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IMPROVING THE EFFICIENCY OF REMOTE RADAR OBSERVATION OF THE OBJECTS

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ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ ДИСТАНЦІЙНОГО РАДІОЛОКАЦІЙНОГО СПОСТЕРЕЖЕННЯ ОБ'ЄКТІВ

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ПОВЫШЕНИЕ ЭФФЕКТИВНОСТИ ДИСТАНЦИОННОГО РАДИОЛОКАЦИОННОГО НАБЛЮДЕНИЯ ОБЪЕКТОВ

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Abstract. *This paper presents the method of radar observation of objects which are located in the zone of atmospheric formation (precipitation of the various phase states). The interconnection of the operational radar information is used and represented by the Stoke's physical parameters. The Stoke's physical parameters are characterized by the total reflecting properties of the object and atmospheric formation with Stoke's parameters which are obtained in advance for a certain type of atmospheric formations and recorded in the radar observation database. The process of scattering of the irradiated wave on the observed radar object is represented by a model built on the concept of understanding the condition of the energy matrix. The energy matrix provides information about the parameters and properties of the scattering process under the conditions that parameters of the irradiation wave are known.*

The objects scattering ability is described by a radar scattering matrix when the object is irradiated by the electromagnetic wave with four polarizations and when an echo signal is received for each polarization of the irradiation wave. For each scattering object there is a strong temporary dependence of the elements of the matrix since the direction of irradiation of the object and the observation of the scattered wave are determined by the conditions of radar observation.

The task of the radar observation of an object located in the atmospheric formation comes down to subtracting the energy matrices of the object plus the atmospheric formation and the atmospheric formation, as a result the energy matrix of an object is determined and its scattering properties are characterized. The optimization procedure of the electromagnetic wave received by the radar polarimeter antenna of an electromagnetic wave was reviewed using the Stoke's vectors and Muller matrices.

Keywords: *object, atmospheric formation, Stoke's vector, Stoke's parameters, polarization, electromagnetic wave, energy matrix, all-polarized antenna, radar system.*

Анотація. *У роботі представлена методика радіолокаційного спостереження об'єктів, які знаходяться в зоні атмосферного утворення (зливові і облогові опади різного фазового стану). Використаний взаємозв'язок оперативної радіолокаційної інформації, що представлений матеріальними параметрами Стокса, які характеризуються сумарними відбивальними властивостями об'єкта і атмосферного утворення з параметрами Стокса, отриманими заздалегідь для певного виду атмосферних утворень і занесеними в банк даних РЛС спостереження. Процес розсіювання хвилі, що опромінює об'єкт, на спостережуваному РЛС, представлений моделлю побудованою на розумінні простору стану енергетичною матрицею, яка забезпечує відомості про параметри та властивості процесу розсіювання за умов відомості параметрів опромінюваної хвилі.*

Розсіювальна здатність об'єктів описується радіолокаційною матрицею розсіювання при опроміненні об'єкту електромагнітною хвилею чотирьох поляризацій та приймання луна-сигналу для кожної поляризації опромінюваної хвилі. Для кожного розсіювального об'єкту часова залежність елементів матриці є жорсткою, тому що напрям опромінення об'єкту і спостереження розсіювальної хвилі визначені умовами радіолокаційного спостереження.

Задача радіолокаційного спостереження об'єкту, що знаходиться в атмосферному утворенні, зводиться до віднімання енергетичних матриць об'єкт + атмосферне утворення і атмосферне утворення, в результаті якого визначається енергетична матриця об'єкту, яка характеризує його розсіювальні властивості. Процедура оптимізації прийнятою антеною радіолокаційного поляриметра електромагнітної хвилі розглянута з використанням векторів Стокса і матриць Мюллера.

Ключові слова: *об'єкт, атмосферне утворення, вектор Стокса, параметри Стокса, поляризація, електромагнітна хвиля, енергетична матриця, всеполяризована антена, радіолокаційна система.*

Аннотация. *В работе представлена методика радиолокационного наблюдения объектов, находящихся в зоне атмосферного образования (ливневые и обложные осадки различного фазового состояния). Использована взаимосвязь оперативной радиолокационной информации, представленной вещественными параметрами Стокса, характеризуемыми суммарными отражающими свойствами объекта и атмосферного образования с параметрами Стокса, полученными заранее для определённого вида атмосферных образований и занесёнными в банк данных РЛС наблюдения. Процесс рассеяния облучаемой волны на наблюдаемом РЛС объекте, представлен моделью, построенной на понятии пространства состоянии энергетической матрицей, обеспечивающей сведения о параметрах и свойствах процесса рассеяния при условии известности параметров облучающей волны.*

Рассеивающая способность объектов описывается радиолокационной матрицей рассеяния при облучении объекта электромагнитной волной четырёх поляризаций и приёме эхо-сигнала для каждой поляризации облучающей волны. Для каждого рассеивающего объекта временная зависимость элементов матрицы является жёсткой, т.к. направление облучения объекта и наблюдение рассеянной волны определены условиями радиолокационного наблюдения.

