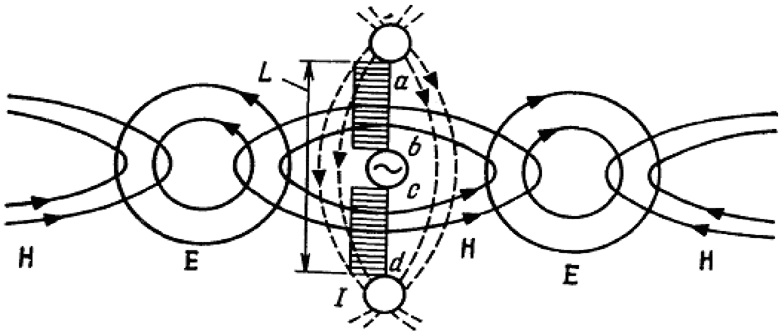


Figure 2 - The appearance of the electromagnetic wave emitted by the dipole of Hertz

On a figure 2 distribution of amplitude of current is graphically represented along the wire of dipole. The same Figure shows the force lines of electric-field of dipole for the moment of time, when spheres are charged. Current bias lines are arranged in the same space as the electric field lines. During the work of generator, the alternating bias current causes on appearance of alternating magnetic-field, where the force lines surrounds the bias current line. In turn, the alternating magnetic field by law of electromagnetic induction causes in surrounding space appearance of alternating electric-field and corresponding bias current. Considered process spreads in an environment self-supportably. If, for example, turn off a generator, which feeds a dipole, then occurred electromagnetic wave continues to spread at surrounding environment - bias current will cause the alternating magnetic field, that, in turn, will create the alternating electric field and bias in the nearby areas of space. If a generator, excitant a dipole, generates voltage changing on harmonic law, the electromagnetic field changes in time and on harmonic law with the same frequency. It is generally known that certain state of vibrator, for example the maximum, is called a phase. The speed of electromagnetic wave propagation phase is called phase velocity. Phase speed of electromagnetic wave in a dielectrics

$$\upsilon_{\Phi} = 1/\sqrt{\mu\varepsilon}.$$

In free space $\varepsilon = \varepsilon_0 = 8{,}85*10^{-12} F/m,\ \mu = \mu_0 = 4\pi*10^{-7}\Gamma/m$ and $\upsilon_p = c \approx 3*10^8 m/s$. This formula theoretically was obtained by Maxwell. Equality of phase velocity of light suggested Maxwell on an idea that light is an electromagnetic wave.

Distance that passes certain phase of wave in times of one period of vibrations of T is called *wavelength*:

$$\lambda = \upsilon_{\Phi} T = \upsilon_{\Phi}/f.$$

A surface on that the phase of wave is identical is called a *wave front*. On large distances of r from a dipole at implementation of condition the r>>λ phase of wave is identical on the surface of sphere. Such wave is called *spherical*.

The electromagnetic wave radiated by a source carries away energy to surrounding space. Power transferred by the wave, is characterized by the Poynting vector. Direction of Poynting vector shows direction of energy movement. The module of this vector is equal to power, transferred by the wave through a unit area perpendicular to the vector. A mathematical analysis shows that Poynting vector

$$\mathbf{\Pi} = [\mathbf{E}\mathbf{H}].$$

We define the dependency of the Poynting vector of the module from the distance r from the emitter. Assume that the transmitter radiates power in all directions with equal intensity. This is called *non-directional* transducer. In this case, the radiated power P_{Σ} is distributed evenly over the area, the area of which is equal to $4\pi r^2$. It follows that the magnitude of the Poynting

$$\Pi = P_{\Sigma} / 4\pi r^2.$$

In fact, all the emitters of radio waves have radiation pattern, where in some areas emit more than others. In this case the radiation power is unevenly distributed over the area surrounding the transmitter, but the quadratic dependence of the Poynting vector of the distance is remained unchanged.

2. Elementary electric vibrator - emitter of radio waves.

Dipole of Hertz typically is not used as an antenna. However, any wired antenna can be composed of elementary wire segments, within each of which the current amplitude can be considered constant. This segment is called the elementary electric vibrator. Dipole of Hertz may also be considered as an elementary electric vibrator. Define the field radiated by the elementary electric vibrator. Arrange the vibrator at the beginning of a spherical coordinate system

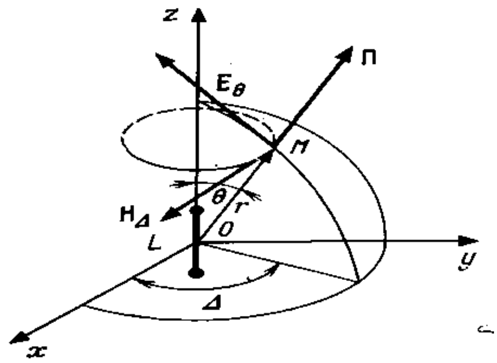


Figure 3 - For determination of constituents of the electromagnetic field of elementary vibrator

Let a vibrator become excited by the generator of harmonic vibrations and current flows through it.

$$i = I_m \sin \omega t.$$

A mathematical analysis shows that in the point of space, for that the terms of r>> L and r>> λ, field of dipole are determined by formulas:

$$E_\theta = \frac{60\pi I_m L}{\lambda r}\sin\theta\cdot\cos(\omega t - \kappa r),$$

$$H_\Delta = E_\theta / W,$$

where

$$\kappa = \omega\sqrt{\mu\varepsilon} = \omega/\upsilon_\Phi = 2\pi/\lambda,$$

Multiplier $\cos(\omega t - \kappa r)$ specifies on that the field spreads as a wave. The voltage phase of the field depends on the distance to the emitter of r. The value k is called a *wave-number* shows how far the wave phase changes at passing by length unit means a way, that at passing a phase with the length of λ phase changes to 2π, and on unit of way it changes to $2\pi/\lambda$. The value of W is called the *characteristic impedance of environment*. In free space $\mu = \mu_0, \varepsilon = \varepsilon_0$ и $W = \sqrt{\mu_0/\varepsilon_0} = 120\pi = 377 Ohm$. Indexes θ and Δ show position of E and H vectors in space. E and H vectors of radio wave are mutually perpendicular and lie in plane, perpendicular to direction of distribution of radio wave. Field voltage decrease proportionally to the first degree of distance of r to the emitter. Poynting vector module $\Pi = \mathrm{EH}\sin 90° = EH$ decreases in proportion to the square of the distance. Thus, the vibrator radiates spherical wave.

