MODELLING OF ELECTROMAGNETIC FIELDS OF POLARIZED STRUCTURE OF RADAR SIGNALS OF SHIPBOARD RADAR

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The model of polarized structure of radar signals used for off-shore finding and identification has been considered. The peculiar significance of circular polarization under shipboard radar operating has been revealed.

Key words: *Circular polarization, identification, finding, off-shore facilities, functional operator.*

The usage of data about the object parameter link with radar signals makes it possible to carry out shipboard radar functioning under the interference or noise conditions. The main task of shipboard radar corresponds to functions upgrading of off-shore facility radar data acquisition by means of finding and acquisition of coordinates about object motion and discrimination identification. If the shipboard radar, when solving radar tasks, did not need the prior information about the object scattering properties, propagation medium of an electromagnetic wave and an object would be an external medium. The problem solution of radar determination and discrimination can be based on usage of non-coordinate objects information, which is connected with data about the type of the radar object, its affiliation to definite class, geometry, dimensions, area electrophysical parameters and other. The non-coordinate object information is directly connected with the change of echo signal polarized condition. The non-coordinate information is a strong factor, which can determine the structure of modern shipboard radar and algorithm of processing radar polarized object information.

Thus, this paper analyzes the spatiotemporal vectors structure of orthogonal components of electromagnetic wave of circular polarization, that is reflected from off-shore facilities.

In accordance with [1], radio wave polarization represents the feature of electromagnetic field that corresponds to radio waves, which is determined by spatiotemporal structure of vectors that make up the fields, and is invariant to field propagation dynamic and time law of its resources. Let us analyze the polarized signals structure of circular polarization, which we will use when solving the problems of objects finding and identification by means of shipboard radar.

Let us write down a flat-topped electromagnetic wave in homogeneous medium in two-component denotation:

$$E(r, t) = x\, E_x(z\text{-}ct) + y\, E_y(z\text{-}ct)\ , \quad (1)$$

where E_x and E_y - component waves according to coordinate axes,

$x,\ y,\ z = r$ - unit vectors of Cartesian coordinate system.

Components $E_x(z\text{-}ct)$ и $E_y(z\text{-}ct)$ can be totally independent and arbitrary. With the help of postulation between components of functional connection, let us impose definite restrictions on the type of polarized components, which are considered simultaneously, i.e.

$$E_y(z\text{-}ct) = P\, E_x(z\text{-}ct)\ . \quad (2)$$

Though, functional connection does not depend on temporal structure $E_x(z\text{-}ct)$. Condition (2) determines the class of polarized waves. Functional operator P meets the following conditions:

1. Class of functions, which describes polarized components, must present continuity, reversibility and closure of functional operator P, otherwise components $E_x(z\text{-}ct)$ and $E_y(z\text{-}ct)$ will be disparate.

2. Propagation operator *P* forms a spaciotemporal structure of waves from certain field source system and should be linear, bounded and regular, i.e.

$$P\left(\Sigma\, C_n(z\text{-}ct)\right) = \Sigma\, C_n\, P\left(E_{x\pi}(z\text{-}cn)\right) = \Sigma\, C_\pi\, E_{y\pi}(z\text{-}ct),\ (3)$$

where $E_{x\pi}(z\text{-}cn)$ and $E_{y\pi}(z\text{-}ct)$ - are polarization components of the n-th signal component,

C - are complex numbers fields, $\forall c_1 \ldots c_n \in C$.

3. Operator P, defined on functions that depends on the argument $(z\text{-}ct)$, coincides with the operator $P_t(z\text{-}ct)$, specified for time

functions at an observation point and with the operator $P_z(z\text{-}ct)$, specified along propagation direction at a fixed timepoint:

$$P(z\text{-}ct) = P_t(z\text{-}ct) = P_z(z\text{-}ct). \quad (4)$$

4. Transformation $P(z\text{-}ct)$ shouldn't change monochromatic oscillation $E_x(t) = E_x\cos(\omega t + f)$, it is allowed to change the amplitude and additional phase change Φ could appear

$$E_y(t) = P\left(E_x\cos(\omega t + f)\right) = E_y\cos(\omega t + f + \Phi). \quad (5)$$

The given condition provides an inclusion of the elliptically polarized monochromatic waves into certain polarized waves class (3.2).

5. If $E_x(t)$ is changed into $E_x(t\text{-}\tau)$, then $E_y(t)$ undergoes delay $E_y(t\text{-}\tau)$. This condition is an equivalent of commutativity of operator $P(z\text{-}ct)$ with differentiation operator $\frac{d}{dt}$, i.e.

$$\frac{d}{dt}P(z\text{-}ct) = P\left(\frac{d(z\text{-}ct)}{dt}\right) \quad (6)$$

We shall consider a class of circularly polarized waves, requiring invariance of the operator $P(z\text{-}ct)$ when rotating the used coordinate system around the propagation direction Z=r, and we shall use another notation of functional operator $K(z\text{-}ct)$, i.e. $K(z\text{-}ct)\,\hat{I}\,P(z\text{-}ct)$.

