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Parametric polarization radio-location method of improvement of radio-location observation of navigational objects against the background of natural hindrances

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It should be taken into account the presence of atmospheric formations on the vessel's route during radar observation of navigational objects which, with sufficient intensity of signals reflected from them, can mask the echo-signals of navigational objects on the indicators of the ship's radar. Taking into account the polarization transformations, radiated electromagnetic waves while their interaction with the navigation and atmospheric objects allows to allocate the echo-signals of the navigation object from the total echo signal. To solve this problem, the principle of separation of the observed ship's radar objects will be used, in terms of the ratio of their basic dimensions to the emitted wave and the features of scattering of electromagnetic waves emitted by the ship's radar antenna. Also will be used method which based on the use of the polarization structure of the radar signals reflected from the navigation object and atmospheric formation when they are irradiated by electromagnetic waves of four polarizations. Electromagnetic waves radiated by the ship's radar antenna and reflected from the navigation and atmospheric objects are represented by means of four Stoke's parameters. The reflecting properties of the navigation object and atmospheric formation are represented as a matrix of 16 coefficients, each of them is the effective reflecting surface of the navigation object and atmospheric formation. The analysis and description of the polarization method for dividing the echoes of the navigation object from the echoes of atmospheric formation is given.

Keywords: *navigation object, polarization selection, atmospheric formations, parametric polarization method, linear basis, circular basis, Stoke's parameters, scattering matrix, polarization plane, anisotropy coefficient, all-polarized antenna, effective scattering surface.*

1. Introduction

The atmosphere and atmospheric formations significantly influence the effectiveness of radio-location observation of navigational objects along the route of the vessel. This influence is caused both by the attenuation of the electromagnetic energy radiated by the ship's radar antenna and by it's scattering by the dielectric inhomogeneities of the turbulent atmosphere and hydrometeoric particles of atmospheric formations. To date, the influence of attenuation of radio waves on the maximum range of detection of navigational objects has been considered in works: [1-3]. Reflection from atmospheric formations affect the effectiveness of radar detection and recognition of navigational objects along the route of the vessel. On the one hand, this influence is manifested in the form of a masking action of the detected navigation objects during their radar observation against the background of atmospheric formations, and on the other hand, this influence is manifested in the appearance of false echo-signals, which in some cases can be mistaken for the echoes of navigational objects. To determine the interfering effects of echoes of atmospheric formations, various methods are used [4-10]. However, the issue of echo-signal isolation of a navigational object from the echo signal of atmospheric formation during radar observation of navigational objects of the ship's radar station has not been finally reserched. To solve this problem, we will use the principle of separation of observable ship's radar objects by the ratio of their basic dimensions to the emitted wave and the features of scattering of electromagnetic waves by the observable objects of the ship's radar. In this case, the physical properties of objects are represented as a function of the wavelength of the ship's radar, which irradiates the navigation object. The classification of objects and their separation will be made from the ratio of their basic dimensions to the radiated wavelength. We divide objects by their dimensions and features of scattering of electromagnetic waves into the following groups:

1. "Rayleigh scattering", when the wavelength radiated by the ship's radar antenna is much larger than the size of the object.
2. Resonance scattering, when the wavelength radiated by the ship's radar antenna is of the same order as the size of the object.
3. "Surface and edge scattering", when the wavelength radiated by the ship's radar antenna is much smaller than the size of the object.

Rayleigh and resonant scattering is inherent in meteorological objects. For Rayleigh scattering, the moduluses of the elements of the object scattering matrix are proportional to their volume and depend little on its geometry, and the phases of the scattered signals do not depend on the scattering direction and the shape of the scatterer. As the size of the reflecting particles increases in the meteorological object, the length of the irradiating wave becomes one order with the particle size and a resonance scattering region arises in the meteorological object. The polarization of the scattered wave is determined by the nature of the particle oscillations within the meteorological object and at the same time it carries information about the internal structure of the meteorological object and the reflecting wave is polarized.

For the navigational object, the main role in the scattering of the wave irradiating the object is played by waves creeping along it’s metal surface, including its shadow surface. The surface and edge scattering occurs as the length of the irradiating wave is much smaller than the dimensions of the navigation object when the polarization structure of the scattered wave depends on the geometry of the surface of the object and the path that the diffracted wave traveled before it’s separation from the object.