It is necessary to note the fact that radiated field is greater, the larger the ratio of length of the vibrator to the wavelength. This dependence can be explained by considering the field of oscillating dipole in charge. In case of fluctuations of the charge change in its field spreads in the surrounding area is not instantaneous, but with the speed of light. As a result, the force lines of electric field are deformed with the oscillations of charge as shown in figure 4 b

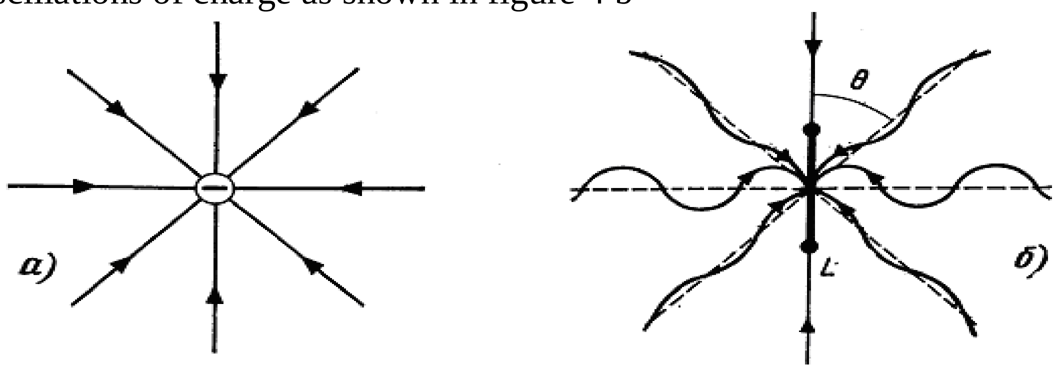


Figure 4 - Electric field of immobile charge (a), the deformation of the electric field occurred in a result of charge oscillation (б)

The greater the amplitude of oscillations and the greater the frequency of the oscillations of the charge, the greater the deformation field, the more variable the radiation field. Elementary emitter has a radiation directivity, since the amplitude of the radiated field depends on the angle θ. Most radiation occurs in the direction perpendicular to the dipole axis (θ= 90 °). This direction is called the *principal*. In the direction of its axis (θ= 0) does not radiate a dipole. The direction of the vibrator radiation can also be explained in Figure 4 b. As can be seen from the figure, in the direction of the dipole axis of its box is not deformed, the largest field deformation occurs at θ = 90 °. The dependence of transmitter field strength from the direction of the measurement point at a constant distance to this point is called the characteristic radiator orientation. This characteristic graphically depicted as a directional pattern

We define the average power emitted by the dipole when feeding its harmonic current. The average time value of Poynting vector:

$$\Pi_{\text{cp}} = E_m H_m / 2.$$

Where E_m and H_m are peak values of voltage of the fields in this point of space. This formula is similar to the formula for determining average power in an electric circuit with given amplitudes of the voltage and current. If a dipole did not possess the orientation of radiation, then power of radiation would be determined by expression:

$$P_\Sigma = \frac{E_m H_m}{2} 4\pi r^2 .$$

Mathematical analysis shows that taking into account the directivity of the radiation leads to the formula:

$$P_\Sigma = \frac{2}{3} \frac{E_{m0} H_{m0}}{2} 4\pi r^2,$$

where E_{mo} and H_{mo} - are amplitudes of voltage of the electromagnetic field in the direction of maximal radiation (θ = 90°).

$$E_{m0} = 60\pi I_m L / \lambda r.$$

Putting (1.17) in (1.16) taking into account a formula (1.11) after the substitution of numeral value $W = 120\pi$ and substituting $2\pi/\lambda$ by k, we will get

$$P_\Sigma = 10 k^2 L^2 I_m^2 .$$

We will express tension of the field of elementary vibrator through the radiated power. From (1.18)

$$I_m = \frac{\sqrt{P_\Sigma}}{\sqrt{10}\, kL} = \frac{\lambda \sqrt{P_\Sigma}}{\sqrt{40}\, \pi L} .$$

Putting (1.19) in (1.10), we will get

$$E_m = \frac{\sqrt{90 P_\Sigma}}{r} \sin\theta .$$

In the direction of most radiation (at θ = 90°)

$$E_{m0} = \sqrt{90P_{\Sigma}}/r.$$

For comparison we will define the field tension created by a non-directional emitter. From (1.15) taking to account that in free space $Hm = \dfrac{Em}{120\pi}$, we will get

$$E_m = \sqrt{60P_{\Sigma}}/r.$$

Comparing these relations, we see that under the same conditions elementary vibrator in the main direction creates a field strength in $\sqrt{1{,}5}$ times greater than the non-directional transducer. To use the non-directional transducer to obtain the same field strength, which gives elementary vibrator in the main direction is necessary to increase the power 1.5 times which emitted by an omnidirectional antenna. The number that indicates how many times it is necessary to increase the output power by replacing the directional antenna to the omni-directional so that it retained the old field strength in the main direction is called antenna gain. At the elementary vibrator G_{ain} equal to 1.5, then

$$Emo = \sqrt{60P_{\Sigma}D}\Big/r$$

This formula can be used with all types of antennas, if you know their gain.

Elemental vibrator as any other antenna may be used not only for the radiation, but also to receive radio waves. If the vibrator is placed in the radio wave, then it will be induced electromotive force (EMF), the voltage appears at its terminals, which can be brought to the door of the radio.

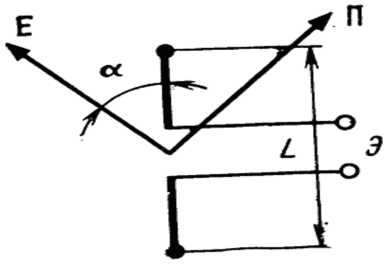


Figure 5 - To determination to the electromotive force (EMF) pointed in receiving antenna

The magnitude of the EMF E induced in the vibrator, the vibrator depends on the length of L, the electric field E of the wave and the angle α between the vector E and a vibrator:

$$Э = EL\cos\alpha.$$

Receiving vibrator has the same directional properties that radiating vibrators. Most EMF induced in the vibrator, which is located parallel to the E vector of the received radio waves ($\alpha = 0$). If the vibrator is located along the Poynting vector of the incident wave at him, then the EMF induced in the vibrator does not. In this case, the electric field is perpendicular to the wire dipole and charge does not move under the influence of radio waves.

Lecture 9. Electromagnetic plane waves

1. *Brief description of lecture.*

All real emitters create only spherical waves. However, at large distances from the transmitter front curvature is small and can be considered small portions of it as flat. For small changes in the distance to the transmitter amplitude of the wave can be regarded as constant if the loss of wave energy in the environment no. Wave, which has a flat front, flat called. The book is often considered to be features of the propagation of plane waves as an example. Consider a plane wave in a perfect dielectric, t. E. In an environment in which there is no conductivity. A free space is the perfect example of dielectric.

Tension of the field of harmonic flat wave spreading along the axis of y, given below:

$$E = E_m \cos(\omega t - \kappa y),$$

$$H = E/W = \frac{E_m}{\sqrt{\mu/\varepsilon}} \cos(\omega t - \kappa y),$$

where E_m - amplitude of voltage of electric-field.