Задача радиолокационного наблюдения объекта, находящегося в атмосферном образовании, сводится к вычитанию энергетических матриц объект + атмосферное образование и атмосферное образование, в результате которого определяется энергетическая матрица объекта, характеризующая его рассеивающие свойства. Процедура оптимизации принятой антенной радиолокационного поляриметра электромагнитной волны рассмотрена с использованием векторов Стокса и матриц Мюллера.

Ключевые слова: *объект, атмосферное образование, вектор Стокса, параметры Стокса, поляризация, электромагнитная волна, энергетическая матрица, всеполяризованная антенна, радиолокационная система.*

Spatiotemporal filtering of interference can be carried out by radar systems which have antennas of different types including phased antenna arrays [1]. The echo signals are received onto the radar receiver from atmospheric formations (hydrometeors) which masks the echo signal of the observed object. Hydrometeor fractions are dipole reflectors for the antenna-emitting radar signal of the centimeter wavelength range (0.8–10 cm) and have a length equal to $\lambda/2$ with an average effective scattering surface dipole $\bar{\sigma}_{ef}$ equal to $0,17\lambda^2$ [2]. The value of the total effective scattering surface of particles is obtained when $\bar{\sigma}_{ef}$ is multiplied by the number of dipole reflectors «n» in the radar volume of the atmospheric formation, i.e.

$$\sigma_{\Sigma ef_{af}} = 0,17\lambda^2 n. \quad (1)$$

The radar observation of an object which is located in the zone of atmospheric formation will be effective if the total effective scattering surface of the hydrometeor particles is less than the effective surface of the object by the value of the suppression coefficient *N*, i.e.

$$\sigma_{\Sigma ef_{af}} << N\sigma_{efob} \quad (2)$$

where N is the coefficient of suppressing the interfering background of atmospheric formation, $N = \dfrac{\sigma_{ef\Sigma af}}{\sigma_{efob}}$.

However, it is difficult to obtain real $\sigma_{ef\Sigma ao}$ and σ_{efob}, therefore a search for the other directions is necessary to make it possible to highlight the object of the radar observation from the passive interference of the atmospheric formation. The interference from the hydrometeors creates identical to the object images on the radar indicator also masks it and reduces its radar observation.

So far, different methods and devices have been developed for the noise suppression such as high and low pass filter systems, band-pass filters, devices with corner selection and blanking , pulse repetition frequency discriminators, frequency range tuning, side lobe noise cancellers, etc. [3 -6]. However, uncertainties caused by interferences, result in misjudgments in actual situation. Various situations occur during radar observation of the objects which force one to take into account the semantics and pragmatics of atmospheric noise echoes. There is a necessity to use a thesaurus which forms information about atmospheric disturbances (intensity of precipitation). The characteristics of the echo signals while observing an object in atmospheric noise are based on temporal, spatial and polarization parameters. The polarization energy parameters allow the object to be recognized against the background of atmospheric noise, taking into account the available thesaurus by comparing the echo signals with the radar signals from precipitates of known intensity available in the data bank. An energy scattering matrix is the simulation model with elements represented by real Stock's parameters which are easily measured by radar. The polarization direction of the atmospheric noise compensation is an alternative solution to the existing problem during radar observation of the objects.

The purpose of this work is to obtain and use energy scattering matrices $\left[S_{en}\right]_{ob+ao}$, $\left[S_{en}\right]_{ao}$ and $\left[S_{en}\right]_{ob}$ in order to suppress atmospheric interference during radar observation of the objects. The remote measurement of the time-averaged polarization of the Stoke's parameters of echo signals of a partially polarized wave during radar observation of the objects in the zone of atmospheric formation was carried out in linear and circular bases. The interrelation of the Stoke's parameters with the amplitudes of the orthogonal components of the electromagnetic wave and the phase difference between them when using a linear basis is established using the following relations [6, 7]:

$$\begin{aligned} S_{1l} &= \left\langle E_{xm}^2 \right\rangle + \left\langle E_{ym}^2 \right\rangle; \\ S_{2l} &= \left\langle E_{xm}^2 \right\rangle - \left\langle E_{ym}^2 \right\rangle; \\ S_{3l} &= 2\left\langle E_{xm}E_{ym} \right\rangle \cos\Phi_{xy}; \\ S_{4l} &= 2\left\langle E_{xm}E_{ym} \right\rangle \sin\Phi_{xy}. \end{aligned} \quad (3)$$