6. Inverse isomorphic functional operator $K^{-1}(z\text{-}ct)$ for circularly polarized wave is defined by the rule:

$$E_x(z\text{-}ct) = K^{-1}\left(E_y(z\text{-}ct)\right) = -K\left(E_y(z\text{-}ct)\right). \quad (7)$$

Equality (7) is set up in view of polarized component transformation when rotating the coordinate system around z about an angle β :

$$\left.\begin{aligned} E_x^{н}\left(z\text{-}c\,t\right) &= \cos\beta\, E_x^{c}\left(z\text{-}c\,t\right)+\sin\beta\, E_y^{c}\left(z\text{-}c\,t\right) \\ E_y^{н}\left(z\text{-}c\,t\right) &= -\sin\beta\, E_x^{c}\left(z\text{-}c\,t\right)+\cos\beta\, E_y^{c}\left(z\text{-}c\,t\right) \end{aligned}\right\}, \quad (8)$$

where $E_x^{н}$ and $E_y^{н}$ - are field vectors components in new (turned over about an angle β) coordinate system,

E_x^{c} , E_y^{c} - are components in old coordinate system.

Then:

$$E_y^{н}\left(z\text{-}c\,t\right)=K\left(E_x^{н}\left(z\text{-}c\,t\right)\right) = K\left[\cos\beta\, E_x^{c}\left(z\text{-}c\,t\right) + \sin\beta\, E_y^{c}\left(z\text{-}c\,t\right)\right], \quad (9)$$

which is according to the superposition principle (condition 2) is transferred into:

$$\begin{aligned} E_y^{н}\left(z\text{-}c\,t\right) &= \cos\beta\, K\left[E_x^{н}\left(z\text{-}c\,t\right)\right]+\sin\beta\, K\left[E_y^{c}\left(z\text{-}c\,t\right)\right]= \\ &= \cos\beta\, E_y^{c}\left(z\text{-}c\,t\right)+\sin\beta\, E_y^{c}\left(z\text{-}c\,t\right). \quad (10) \end{aligned}$$

Here the invariance from β is provided only in case the condition (6) is met. The Hilbert transform satisfies all listed conditions for circularly polarized waves :

$$E_y\left(\xi\right)=K\left[E_x\left(\xi\right)\right]=\Gamma\left[E_x\left(\xi\right)\right]=\frac{1}{\pi}\int\limits_{-¥}^{+¥}\frac{E_x\left(n\right)}{\eta\text{-}\xi}\,d\eta, \quad (11)$$

where $\xi=z\text{-}c\,t$.

equality $K\left(z\text{-}c\,t\right)=\Gamma\left(z\text{-}c\,t\right)$ reduces to the fact that in (4) phase angle Φ for circularly polarized monochromatic wave is found to be equal $-\frac{\pi}{2}$, and the component $E_y\left(t\right)$ is as follows:

$$E_y(t) = E_x \sin(\omega t + n). \quad (12)$$

7. If polarized component $E_x(t)$ can be factorized $E_x(t) = E_x^s(t)\, E_x^f(t)$, where a slow multiplier spectrum $E_x^s(t)$ does not reverse with a fast multiplier spectrum $E_x^f(t)$, then existence of circularly modulated waves is true:

$$E_y(z\text{-}c\,t) = \Gamma\left[E_x^s(z\text{-}c\,t)\, E_x^f(z\text{-}c\,t)\right] = E_x^s(z\text{-}c\,t)\, E_y^f(z\text{-}c\,t). \quad (13)$$

The signal spectrum $E(r, \omega)$ can be divided into positive and negative frequency harmonics, and set out it as a sum of right- and left-hand circularly polarized oscillations:

$$E(z, t) = E_{пк}(r, t) + E_{лк}(r, t), \quad (14)$$

polarized structure of which is orthogonal, i.e.

$$\left[E_{пк}(r, t), E_{лк}(r, t)\right] = 0. \quad (15)$$

The preceding analysis of polarized structure of electromagnetic wave revealed a significant role of circularly polarization signals, which will be used while finding and identification of objects against the background of natural disturbance.

We introduce the diverging operator or diverging matrix C for the characteristics of diverging features of the object, which changes polarization of illuminating wave. Transmitting and receiving circular polarization will be specified with the Stokes parameter. Then the connection between transmitting and diverging wave and object diverging operator is as follows:

$$\begin{bmatrix} I_{рас} \\ Q_{рас} \\ U_{рас} \\ V_{рас} \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} \\ C_{21} & C_{22} & C_{23} & C_{24} \\ C_{31} & C_{32} & C_{33} & C_{34} \\ C_{41} & C_{42} & C_{43} & C_{44} \end{bmatrix} \times \begin{bmatrix} I_{изл} \\ 0 \\ 0 \\ V_{изл} \end{bmatrix} \quad (16)$$

Conclusions

1. Functional connection between orthogonal components of electromagnetic wave reflected from off-shore facilities.
2. The class of circularly polarized electromagnetic waves with positive and negative harmonics spectrum.
3. Radiolocation signal spectrum is set out as a sum of right- and left-hand circularly polarized electromagnetic oscillations.

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Моделирование электромагнитных полей поляризационной структуры радиолокационных сигналов судовых РЛС.

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РЕЗЮМЕ

В работе проведен анализ пространственно-временной структуры векторов ортогональных компонент электромагнитной волны круговой поляризации, которая может излучаться антенной судовой РЛС, или поступать на ее вход при отражении от объектов. Излучение и прием электромагнитной волны может осуществляться поляризованной как по правому, так и по левому кругу. Анализ поляризационной структуры электромагнитной волны выявил особую роль круговой поляризации при ее использовании для измерения некоординатной информации навигационных объектов, которая связана со сведениями о типе объекта, его размерах, геометрии и электрических параметрах поверхности.

При дальнейшем исследовании, рассмотренный анализ пространственно-временной структуры векторов ортогональных компонент электромагнитной волны круговой поляризации предполагается применить для обнаружения и распознавания объектов судовыми РЛС.