THE PREDICTION OF LONG AND MEDIUM RADIOWAVES PROPAGATION ALONG MOUNTAIN AND FOREST PATHS

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Much interest has been recently shown in propagation of long and medium radiowaves in mountain and forest regions which are typical of the considerable part of land.

The main problem of radiowaves propagation prediction along earth surface is reduced to the prognosis of W attenuation function in some region of this surface. For vertical electric radiator placed on the earth surface the intensity of vertical component of electric field E_z in arbitrary point of the earth surface is determined by the following expression:

$$E_z = E_{0z} \cdot W \quad ,$$

where E_{0z} is the field intensity over ideal conducting surface; W is the attenuation function.

The method of W attenuation function prediction of electromagnetic field over the real earth surface taking into account its electric properties, relief and plant vegetation is grounded in the report.

In the process of developing of the prediction method of long and medium radiowaves propagation:

- the thorough investigations of stratified media electric characteristics including soils, forests, rivers and lakes were conducted /1/;
- the regularities of the uppermost ground electric properties space-time change of large regions of Asia were established /2/;
- the main types of geoelectric structures were distinguished and classified;
- the prediction method of electric properties of stratified semiconducting media was developed;
- the prediction maps of geoelectric sections parameters were compiled;
- the high precision of geoelectric prediction in the wide range of radiowaves was experimentally shown.

While solving the task of radiowave propagation along the earth surface the boundary conditions are determinated by the normalized surface impedance of the uppermost ground δ . The values of module $|\delta|$ and phase φ_δ of the normalized surface impedance are obtained by measuring the amplitude-phase structure of electromagnetic field of LF/MF radiostations or by using the parameters $\sigma_i, \varepsilon_i, h_i$ of stratified geoelectric section /1,2/.

The prediction maps of the surface impedance δ and topographic maps characterizing relief and area distribution of different types of forest vegetation serve as the basis for calculations of the attenuation function W predicted values. The electric parameters of forest are defined by its density, for coniferios forest $\sigma = (1,2-3) \cdot 10^{-5}$ Sm/m, $\varepsilon = 1,2-1,4$ and for deciduous forest and bushers $\sigma = (3,7-6,7) \cdot 10^{-5}$ Sm/m, $\varepsilon = 2-2,9$. The specification of W prediction during different seasons of a year is achieved by using the data of season variations of the uppermost ground electric properties /2/.

The predicted values $|W|$ and arg W are calculated for the model of multisectional impedance radiopath on the basis of numerical solution of one-dimensional integral equation for the attenuation function /3/. The effect of depolarisation and field reflection from the impedance boundaries in the design model is not taken into account, neither are the heterogeneity of the impedance and relief in transverse direction regarding the propagation path. The integral equation for the attenuation function along electrically and geometrically heterogeneous path has the following form /4/:

$$W(D)=1+i\sqrt{\frac{ikD}{2\pi}}\int_0^D W(x)\left[\delta(x)+\left(1-\frac{1}{ikr_2}\right)\frac{\partial r_2}{\partial n}\right]\frac{\exp[ik(r_1+r_2-r_0)]\,dx}{\cos\psi\sqrt{x(D-x)}} \qquad (1)$$

where $k=\omega/C$ is the wave factor in vacuum; x is the distance along the earth surface between the source and the integration point; r_0, r_1, r_2 is the distance along the straight line between the source and the receiver, the source and the integration point, the receiver and the integration point, respectively; n is outer normal in regard to Earth in the integration point. The dependence of field on time is accepted in the form of $\exp(-i\omega t)$. The relief along the path is characterized by the normal derivative $\partial r_2/\partial n$.

For the numerical integration of the equation (1) the algorithm /4/ was used, based on the finite sums method. At the initial part of the path attenuation function is calculated according to the model of the plane earth surface of the homogenous impedance. In order to define the boundaries of the usage of the numerical solution integral equation (1) as for distance and path conductivity the W calculations were carried out at the frequencies of 60, 200, 600 kHz for paths with parameters: $\sigma=1$ Sm/m, $\varepsilon=80$; $\sigma=10^{-2}$ Sm/m, $\varepsilon=20$; $\sigma=10^{-3}$ Sm/m, $\varepsilon=10$; $\sigma=10^{-4}$ Sm/m, $\varepsilon=5$. The results of calculations are compared with the numerical data /5/, being obtained according to V.A.Fock's formula for a series of normal waves. The instability of the numerical solution of the integral equation for W under low conductivities of the uppermost ground and high frequencies was established /6/. Thus, for $\sigma=10^{-3}$ Sm/m, $\varepsilon=10$ at the frequency of 200 kHz the numerical solution provides a good coincidence with a series of normal waves for 600 km path in length, but at the frequency of 600 kHz - only as far as 200 km.