Reflective elements of the navigation object are numerous and diverse and can consist of:

- a flat plane of arbitrary shape with area A, and the incident wave is oriented normally to the plane, then the effective reflecting surface of the object σ_0 is determined from the formula [2]:

$$\sigma_0 = \frac{4\pi A^2}{\lambda^2}, \tag{1}$$

λ - the wavelength, cm;;

- there is a triangular corner reflector at some point of the surface of the navigation object with the length of the edge a, then σ_0 determined from the condition:

$$\sigma_0 = \frac{4\pi a^4}{3\lambda^2}; \tag{2}$$

- if there is a cylinder of length L and radius R on the surface of the navigation object, then σ_0 will be written in the form:

$$\sigma_0 = \frac{2\pi RL^2}{\lambda}; \tag{3}$$

- an infinite cone whose irradiation occurs along it's axis, and half the angle at the vertex is equal θ_0, then σ_0 determined by the relation:

$$\sigma_0 = \frac{\lambda^2}{16\pi} tg^4\theta_0, \tag{4}$$

θ_0 - the angle in radians;;

- an elongated spheroid with a length of the semimajor axis *l* and a length of the semimajor axis *k*, then σ_0 determined by the formula:

$$\sigma_0 = \pi \frac{l^2}{k^2}. \tag{5}$$

In general, the navigation object is complex and consists of elements of various geometric shapes that are characterized by surface and edge scattering of electromagnetic waves, and the reflected electromagnetic plane at the receiving antenna of the ship's radar is the vector sum of the planess excited by each element. Then the navigation object, as a set of independent reflectors, is determined by the following relationship:

$$\sigma_{об} = \left| \sum_{k=1}^{n} \sqrt{\sigma_0} e^{(4\pi d_k/\lambda)} \right|^2, \tag{6}$$

σ_0 - the effective reflecting surface of any element on the surface of the navigation object;

d_k - the distance from this element on the surface of the navigation object to the radar antenna, km.

Atmospheric formation, as a background object, when observing the ship's radar of navigational objects, consists of a set N_0 of elementary reflectors occupying a volume in the form of a cylinder with a base $\theta_A R^2$ and a height $\frac{c\tau_u}{2}$. The volume of such a reflecting cylinder is determined from the condition [2]:

$$V = \pi \frac{c\tau_u}{2} R^2 \theta_A^2, \tag{7}$$

c - the speed of light, m / s;

τ_u - the duration of the pulse radiated by the ship's radar antenna, mks;

R - the distance from the ship's radar antenna to the reflective volume of atmospheric formation, km;

θ_A - the beamwidth of the radar antenna antenna radar, rad.

All the elementary reflectors of the electromagnetic energy of atmospheric formation, which are inside the impulse volume, simultaneously participate in the creation of the reflected signal.

The width of the radiation pattern of the ship's radar antenna is expressed in terms of the directivity coefficient by the following relationship:

$$\theta_A = 4\pi D, \tag{8}$$

D - the directivity factor of the antenna.

Then, taking into account (8), the reflecting volume of atmospheric formation is written in the form:

$$V = R^2 \frac{2\pi}{D} \frac{c\tau_u}{2}, \tag{9}$$

and the effective reflecting surface of atmospheric formation with allowance for (9) is determined from the condition::

$$\sigma_{mn.ao} = 4\pi\sigma_{0mn.ao} N_0 \frac{R^2}{D} \frac{c\tau_u}{2}. \tag{10}$$

2. Parametric polarization radar method for improving radar observation of navigational objects in the presence of atmospheric formations on the ship's route.

When observing navigation objects, against the background of atmospheric formations, the ship radar receives echo signals from the aggregate "object-atmospheric formation" to the antenna input. The electromagnetic wave for radiation and reception is represented by four Stoke's parameters $I, Q, U, V,$ which in a linear basis are related to the amplitudes of the linearly polarized components E_x, E_y, and the phase difference Φ_{xy} of the electromagnetic wave by the following relations [7]:

$$\begin{aligned} I &= E_{xm}^2 + E_{ym}^2, \\ Q &= E_{xm}^2 - E_{ym}^2, \\ U &= 2E_{xm}E_{ym}\cos\Phi_{xy}, \\ V &= 2E_{xm}E_{ym}\sin\Phi_{xy}. \end{aligned} \tag{11}$$

Since the electromagnetic wave reflected from the aggregate "navigation object-atmospheric formation" is partially polarized, the Stoke's parameters for such a wave in the linear basis will be written as:

$$\begin{aligned} I &= \left|\overline{E_x(t)}\right|^2 + \left|\overline{E_y(t)}\right|^2, \\ Q &= \left|\overline{E_x(t)}\right|^2 - \left|\overline{E_y(t)}\right|^2, \\ U &= 2\overline{\left|E_x(t)E_y(t)\right|\cos\Phi_{xy}}, \\ V &= 2\overline{\left|E_x(t)E_y(t)\right|\sin\Phi_{xy}}. \end{aligned} \tag{12}$$

In the linear basis, rotated by 45 ° with respect to the linear basis (0,0) the Stoke's parameters are written as follows:

$$\begin{aligned} &I = E_{xm}^2 + E_{ym}^2, \\ &Q = -2E_{xm}E_{ym}\cos\Phi_{xy}, \\ &U = E_{xm}^2 - E_{ym}^2, \\ &V = 2E_{xm}E_{ym}\sin\Phi_{xy}. \end{aligned} \tag{13}$$

