MONITORING OF COASTAL ECOSYSTEMS BY METHOD OF REMOTE SENSING IN THE SHORT-WAVE RANGE OF RADIO WAVES

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A new method for estimating the parameter noncoherent signal/noise β_K of ionospheric signal is offered. A comparative analysis is carrying out. This new method exceeds an order of magnitude widely used standard one by analytical (relative) accuracy of determining a parameter β_K. It has the same order as the well-known coherent methodology.

Key words: remote sensing, measurement technique, the scattering parameter signal/noise ratio. vertical sounding, Earth Surface Scattering Power β_K.

I. INTRODUCTION

Parameter of returned partially scattered ionospheric signal β_K is of interest to an important characteristic of the "perturbation" and "turbidity" of statistically inhomogeneous ionospheric plasma and to the work index of reliability of ionospheric communication channels including diagnostic one. Prompt and reliable estimate of the parameter β_K is of interest to radio physics, geophysics, and optics. Specification for ionospheric case is implemented.

This range allows us to diagnose sub-surface layer of the earth because scattering parameter is formed by inhomogeneities dielectric permittivity of the subsurface structures.

The problem of measuring and accounting of scattering power of the earth's surface in the short-range radio waves is an important for solving such challenges as diagnostic properties of the environment by means of methods that use this radio band, when in the channel there is an intermediate reflection (scattering) of the earth's surface, which is of interest for exploration and environmental studies.

Selection of the working sensing range and the impact of environment on the passing radiation are an important issues for using space-based tools, for environmental management and environmental monitoring.

The most important aspects of using space-based tools for environmental management and environmental monitoring are the choice of the operating range and probing questions about the influence of media on the passing radiation [1]. The problem of this discussion is the "rough" remote diagnostics of the earth's surface and subsurface of the dielectric structures in the SW range [2]. Selection of SW range takes into account the subsurface layer (thickness of the order of the wavelength of the incident signal). Interpretation of the data is based on a statistical multiplicative model of the signal [3]. Testing the method of obtaining a signal/noise ratio in this model was produced by the example of a double reflection of the probe signal from the SW ionosphere in a

vertical sounding (remember that when using a satellite, the signal passes twice through the atmosphere and ionosphere). The work addressed issues of sensitivity of the model parameters that were studied.

The measurement, mapping, and computation of the "rough" Earth Surface Scattering Power (ESSP) in the SW range are of interest for a set of problems (communication, geology, etc.). The ESSP parameter is the signal/noise ratio of the β_K waves reflected from the earth's "rough" backing. There is the back of the β_K-data and measuring method is in SW range. [4] presents the experimental method of β_K determination.

In this paper, this method is tested on the parameter of β_K sensitivity. According to the statistical model (SM), a database ("records" for the numerical experiment) adequate to the real conditions was created. The properties of the "rough" earth area were defined by the theoretical β_K value. Based on the method of [5], β_K (numerical experiment) was determined. Then, the arrays of the β_K and β_K^t were compared and analyzed. In this paper, the admissible sensitivity and stability of the method [6] were justified. The comparative analysis of the real experimental data and adequate numerical ones were fulfilled. As a result, the plausibility of the ionosphere echo statistical structures used were justified [7].

In this paper, we propose a new method for estimating the parameters of noncoherent signal/noise ratio β_K ionospheric echo [8]. A comparative analysis shows that the analytical (relative) accuracy of the determination of the parameter β_K using the new method exceeds the widely-used standard, and the same order of known coherent methodology [9].

The paper presents the results of comparison of the measurement method from the point of view of their admissible relative analytical errors. The new method is suggested.

II. Calculation methods

Narrowband random process $\mathcal{E}(t)$ in fixed point of reception in the ground in scalar approximation is the superposition of mirror $\mathcal{E}_0(t)$ and scattered $\mathcal{E}_P(t)$ components distributed by the normal law:

$$\begin{aligned}\mathcal{E}(t) = \mathcal{E}_0(t) \ + \ \mathcal{E}_P(t) \ &= E_{00}\cdot e^{i\cdot\left(\omega_0\cdot t-\varphi(t)\right)} + \mathcal{E}_P(t) = \\ &= R(t)\cdot e^{i\cdot\left(\omega_0\cdot t-\Phi(t)\right)} = \left[E_C(t) + i\cdot E_S(t)\right]\cdot e^{i\cdot\omega_0\cdot t}\ ,\end{aligned} \tag{1}$$

where $\varphi(t)$, $\Phi(t)$, $R(t)$, $E_m(t)$, m=c,s – shown to slow random processes on the period $T = \dfrac{2\cdot\pi}{\omega_0}$; E_{00} = Const.

