EXPERIMENTAL STUDY OF THE INFORMATION COMPONENT IN SCATTERING FIELD OF RECEIVING ANTENNAS

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ABSTRACT

In previous theoretical works, it was shown that the total scattering field of an arbitrary receiving antenna includes an information component responsible for transmitting information from a plane wave to the antenna load, and its properties were studied. This work is devoted to the formulation of conditions that must be satisfied by receiving antennas used for experimental detection of the information component of the antenna scattering field. All the results indicated in these works were obtained in analytical form by solving the problem of plane wave scattering by an arbitrary receiving antenna in a rigorous formulation. Therefore, experiments to detect and study the properties of the information component of the antenna scattering field are becoming relevant at present. Since the shape of the information component of the antenna scattering field is known to us and is associated with the antenna polar pattern in transmission mode, when carrying out experimental work to study it, the reduction of the unknown orthogonal component of the antenna scattering field, unknown to us, against which it is necessary to highlight the information component, comes to the fore. component of the antenna scattering field. In order to be able to control the orthogonal component of the antenna scattering field, it is necessary to first find out on what parameters of the measuring setup it depends and the reason for its appearance. It is shown that on the surface of such an antenna in the receiving mode the current component should dominate, which is complex conjugate to the current on the surface of the same antenna in the transmitting mode, and the reason for the appearance of the stray field component of the antenna not participating in the process of transmitting information from plane wave to the antenna load.

KEYWORDS: *Information Component, Scattering Pattern, Reflection Coefficient, Receiving Antenna, Orthogonal Component.*

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1 Introduction

In works [1,2,6,8], it was shown that the stray field of an arbitrary receiving antenna can be considered as the sum of two stray fields, one of which is associated with the transfer of energy from a plane wave incident on the antenna to the load, and the other , is not related to this process. Since the transmission of information over a radio channel is associated with the transfer of energy to the load of the receiving antenna, the first of these components was called the information component of the antenna scattering field, and the second was called the orthogonal component of the antenna scattering field, meaning by this the absence of mutual power between the information component of the antenna scattering field and the orthogonal component of the field antenna scattering.

It was further shown that the shape of the information component of the antenna scattering field is centrally symmetrical to the antenna polar pattern in the mode of transmitting the information component of the antenna scattering field, and the structure of the scattering field component, which coincides in shape with the information component of the antenna scattering field, was clarified. All the above results are theoretical and were obtained in analytical form by solving the problem of plane wave scattering by an arbitrary receiving antenna in a rigorous formulation. Therefore, experiments to detect and study the properties of the information component of the antenna scattering field are becoming relevant at present. Since the shape of the information component of the antenna's scattering field is known to us and is associated with the antenna's polar pattern in transmission mode, when carrying out experimental work to study it, the reduction of the unknown orthogonal component of the antenna's scattering field comes to the fore. Against its background, it is necessary to highlight the information component of the antenna scattering field.

In order to be able to control the antenna scattering field orthogonal component. It is necessary to first find out on what parameters of the measuring setup it depends and the reason for its appearance. Considering that the receiving antenna, which is supposed to be used for the experimental study of the information component of the antenna scattering field, is not subject to the requirements of any specific radio engineering system. It is advisable to develop it only from the condition of ensuring the maximum value of the information component of the antenna scattering field and the minimum value of the orthogonal component of the scattering field antennas. The present work is devoted to discussing these issues.

