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Polarization method for navigation object selection in ship radar systems

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Abstract

This paper substantiates the method of polarization selection of navigation objects located in the zone of atmospheric formations (i.e., precipitation of different intensity and phase state), based on polarization differences in the parameters of their echo signals in a partially polarized electromagnetic wave arriving at the input of the all-polarized antenna of the ship radar polarization complex (SRPC). The partially polarized wave is represented as consisting of two polarized streams with polarization degrees m_1 and m_2 corresponding to the echo signals of the navigation object and atmospheric formation. The property of the partially polarized electromagnetic wave reflected from a complex object (i.e., navigation object located in the zone of atmospheric formation) is represented by real energy polarization Stokes parameters having intensity dimension. The scattering ability of the complex object is represented by the Mueller scattering matrix, the elements of which are measured by SRPC when it is sequentially irradiated with electromagnetic waves of four fixed polarizations. Polarization selection of navigation objects located in the zone of atmospheric formations uses the difference of polarization degrees of echo signals of the navigation object and atmospheric formation. The process of selection of the navigation object echo signal from the echo signal of the complex object and its observation on the screen of the SRPC indicator or computer display is based on the relationship between the degree of polarization of the electromagnetic wave and the polarization parameters of the navigation object echo signal and the atmospheric formation. The aim of this research is to develop polarization criteria of optimality of radar parameters of echo signals of partially polarized electromagnetic waves, represented by polarization degrees m_1 and m_2 corresponding to the navigational object and atmospheric formation observed by SRPC. As a result of the performed research, the problem of polarization selection of navigation objects located in the zone of atmospheric formations along the ship's trajectory according to the values of the polarization degree of the navigation object echo signal is solved.

Introduction: statement of the problem in general terms and its relation to scientific and practical tasks

During radar observation of navigational objects along a ship's route, alongside the echo signals of the navigational object, the receiver input of the ship radar receives echo signals from atmospheric formations, which screen the echo signals of navigational objects and create a dangerous situation when the ship moves in the zone of the atmospheric formation. To eliminate the influence of echo signals of atmospheric formation, nowadays, methods have been created that use mathematical models for the scattering fields of the distributed radar objects and scenes, allowing us to obtain analytical relations with the help of which the parameters of the scattered electromagnetic field in different points of space are calculated (Atamaniuk, 2015). Methods are based on physical models of radar scattering fields of objects of complex shape (Antifeev, Borzov & Suchkov, 2003), models of receiving channels, considering the movement of the source or receiver of the radio signal (Jeruchim, Balaban & Shanmugan, 2002), terrain, and the presence of re-reflecting objects (Gavrilenko, 2000). The influence of interference on interference protection systems is considered for pulse-Doppler radars (Piza, Zalevskij & Sirenko, 2013). Coherent processing of the radar signals, with the memory of the spatial filter weight coefficients, is considered in previous work (Piza & Zalevskij, 2005). The apparatus of probabilistic neural networks was applied for the task of recognition and classification of surface objects (Bogdanov et al., 2002). In Gorshkov et al. (Gorshkov et al., 2014), the method for calculating the range of pulsed radars within the centimeter range against the background of a set of interference, considering the attenuation of electromagnetic waves in the atmosphere, was considered. In Shirman (Shirman, 2007), the power of the echo signal in the presence of the attenuation was determined. In Barton (Barton, 2005), the amplification of the radar receiver in the presence of interference was justified. In Kulemin (Kulemin, 2003), the analysis of the influence of atmospheric interference on the operation of communication systems was presented. In Bringi and Chandrasecar (Bringi & Chandrasecar, 2002), an assessment of the influence of interference on the polarization parameters of the electromagnetic wave was justified.

An analysis of the millimeter-range radar operation in the presence of interference was carried out in earlier work (Gorshkov et al., 2004). Features of the impact of combined interference on radar operation are presented in Barton (Barton, 2013). Previous research (Zajcev, 2012) presented methods and algorithms of information processing in interference conditions with the use of neural network algorithms. However, there is no information on the practical application of these methods and algorithms. In Dikul et al. (Dikul et al., 2005), target recognition based on the results of radar measurements in a complex interference environment was considered. In Kolyadov (Kolyadov, 2001), an analysis of the influence of polarization characteristics of targets on their distinguishability was carried out and, in Verdenskaya, Ivanova and Sazonov (Verdenskaya, Ivanova & Sazonov, 2009), modeling of algorithms for object detection under different types of polarization reception was considered.