Scattering parameter is the ratio:

$$\beta_k^2 = \frac{\text{power of mirror components}}{\text{power of scattered components}} = \frac{E_{00}^2}{2\cdot\overline{E_P^2}}\ . \tag{2}$$

Here and below, “ — ” means statistical averaging. $E_C(t) = R(t)\cdot\cos\Phi(t)$ and $E_S(t) = R(t)\cdot\sin\Phi(t)$ are low-frequency quadrature of the ionospheric signal, R(t) is envelope, $\Phi(t)$ is total phase.

The subscript k = E4, R2, R4 means experimentally recorded primary random processes and appropriate method of their registration: E4 – coherent; R2, R4 – noncoherent amplitude. Index k indicates the primary parameter recorded: E – quadrature, R – envelope of the ionospheric signal.

Standard noncoherent R2-method based on the relationship (3) is widely used for estimating β_K (2) [1]:

$$\frac{\overline{R^2}}{\left(\overline{R}\right)^2} = f\left(\beta_{R2}\right) = \frac{4}{\pi}\cdot\frac{\left(1+\beta_{R2}^2\right)\cdot\exp\left(\beta_{R2}^2\right)}{\left[\left(1+\beta_{R2}^2\right)\cdot I_0\left(\beta_{R2}^2/2\right)+\beta_{R2}^2\cdot I_1\left(\beta_{R2}^2/2\right)\right]^2}. \qquad (3)$$

$I_n(x)$ is Bessel function of nth order of a purely imaginary argument [10].

Using coherent E4-method and estimating β_{E4} by γ_{E4} kurtosis of quadrature [11]:

$$\gamma_{E4}\left(\beta_{E4}\right) = \frac{\overline{E_m^4}}{\left(\overline{E_m^2}\right)^2} - 3 = -\frac{3}{2}\cdot\frac{\beta_{E4}^4}{\left(1+\beta_{E4}^2\right)^2}; \quad m=c,s. \qquad (4)$$

It should be noted that measured primary parameters are the ratio of moments $\overline{R^2}/\left(\overline{R}\right)^2$, $\overline{E_m^4}/\left(\overline{E_m^2}\right)^2$ respectively. Relations (3), (4) are obtained by taking into account the specific models of structure of the ionospheric signal.

Probabilistic properties of the ionospheric signal (1) of the first multiplicity response is well described by Rice model with a displaced spectrum (RS-model) [12, 13]. Expressions (3) and (4) are obtained based on Rice model with a displaced spectrum.

A priori expression (4) of coherent method E4 contributes an order of magnitude higher relative analytical accuracy of the estimation of parameter β_K [14, 15].

In this paper, we propose new noncoherent R4-method of determination β_{R4} by γ_{R4} kurtosis of envelope for RS-model [16]:

$$\gamma_{R4}\left(\beta_{R4}\right) = \frac{\overline{R^4}}{\left(\overline{R^2}\right)^2} - 3 = \gamma_{R4}\left(\beta_{R4}\right) = -1 - \frac{\beta_{R4}^4}{\left(1+\beta_{R4}^2\right)^2}. \qquad (5)$$

For compare the given methods in the sense of relative errors permitted in calculating β_K resulting view of functional dependencies $f(\beta)$, $\gamma_{E4}(\beta)$ and $\gamma_{R4}(\beta)$, we obtain expressions (6):

$$\varepsilon_k = \left|\frac{\Delta\beta_K}{\beta_K}\right| = \left|\frac{1}{\beta_K}\cdot\frac{dG_K}{dZ_K}\cdot\Delta\left(Z_K\right)\right|, \qquad (6)$$

where $K = R2, E4, R4$; $G_K = f, \gamma_{E4}, \gamma_{R4}$; $\Delta(Z_K)$ – absolute statistical errors of measured values:

$$Z_K = \frac{\overline{R^2}}{\left(\overline{R}\right)^2}, \ \frac{\overline{E_m^4}}{\left(\overline{E_m^2}\right)^2}, \ \frac{\overline{R^4}}{\left(\overline{R^2}\right)^2}.$$