When using a circular basis, the specified correlation is written in the following form:

$$\begin{aligned} S_{1c} &= \left\langle E_{rm}^2 \right\rangle + \left\langle E_{lm}^2 \right\rangle; \\ S_{2c} &= \left\langle E_{rm}^2 \right\rangle - \left\langle E_{lm}^2 \right\rangle; \\ S_{3c} &= 2\left\langle E_{rm}E_{lm} \right\rangle \cos\Phi_{rl}; \\ S_{4c} &= 2\left\langle E_{rm}E_{lm} \right\rangle \sin\Phi_{rl}. \end{aligned} \quad (4)$$

where S_1, S_2, S_3, S_4 are the Stoke's parameters, and E_x, E_y, Φ are the amplitudes of the orthogonal components of the electromagnetic wave and the phase difference between them in a linear basis, and E_r, E_1, Φ_{r1} are the amplitudes of waves of the right and the left direction of the rotation and the phase difference between them.

The combination of the Stoke's parameters of the echo signals of the electromagnetic wave of the observed by the radar object, at each considered moment of time, reflects the functioning of the object. The use of linear and circular bases being considered in terms of the value of the information obtained when observing an object. We introduce the Stoke's parameter vector for a quasimonochromatic wave which is emitted by a radar antenna in the form of grouped Stoke's parameters in a 4×4 column vector

$$S = \begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \end{bmatrix}. \quad (5)$$

Let the radar observed object be sequentially irradiated by an electromagnetic wave of four polarizations. Three of them are linear (one – vertical, second – horizontal and third one with an electric vector tilted at an angle of 45°) and the fourth is circular. For each polarization of the emitted wave, the Stokes vector is written by the following relations:

$$\left.\begin{array}{l} S_{vert.l} = S_1^{irr}, S_2^{irr}, 0, 0 \\ S_{hor.l} = S_1^{irr}, -S_2^{irr}, 0, 0 \\ S_{45.l} = S_1^{irr}, 0, S_3^{irr}, 0 \\ S_c = S_1^{irr}, 0, 0, S_4^{irr} \end{array}\right\}. \quad (6)$$

During scattering of an irradiation wave, of any four polarities, by an object or an atmospheric formation or both, an echo signal of definite polarization is formed, which carries information about its reflective properties. The Stoke's parameters of the irradiation wave undergo transformations during reflection, since in both cases the reflected electromagnetic wave has a polarization structure different from the polarization structure of the irradiating wave. Reflection coefficients will also be changed. By virtue of the linearity of the process of scattering of an electromagnetic wave, the interrelation of the polarization parameters of the reflected wave with the reflection coefficients for each of the above polarizations of the irradiated wave is determined by the relations:

a) for vertical polarization of the irradiation wave:

$$\begin{array}{l} S_1^{Iref} = l_{11}S_1^{irr} + l_{12}S_1^{irr}; \\ S_1^{IIref} = l_{11}S_1^{irr} - l_{12}S_1^{irr}; \\ S_1^{IIIref} = l_{11}S_1^{irr} + l_{13}S_1^{irr}; \\ S_1^{IVref} = l_{11}S_1^{irr} + l_{14}S_1^{irr}; \end{array} \quad (7)$$

b) for horizontal polarization of the irradiation wave:

$$\begin{array}{l} S_2^{Iref} = l_{21}S_1^{irr} + l_{22}S_1^{irr}; \\ S_2^{IIref} = l_{21}S_1^{irr} - l_{22}S_1^{irr}; \\ S_2^{IIIref} = l_{21}S_1^{irr} + l_{23}S_1^{irr}; \\ S_2^{IVref} = l_{21}S_1^{irr} + l_{24}S_1^{irr}; \end{array} \quad (8)$$

c) for the linear polarization with the slope of the electric vector under 45° of the irradiating wave:

$$\begin{array}{l} S_3^{Iref} = l_{31}S_1^{irr} + l_{32}S_1^{irr}; \\ S_3^{IIref} = l_{31}S_1^{irr} - l_{32}S_1^{irr}; \\ S_3^{IIIref} = l_{31}S_1^{irr} + l_{33}S_1^{irr}; \\ S_3^{IVref} = l_{31}S_1^{irr} + l_{34}S_1^{irr}; \end{array} \quad (9)$$

d) for an irradiating electromagnetic wave of circular polarization:

$$
\begin{aligned}
S_4^{Iref} &= l_{41}S_1^{irr} + l_{42}S_1^{irr};\\
S_4^{IIref} &= l_{41}S_1^{irr} - l_{42}S_1^{irr};\\
S_4^{IIIref} &= l_{41}S_1^{irr} + l_{43}S_1^{irr};\\
S_4^{IVref} &= l_{41}S_1^{irr} + l_{44}S_1^{irr}.
\end{aligned} \tag{10}
$$

In the ratios (7–10) the coefficients l_{11}, l_{22}, l_{33}, l_{44} characterize the straight lines and l_{12}, l_{13}, $l_{14}, l_{21}, l_{23}, l_{24}, l_{31}, l_{32}, l_{34}, l_{41}, l_{42}, l_{43}$ Stokes parameters of the reflected wave. The reflection coefficients fully characterize the reflecting properties of the observed radar objects and atmospheric formation. In the polarization basis, the direct and cross reflection coefficients form the energy scattering matrix:

$$
[S_{en}] = \begin{bmatrix}
\frac{S_1^{Iref}+S_1^{IIref}}{2} & \frac{S_1^{Iref}-S_1^{IIref}}{2} S_1^{IIIref} & -\frac{S_1^{Iref}+S_1^{IIref}}{2} S_1^{IVref} & -\frac{S_1^{Iref}+S_1^{IIref}}{2}\\
\frac{S_2^{Iref}+S_2^{IIref}}{2} & \frac{S_2^{Iref}-S_2^{IIref}}{2} S_2^{IIIref} & -\frac{S_2^{Iref}+S_2^{IIref}}{2} S_2^{IVref} & -\frac{S_2^{Iref}+S_2^{IIref}}{2}\\
\frac{S_3^{Iref}+S_3^{IIref}}{2} & \frac{S_3^{Iref}-S_3^{IIref}}{2} S_3^{IIIref} & -\frac{S_3^{Iref}+S_3^{IIref}}{2} S_3^{IVref} & -\frac{S_3^{Iref}+S_3^{IIref}}{2}\\
\frac{S_4^{Iref}+S_4^{IIref}}{2} & \frac{S_4^{Iref}-S_4^{IIref}}{2} S_4^{IIIref} & -\frac{S_4^{Iref}+S_4^{IIref}}{2} S_4^{IVref} & -\frac{S_4^{Iref}+S_4^{IIref}}{2}
\end{bmatrix}. \tag{11}
$$

All the coefficients included in the matrix (11) are real Stoke’s parameters reflected from the object observed by the ships radar, atmospheric formation or from both and are easily measured by the radar. The separation of the object's and atmospheric formation echoes is made by distinguishing their energy scattering matrices after subtracting the total object echo from the matrix and the atmospheric formation of an atmospheric formation matrix, which is known in advance. Most environments have electrodynamic parameters corresponding to a substantial, symmetric and energy matrix (9). The Stoke’s parameter measurements are carried out in one-dimensional radar channels, when there are no physical and geometric boundaries. The selected irradiation and reflection signals from the object and its meteorological formation determined the form of the energy scattering matrix, which allowed making a connection, of the objects parameters and its radar signals, with the operation of the radar station under the conditions of meteorological interference in solving the problem of object selection.

The energy matrix of the atmospheric formation is related with an idea of a thesaurus-accumulated information about the structure of atmospheric formation and the processes occurring in it (clouds, precipitation, fogs). The radar signal reflected from the object and meteorological formation is represented by a model of a total electromagnetic field consisting of a completely polarized and partially polarized fields. Radar cumulative processing of the measured real Stoke’s parameters allows to apply the energy matrix to highlight the object's echo signal from the atmospheric noise echo signal.