2 Research methods and results

In what follows we will assume a complex polar pattern $\dot{\vec{F}}(\vec{r}_0)$, of the receiving antenna under study in known transmission mode, and

$$\dot{\vec{F}}(\vec{r}_0) = F(\vec{r}_0)\exp[i\Psi(\vec{r}_0)]\vec{p}(\vec{r}_0), \quad (1)$$

where $F(\vec{r}_0)$ – amplitude polar pattern normalized in the direction of maximum; $\Psi(\vec{r}_0)$ – phase polar pattern; $\vec{r}_0$ – unit vector in a spherical coordinate system (r,θ,φ); $\vec{p}(\vec{r}_0)$ – unit complex vector characterizing the polarization of the antenna polar field

$$\vec{p}_0(\vec{r}_0) = \cos\eta\vec{\theta}_0 + \exp[i\beta]\sin\eta\vec{\varphi}_0, \quad (2)$$

where is the parameter $\eta\,(0 \le \eta \le \pi/2)$ determines the amplitudes ratio of the vector components $\vec{p}(\vec{r}_0)$; β-phase shift between components; $\vec{\theta}_0\, u\, \vec{\varphi}_0$ – spherical coordinate system vectors.

The antenna with pattern (1) is irradiated by a plane wave specified in the form

$$\dot{\vec{\mathrm{E}}}_i(\vec{n}_0,\vec{r}_0)=\dot{\vec{\mathrm{e}}}_0\exp[\text{-ik}(\vec{n}_0\vec{r}_0)r], \tag{3}$$

$$\dot{\vec{H}}_i(\vec{n}_0,\vec{r}_0)=\frac{1}{Z_0}\left[\vec{r}_0,\dot{\vec{\mathrm{e}}}_0\right]\exp[\text{-ik}(\vec{n}_0\vec{r}_0)r]. \tag{4}$$

In (4) vector $\vec{n}_0$ determines the direction of a plane wave incident propagation on the receiving antenna, vector $\dot{\vec{\mathrm{e}}}_0$ – unit complex vector ($|\dot{\vec{\mathrm{e}}}_0|=1$), characterizing the primary wave polarization, and

$$\dot{\vec{\mathrm{e}}}_0(\vec{r}_0)=\cos\nu\vec{\theta}_0+\exp[i\kappa]\sin\nu\vec{\varphi}_0, \tag{5}$$

options ν and κ similar to values η and β in (2), k and Z_0 wave number and characteristic impedance of free space, respectively.

When a plane wave is incident on a receiving antenna, an antenna scattering field appears $\dot{\vec{\mathrm{E}}}_s(\vec{n}_0,\vec{r}_0)$, which is related to the scatterplot $\dot{\vec{A}}_s(\vec{n}_0,\vec{r}_0)$ ratio

$$\dot{\vec{\mathrm{E}}}_s(\vec{n}_0,\vec{r}_0)=\dot{\vec{A}}_s(\vec{n}_0,\vec{r}_0)\frac{\exp(-ikr)}{r}. \tag{6}$$

In general, the stray field $\dot{\vec{\mathrm{E}}}_s(\vec{n}_0,\vec{r}_0)$ can be represented as the sum of two components, one of which is involved in the transfer of energy from a plane wave to the antenna load ($\dot{\vec{E}}_{\text{inf}}$), and the other ($\dot{\vec{E}}_{\perp}$) does not participate, and there is no mutual power between them, that is, they are orthogonal to each other in the sense of fulfilling the condition

$$P_{mut}=\frac{1}{Z_0}\oint_s\dot{\vec{E}}_{\perp}(\vec{n}_0,\vec{r}_0)\overset{*}{\dot{\vec{E}}}_{\text{inf}}(\vec{n}_0,\vec{r}_0)d\vec{S}=0. \tag{7}$$

The stray field component structure, which coincides in shape with the information component, was studied earlier [8] and has the form

$$\dot{\vec{E}}_{\text{inf}}(\vec{n}_0,\vec{r}_0)=\dot{\vec{E}}^{bas}_{\text{inf}}(\vec{n}_0,\vec{r}_0)+\dot{\vec{E}}^{add}_{\text{inf}}(\vec{n}_0,\vec{r}_0), \tag{8}$$

where $\dot{\vec{E}}^{bas}_{\text{inf}}(\vec{n}_0,\vec{r}_0)$ and $\dot{\vec{E}}^{add}_{\text{inf}}(\vec{n}_0,\vec{r}_0)$ – main and additional components of the information component, determined by the relations