As shown on a figure 1, the vectors of *E* and *H* in space are perpendicular to each other. On a figure 2 distribution of the field of flat harmonic wave is represented in an ideal dielectric for one certain moment of time:

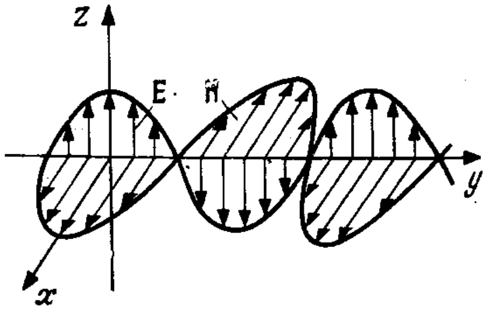


Figure 1 - Distribution of electromagnetic plate at *E* and *H* fields space at certain moment of time

The front wave coincides with the plane *hoz*. Field pattern shown in the figure, moves continuously along the y axis at a speed of:

$$v_ф = 1/\sqrt{\mu\varepsilon}.$$

Expression for the field of harmonic wave is often presented in a symbolic kind, using the method in detail studied in a course the theory of electric chains:

$$\dot{E} = E_m e^{i(\omega t - \kappa y)}$$

$$\dot{E} = E_m e^{i\omega t} e^{-i\kappa y}$$

An important characteristic of radio is its polarization. The *polarization* is determined by the position in space of the electric field vector E. If the end of the vector E at a given point during the period of oscillation describes a straight line, the polarization is called *linear*.

Applying special emitters, can be obtained elliptically polarized waves. At the end of the elliptical polarization vector E during the period is an ellipse. A special case of elliptical polarization is *circular polarization*. The linearly polarized waves are distinguished by the position of the vector E relative to the Earth's surface. If the vector lies in a plane E perpendicular to the earth's surface, it has a vertical polarization wave. At horizontally polarized waves E vector lies in a plane parallel to the surface of the Earth.

2 Radio propagation in absorbing media.

All media, except a free space, are not really ideal dielectrics. While the propagation, such as sea water in the soil part of the wave energy is converted into heat, absorbed by the medium. Energy losses can occur either due to the conductivity of the medium, or by dielectric loss. Dielectric loss of radio frequency energy in the environment associated with hysteresis (lag) of the polarization of the molecules of matter in an alternating electromagnetic field. Radio frequency energy with partially goes to "wobble" molecular substance and converted into heat. For the convenience of calculating the dielectric loss characterize the equivalent conductivity, the presence of which would cause the loss of the same, which in fact causes dielectric hysteresis. Thus, energy loss in a medium characterized by the equivalent conductivity that allows for all kinds of losses. Since the polarization of the molecules of the material occurs in different ways at different frequencies, the dielectric constant of the medium and its equivalent conductivity depends on the frequency. Practically, this dependence does not matter at wavelengths longer than centimeter. Table. 1.1 shows the average values of the equivalent conductivities σ and relative dielectric constants $\varepsilon' = \varepsilon / \varepsilon_0$ for some of environments at $\lambda \rangle 10cm$.

Absorbing medium is characterized by the ratio of the amplitudes of the density of the conduction current and displacement $\delta np.m / \delta см.m$. At $\delta np.m / \delta см.m \to \infty$ the media is close in its properties to an ideal conductor, and when $\delta np.m / \delta см.m \to 0$ - the ideal dielectric. In symbolic form offset current density can be written as:

$$\dot{\delta}_{см} = \varepsilon \frac{d\dot{E}}{dt} = \varepsilon \left(\dot{E}_m e^{i\omega t} e^{-i\kappa y}\right) = i\omega\varepsilon \dot{E}.$$

$$\delta_{см\, m} = \omega\varepsilon E_m.$$

$$\delta_{пр\, m}/\delta_{см\, m} = \sigma/\omega\varepsilon.$$

Putting in the last formula $\varepsilon = \varepsilon'\varepsilon_0$ and $\omega = 2\pi c / \lambda_0$ (λ_0 a wave-length is in free space, ε_0=8,85-10-12 Ф/м, c = 3*108 м/c), we will get $\delta_{пр m}/\delta_{см\, m} = 60\sigma\lambda_0/\varepsilon'.$

Relations $\delta np.m / \delta см.m$ for some environments at different are driven.

Lecture 10 - 11. Distribution of centimetric, decimetric and metric radiowaves

1. Brief description of lecture.

Features of distribution and application areas.

Radio waves shorter than 10 meters in length are called ultrashort (USW). These waves cover a very wide range of frequencies. Width only centimeter wave band of 27 000 MHz, which is a thousand times greater than the width of decameter wave band. Therefore, on the USW transmission is possible much greater flow of information than at longer wavelengths. Only possible on USW channels and high-quality broadcasting with frequency modulation (FM).

Terrestrial USW wave communicates almost exclusively in the line of sight. Beyond that naturally USW can be stably distributed only by scattering in the ionosphere and troposphere. However, for communication by scattering it requires very powerful transmitters and sophisticated antenna installations.

To increase the distance of the line of sight of the antenna stations, telecentres and FM broadcasting mounted on high towers. In order to transmit radio signals over long distances in the USW band using terrestrial microwave links and repeaters placed on artificial earth satellites.

Define what distance is equal to the limit r0 line of sight between the antennas, raised above the Earth at a height of h_1 and h_2.

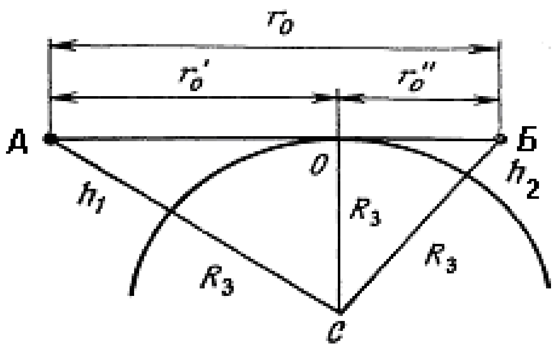


Figure 1 - The distance of line-of-sight

Maximum distance of line-of-sight, like a ray connecting antennas, touches an earth surface. From the rectangular triangle of *AOC* we will find distance $r_0' = \sqrt{(R_3 + h_1)^2 - R_3^2} = \sqrt{2R_3 h_1 + h_1^2}$. If height of antenna location h1 less than the radius of Earth *R3* equal 6370 kilometres, the last formula can be simplified $r_0' = \sqrt{2R_3 h_1}$, because $2R_3 h_1 \rangle\rangle h_1^2$. From the triangle of *OCB* we get $r_0'' = \sqrt{2R_3 h_2}$. Maximum distance of line-of-sight

$$r_0 = \sqrt{2R_3}\,(\sqrt{h_1} + \sqrt{h_2}).$$

Putting in a numeral value R_3 and expressing r_0 in kilometers, and heights h_1 and h_2 are in meters, we get

$$r_0 = 3,57\,(\sqrt{h_1} + \sqrt{h_2}).$$

Methods of calculation of the field voltage at connection within the limits of line-of-sight:

1) If distance between transmitter and receiving antennas of r<<ro (3 times more), then it is possible to ignore sphericity of Earth and to apply a formula:

$$E_m = \frac{\sqrt{60\,PD}}{r}\, 2\left|\sin\left(\frac{2\pi}{\lambda}\,\frac{h_1 h_2}{r}\right)\right|.$$

2) At large distances of r, when a condition is executed

$$\sin\left(\frac{2\pi}{\lambda}\,\frac{h_1 h_2}{r}\right) \approx \frac{2\pi}{\lambda}\,\frac{h_1 h_2}{r},$$

$$E_д = \frac{2{,}18\sqrt{PD}\,h_1 h_2}{r^2 \lambda},$$

it is Formula of B.A. Vvedenskiy

P in kilowatts, r - in kilometers, h_1, h_2 and - in meters, N, мB/m, - is a virtual (effective) value of the field tension.