In a circular basis, the Stoke's parameters are written as:

$$\begin{aligned} &I = E_{mП}^2 + E_{mЛ}^2, \\ &Q = 2E_{mП}E_{mЛ}\sin\Phi_{ПЛ}, \\ &U = 2E_{mП}E_{mЛ}\cos\Phi_{ПЛ}, \\ &V = E_{mП}^2 - E_{mЛ}^2. \end{aligned} \tag{14}$$

The matrix of the reflecting properties of the navigation object and atmospheric formation, taking into account their effective reflecting surfaces, is written as:

$$\begin{bmatrix}
\left|\sum_{k=1}^{n}\sqrt{\sigma_{011об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{011ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{012об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{012ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{013об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{013ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{014об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{014ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} \\
\left|\sum_{k=1}^{n}\sqrt{\sigma_{021об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{021ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{022об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{022ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{023об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{023ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{024об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{024ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} \\
\left|\sum_{k=1}^{n}\sqrt{\sigma_{031об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{031ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{032об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{032ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{033об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{033ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{034об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{034ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} \\
\left|\sum_{k=1}^{n}\sqrt{\sigma_{041об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{041ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{042об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{042ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{043об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{043ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{044об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{044ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2}
\end{bmatrix} \tag{15}$$

Taking into account the fact that the Stoke's parameters of the reflected wave represent the sum of the parameters of the reflected wave from the navigation object and the atmospheric formation, the equation of connection of the Stoke's parameters of the emitted wave with the

Stoke’s parameters of the reflected wave and the scattering properties of the radar object and atmospheric formation will be written as:

$$\begin{bmatrix} I_{отр.об} + I_{отр.ао} \\ Q_{отр.об} + Q_{отр.ао} \\ U_{отр.об} + U_{отр.ао} \\ V_{отр.об} + V_{отр.ао} \end{bmatrix} =$$

$$= \begin{bmatrix}
\left|\sum_{k=1}^{n}\sqrt{\sigma_{011об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{011ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{012об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{012ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} \\
\left|\sum_{k=1}^{n}\sqrt{\sigma_{021об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{021ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{022об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{022ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} \\
\left|\sum_{k=1}^{n}\sqrt{\sigma_{031об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{031ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{032об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{032ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} \\
\left|\sum_{k=1}^{n}\sqrt{\sigma_{041об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{041ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{042об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{042ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2}
\end{bmatrix}$$

$$\begin{bmatrix}
\left|\sum_{k=1}^{n}\sqrt{\sigma_{013об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{013ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{014об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{014ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} \\
\left|\sum_{k=1}^{n}\sqrt{\sigma_{023об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{023ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{024об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{024ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} \\
\left|\sum_{k=1}^{n}\sqrt{\sigma_{033об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{033ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{034об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{034ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} \\
\left|\sum_{k=1}^{n}\sqrt{\sigma_{043об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{043ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2} & \left|\sum_{k=1}^{n}\sqrt{\sigma_{044об}}e^{(4\pi d_k/\lambda)}\right|^2 + 4\pi\sigma_{044ao}N_0\frac{R^2}{D}\frac{c\tau_u}{2}
\end{bmatrix} \cdot \begin{bmatrix} I_{изл} \\ Q_{изл} \\ U_{изл} \\ V_{изл} \end{bmatrix} \qquad (16)$$

A partially polarized wave reflected from the navigation object and atmospheric formation by means of the Stoke’s parameters can be decomposed into the sum of two waves, one of which is completely polarized, and the other, independent of it, is not polarized. Then the intensity of the unpolarized component I_H of a partially polarized wave $I_{ЧП}$ reflected from atmospheric formation is expressed in terms of the Stoke’s parameters in the form:

$$I_H = I_{ЧП} - \sqrt{Q_H^2 + U_H^2 + V_H^2}\ , \qquad (17)$$

Q_H, U_H, V_H - Stokes parameters of unpolarized wave reflected from atmospheric formation.

The intensity of the polarized component $I_П$ of the partially polarized wave reflected from the navigation object will be written as:

$$I_{П} = \sqrt{Q_{П}^2 + U_{П}^2 + V_{П}^2}\,, \qquad (18)$$

$Q_{П}, U_{П}, V_{П}$ - Stoke's parameters of the polarized component of the partially polarized wave reflected from the navigation object.

By measuring the Stoke's parameters of the fully polarized component of the reflected partially polarized wave from the navigation object and presenting them on the ship's radar indicators or on the computer display, it is possible to obtain all the information about the navigation object by eliminating the information of the interfering background from atmospheric formation. To isolate the Stoke's parameters of a fully polarized component, it is sufficient that the navigation object located in the atmospheric formation zone be irradiated with an unpolarized electromagnetic wave and measure the four Stoke's parameters of the reflected wave, with their subsequent separation into completely polarized and unpolarized components.

3. Conclusion.

The possibility of isolating the echo signal of the navigation object from the total echo signal "navigation object-atmospheric formation" is shown using the principle of separation of the observed ship's radar objects by the ratio of their basic dimensions to the emitted wavelength and the features of scattering of electromagnetic waves. And polarization method is used which based on the decomposition of a partially polarized wave into a completely polarized wave for the navigation object and completely unpolarized for atmospheric formation.

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