$$\dot{\vec{E}}^{bas}_{\text{inf}}(\vec{n}_0,\vec{r}_0)=\frac{D}{2ik}(\dot{\vec{F}}(-\vec{n}_0)\cdot\dot{\vec{\mathrm{e}}}_0)\overset{*}{\vec{F}}(-\vec{r}_0)\frac{\exp(-ikr)}{r}, \tag{9}$$

$$\dot{\vec{E}}_{\inf}^{add}(\vec{n}_0,\vec{r}_0)=\left(\alpha_2+\alpha_3\frac{\tilde{A}-\overset{*}{\gamma}}{1-\gamma\tilde{A}}\right)\dot{\vec{E}}_{\inf}^{bas}(\vec{n}_0,\vec{r}_0). \quad (10)$$

In (10) $\tilde{A}$ and γ reflection coefficients from the load and antenna input, respectively, and the coefficients α_2 and are determined by the relations

$$\alpha_2=\pm\sqrt{1-\frac{D}{D_s\alpha_1^2}\left|(\dot{\vec{F}}(-\vec{n}_0)\cdot\dot{\mathrm{e}}_0)\right|^2}, \quad (11)$$

$$\alpha_3=\frac{D}{4\pi}\oint_{4\pi}\dot{\vec{F}}(\vec{r}_0)\,\dot{\vec{F}}(-\vec{r}_0)\partial\Omega. \quad (12)$$

In (11) D_s and D – these are the maximum values of th antenna scattered field diagram efficiency at $\Gamma=\overset{*}{\gamma}$ and antenna radiation pattern, and α_1 is determined by the expressions

$$\alpha_1=Jm\left(\overset{*}{\vec{\mathrm{e}}}_0,\ \mathrm{e}^{i\varphi_s}\dot{\vec{F}}_s(\vec{n}_0,\vec{n}_0))\right), \quad (13)$$

where $\dot{\vec{F}}_s(\vec{n}_0,\vec{n}_0)$ – complex antenna scattering diagram normalized to the maximum in the plane wave incidence direction, φ_s – argument of the scattering diagram complex amplitude $\dot{\vec{A}}_s(\vec{n}_0,\vec{r}_0)$.

When planning an experiment to detect the information component of the scattering field of a receiving antenna, taking into account that the total scattering field is the sum of the information component of the antenna scattering field and the orthogonal component of the antenna scattering field, it is necessary to select the parameters of the antenna under study and the angle of its irradiation in such a way as to ensure the maximum information component of the field antenna scattering and the minimum orthogonal component of the antenna scattering field.

From (9) it follows that the scattering field component amplitude in shape, coinciding with the antenna scattering field information component, is proportional to the maximum value of antenna gain D and radiation pattern value in the plane wave source direction $\dot{\vec{F}}(-\vec{n}_0)$. From which it follows that to study the information component of the antenna's scattering field, it is advisable to use antennas with a high efficiency and they should be irradiated in the direction of the maximum of the antenna's radiation pattern.

It is necessary to take into account that the field component, which coincides in shape with the information component of the antenna scattering field, in the general case, consists of a main and an additional component. Moreover, only the main component participates in the transfer of energy from a plane wave to the antenna load. Therefore, for the purity of the experiment to detect the actual information component of the antenna scattering field, it is advisable to eliminate the additional component.

This can be achieved in two ways. If, when conducting a study of the information component of the antenna scattering field, an arbitrary antenna is used, then by choosing the reflection coefficient from the antenna load, it is possible to achieve the fulfillment of the condition $\dot{\vec{E}}_{\inf}^{add}(\vec{n}_0,\vec{r}_0)=0$.