According to the listed scientific publications on solving the problems of radar visibility of navigation objects located in complex atmospheric conditions, the most difficult problem is the task of separating the echo signal of a navigation object from the echo signal of atmospheric interference. The solution to this problem is associated with the study of radar characteristics of a complex object considering their random variation in the process of radar observation of navigation objects. At present, this problem has no direct and unambiguous solution and, therefore, any attempt to use new approaches to search for the solution to this problem is significant for scientific and practical provisions of navigation safety in dangerous atmospheric conditions.

Presentation of the research methods with the substantiation of the obtained scientific results

Based on the modern development of computer technology with computer processing of radar information for the material of this article, we use physical and mathematical models of the representation of the relationship between the polarization characteristics of electromagnetic waves on radiation and the reception with the physical characteristics of atmospheric formations. Methods of polarization representation by real Stokes parameters of electromagnetic waves are used.

To solve the task at hand for polarization selection of navigation objects, four polarizations of the electromagnetic waves for the radiation are used. Moreover, the reception of the echo signal of any polarization is made by an all-polarized SRPC antenna with measuring at the output of a two-channel linear receiver of Stokes energy parameters S_1, S_2, S_3, and S_4, recorded as follows:

$$S_1 = \langle E_x^2(t) \rangle + \langle E_y^2(t) \rangle = \langle P_x(t) \rangle + \langle P_y(t) \rangle \quad (1)$$

$$S_2 = \langle E_x^2(t) \rangle - \langle E_y^2(t) \rangle = \langle P_x(t) \rangle - \langle P_y(t) \rangle \quad (2)$$

$$S_3 = 2\langle E_x(t)E_y(t)\cos[\varphi_y(t) - \varphi_x(t)] \rangle = = 2\langle \sqrt{P_x(t)P_y(t)}\cos[\varphi_y(t) - \varphi_x(t)] \rangle \quad (3)$$

$$S_4 = 2\langle E_x(t)E_y(t)\sin[\varphi_y(t) - \varphi_x(t)] \rangle = = 2\langle \sqrt{P_x(t)P_y(t)}\sin[\varphi_y(t) - \varphi_x(t)] \rangle \quad (4)$$

where $E_x(t)$ and $E_y(t)$ are the amplitudes of orthogonally polarized components of an echo signal of a partially polarized wave; in addition, $P_x(t)$ and $P_y(t)$ are the power of the orthogonal components of the echo signal of a partially polarized wave and $\varphi_x - \varphi_y$ is the phase difference between the orthogonal components of the echo signal, $E_x(t)$ and $E_y(t)$, of a partially polarized wave.

Generally, we use the polarization characteristics of the electromagnetic wave emitted by the SRPC antenna, and the wave reflected from a complex object by the actual Stokes parameters in the form of two matrices emitted wave [$\mathbf{S_{rad}}$] and reflected wave [$\mathbf{S_{ref}}$] expressed as:

$$[\mathbf{S_{rad}}] = \begin{bmatrix} S_1^{\text{rad}}(t) \\ S_2^{\text{rad}}(t) \\ S_3^{\text{rad}}(t) \\ S_4^{\text{rad}}(t) \end{bmatrix} \tag{5}$$

$$[\mathbf{S_{ref}}] = \begin{bmatrix} S_1^{\text{ref}}(t) \\ S_2^{\text{ref}}(t) \\ S_3^{\text{ref}}(t) \\ S_4^{\text{ref}}(t) \end{bmatrix} \tag{6}$$

where $S_1^{\text{rad}}(t), S_2^{\text{rad}}(t), S_3^{\text{rad}}(t), S_4^{\text{rad}}(t)$ are the Stokes energy parameters of the emitted electromagnetic wave and $S_1^{\text{ref}}(t), S_2^{\text{ref}}(t), S_3^{\text{ref}}(t), S_4^{\text{ref}}(t)$ are the Stokes energy parameters of the reflected electromagnetic wave.