The interrelation of the Stoke’s parameters of the reflected partially polarized wave with the reflection coefficients for each of the four polarizations of the irradiated wave of an object located in the zone of atmospheric formation (heavy rainfall of varying intensity) is described by sixteen linear equations characterizing the overall polarization state (object + atmospheric formation):

1) The object + atmospheric formation is irradiated with a vertical linearly polarized wave:

$$
\begin{aligned}
S_{1\,ob+af}^{Iref} &= \left(l_{11\,ob}+l_{11\,af}\right)S_1^{irr}+\left(l_{12\,ob}+l_{12\,af}\right)S_1^{irr};\\
S_{1\,ob+af}^{IIref} &= \left(l_{11\,ob}+l_{11\,af}\right)S_1^{irr}-\left(l_{12\,ob}+l_{12\,af}\right)S_1^{irr};\\
S_{1\,ob+af}^{IIIref} &= \left(l_{11\,ob}+l_{11\,af}\right)S_1^{irr}+\left(l_{13\,ob}+l_{13\,af}\right)S_1^{irr};\\
S_{1\,ob+af}^{IVref} &= \left(l_{11\,ob}+l_{11\,af}\right)S_1^{irr}+\left(l_{14ob}+l_{14\,af}\right)S_1^{irr}.
\end{aligned} \tag{12}
$$

2) The object + atmospheric formation is irradiated by a horizontal polarized wave:

$$
\begin{aligned}
S_{2\,ob+af}^{Iref} &= \left(l_{21\,ob}+l_{21\,af}\right)S_1^{irr}+\left(l_{22\,ob}+l_{22\,af}\right)S_1^{irr}\\
S_{2\,ob+af}^{IIref} &= \left(l_{21\,ob}+l_{21\,af}\right)S_1^{irr}-\left(l_{22\,ob}+l_{22\,af}\right)S_1^{irr}\\
S_{2\,ob+af}^{IIIref} &= \left(l_{21\,ob}+l_{21\,af}\right)S_1^{irr}+\left(l_{23\,ob}+l_{23\,af}\right)S_1^{irr}\\
S_{2\,ob+af}^{IVref} &= \left(l_{21\,ob}+l_{21\,af}\right)S_1^{irr}+\left(l_{24ob}+l_{24\,af}\right)S_1^{irr}
\end{aligned} \tag{13}
$$

3) The object + atmospheric formation is irradiated with a linearly polarized wave with the slope of the electric vector below 45°:

$$
\begin{aligned}
S_{3\,ob+af}^{Iref} &= \left(l_{31\,ob}+l_{31\,af}\right)S_1^{irr}+\left(l_{32\,ob}+l_{32\,af}\right)S_1^{irr};\\
S_{3\,ob+af}^{IIref} &= \left(l_{31\,ob}+l_{31\,af}\right)S_1^{irr}-\left(l_{32\,ob}+l_{32\,af}\right)S_1^{irr};\\
S_{3\,ob+af}^{IIIref} &= \left(l_{31\,ob}+l_{31\,af}\right)S_1^{irr}+\left(l_{33\,ob}+l_{33\,af}\right)S_1^{irr};\\
S_{3\,ob+af}^{IVref} &= \left(l_{31\,ob}+l_{31\,af}\right)S_1^{irr}+\left(l_{34ob}+l_{34\,af}\right)S_1^{irr}.
\end{aligned} \tag{14}
$$

4) The object + atmospheric formation is irradiated by an electromagnetic wave of circular polarization:

$$
\begin{aligned}
S_{4\,ob+af}^{Iref} &= \left(l_{41\,ob}+l_{41\,af}\right)S_1^{irr}+\left(l_{42\,ob}+l_{42\,af}\right)S_1^{irr};\\
S_{4\,ob+af}^{IIref} &= \left(l_{41\,ob}+l_{41\,af}\right)S_1^{irr}-\left(l_{42\,ob}+l_{42\,af}\right)S_1^{irr};\\
S_{4\,ob+af}^{IIIref} &= \left(l_{41\,ob}+l_{41\,af}\right)S_1^{irr}+\left(l_{43\,ob}+l_{43\,af}\right)S_1^{irr};\\
S_{4\,ob+af}^{IVref} &= \left(l_{41\,ob}+l_{41\,af}\right)S_1^{irr}+\left(l_{44ob}+l_{44\,af}\right)S_1^{irr}.
\end{aligned} \tag{15}
$$

