DETERMINATION OF PROPAGATION MEDIUM STATISTICAL CHARACTERISTICS FROM REMOTE SENSING RADIO DATA

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INTRODUCTION

It is necessary to find out the fluctuation characteristics of wave amplitude and phase and parameters connected with them (phase and amplitude difference, coming wave angles and others) in radiosystem analysis. Besides that, the availability of information about propagation medium variations in signal distortions determines the possibility of inverse problem solution in remote sensing, i.e. retrieval of propagation medium refraction statistical indices (three-dimensional correlation function of the refraction index $n(\vec{\rho}, z)$, the altitude profile of the structural constant $C_n^2(z)$ and others) [1,2] .

Two schemes of the retrieval problem solution of $C_n^2(z)$, the results of statistical simulation of them with ECM and accuracy analysis of the suggested algorithms have been given in this paper. The problem is solved by statistical solution theory methods which guarantee the obtaining of the most accurate and stable solution [3] . The retrieved mean value $\langle n(z)\rangle$ [4] and structural constant $C_n^2(z)$ altitude profiles allow to estimate the current errors of radio measurements.

The Inverse Problem Solution

Recorded in the space frequencies region $\vec{\omega}=(\omega_x, \omega_y)$, equations for the fluctuation of phase V_2 and of the level of amplitude V_1 approaching Rytov's method [1,2] , are original in the first scheme

$$V_{\frac{1}{2}}(\vec{\omega}',\vec{\theta})=\frac{K}{2}\left[1-|\vec{\omega}'+\vec{\theta}|^2\right]^{-1/2}\int_0^{z_0} dz' \begin{matrix}\sin\\ \cos\end{matrix}\left[K\theta_z(z_0-z')-K\sqrt{1-|\vec{\omega}'+\vec{\theta}|^2}(z_0-z')\right]\tilde{n}(\vec{\omega}',z') \tag{1}$$

Where $\vec{\omega}'=\vec{\omega}/K$, K - wave number, $\vec{\theta}=(\theta_x, \theta_y)$, θ_z -

- directing cosines of the plane wave, which falls on the irregular layer; $\tilde{n}(\vec{\omega}', z')$ - Fourrier transformation from $n(\vec{\rho}, z')$ by $\vec{\rho}$.

The idea of the solution method consists in the determination of the estimate $\hat{n}(\vec{\omega}', z')$ from (1) by $\tilde{V}_1(\vec{\omega}', \vec{\theta})$ on the set ϑ_x, ϑ_y $\left(\theta_{\frac{x}{y}} = \cos \vartheta_{\frac{x}{y}}\right)$, formation of the current space spectrum $\Phi_n(\vec{\omega}', z)$, and then the integration by $\vec{\omega}'$ and the estimation of $\hat{C}_n^2(z)$. Usually the main information which is not connected with $n(\vec{\rho}, z)$ is encoded in the radiosignal phase. That is why the amplitude level fluctuation V_1 are used for the retrieval of $C_n^2(z)$.

The relationship between the space spectra $\Phi_n(\vec{\omega}', z)$ and $\Phi_{V_1}(\vec{\omega}'; \gamma_1, \gamma_2)$ has been discovered (here $\langle \tilde{V}_1(\vec{\omega}_1', \vec{\gamma}_1) \tilde{V}_1^*(\vec{\omega}_2', \vec{\gamma}_2) \rangle = \Phi_{V_1}(\vec{\omega}_1'; \vec{\gamma}_1, \vec{\gamma}_2)\, \delta(\vec{\omega}_1' - \vec{\omega}_2')$)

$$\hat{\Phi}_n(\vec{\omega}', z_0 - u) = \int_\Gamma \int_\Gamma d\gamma_1 d\gamma_2\, \Phi_{V_1}(\vec{\omega}'; \gamma_1, \gamma_2) \exp\{j(\gamma_1 - \gamma_2)\omega_x' u\} \qquad (2)$$

where $\vec{\gamma} = K\vec{\theta}/(1 - |\vec{\theta}|^2)^{1/2}$ - generalized angle parameter and with $\theta_y = 0$, $\gamma = K\theta_x/(1 - \theta_x^2)^{1/2}$

The following equation for $\hat{C}_n^2(z)$ has been derived from (2) by transforming it into the correlation function of the wave amplitude level B_{V_1} fluctuations

$$\hat{C}_n^2(z) = \int_\Gamma \int_\Gamma d\gamma_1 d\gamma_2\, B_{V_1}[\Delta x = (\gamma_1 - \gamma_2)z; \gamma_1, \gamma_2] \qquad (3)$$

The wave amplitude level fluctuations from the directions ϑ_{x_1}, ϑ_{x_2} in B_{V_1} are registered when placing along the axis OX on $\Delta x = (\gamma_1 - \gamma_2)z$.