The scattering properties of the complex object can also be represented in the form of the Muller scattering matrix [$\mathbf{S_{scat}}$] consisting of 16 items, i.e.:

$$[\mathbf{S_{scat}}] = \begin{bmatrix} S_{11}(t) & S_{12}(t) & S_{13}(t) & S_{14}(t) \\ S_{21}(t) & S_{22}(t) & S_{23}(t) & S_{24}(t) \\ S_{31}(t) & S_{32}(t) & S_{33}(t) & S_{34}(t) \\ S_{41}(t) & S_{42}(t) & S_{43}(t) & S_{44}(t) \end{bmatrix} \tag{7}$$

where $S_{11}(t) \ldots S_{44}(t)$ are the elements of the Mueller scattering matrix.

Then, the relationship between the three matrices can be written by the following expression:

$$\begin{bmatrix} S_1^{\text{ref}}(t) \\ S_2^{\text{ref}}(t) \\ S_3^{\text{ref}}(t) \\ S_4^{\text{ref}}(t) \end{bmatrix} = \begin{bmatrix} S_{11}(t) & S_{12}(t) & S_{13}(t) & S_{14}(t) \\ S_{21}(t) & S_{22}(t) & S_{23}(t) & S_{24}(t) \\ S_{31}(t) & S_{32}(t) & S_{33}(t) & S_{34}(t) \\ S_{41}(t) & S_{42}(t) & S_{43}(t) & S_{44}(t) \end{bmatrix} \times \begin{bmatrix} S_1^{\text{rad}}(t) \\ S_2^{\text{rad}}(t) \\ S_3^{\text{rad}}(t) \\ S_4^{\text{rad}}(t) \end{bmatrix} \tag{8}$$

Equation (8) can be written in the form of four linear equations, considering the physical meaning of the Stokes parameters of the electromagnetic wave reflected from a complex object, i.e.:

$$\begin{aligned} S_1^{\text{ref}}(t) &= S_{11}(t)\,S_1^{\text{rad}}(t) + S_{12}(t)\,S_2^{\text{rad}}(t) + \\ &+ S_{13}(t)\,S_3^{\text{rad}}(t) + S_{14}(t)\,S_4^{\text{rad}}(t) = \\ &= S_{11}(t)\left[P_x^{\text{rad}}(t) + P_y^{\text{rad}}(t)\right] + S_{12}(t)\left[P_x^{\text{rad}}(t) - P_y^{\text{rad}}(t)\right] + \\ &+ S_{13}(t)\,2\sqrt{P_x^{\text{rad}}(t)\,P_y^{\text{rad}}(t)}\cos\varphi_{xy}(t) + \\ &+ S_{14}(t)\,2\sqrt{P_x^{\text{rad}}(t)\,P_y^{\text{rad}}(t)}\sin\varphi_{xy}(t) \end{aligned} \tag{9}$$

$$\begin{aligned} S_2^{\text{ref}}(t) &= S_{21}(t)\,S_1^{\text{rad}}(t) + S_{22}(t)\,S_2^{\text{rad}}(t) + \\ &+ S_{23}(t)\,S_3^{\text{rad}}(t) + S_{24}(t)\,S_4^{\text{rad}}(t) = \\ &= S_{21}(t)\left[P_x^{\text{rad}}(t) + P_y^{\text{rad}}(t)\right] + S_{22}(t)\left[P_x^{\text{rad}}(t) - P_y^{\text{rad}}(t)\right] + \\ &+ S_{23}(t)\,2\sqrt{P_x^{\text{rad}}(t)\,P_y^{\text{rad}}(t)}\cos\varphi_{xy}(t) + \\ &+ S_{24}(t)\,2\sqrt{P_x^{\text{rad}}(t)\,P_y^{\text{rad}}(t)}\sin\varphi_{xy}(t) \end{aligned} \tag{10}$$

$$\begin{aligned} S_3^{\text{ref}}(t) &= S_{31}(t)\,S_1^{\text{rad}}(t) + S_{32}(t)\,S_2^{\text{rad}}(t) + \\ &+ S_{33}(t)\,S_3^{\text{rad}}(t) + S_{34}(t)\,S_4^{\text{rad}}(t) = \\ &= S_{31}(t)\left[P_x^{\text{rad}}(t) + P_y^{\text{rad}}(t)\right] + S_{32}(t)\left[P_x^{\text{rad}}(t) - P_y^{\text{rad}}(t)\right] + \\ &+ S_{33}(t)\,2\sqrt{P_x^{\text{rad}}(t)\,P_y^{\text{rad}}(t)}\cos\varphi_{xy}(t) + \\ &+ S_{34}(t)\,2\sqrt{P_x^{\text{rad}}(t)\,P_y^{\text{rad}}(t)}\sin\varphi_{xy}(t) \end{aligned} \tag{11}$$