For the calculation of difference of motion $\Delta r = {h1h2}/{r}$ at the account of sphericity of Earth enter a concept about the brought *heights over of antennas*.

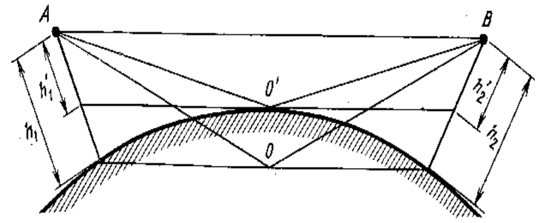


Figure 2 - For determination resulted heights of antennas

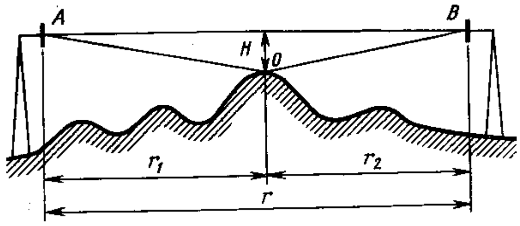


Figure 3 - To determination the size of road clearance on a route

In the propagation of USW over rugged terrain is almost impossible to calculate field strength at the receiving end as the sum of direct and reflected waves. In addition, relief bumps having sharp peaks cannot create reflections, if the node does not cover area that is sufficient to repel (§ 2.1). When calculating a field in the case of the spread over the rugged terrain introduce the concept of the lumen H.

The lumen defined by the distance between the highest point of the path profile and the line connecting the centers of the transmitting and receiving antennas. From the clearance depends on the number of Fresnel zones on the wave front, participating in the creation of the field at the receiving antenna (§2.1), and in the presence of reflections from H depends on the phase difference between the direct and reflected waves. Etalon of lumen is the lumen H0 wherein the difference in the lengths of AB and AOB is ${\lambda}/{6}$. In this case, if the reflected wave propagating along the path AOB, its phase shift relative to the direct wave $\left({2\pi}/{\lambda}\right)\Delta r$ is 60 ° and when R = 1 and F = 180 ° in formula $Em = \frac{\sqrt{60PD}}{r}F$ (2.8) factor F = 1. Etalon of lumen defined by the formula:

$$H_0 = \sqrt{\lambda r_1 r_2/(3r)}.$$

The values r, r1 and r2 shown in Fig. 3.3. If the gap on the track is less than zero, the route is called closed. On a closed course, the field of the reception point is created by diffraction. If the condition 0 <H <H0, the route is called a semi-open or half-closed, at H> H0 track open. The method of constructing the path profile is given in [2]. There's also given method of determining the factor F for different tracks. Fig. 3.4 shows a typical dependence of F factor on the size of the lumen.

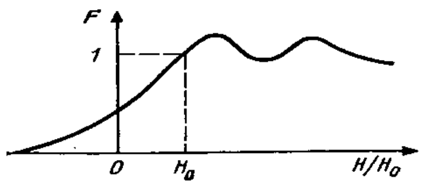


Figure 4 - The dependence of attenuation factor the size of the lumen

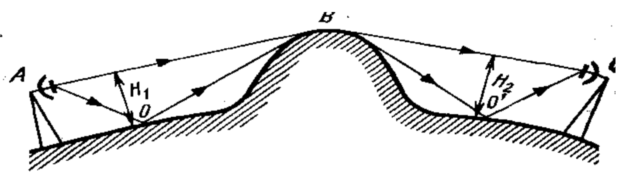


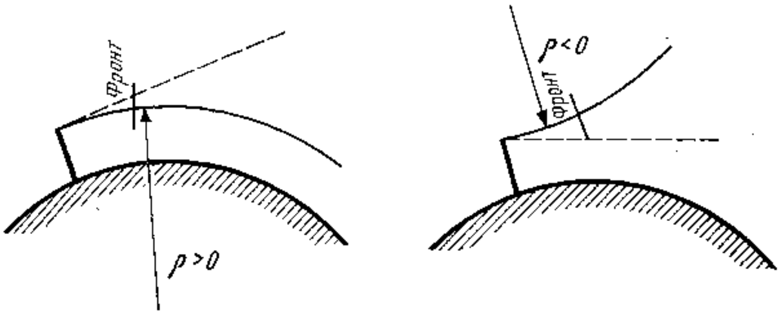
Figure 5 - The explanation of the amplification effect due to obstacles

On long closed roads sometimes observed intensification of the field at the point of reception due to obstacles on the track. The presence of obstacles leads to the fact that it becomes the top of the reemission electromagnetic field excited at the top of waves propagating in an open area AO. On the site of the BC the reemission wave propagates along the open road. For some values of clearances H_1 and H_2 field at the point of reception is greater than would be obtained by a surface wave propagating along the path of the AC in the absence of obstacles. Strengthening field barrier used in the organization of ultra-short-wave USW radio links in the mountainous terrain.

In the cities, the spread of ultra-short wave is accompanied by numerous reflections from buildings, power lines, and its other facilities. If the transmitting and receiving antennas are located above the roof, rough calculation field can be carried out according to the formulas (2.12) or (3.4) by calculating the height of the suspension of antennas from the average roof. The field strength in the city in closed roads and inside buildings must be determined experimentally.

The radius of curvature is positive for g <0. In this phase velocity increases with height, the upper boundary of the front lower spreads quickly, and the beam is bent in the direction of the Earth's surface. This is called positive refraction. When g> 0 there is a negative refraction. Tropospheric refraction changes the distance line of sight. With regard to the line of sight tropospheric refraction affects the field strength at the receiver due to the fact that the curvature of the trajectory of the direct and reflected rays change the phase shift between their fields. The curvature of the trajectory and alters clearance H.

As a result, the positive refractive closed circuit can be open at a negative refraction open road can turn into closed.



а) б)

a - with a positive refraction; b - with negative refraction.

Figure 6 - The trajectories of rays in the troposphere

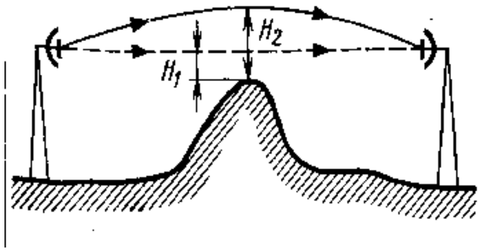


Figure 7 - The lumen zoomed at positive refraction

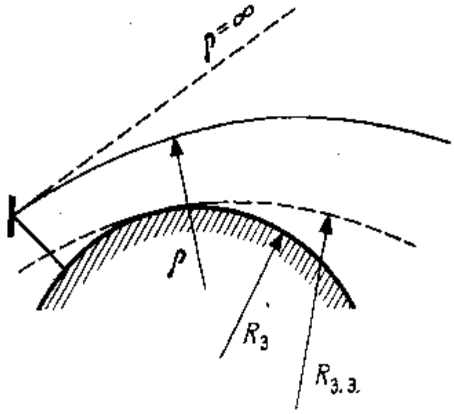
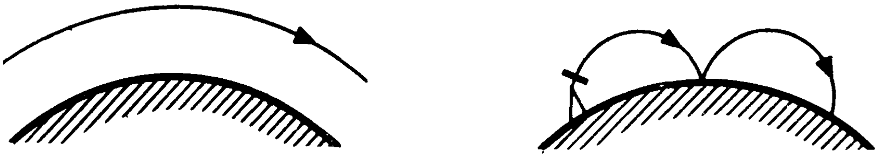


Figure 8 - The equivalent radius of the Earth

Since the degree of refraction is variable and depends on the weather conditions, the field strength at the point of reception in the USW - changes over time. These changes are referred to as *fading*.