The solution of the systems of equations (12–15) allows to obtain the energy matrix of the observed by radar objects, in the polarization basis (linear, circular), against the background of atmospheric formations:

$$
\left[S_{en}\right]_{ob+af}=\begin{bmatrix}
\frac{S_{1\,ob+af}^{Iref}+S_{1\,ob+af}^{IIref}}{2} & \frac{S_{1\,ob+af}^{Iref}-S_{1\,ob+af}^{IIref}}{2}S_{1\,ob+af}^{IIIref} & -\frac{S_{1\,ob+af}^{Iref}+S_{1\,ob+af}^{IIref}}{2}S_{1\,ob+af}^{IVref} & -\frac{S_{1\,ob+af}^{Iref}+S_{1\,ob+af}^{IIref}}{2}\\
\frac{S_{2\,ob+af}^{Iref}+S_{2\,ob+af}^{IIref}}{2} & \frac{S_{2\,ob+af}^{Iref}-S_{2\,ob+af}^{IIref}}{2}S_{2\,ob+af}^{IIIref} & -\frac{S_{2\,ob+af}^{Iref}+S_{2\,ob+af}^{IIref}}{2}S_{2\,ob+af}^{IVref} & -\frac{S_{2\,ob+af}^{Iref}+S_{2\,ob+af}^{IIref}}{2}\\
\frac{S_{3\,ob+af}^{Iref}+S_{3\,ob+af}^{IIref}}{2} & \frac{S_{3\,ob+af}^{Iref}-S_{3\,ob+af}^{IIref}}{2}S_{3\,ob+af}^{IIIref} & -\frac{S_{3\,ob+af}^{Iref}+S_{3\,ob+af}^{IIref}}{2}S_{3\,ob+af}^{IVref} & -\frac{S_{3\,ob+af}^{Iref}+S_{3\,ob+af}^{IIref}}{2}\\
\frac{S_{4\,ob+af}^{Iref}+S_{4\,ob+af}^{IIref}}{2} & \frac{S_{4\,ob+af}^{Iref}-S_{4\,ob+af}^{IIref}}{2}S_{4\,ob+af}^{IIIref} & -\frac{S_{4\,ob+af}^{Iref}+S_{4\,ob+af}^{IIref}}{2}S_{4\,ob+af}^{IVref} & -\frac{S_{4\,ob+af}^{Iref}+S_{4\,ob+af}^{IIref}}{2}
\end{bmatrix}. \tag{16}
$$

The elementary reflectors in the navigation object on its surface form fluctuating echo signals, as well as elements with a large effective scattering surface form a deterministic component, which remains stable during the measurement time. Atmospheric formation, in which the radar observed object (aircraft, ship) is situated and which consist of a large number of reflectors of different shapes, phase states, sizes and different orientations in space, form a fluctuating echo signal on the input of the radar receiving system. These joint echoes form a total illumination on the radar indicator against the background of which the echo signal of the observed object is hidden.

To solve the problem of extracting an object's echo from the total echo $(af + ob)$, two energy matrices $[S_{en}]_{af}$ and $[S_{en}]_{ob}$ are used. The energy matrix of atmospheric formation is known in advance, taking into account it’s parameters (for heavy rainfall and it’s intensity, for clouds and their radar reflectivity). The Stoke’s parameters of the total echo signal (object + atmospheric formation) are measured using the radar and with their help the energy calculated for a particular type of irradiation wave. With the help of the second Stoke’s parameter S_2, the intensity of the precipitations I mm/hour is determined. According to this intensity of precipitation, an energetic matrix of atmospheric formation is selected (heavy rainfall of measured intensity). The energy matrix of the atmospheric formation corresponding to the rainfall of a given intensity at the time of the radar observation of the object is subtracted from the energy matrix of the total echo signal (object + atmospheric formation) in the automatic mode. The energy coefficients of the resulting matrix belongs to the observed object, which appear on the radar indicator or computer display in the certain color, for the purpose of radar object observation and determination of its coordinates. The procedure of sequential emission of an electromagnetic wave of the four considered polarizations is easily implemented in the antenna radar device in automatic mode. For heavy precipitation (25 mm/h), there is energy scattering matrix with the following coefficients:

$$[S_{en}]_{af} = \begin{bmatrix} 12.75 & 12.25 & 0.25 & 0.25 \\ 12.75 & 12.25 & -0.75 & -0.75 \\ 0 & 0 & 3.50 & 0.40 \\ 0 & 0 & 0.40 & 3.50 \end{bmatrix}.$$

The energy scattering matrix of the total echo signal $[S_{en}]_{ob+af}$ has the following coefficient values:

$$[S_{en}]_{ob+af} = \begin{bmatrix} 15.4 & 14.5 & 0.45 & 0.45 \\ 15.4 & 14.5 & -0.45 & -0.45 \\ 0 & 0 & 4.20 & 0.70 \\ 0 & 0 & 0.70 & 4.20 \end{bmatrix}.$$