As can be seen from (10), this requirement is satisfied by a load of the form

$$\tilde{A} = \frac{\alpha_3 \overset{*}{\gamma} - \alpha_2}{\alpha_3 - \alpha_2 \gamma}. \tag{14}$$

If an antenna is developed specifically to study the antenna's scattering field information component, then at the design stage it is possible to establish the requirement that the condition be met $\alpha_2 = 0$ for a given irradiation angle. Then, if we use a load with a reflection coefficient as an antenna load $\Gamma = \overset{*}{\gamma}$, as can be seen from (10), requirement $\dot{\vec{E}}_{\text{inf}}^{add}(\vec{n}_0, \vec{r}_0) = 0$ will also be executed. The second method is more preferable, since if the condition is met $\Gamma = \overset{*}{\gamma}$ in the antenna scattering field there is no component that matches the shape of the antenna pattern, which can be the source of the orthogonal component of the antenna scattering field, while in the first case such a component is present.

Let us move on to the formulation of the requirements for the antenna under study, arising from the need to reduce the power of the orthogonal component of the antenna's scattering field. To formulate these requirements, it is necessary to find out the reason for the appearance of the orthogonal component of the antenna scattering field. To do this, we use the following approach. Since we consider the scattering field of the receiving antenna as consisting of two components $\dot{\vec{E}}_{\text{inf}}(\vec{n}_0, \vec{r}_0)$ and $\dot{\vec{E}}_{\perp}(\vec{n}_0, \vec{r}_0)$, then the currents induced on its surface by a plane wave can be considered as the sum of currents $\dot{\vec{J}}_{\perp}(s)$ and $\dot{\vec{J}}_{\text{inf}}(s)$, creating an orthogonal and information component, respectively, that is

$$\dot{\vec{J}}(s) = \dot{\vec{J}}_{\perp}(s) + \dot{\vec{J}}_{\text{inf}}(s). \tag{15}$$

Considering that the antenna scattering field information component is expressed through the antenna pattern in the transmission mode, it can be assumed that the currents creating $\dot{\vec{E}}_{\text{inf}}(\vec{n}_0, \vec{r}_0)$ can also be expressed in terms of currents flowing along the surface of the antenna in transmission mode $\dot{\vec{J}}_T(s)$. To find this connection, we write the expression for the antenna field in transmission mode $\dot{\vec{E}}_T(\vec{r}_0)$ through the current density distribution on the antenna surface in this mode

$$\dot{\vec{E}}_T(\vec{r}_0) = -i\frac{W}{2\lambda}\oint_{S_A} \dot{\vec{J}}_T(\vec{q})\exp(ik(\vec{q}\vec{r}_0))\partial S\,\frac{\exp(-ikr)}{r}, \tag{16}$$

where $\vec{q}$ – radius vector of the integration point on the antenna surface S_A.

Taking into account (9)

$$\dot{\vec{E}}_{\inf}(\vec{n}_0,\vec{r}_0) = -i\frac{Z_0\grave{A}(\vec{n}_0)}{2\lambda}\oint_{S_A}\overset{*}{\dot{\vec{J}}}_T(\vec{q})\exp(ik(\vec{q}\vec{r}_0))\partial\vec{S}\,\frac{\exp(-ikr)}{r}, \quad (17)$$

where $\grave{A}(\vec{n}_0)$ – amplitude multiplier determined by normalizing the antenna radiation pattern $\dot{\vec{F}}(\vec{r}_0)$ and $\dot{\vec{F}}_{\inf}(\vec{r}_0)$.

From (17) it is clear that the distribution of the current density component responsible for the creation of the antenna scattering field information component coincides in shape with the current density distribution in transmission mode, and is complex conjugate with it in phase. Using (15) and (16) can be determined as a current density component $\dot{\vec{J}}_{\perp}(s)$, responsible for creating the antenna scattering field information component and the antenna scattering field orthogonal component itself in the form

$$\dot{\vec{J}}_{\perp}(s) = \dot{\vec{J}}(s) - \grave{A}(\vec{n}_0)\overset{*}{\dot{\vec{J}}}_T(s) \quad (18)$$

$$\dot{\vec{E}}_{\perp}(\vec{n}_0,\vec{r}_0) = -i\frac{Z_0}{2\lambda}\oint_{S_A}\left(\dot{\vec{J}}(\vec{q}) - \grave{A}(\vec{n}_0)\overset{*}{\dot{\vec{J}}}_T(\vec{q})\right)\exp(ik(\vec{q}\vec{r}_0))\partial\vec{S}\,\frac{\exp(-ikr)}{r}. \quad (19)$$