2. Over distant distribution of ultra short waves (USW).

If a positive refractive the radius of trajectory flexure is $\rho = R_3$, there is a critical refraction. When it comes super refraction.



а) б)

a) at a critical refraction; б) at super refraction.

Figure 10 - Trajectories of rays are in troposphere

In these cases, the wave can propagate beyond line of sight. Super refraction occurs when the condition g <0,157 1 / m. The index of refraction N must decrease very rapidly with a height that is in the case when the air temperature falls from height, as usual, but increases. These conditions are called temperature inversion.

The region of the troposphere, where super refraction, called tropospheric waveguide. The most common tropospheric waveguides occur in coastal areas where there is a large temperature difference between the air over the land and over the sea. In these cases, the wind can move the warm air, which is located above the cold, and there will be a temperature inversion. Since tropospheric waveguides occur regularly, they cannot be used to build radio links. The possible occurrence of tropospheric waveguides must be considered in the allocation of frequencies in the radio lines, in order to avoid interference.

Tropospheric scatter. Tropospheric scatter causing inhomogeneity represents areas where pressure, temperature and humidity different from the average values observed in the environment. An example of heterogeneities are clouds. Inhomogeneities occur in the absence of cloudiness due to turbulence resulting from the movement of air masses. These eddies are present in all weather conditions. The most intensive form of heterogeneity at altitudes of 1 ... 2 km. Each heterogeneity different permittivity from its environment. This difference is small (maximum 20%), so the radio wave incident on the non-uniformity mainly goes through it. However, part of the energy is dissipated in this radio in different directions. Mirroring the heterogeneity of causes, since it has no clear boundary. Field reemitted towards the receiving antenna, formed irregularities arranged in V volume bounded by radiation patterns of transmitting and receiving antennas. Studies show that with increasing scattering angle field re-emitted in the direction of the receiving antenna is reduced.

The field at the point of reception is formed by addition (interference) of a set of waves scattered by individual irregularities in the volume V. The phase shift between the interfering waves constantly change randomly. As a result, the value of the total field strength is changed randomly. These changes are called *interference field fading.*

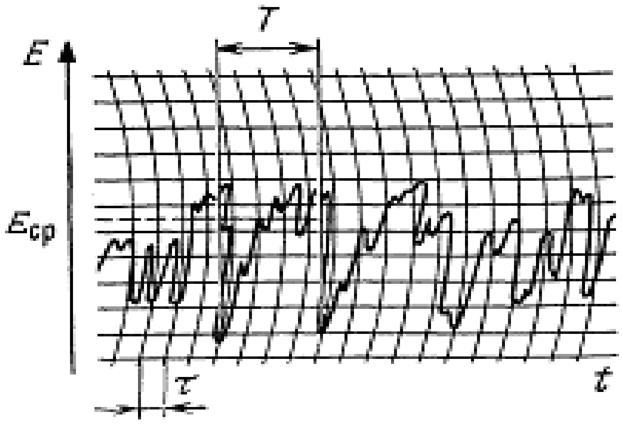


Figure 11 - Typical dependence of field voltage level on time at fading (Recording on a tape recorder)

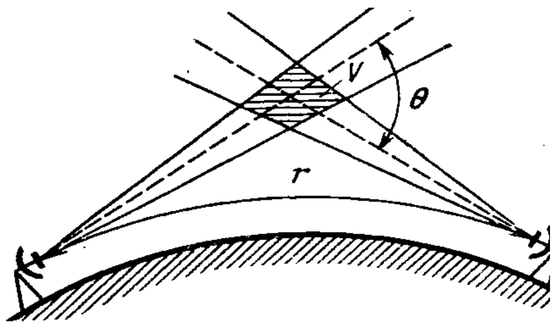


Figure 12 - Tropospheric scattering

The phase shift between the interfering waves are frequency dependent. When the wide frequency range a signal phase shifts for the individual spectral components are different: some components may currently have the highest level, the other - the minimum. If some parts of the spectrum freeze asynchronously, called selective fading. Selective fading does not allow you to send tropospheric lines of broadband signals, such as television.

Outbound distribution of USW and perhaps due to the influence of the ionosphere. In the event of sporadic Es them reflected wave overcomes one jump 2000 km. Regular communication by reflections from the Es layer is impossible to organize.

Regular dissemination of ultra-long meter waves occurs due to scattering on inhomogeneities electrode concentration of N, existing in the layer D and in the lower regions of the E layer propagation mechanism similar to that observed in the scattering in the troposphere. The high altitude areas in which the ionospheric scattering, allows communication with one jump over distances up to 2000 km. When you change the distance between the transmitting and receiving points necessary to change the position of the antenna patterns to provide them with the intersection at the height where there is intense ionospheric scattering (75 ... 90 km). At distances less than 1000 km, the connection by ionospheric scattering is virtually impossible, because of the large scattering angle on short Tracy signal attenuation is very large. With the shortening of the wavelength of the intensity of ionospheric scattering is reduced due to reduced permittivity inhomogeneities differences from unity. On ionospheric scattering lines apply frequency 30 ... 60 MHz. Due to multipath communication by ionospheric scattering is accompanied by selective fading. Therefore, these lines cannot transmit information to the band more than several kilohertz using transmitters with a power of several kilowatts and using diversity reception.

Outbound spread meter waves also occur due to reflections from ionized meteor trails. In the Earth's atmosphere every day from space invaded speed meteors tens of billions of forming ionized columns of air - meteor trails. Some of these tracks cause specular reflection meter waves, others provide their intense scattering. Due to the movement of ionized gas meteor traces usually spread out in a few seconds. On average, a strong reflection of radio waves from meteor trail lasts

0.2 ... 0.4 s, and repeats several times per minute. Because of Earth's rotation around its axis meteors reaching conditions in the atmosphere depends on the time of day, the maximum number observed in the morning, the minimum - in the evening.

Meteor intermittent connection, as the signal level is sufficient to transmit the information exists only during an appearance on the track meteor trail. To transmit information meteoric link information at the transmitting end, accumulate in the gaps between bursts of meteoric and during outbreaks rapidly transmitted through the line. The average transmitted several kilobits per second at the transmitter power of about 1 kW. Range Meteor Communications is about 2000 km. Organization of communication through ionospheric scattering and reflection from meteor instrumental in the polar regions, where ionospheric storms often disrupt the spread hectometer waves and cable mounting and tropospheric establishment of communication due to the low density of the population is economically inexpedient.

3. Distribution of radio waves on space flow lines.

Currently, the most advanced long-range USW radio, which as repeaters use artificial earth satellites (AES). The satellites are located at an altitude of 30 ... 40 thousand Km, provide relay signals within 1/3 of the globe. On the radio links Earth - satellites and satellites – Land use wavelength of less than 3 m, which is not reflected by the ionosphere.