The experimental estimation of the prediction precision of the field attenuation in the LF/MF ranges along 14 mountain and forest paths of Asia /2,6/ using the predicted values of the surface impedance and taking into account relief and forest vegetation showed that disagreement between the predicted and measured values did not exceed at an average 25% along the paths with the length up to 600 km. For example, we consider two radiopaths with different electric properties: path I with the length of 600 km and with low and medium values of the surface impedance module, path II with the length of 50 km and with high value of the surface impedance module. The relief of the paths is mountainous with relative exceeding of 200-800 m. The height of mountains is commensurable with the wavelength and the path relief influences considerably the process of radiowave propagation. The graphs of predicted $|W|$, arg W and experimental values $|W|_e$ are presented in Fig. 1 as well as the profiles and the predicted areas of the impedance. The definition method of $|\delta|, \varphi_\delta, |W|_e$ is given in our works /1,2/. The definition module error of the attenuation function $|W|$ did not exceed ±(5-7)%.

The predicted values of the surface impedance δ of path I are given in Table 1.

Table 1.

f , kHz	Predicted region				
	1	2	3	4	5
50	0.026* / -52	0.021 / -46	0.03 / -45	0.066 / -33	0.02 / -45
236	0.065 / -48	0.044 / -44	0.064 / -44	0.114 / -30	0.044 / -45

*in numerator is module; in denominator is phase in degrees.

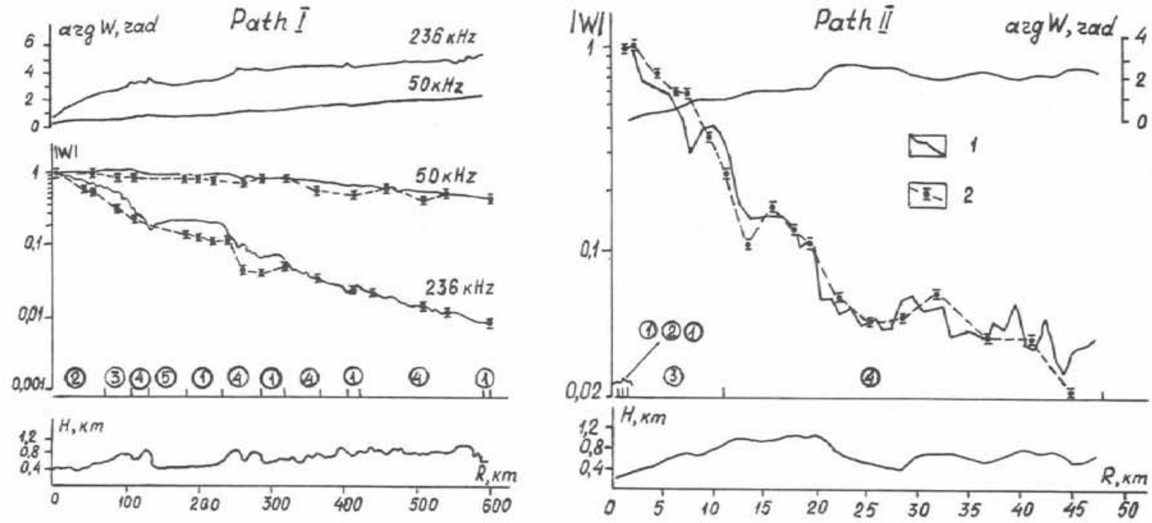

Fig.1. The predicted (1) and measured (2) values of |W| and arg W. Numerals in circles are predicted regions.

The forest coverage of path I is 84%. When calculating W the forest vegetation was taken into account by introducing additional forestlayer with $\sigma = 1{,}9\cdot10^{-5}$ Sm/m, $\varepsilon = 1{,}3$ and with 12.5m effective height of trees.

The disagreements between the predicted |W| and experimental $|W|_e$ values are estimated by their relation $|W|/|W|_e$. Its value at the frequency of 50 kHz is in the range 0.98-1.46, at the frequency of 236 kHz 0.9-1.98 and on the average along the path it is 1.16 and 1.23, respectively.

The presence of forest vegatation and mountainous relief of the path leads to considerable (from 2 to 5 times) increase of the field attenuation in the LF range as compared with slightly hilly and without forest path.

Path II according to the results of the surface impedance δ local values measurements in 18 points at the frequency of 545 kHz is divided on 5 multisectional impedance paths (Table 2).

Table 2.

f, kHz	Predicted region			
	1	2	3	4
545	$\frac{0.149}{-23}$	$\frac{0.065}{-35}$	$\frac{0.173}{-27}$	$\frac{0.231}{-12}$

The average relative disagreement between |W| and $|W|_e$ does not exceed ±21%. Only in some points of the path the disagreements of the predicted and measured values |W| achieve 40-50%. These disagreements are conditioned by the fact that the design model of multi-sectional path does not completely take into account the real distribution of electric properties of the uppermost ground, forest vegetation and relief in the range of first Fresnel zone i.e., in longitudinal and transverse directions.

The method proposed may be used for field prediction of LF/MF radiostations placed in mountain and forest region. Further development of studies concerning the prediction of "terrestrial" wave propagation is to work out the algorithms of electromagnetic fields over two-dimensional heterogeneities with more precise account of refraction.

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