From (19) it follows that the reason for the antenna scattering field component appearance, which is not involved in the transmitting information process from a plane wave to the antenna load, is the difference in the current density distribution shape on the antenna surface in the receiving mode from the complex conjugate current transmissions density distribution in the same antenna. The more significant this difference is, the greater power of the antenna scattering field orthogonal component.

From this we can conclude that on the antenna surface, which is supposed to be used for studying the antenna scattering field information component at the selected irradiation angle, the current component, complex conjugate to the current in the transmission mode in this antenna, should dominate.

Expressions (15-19) were obtained under the assumption that the field scattered by the antenna is created by a system of electric currents flowing along the surface of the antenna. When analyzing aperture-type antennas, an aperture with vectors known on its surface is often considered as a surface that participates in the antenna polar pattern formation $\dot{\vec{\mathrm{E}}}$ and $\dot{\vec{H}}$.

Considering that according to vector equivalence principle $\dot{\vec{\mathrm{E}}}$ and $\dot{\vec{H}}$ are simply related to the equivalent magnetic density and electric currents by the relations $\dot{\mathrm{J}}_m = -\left[\vec{n}_0,\dot{\vec{\mathrm{E}}}\right]$ and $\dot{\mathrm{J}}_e = \left[\vec{n}_0,\dot{\vec{H}}\right]$, then for aperture antennas, above reasoning remains valid. That is, the reason for antenna scattering field orthogonal component appearance in aperture antennas is the difference in shape of antenna aperture field distribution in the receiving mode, from the complex conjugate field distribution in same antenna aperture in the transmitting mode.

The difference in the antenna aperture field distribution in the receiving and transmitting modes is explained by the fact that in transmitting mode the aperture is excited by a waveguide-type wave, and in the receiving mode by a flat homogeneous wave. For illustration, Figures (1-4) show the results of measurements of the distribution of the electric field in the horn antenna aperture in transmission mode (Fig. 1-2) and reception (Fig. 3-4) in different sections of the horn parallel to the antenna aperture [9]. The cross section Z=0 corresponds to the horn antenna aperture. Positive Z values point toward the inside of the horn.

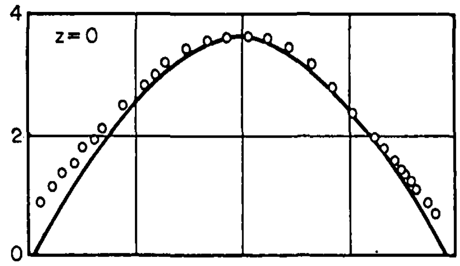

Fig. 1: Field distribution in the horn antenna aperture in transmit mode.

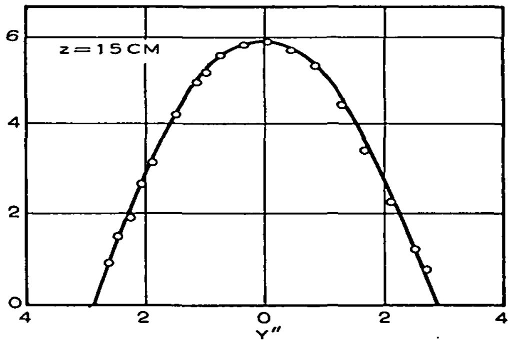

Fig. 2: Field distribution inside the horn antenna in the Z=15 cm plane in transmit mode.

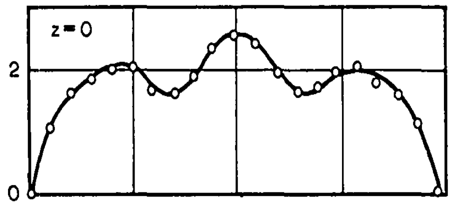

Fig. 3: Field distribution in the horn antenna aperture in receiving mode.