$$\begin{aligned} S_4^{\text{ref}}(t) &= S_{41}(t)\,S_1^{\text{rad}}(t) + S_{42}(t)\,S_2^{\text{rad}}(t) + \\ &+ S_{43}(t)\,S_3^{\text{rad}}(t) + S_{44}(t)\,S_4^{\text{rad}}(t) = \\ &= S_{41}(t)\left[P_x^{\text{rad}}(t) + P_y^{\text{rad}}(t)\right] + S_{42}(t)\left[P_x^{\text{rad}}(t) - P_y^{\text{rad}}(t)\right] + \\ &+ S_{43}(t)\,2\sqrt{P_x^{\text{rad}}(t)\,P_y^{\text{rad}}(t)}\cos\varphi_{xy}(t) + \\ &+ S_{44}(t)\,2\sqrt{P_x^{\text{rad}}(t)\,P_y^{\text{rad}}(t)}\sin\varphi_{xy}(t) \end{aligned} \tag{12}$$

where P_x^{rad} and P_y^{rad} are the power of the orthogonal components of the emitted electromagnetic wave. In the general case, a partially polarized electromagnetic wave reflected from a complex object can be decomposed into two independent components: fully polarized and unpolarized.

The fully polarized component $Cn_{\text{pol}}^{\text{ref}}(t)$ of the echo signal of the complex object of the partially polarized electromagnetic wave is written in terms of the Stokes parameters as follows:

$$Cn_{\text{pol}}^{\text{ref}}(t)=\left[\left(S_2^{\text{ref}}(t)\right)^2+\left(S_3^{\text{ref}}(t)\right)^2+\left(S_4^{\text{ref}}(t)\right)^2\right]^{1/2} \quad (13)$$

The fully unpolarized component $Cn_{\text{unpol}}^{\text{ref}}(t)$ of the echo signal of a complex object of a partially polarized electromagnetic wave is written in terms of the Stokes parameters in the form:

$$Cn_{\text{unpol}}^{\text{ref}}(t)= = S_1^{\text{ref}}(t)-\left[\left(S_2^{\text{ref}}(t)\right)^2+\left(S_3^{\text{ref}}(t)\right)^2+\left(S_4^{\text{ref}}(t)\right)^2\right]^{1/2} \quad (14)$$

The normalized intensity of the polarized component in the echo signal of a complex object partially polarized wave can be represented as a degree of polarization m and written as follows:

$$m=\frac{\left(\left(S_2^{\text{ref}}\right)^2+\left(S_3^{\text{ref}}\right)^2+\left(S_4^{\text{ref}}\right)^2\right)^{1/2}}{S_1^{\text{ref}}} \quad (15)$$

However, equation (15) does not allow us to solve the problem of polarization selection of the navigation object echo signal. To tackle this problem, a completely unpolarized component of the echo signal of the complex object of a partially polarized wave is represented as a sum of two independent and oppositely polarized streams, $Fl_1(t)$ and $Fl_2(t)$ with the intensities:

$$\frac{S_1+\sqrt{S_2^2+S_3^2+S_4^2}}{2} \text{ and } \frac{S_1-\sqrt{S_2^2+S_3^2+S_4^2}}{2}.$$

The polarization of the $Fl_1(t)$ stream coincides with the polarization of the $Fl_{\text{full}}^{\text{ref}}(t)$ stream, and the polarization of the $Fl_2(t)$ stream is orthogonal to the polarization of the $Fl_{\text{full}}^{\text{ref}}(t)$ stream. As a result, the partially polarized echo signal of a complex object observed by SRPC in relation to a ship, represented by Stokes polarization parameters, is a sum of two independent fully polarized streams, $Fl_{1\,\text{full}}(t)$ and $Fl_{2\,\text{full}}(t)$ with intensities:

$$Fl_{1\,\text{full}}(t)=\frac{S_1+\sqrt{S_2^2+S_3^2+S_4^2}}{2} \quad (16)$$

$$Fl_{2\,\text{full}}(t)=\frac{S_1-\sqrt{S_2^2+S_3^2+S_4^2}}{2} \quad (17)$$

Then, the normalized intensities of the fully polarized streams, $Fl_{1\,\text{full}}(t)$ and $Fl_{2\,\text{full}}(t)$, in the partially polarized echo signal of the complex object are the degrees of polarization m_1 and m_2, which are presented in the form:

$$m_1=\frac{S_1+\sqrt{S_2^2+S_3^2+S_4^2}}{2S_1} \quad (18)$$

$$m_2=\frac{S_1-\sqrt{S_2^2+S_3^2+S_4^2}}{2S_1} \quad (19)$$

where S_1 represents the summarized intensity of the echo signal of a partially polarized wave of a complex object.