Measures of inaccuracy including statistics for the different techniques of determination β_K are:

$$\varepsilon_{R2}(\beta) = \frac{\pi}{8} \cdot \frac{\left[\left(1+\beta^2\right)\cdot I_0\left(\beta^2/2\right) + \beta^2 \cdot I_1\left(\beta^2/2\right)\right]^3}{\beta^2 \cdot \exp\left(\beta^2\right) \cdot I_1\left(\beta^2/2\right)} \cdot \Delta\left(Z_{R2}\right); \tag{7а}$$

$$\varepsilon_{E4}(\beta) = \frac{\left(1+\beta^2\right)^3}{6\cdot\beta^4} \cdot \Delta\left(Z_{E4}\right); \tag{7б}$$

$$\varepsilon_{R4}(\beta) = \frac{\left(1+\beta^2\right)^3}{4\cdot\beta^4} \cdot \Delta\left(Z_{R4}\right). \tag{7в}$$

Statistical error $\Delta(Z_K)$ depends on the sample volume N. It may be different at identical sample volume for each of the methods. We normalize (7) on $\Delta(Z_K)$ for focusing on the errors due to differences in functional dependencies (3) – (5).

Dependency Graphs $\varepsilon_K^* = \dfrac{\varepsilon_K}{\Delta\left(Z_K\right)}$ for β_{R2} , β_{E4} and β_{R4} are shown in Fig. 1. ε_K^* will be called analytic (relative) error method.

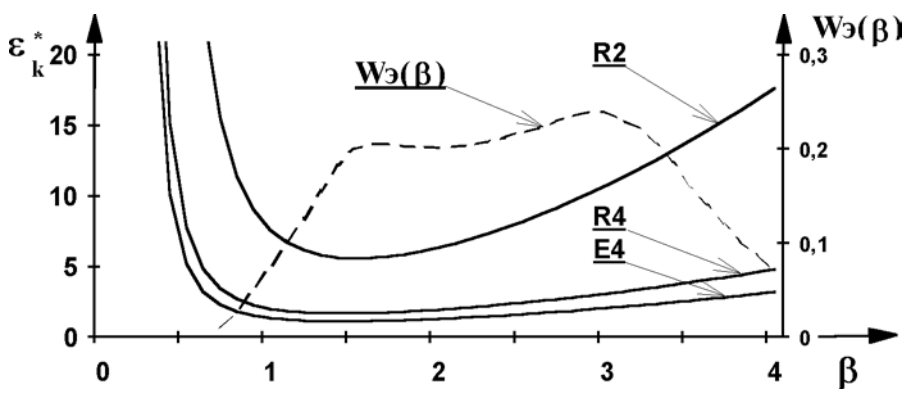

Fig. 1. Dependency Graphs ε_K^*, K = R2, R4, E4 (solid curves) and the experimental distribution $W_Э(\beta)$ (dashed curve) (F2-layer, 4,5 – 9,5 MHz, single signal).

Experimental distribution $W_Э(\beta)$ determines the range of variation of β.

From equation (4) and (5) we conclude that $\varepsilon_{E4}^* = \frac{2}{3} \cdot \varepsilon_{R4}^*$ have the same order and significantly (by order) exceed measurement accuracy of standard R2-method [17, 18].

Analysis of analytical error of estimation of the parameter β_K allowed to recommend R4-method instead of standard R2-method. Sufficiently high analytical (relative) accuracy of parameter estimation β_K can be achieved using noncoherent apparatus using (5) of R4-method [19]. Naturally, the ability to optimize the statistical error by the relevant special digital processing of ionospheric signal is keep on coherent methodology E4 [20].

III. Conclusion

The comparative analysis of the normalized relative analytical errors ε_K^* of the known methods and the new one was performed [9]. It was shown that errors ε^*_E and ε^*_{R4} have the same order, and both errors significantly exceed the error ε^*_{R2} in comparison with the standard R2-method by a measurement accuracy of β_K [14].

Environmental monitoring of the earth's surface by remote sensing in the short-wave band can provide quick identication of some ecological characteristics. This band range allows one to diagnose subsurface aspects of the earth, as the scattering parameter is affected by irregularities in the dielectric permittivity of subsurface structures. This method based on the organization of the monitoring probe may detect changes in these environments, for example, to assess seismic hazard and seismic risk [17]. The problem of measuring and accounting for the scattering power of the earth's surface in the short-range of radio waves is important for a number of purposes, such as diagnosing properties of the medium using the radio band when going on the road to interpret the intermediate reflection (scattering) from the earth's surface, which is of interest for geological and environmental studies [4].

As a result, it was found that sufficient β_K analytical measurement accuracy can be achieved when using an noncoherent apparatus [13] using a new R4-method. But the coherent E-method reserves the possibility of statistical error optimization with a special processing of the ionospheric signal [20].

IV. References

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