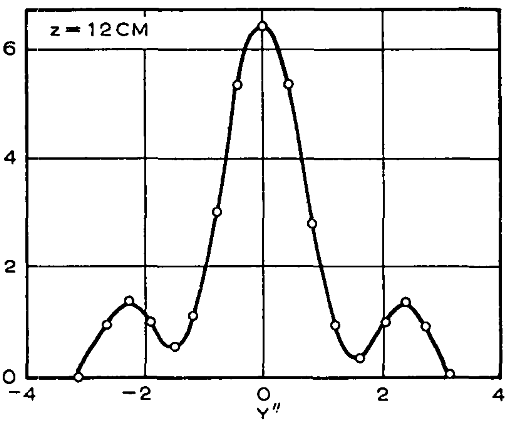

Fig. 4: Field distribution inside the horn antenna in the Z=12cm plane in reception mode.

From Figures 1 and 2 it can be seen that the field distribution in horn antenna aperture in the transmission mode completely repeats the main type wave field distribution in a rectangular waveguide.

In contrast, as can be seen from Figures 3 and 4, when the antenna operates in receiving mode, the aperture clearly field distribution shows presence of higher harmonics, which disappear as they approach the waveguide. The difference in the field distributions shown in Figures 1 and 3, taking into account their complex amplitudes, gives us the field distribution in the aperture, which is the orthogonal component source of the receiving antenna scattering field.

3 Conclusion

In previous theoretical works [1-8], the properties of scattering field information component in receiving antennas were studied in detail, both from the point of view of its structure and from the point of view of the dependence of its parameters on the characteristics of the antenna and the plane wave incident on it. But beyond the scope of these studies, questions related to the sources of the information component of the antenna scattering field and the orthogonal component of the antenna scattering field remained.

Understanding the appearance reasons of these components is important both from a theoretical and practical point of view, since at present experimental work on detecting and studying the properties of the information component of the antenna scattering field is becoming especially relevant. Since the antenna scattering field is the sum of the antenna information component scattering field and antenna scattering field orthogonal component, when conducting an experiment, the first question that arises is to isolate the information component of the antenna scattering field under study from the total antenna scattering field.

In order for the antenna's scattering field information component to be clearly visible in the general scattering field, it is necessary to design an antenna in which the information component of the antenna's scattering field would be much larger than the orthogonal component of the antenna's scattering field. It should be noted here that the relationship between them is determined not only by the parameters of the following antenna, but also by the angle of its irradiation. This work shows that in order to increase the information component of the antenna scattering field, it is necessary to use antennas with a high gain and irradiate it in the direction of the main lobe of the antenna radiation pattern.

Considering that the antenna scattering field information component consists of a main and an additional component, which is not involved in the process of information transmission, it is necessary to ensure its suppression at the stage of experiment planning, which will significantly facilitate the analysis and interpretation of the experimental results obtained.

This can be achieved either by choosing an antenna load that satisfies condition (14), or for a given irradiation angle, design an antenna that satisfies the requirements $\alpha_2 = 0$ and $\Gamma = \overset{*}{\gamma}$. The second method is more preferable, since in this case there is no component in the antenna scattering field that matches the shape of the antenna radiation pattern, which can serve as an additional source of the information component of the antenna scattering field.

As shown in this work, the main source of the antenna scattering field orthogonal component is the antenna surface component current equal to the difference between the total current flowing along the receiving antenna surface and the component responsible for the formation of antenna scattering field information component. This component coincides in shape with current distribution on the same antenna surface in the transmission mode, and is complexly conjugate in phase to it.

Thus, in order to reduce the orthogonal component power of the antenna scattering field, when developing an antenna that is supposed to be used to study the information component of the antenna scattering field, it is necessary to strive to ensure that the distribution of fields and currents on the surface of the receiving antenna is close in shape to the distribution of fields and currents on surface of this antenna in transmit mode.

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