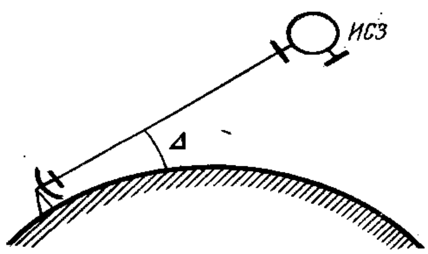


Figure 13 - Elliptic orbit of AES radio waves at satellite communication

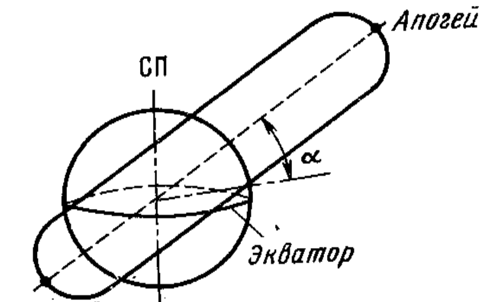


Figure 14 - For determination of corner rises of trajectory

Companions-repeaters dispose either on high elliptic (fig. 3.18) or on a circular geostationary orbit.

Control questions.

1 Why the fading occurs on observation in communication due to tropospheric scatter?

2 What is the purpose and manner of diversity reception implementation on communication lines with tropospheric scattering?

3 What features has the radio using the reflection of radio waves from meteor trails?

4 Why the radio waves longer than 3 m cannot be applied in order to communicate via AES?

5 What are the advantages of relay signals via AES in geostationary orbit?

6 What is the Doppler effect, in which cases it should be considered in space communications?

7 What are the advantages of waves in centimetric, decimetric and metric bands?

8 What changes with mounting heights of antennas USW field strength in communication within the line of sight?

9 What is the effect of field enhancement due to the obstacles and how to determine it?

10 Which refraction can be considered as positive?

11 How can the negative refraction of the relationship within the line of sight?

12 What is the effective radius of the Earth?

13 Why the fading occurs on observation in communication due to tropospheric scatter?

Lecture 12. Features of distribution and application of decametric (short) waves

Surface wave in decameter when transmitter power several tens of kilowatts can be accepted distances not more than a few tens of kilometers. Short waves propagate mainly in the form of spatial ionospheric waves. Upon reflection from the F2 layer radio wave can block a jump distance 3500 ... 4000 km (jump distance is measured along the surface of the Earth). Upon reflection from the layers E or Es jump maximum distance of 2000 km. The conductivity of the ionosphere on short waves is relatively small, and the absorption of radio waves in the ionosphere, the correct choice of the operating frequency is low. This waves through multiple reflections from the ionosphere and the Earth's surface can provide connectivity between any two points on the globe without the use of repeaters. However, at decameter wavelengths is not possible to organize the same broadband radio channels as USW. Decameter waves used for broadcasting over long distances, for the construction of main telephone and telegraph lines a large extent in cases where the organization is impractical VHF radio links, as well as for communication with ships and aircraft.

When broadcasting to decameter wavelengths is necessary to consider the possibility of so-called zone of silence. For the reflection of radio waves from the ionosphere is necessary to satisfy conditions:

$$\sin\varphi_0 = \sqrt{1 - 80{,}8\frac{N_{\text{отр}}}{f^2}}.$$

Minimum angle of incidence, at φ_{0KP} that the reflection of radio wave is yet possible from an ionosphere, named *critical*. If distance between transmitter and receiving points small, the angle of incidence of radio wave on an ionosphere can appear less than φ_{0KP} and a wave will go away in outer space. A dead-spot within the limits of that the reception of signals on this frequency is impossible appears on a terrene. A dead-spot has the appearance of ring. The internal border of zone is determined by maximal distance on that the reception of superficial wave is possible, and external - by distance at that corner $\varphi_0 = \varphi_{0KP}$. With the height of frequency, a dead-spot increases other things being equal, as a superficial wave at greater frequency spreads to less distance, φ_{0KP} and a corner grows, that results in the increase of radius of external border of zone of r_2. If frequency is near to critical, $f = f_{\text{КР}}$ a dead-spot disappears, because if, a radio wave is reflected from an ionosphere at $\varphi_0 = 0$.

At high frequency wave field at the point of reception is almost always formed by the addition of a plurality of beams. When the angle of incidence on the ionosphere equally critical, to the point of receiving the beam coming, experienced "mirror" reflection in the ionosphere, and a plurality of rays scattered by ionospheric irregularities. At the receiving point may come as ordinary and extraordinary rays. At an angle of the reception point might come rays, performed various number of jumps on a given route. If we consider at the same time that each such ray in addition to the mirror component comprises a plurality of scattered, as well as ordinary and extraordinary components, a lot of radiation at greatly increased. Many of radiation leads to interference fading, the average period of nearly 1 c.

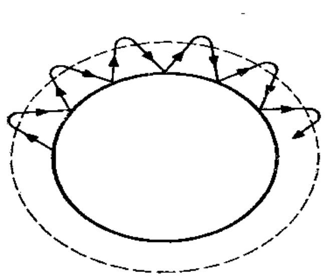


Figure 1 - Distribution of high-frequency waves over long distances with multiple reflections from the earth's surface and the ionosphere

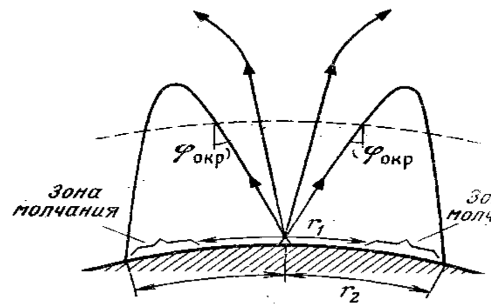
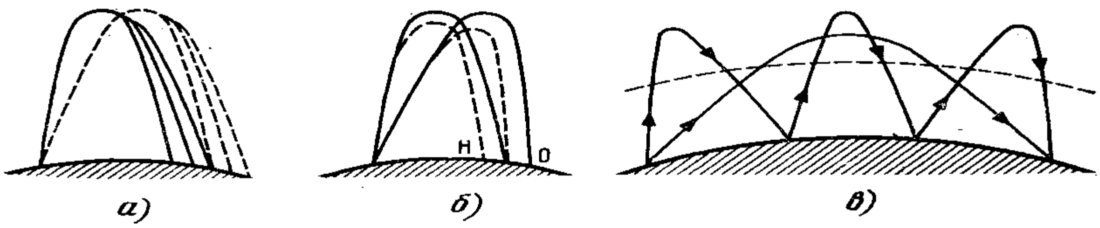


Figure 2 - By the formation of dead spots

These stopping beating can have selective character, that results in distortions of the accepted signal. Especially noticeable distortions due to the selective stopping beating take place at weakening of level of bearing frequency of the peak-modulated oscillation, because here a form is strongly distorted by circumflex signal. These distortions diminish at the use of single-sideband modulation with the low-spirited bearing. Thus oscillation of bearing frequency is restored in a receiver with large enough amplitude and detection of vibrations takes place without distortions.



a - is interference of the dissipated rays; б - is interference usual and unusual waves, c - is interference of rays accomplishing the different number of jumps.