The equation for the estimation of $\hat{C}_n^2(z)$ has been obtained also when the observation area is $\{\vec{\theta}_i\}$, $i = \overline{1, J}$

$$\hat{C}_n^2(z) = \sum_{i=1}^{J} \sum_{j=1}^{J} \iint_{-\infty}^{\infty} d\vec{\omega}' |A(\vec{\omega}')|^2 \tilde{\ell}^0(\vec{\omega}', z; \vec{\gamma}_j) \tilde{\ell}^{0*}(\vec{\omega}', z; \vec{\gamma}_i) \Phi_{V_1}(\vec{\omega}'; \vec{\gamma}_i, \vec{\gamma}_j), \qquad (4)$$

where $\tilde{\ell}^{o}(\vec{\omega}', z; \vec{\gamma}_i)$ complies with the system of the algebraic equations given in the paper and $|A(\vec{\omega}')|^2$ is the smoothing function determined from the stability solution conditions [3].

Equation for the correlation function of the amplitudes which are registered when placed on $\Delta X = \rho$ with time shift τ $B_{V_1}(\rho, \tau)$ has been used in the second scheme of estimation of $C_n^2(z)$ [1]. Integral equation for

$$B_{V_1}(\rho, \tau) = \int_0^{z_0} dz\, K(\rho, \tau; z)\, C_n^2(z) \tag{5}$$

with nuclei for the spherical and plane waves K_1 and K_2 respectively, has been obtained in the approach of geometrical optics and Kolmogorov's spectrum (when plane wave radiator moves in the plane of base ρ with angle velocity $\dot{\theta}$):

$$K_{\substack{1\\2}}(\rho, \tau; z) = A(z_0 - z)^2 \mathcal{G}_{\substack{1\\2}}(\rho, \tau; z)\ ;\ A = 2\pi^2\, 0{,}033\, \kappa^2\, \Gamma(7/6)\, 2^{4/3} / \Gamma(-1/6)$$

$$\mathcal{G}_1 = \frac{z^2}{z_0} \left| \frac{\rho z}{z_0} - V\tau \right|^{-7/3}, \quad \mathcal{G}_2 = \left| \rho - \dot{\theta} z \tau \right|^{-7/3}, \tag{6}$$

where V - wind velocity.

The asimptotical solution of equation (5) have been found by which the intersection link method is confirmed in particular. In that case $B_{V_1}(\rho, \tau)$ determines $C_n^2(z_n)$ with the accuracy up to coefficients in the crossover point ($z_n = V\tau z_0/\rho$ or $z_n = \rho/\dot{\theta}\tau$) of the links.

Statistical Simulation with ECM

Accuracy analysis of the estimates of $C_n^2(z)$ from (3), (4), (5), (6) was carried out with the inclusion of the simulated normal random field noise in $V_1(\rho, \tau)\,(V_1(\rho, \theta_i))$. As it has been found complementary errors on the descrete area $\{\theta_i\}$ for the algorithm (4) are determined by the relative error of the retrieval of $n(\vec{\rho}, z)$: $\sigma^2_{n-\hat{n}} / \sigma^2_n$. The calculations of the estimate accuracy have indicated the practical possibility of the definition of $\hat{C}_n^2(z)$. Statistical simulation carried out with ECM, has confirmed the efficiency of procedures (3), (4) and of the next one from (5), (6). Invariant to the statistical characteristics, procedures (3), (4) still maintained the capability for work at the size of the maximum angular placing $\Delta\gamma \geqslant 0,1$ and $J \geqslant 10 \div 15$. The simulation of the estimate of the phase fluctuations $V_2(\vec{\rho}, \theta_0)$ according to amplitude ones has produced the relative reduction of the error $\sigma^2_{V_2}/\sigma^2_{V_2 \cdot \hat{V}_2} \simeq \simeq 4 \div 6$

SUMMARY

Practical use of the investigated estimation procedures for $C_n^2(z)$ is marked by the following stages:

for algorithm (3) - by registration of the amplitude levels $V_1(x, y=0, \theta_x)$, by forming the correlation function $B_{V_1}(\Delta x = (\gamma_1 - \gamma_2)z; \gamma_1, \gamma_2)$ and by its accumulation in the area of the angles Γ;

for algorithm (4) - by registration of $V_1(x, y=0; \theta_{x_i})$ on the set of the angles $i = \overline{1,J}$, by forming on $B_{V_1}(x_1 - x_2, 0; \theta_{x_i}, \theta_{x_j})$ of the spectrum $\Phi_{V_1}(\omega_x'; \gamma_i, \gamma_j)$, by its filtration in the field ω_x' in accordance with the filter $\tilde{\ell}^o(\omega_x', z; \gamma_i)\tilde{\ell}^{o*}(\omega_x', z; \gamma_j)$ and by accumulation in the area of the angles γ_i, γ_j;

for the algorithm which follows from (5), (6) - by registration of the amplitude levels on the bases ρ at time t, by forming $B_{V_1}(\rho, \tau)$.

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