Practical implementation of the polarization selection of the navigation object, which is located in the danger zone for navigation atmospheric formation (i.e., heavy rainfall), is carried out by using a normalized intensity of two polarized streams with degrees of polarization m_1 and m_2. At the same time, sequential irradiation of a complex object by electromagnetic waves of four polarizations (i.e., three linear and one circular) with measurements of polarization parameters of the Stokes echo signal at the output of a linear two-channel receiver for each polarization of the radiated wave via an SRPK antenna is performed. According to the measured Stokes parameters of the echo signal of the complex object, the degrees of polarization of each of the two objects are determined. Here, m_1 corresponds to the navigation object, m_{NO}, and m_2 to the atmospheric formation, m_{AF}.

An algorithm of the polarization selection method for the navigation object is implemented in the following sequence:

- electromagnetic wave of the linear vertical polarization, linear horizontal polarization, linear polarization with an inclination of the electric vector by 45°, and circular polarization are sequentially irradiated to the complex object;
- all-polarized SRPC antenna receives an echo signal of the complex object and, at the output of the linear receiver, the Stokes energy parameters are measured for each polarization of the wave, which irradiates the complex object;
- according to the measured Stokes parameters, the degrees of polarization of each of the objects are calculated according to the value of which the selection of the navigation object and atmospheric formation is made according to the following formulas:

$$m_{NO}=\frac{S_{1\,LVP}+\sqrt{S_{2\,LVP}^2+S_{3\,LVP}^2+S_{4\,LVP}^2}}{2S_{1\,LVP}} \quad (20)$$

$$m_{AF}=\frac{S_{1\,LVP}-\sqrt{S_{2\,LVP}^2+S_{3\,LVP}^2+S_{4\,LVP}^2}}{2S_{1\,LVP}} \quad (21)$$

for linear vertical polarization (LVP),

$$m_{NO} = \frac{S_{1\,LHP} + \sqrt{S^2_{2\,LHP} + S^2_{3\,LHP} + S^2_{4\,LHP}}}{2S_{1\,LHP}} \quad (22)$$

$$m_{AF} = \frac{S_{1\,LHP} - \sqrt{S^2_{2\,LHP} + S^2_{3\,LHP} + S^2_{4\,LHP}}}{2S_{1\,LHP}} \quad (23)$$

for linear horizontal polarization (*LHP*),

$$\pm m_{NO} = \frac{S_{1\,LP45^\circ} + \sqrt{S^2_{2\,LP45^\circ} + S^2_{3\,LP45^\circ} + S^2_{4\,LP45^\circ}}}{2S_{1\,LP45^\circ}} \quad (24)$$

$$\pm m_{AF} = \frac{S_{1\,LP45^\circ} - \sqrt{S^2_{2\,LP45^\circ} + S^2_{3\,LP45^\circ} + S^2_{4\,LP45^\circ}}}{2S_{1\,LP45^\circ}} \quad (25)$$

for linear polarization with an electric vector tilt of 45° (*LP*45°),

$$\pm m_{NO} = \frac{S_{1\,CPR} + \sqrt{S^2_{2\,CPR} + S^2_{3\,CPR} + S^2_{4\,CPR}}}{2S_{1\,CPR}} \quad (26)$$

$$\pm m_{AF} = \frac{S_{1\,CPR} - \sqrt{S^2_{2\,CPR} + S^2_{3\,CPR} + S^2_{4\,CPR}}}{2S_{1\,CPR}} \quad (27)$$

for circular polarization (*CRP*).