Figure 3 - Reasons of the interference stopping beating on highly frequency waves

At decameter waves besides the interference observed polarization fading caused by changes in the type of polarization of the radio wave during its propagation in the ionosphere. The average period of fading at decameter wavelengths of a second. receivers provided with automatic controls amplified (AGC), which alter the gain of the receiver when the signal changes level to combat fading. If the level drops, the receiver gain is increased when the signal level increases, the gain decreases. In this case the signal level at the receiver output is maintained constant. However, when deep fading minimum signal level at the receiver may be sufficient to provide the necessary signal-to-noise ratio. On the professional lines to combat fading diversity reception is used in addition to the automatic gain control. In this receiver antennas must be separated in space by a distance equal to about ten wavelengths. With such diversity signal fading occurs at the outputs of the antennas of mutually independent. In addition to the spatial diversity polarization is sometimes used, in which the reception is carried out simultaneously at the antenna, receiving radio waves with vertical and horizontal polarizations.

When you send short radio pulses multipath can cause radio echo. Echo occurs when the signal propagation delay over a longer path compared with a shorter duration than signal. Interference signals at the same time there is no fading and no, but repeated by the echo signals violate the slave radio, causing false positive terminal devices such as telegraphs. To echo canceller should operate at angles of incidence on the ionosphere, near-critical. In this case, only one secularly reflected beam propagates along the route. The echo caused by multipath, called a neighbor. At high frequency waves can occur around the world echo, in which radio waves arrive at the receiving point is not only the shortest path, but also surpassing the globe. The delay echo round the world with approximately 0,137.

Control questions.

1 Why do high frequency waves arise silence zone?
2 How to define the boundaries of silence zone?
3 What causes interference fading on high frequency waves?
4 What is the echoes and why it occurs?
5 Explain the causes and manifestation of selective fading.
6 Explain the phenomenon of echo round the world on high frequency waves.

1. Working frequency on short waves.

The frequency at which operates the radio link is called working. The highest frequency that can be reflected from the ionosphere at this track and at this time is called the maximum usable frequency (MUF). This frequency must comply with the law secant. To determine the MUF is necessary to know the track length, the height of the reflective layer of the ionosphere and its dependence of the electron concentration on the height. The maximum usable frequencies determined by ionospheric forecasts issued by IZMIRAN. MUF dependence on the time of day has the same character as the corresponding dependence of the critical frequency of the ionospheric layer. Operating frequency cannot be more than MUF, as waves whose frequency is greater MUF, from the ionosphere is not recognized and go into space. The higher the operating frequency, the less energy is absorbed by the radio waves in the ionosphere. This is because the conductivity of the ionized gas decreases as the frequency increases. Therefore, it is desirable that the operating frequency was the closest to the MUF. However, please note that the actual value of the MUF may differ from values determined according to the forecasts. Upon reflection from the layer F (winter) or F2 it is recommended to select an operating frequency not exceeding 80% of the value of the MUF. Layers of E and F1 are more stable, the upper value of the operating frequency for them may be 90 ... 95% of MUF. Maximum operating frequency provides a stable radio waves reflected from the ionosphere at this track and at this time, is called the optimum operating frequency (OOF).

A typical plot of the OOF by the reflection of the time of day for the winter from the F layer is shown in Fig. 4.4.

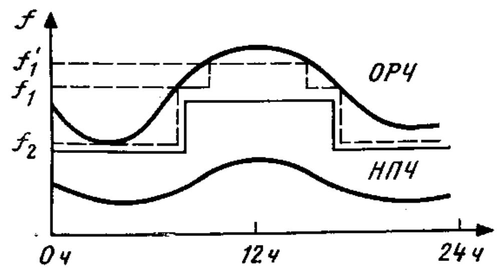


Figure 4 - Waves in communication at decameter wavelengths

Figure 4 shows an example schedule change waves when using two (solid line) and three (dashed line) frequency bands. In summer, the diurnal variation of critical frequency of the F2 layer is weakly pronounced maximum, and in the months to one-hop circuits cannot operate on the same frequency around the clock. When broadcasting to decameter waves usually use different working frequencies in the daytime and nighttime. During the day, depending on season and solar activity are used wavelength of 10...30 m, and in the night -30...100 m The greatest set of operating frequencies have to be used on long-haul routes (over 4,000 km) along parallels. On such tracks wave that provides a reflection on the night area, it is strongly absorbed by the ionosphere on the illuminated area.

Requirements for antennas with decametric wavelength.

Ionospheric wave usually distributed along the arc of a great circle. The big circle is a section of the globe by a plane passing through its center. Antenna pattern maxima must lie in the plane of the great circle on which are arranged the transmission and reception points. Due to the tilt of the ionospheric layers and the impact of ionospheric irregularities observed a deflection propagation direction of the great circle arcs. To this deviation is not violated radio work width DN antennas should not be less than the horizontal bone 6...10 °, if you cannot change the direction of the maxima of the charts.

The vertical antenna pattern highs should be directed at an angle of elevation at which the wave is propagated on this track. The calculation uses the equivalence theorem, which shows that the true curvilinear trajectory radio waves in the ionosphere can be replaced by a trajectory formed by straight lines, the apex of which is at the current height of reflection (Fig. 4.5). According to the law of sines from the triangles ASO obtain

$$\cos\Delta = [(R_з + h_д)/R_з]\sin\varphi_0.$$

$$\operatorname{tg}\varphi_0 = \frac{AD}{OD},\quad AD = R_з\sin\theta/2,\quad OD = h_д + (R_з - DC),\quad DC = R_з\cos$$

$$\operatorname{tg}\varphi_0 = \frac{R_з\sin\theta/2}{h_д + R_з(1 - \cos\theta/2)}.$$

$$\theta = r/R_з,$$

where Rз = 6,370 km - the Earth's radius.

Reflected hД height required for the calculation Δ are given in ionospheric predictions. In rough calculations can be taken to the *E* layer hД = 110 km to 240 km layer F1, F2 layer for winter: 250 days, 350 km at night, in summer: 400 km of the day, 250 km at night. Height hД radio waves and reflect conditions on shortwave unstable slopes. Deviations from the average actual values Δ, calculated by (4.4), may be a few degrees in the summer and during the day in winter and more than 10° in the winter night. Therefore, it shall be possible to change the inclination angles of antenna pattern in the vertical plane or antenna should be applied with sufficient radiation pattern width in the vertical plane.

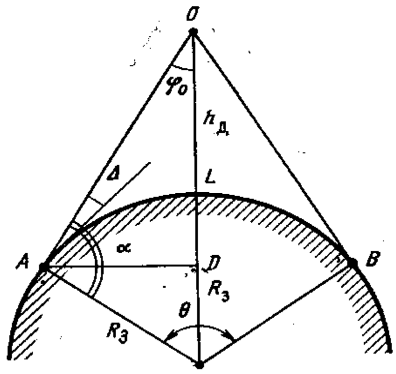


Figure 5 - The calculation of elevation on the short-circuit connection

Control questions.