Then the energy matrix of the scattering of the echo signal of the object is defined as the difference $[S_{en}]_{ob+af} - [S_{en}]_{af}$ and is written in the following form:

$$[S_{en}]_{ob} = \begin{bmatrix} 2.65 & 2.25 & 0.20 & 0.20 \\ 2.65 & 2.25 & -0.30 & -0.30 \\ 0 & 0 & 0.70 & 0.30 \\ 0 & 0 & 0.30 & 0.70 \end{bmatrix}.$$

When the intensity of liquid precipitation is $I = 10$ mm/hour, the energy scattering matrix of the atmospheric formation has the following values of its coefficients:

$$[S_{en}]_{af} = \begin{bmatrix} 1.18 & 0.35 & 0 & 0.01 \\ 0.35 & 1.18 & -0.84 & -0.01 \\ 0 & 0 & 1.12 & 0.04 \\ 0 & 0 & -0.04 & 1.12 \end{bmatrix}.$$

Energy scattering matrix of an object in atmospheric formation $[S_{en}]_{ob+af}$:

$$[S_{en}]_{ob+af} = \begin{bmatrix} 3.05 & 2.10 & 0.85 & 0.85 \\ 3.05 & 2.10 & -0.75 & -0.75 \\ 0 & 0 & 1.90 & 0.08 \\ 0 & 0 & -0.08 & 1.90 \end{bmatrix}.$$

Energy scattering matrix of the radar observed object $[S_{en}]_{ob}$:

$$[S_{en}]_{ob} = \begin{bmatrix} 1.87 & 1.65 & 0.85 & 0.84 \\ 2.70 & 0.92 & 1.69 & -0.76 \\ 0 & 0 & 1.78 & 0.04 \\ 0 & 0 & -0.12 & 0.78 \end{bmatrix}.$$

When the air temperature is below $-2^{o}\mathrm{C}$ the intensity of snowfall is determined by three gradations: weak $(I = 0.02 \div 0.1 \text{ mm/hour})$, moderate – $(I = 0.11 \div 1.0 \text{ mm/hour})$ and strong $(I > 1.0 \text{ mm/hour})$. The energy scattering matrix of moderate snowfall is written as follows:

$$[S_{en}]_{af} = \begin{bmatrix} 1.48 & 0.75 & 0.01 & 0.01 \\ 1.48 & 0.75 & -0.73 & -0.73 \\ 0 & 0 & 1.26 & 0.22 \\ 0 & 0 & -0.04 & 1.12 \end{bmatrix}.$$

The energy matrix of the total echo signal (object + atmospheric formation) consists of the following coefficients:

$$[S_{en}]_{ob+af} = \begin{bmatrix} 1.83 & 1.01 & -0.02 & -0.02 \\ 1.83 & 1.01 & 0.85 & 0.85 \\ 0 & 0 & 1.83 & 0.53 \\ 0 & 0 & 0.53 & 1.83 \end{bmatrix}.$$

The energy matrix of the object observed by the radar is presented as:

$$[S_{en}]_{ob} = \begin{bmatrix} 0.35 & 0.26 & -0.01 & -0.01 \\ 0.35 & 0.26 & 1.58 & 1.58 \\ 0 & 0 & 0.57 & 0.31 \\ 0 & 0 & 0.57 & 0.71 \end{bmatrix}.$$

The resulting energy scattering matrix corresponds to the representation of the object by a set of “bright dots”, non-standard choice of the type of polarizations of the electromagnetic wave irradiating the object and received orthogonal vertical and horizontal polarizations.

The advantage of the considered method of radar recognition of an object located in the zone of atmospheric formation manifests the accumulated meteorological radar thesaurus about the signals reflected from existing atmospheric formations and entered into the radar data bank. The task of the radar is to measure the Stoke’s parameters of atmospheric formation echoes, which determine the intensity of the process in atmospheric formation (intensity of rain or snowfall), and based on the available thesaurus, compare the received echoes with the existing atmospheric formation matrix . The generated thesaurus of meteo-objects allow the radar to use the accumulated information efficiently and to take full account of environmental factors during recognition of objects in remote radar observation.

The results of a methodological nature, which can be further embodied in the task of unification procedures for improving a certain type of radar and it’s functionality, and the practical usefulness of the considered methods of recognizing objects that are on the background of atmospheric formation is aimed at applying program-targeted methods of selection and recognition of objects.