In operational navigation practice, depending on the intensity of the precipitation in which a navigation object is located, to solve the problem of polarization selection of a navigation object, we can use the degrees of polarization m_{NO} and m_{AF} for any of the four polarizations of the electromagnetic wave irradiating the complex object, or in cases of high intensity of precipitation for all four polarizations of the electromagnetic wave irradiating the complex object. The considered possibility of using the optimization criteria for the polarization parameters, which are the degrees of polarization of the echo signals of the partially polarized electromagnetic waves of four polarizations, allows us to solve the problem of polarization selection of navigation objects located in the zone of precipitation of different intensity in relation to the ship.

Experimental studies on the use of the degree of polarization to solve the problem of polarization selection of navigational objects located in complex atmospheric conditions were conducted in the Zaporizhzhia region (Ukraine) in 2019–2020 by means of joint radar observation using the experimental mock-up of the ship radar polarization complex (SRPC) developed by the author and the network automated meteorological complex AMRC "Meteoyacheika" serving the airport "Zaporizhzhia". Table 1 presents the polarization parameters of the Stokes echo signals of a complex object, by which the degrees of polarization of the navigation object and atmospheric formation were measured for their observation on the SRPC screens.

Table 1. Results of measuring the degree of polarization of the echo signal for the navigation object *NO* and atmospheric formation *AF* at certain intensities *I* of precipitation, average radius r_{av}, and measured Stokes parameters with irradiation of a complex object by an electromagnetic wave of linear vertical polarization (*LVP*) and dielectric permittivity of water particles of precipitation ε = 81

I = 0.25 mm/h r_{av} = 0.75 mm	I = 1.25 mm/h r_{av} = 1.0 mm	I = 2.50 mm/h r_{av} = 1.13 mm	I = 12.50 mm/h r_{av} = 1.38 mm
S_{1LVP} = 4.5	S_{1LVP} = 5.5	S_{1LVP} = 5.2	S_{1LVP} = 6.0
S_{2LVP} = 3.5	S_{2LVP} = 4.0	S_{2LVP} = 4.1	S_{2LVP} = 5.2
S_{3LVP} = 0.8	S_{3LVP} = 1.6	S_{3LVP} = 1.7	S_{3LVP} = 1.9
S_{4LVP} = 0.0	S_{4LVP} = 0.0	S_{4LVP} = 0.0	S_{4LVP} = 0.0
m_{NO} = 0.90	m_{NO} = 0.93	m_{NO} = 0.92	m_{NO} = 0.96
m_{AF} = 0.10	m_{AF} = 0.07	m_{AF} = 0.08	m_{AF} = 0.09
I = 25.0 mm/h r_{av} = 1.5 mm	I = 50.0 mm/h r_{av} = 1.63 mm	I = 100.0 mm/h r_{av} = 1.75 mm	I = 150.0 mm/h r_{av} = 1.81 mm
S_{1LVP} = 7.2	S_{1LVP} = 8.4	S_{1LVP} = 12.0	S_{1LVP} = 13.5
S_{2LVP} = 5.4	S_{2LVP} = 5.9	S_{2LVP} = 10.0	S_{2LVP} = 12.0
S_{3LVP} = 2.1	S_{3LVP} = 2.5	S_{3LVP} = 3.2	S_{3LVP} = 4.1
S_{4LVP} = 0.0	S_{4LVP} = 0.0	S_{4LVP} = 0.0	S_{4LVP} = 0.0
m_{NO} = 0.89	m_{NO} = 0.88	m_{NO} = 0.94	m_{NO} = 0.97
m_{AF} = 0.11	m_{AF} = 0.12	m_{AF} = 0.06	m_{AF} = 0.03

Conclusions and prospects for further research in this area

1. The presented results testify to the possibility of the increase of efficiency of the functioning of ship radar polarization complexes by the use of different degrees of polarization of echo signals of navigation objects and atmospheric formation, with their consecutive irradiation via electromagnetic waves of certain polarizations.
2. According to the algorithm obtained, the polarization selection can be performed on any of the four polarizations of the emitted wave or on all four polarizations, depending on the intensity of the process in the atmospheric formation.
3. The presented method of polarization selection of navigation objects, using the degree of polarization as an informative radar parameter, is implemented by a special program of ship radar polarization complex.
4. The normalized degree of polarization of the electromagnetic wave of the echo signals of the

navigation object was used, which made it possible to theoretically and experimentally solve the problem of polarization selection of navigation objects located in the zone of dangerous atmospheric formations by means of complete neutralization of the echo signals of atmospheric formations.

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