1 What are the considerations to choose the working frequency on shortwave communication lines?

2 Why is the most difficult to organize short-wave communication on a long road stretched along the parallel?

3 What is the frequency of the maximum usable frequency (MUF) on the short-wave communication lines?

4 What is the frequency of the optimum operating frequency (OOP) on the short-wave communication lines?

5 What is the purpose in the short-wave communication lines drawn wave writing?

6 What are the requirements for antennas with decameter waves?

Distribution of hectometric, kilometric and miriametric waves.

Features of distribution and applications.

To reflect hectometric and longer waves from ionospheric electron density requires less than reflection decameter waves. Hectometric wave of fighting on the layer E. This afternoon they are very strongly absorbed by D layer, even at high power transmitters (hundreds of kilowatts) daily field level at these wavelengths is lower than the noise level. Admission to the sky wave hectometric (secondary) waves is possible only at night. Ground wave in this range extends over long distances than for short wavelengths, which allows for broadcasting at a distance of about 300 ... 400 km with a transmitter power of 100 kW and using a transmission antenna height of 100 ... 200 m.

At night, in addition to the ground-wave appears ionosphere wave. Due to the interference of these waves occur fading. fading period of a few minutes. The relatively long period of fading on hectometric waves due to the fact that at long wavelengths requires a strong change in the height of reflection in the ionosphere for a significant change in ionospheric wave phase. Fading can be selective. To combat fading apply special anti-feeder transmitting antennas (sometimes referred to as fading fading). Anti-feeder antenna unlike elemental vibrator has a DP in the vertical plane strongly pressed to earth (Fig. 5.1). Therefore, sky wave takes a significant level only at great distances from the transmitter outside the area served by terrestrial wave, fading in this area are eliminated. At night, when the D layer disappears waves can be received at greater distances from the transmitter due to ionospheric propagation. In this leads to multipath fading of the signal.

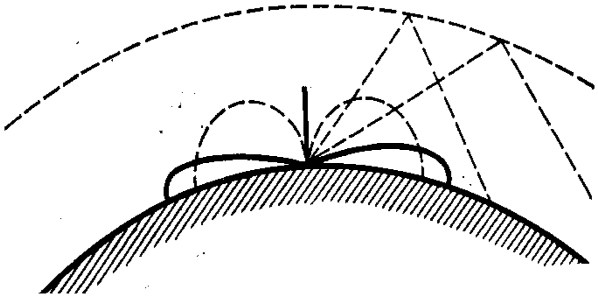


Figure 6 - Radiation pattern of anti-feeder antenna

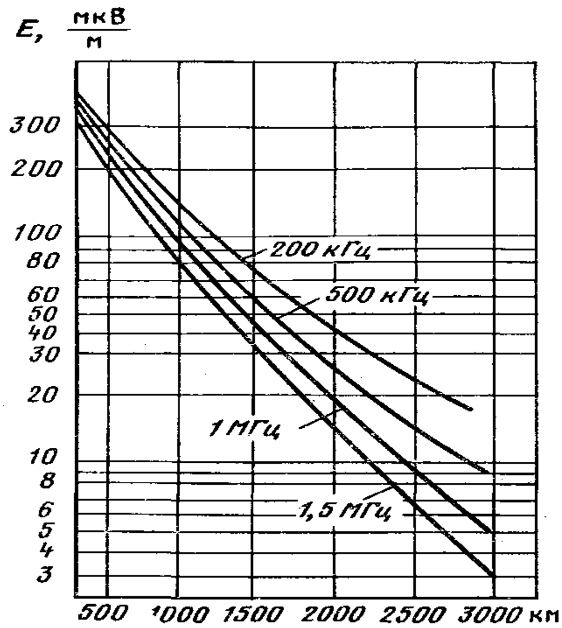


Figure 7 - Charts for calculating the field strength of the ionospheric wave on wave hectometric at night

A feature of the ionospheric propagation of waves in the hectometer range are nonlinear effects occurring in the ionosphere. The nonlinearity of the ionosphere is manifested in the fact that its parameters - dielectric permittivity and conductivity - dependent on the amplitude of the wave propagating in the ionosphere. This dependence is due to the fact that, depending on the frequency of collisions v electrons and heavy particles. This collision frequency depends on the speed of motion of the electrons, which consists of two components: the thermal velocity and the velocity of the electrons acquired under the influence of radio waves. The latter is inversely proportional to the frequency and conventional power transmitters at decameter and shorter wavelengths is small compared with the velocity of the thermal motion. On hectometric and longer wavelengths at the transmitter power of about 100 kW *Vel* becomes comparable with the speed of thermal motion, and under the influence of radio waves increases the frequency v and the radio wave absorption. In practice, it is necessary to take into account non-linear effect, which consists in the cross modulation of radio waves. Cross amplitude modulation occurs when two amplitude-modulated waves are reflected from the various stations of a region of the ionosphere. At the same time more powerful field changes the absorption in the ionosphere in time with amplitude modulation: the greater the amplitude of the absorption increases with less - falls. This changes the absorption of the other wave in the ionosphere, which results in an additional modulation from which the receiving device can not eliminate. The possibility of cross-modulation should be considered when placing hectometric radio waves and in the selection of their power.

Hectometric waves used for communication over short distances using a ground wave and for the organization of regional and national broadcasting.

Kilometric (long) and miriametric (extra-long) waves are reflected from the bottom boundary of the ionosphere - the day of the layer D and by night the E layer without penetrating into its depth. Energy loss of radio waves in the ionosphere is negligible. Ground wave in the range of long and super-long waves also applies to a relatively small absorption. With this kilometer and miriametric waves propagate in the spherical waveguide formed by the surface of the Earth and the lower boundary of the ionosphere. This is critical for the waveguide wavelength of about 100 km. Longer waves in space cannot be distributed between the Earth and the ionosphere. As the long and extra-long waves are reflected from the lower boundary of the ionosphere, their distribution is subject to little ionospheric disturbances. This allows the use of wave bands for emergency communications in the polar regions. Due to the narrowness of the frequency band on the long and super-long waves manage to transmit small data flows (low speed telegraph). Kilometer and miriametric waves penetrate relatively deep into the sea water (see. § 1.5). Therefore, their use with submarines, located in the submerged states-NII. Kilometer and miriametric waves used for transmitting signals of exact time and frequency radio navigation. To use radio waves up to 2 km, features of distribution which differ little from those of the propagation of hectometric waves.

Calculation of the field strength.

Field strength of ground wave on hectometric waves calculated by the CCIR graphs given in [1]. Approximately field strength of the ionospheric wave can also be determined from the graphs shown in figure 7. These graphs show the quasi-maximum values of tension, t. E. The value exceeded for 5% of the observation time. The average value of the field is about 0.35 from the quasi-maximum. Charts are built for the product PD of 1 kW. To calculate the field strength at a different PD is necessary to multiply the tension determined according to the schedule on $\sqrt{PD}$.

At kilometer and miriametric waves at distances up to 2000 km calculation field, you can use the same graphics as for hectometric waves.

Control questions.

1 Explain the features of propagation of long waves.

2 Explain the features of propagation of the decametric waves.

3 Explain the features of propagation of super long waves.

4 Why do we use an anti-feeder antenna?

5 Why kilometer and miriametric waves provide a more accurate signal transmission time than decameter?

6 Explain the methods of calculation of the field strength.

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