When implementing the algorithm of radar recognition of objects, the RL antenna is the main element of structure of radar polarization that implements the recognition algorithm using the energy scattering matrix of the object. When solving the problem of radar object recognition, an all-polarized antenna is used, being a polarization analyzer, in which the amplitude, phase and polarization of the radiated electromagnetic wave is controlled. A round horn is used as an irradiator, and antenna tuning with controlled polarization of radiation is managed by operator $G(0,\varphi)$, that consist of the product of two linear operators: the operator of rotation of the polarization plane $G(\beta,\theta,\varphi)$ and the ellipticity transformation operator $G(\alpha,\theta,\varphi)$ given the laws of variation of the arguments $\alpha=\alpha(t)$ and $\beta=\beta(t)$ [7]. The structure of the antenna with controlled polarization characteristics, which was used in experimental studies on the radar recognition of objects in the zone of atmospheric formations using the energy matrix (9), is shown in Fig. 1.

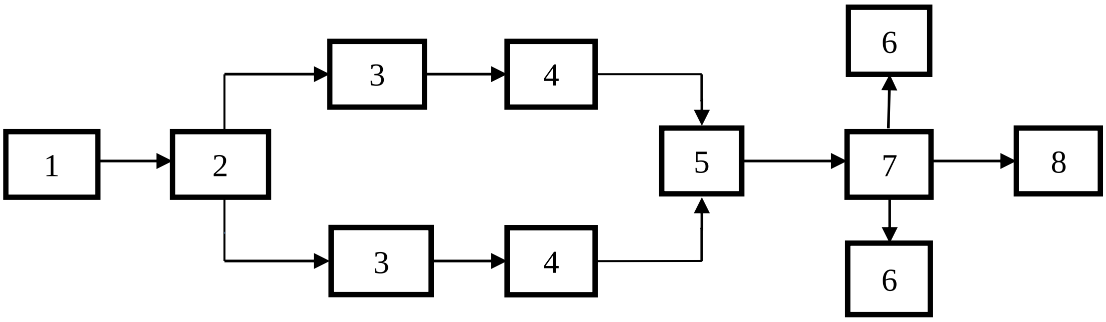

Figure 1 – Structural diagram of the antenna with controlled polarization parameters: 1 – transmitter; 2 – power splitter; 3 – amplitude controls; 4 – phase shifters; 5 – polarization selector; 6 – receivers of orthogonal channels; 7 – switch, 8 – radiator

The amplitude regulators 3 create a specific amplitude relationship between the orthogonal components of the electromagnetic wave, 4 – phase shifters, creating phase relationships between the orthogonal components of the electromagnetic wave to obtain a certain polarization of the emitted wave at the output of the polarization selector. Switch 7 alternately connects the antenna in the transmission mode to the polarization selector, and in the reception mode to the two receivers 6 orthogonal channels. For a radiated linearly polarized wave of a paraboloid of rotation, the radiation pattern $G(\theta,\varphi)$. $G(\theta,\varphi)$ has the following form:

$$G(\theta,\varphi)=\begin{bmatrix} G_{11}\dfrac{\sin(P\sin\varphi)}{P\sin\varphi} & G_{12}\left[1-(\cos m_\theta\theta)\sin 2m_\varphi\varphi\right] \\ G_{12}\left[1-(\cos m_\theta\theta)\sin 2m_\varphi\varphi\right] & G_{22}\dfrac{\sin(P\sin\varphi)}{P\sin\varphi} \end{bmatrix}, \qquad (17)$$

where the parameters P, m_θ, m_φ determine the width of the radiation pattern both in the main and in the cross-polarization lobes; $G_{lm}(l,m=1,2)$ – antenna gain factors for the main and cross-polarization components.

At small angles θ and approximate equality $G_{11}\approx G_{22}$ equation (17) is written in abbreviated form:

$$G(\theta,\varphi,t)=G(t)T, \qquad (18)$$

where T is the unit 2×2 matrix.

The antenna's operator commutes with the electromagnetic wave of linear, circular and elliptical polarization. The radar antenna becomes all-polarized.

Conclusion and prospects for further work in this area:

1 In the current paper, a mathematical model is formed, on quantitative assessment of the selection of a radar observation object from atmospheric interference in the form of precipitation of various intensity and phase conditions.

2 The process of matrix transformation of an electromagnetic wave in its interaction with an object is discussed. This process made it possible to form the energy matrix of a radar object observation in the presence of natural atmospheric interference.

3 Processing and analysis of radar information in solving the problem of selection and recognition of the object was carried out on the basis of the thesaurus by comparing an echo signals received from the object with an echo signals of known atmospheric objects available in the radar data bank.

Further research into use of ultra-wideband signals will follow.

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