The use of "ant" algorithm in constructing models of objects that have maximum average values of the scattering characteristics

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Abstract. The paper shows the possibility of constructing models of objects that have the highest average values of scattering characteristics in certain sectors of observation angles. With the use of the designed algorithm, we made the calculation of the dependencies of the characteristic dimensions of the hollow structure with maximum average values of the scattering characteristics.

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Introduction

Conducting processes of modelling of electromagnetic waves scattering on various objects with a complex shape is of great importance in connection with the need to meet the challenges of radar recognition, to solve problems of electromagnetic compatibility [1-3].

At the moment, we know a great number of models on the basis of which, including those with analytical formulas we can carry out evaluation of scattering characteristics of various objects [4, 5].

For certain conditions it is necessary to have information not about the angular dependence of scattering characteristics, but about their average values in the specified sectors of observation angles [6]. In various literature data can be found on average values of RCS (radar cross section) on objects of simple shape (disc, plate, etc.) [7]. But for the general case in the calculation of the scattering characteristics it is necessary to use numerical methods [8].

It is of particular interest to carry out the development of a fairly simple model for calculating the size of the object that has maximum average values of scattering characteristics for a particular sector of observation angles.

The aim of the paper is to conduct research on the possibility of using the "ant" algorithm for constructing objects that have maximum average scattering characteristics.

To achieve this goal it is necessary to do the following:

1. To suggest a structure of a subsystem for the analysis of the diffraction patterns.
2. To examine the model of calculating the scattering characteristics of hollow structures having maximum average scattering characteristics based on a combination of the method of integral equations and the "ant" algorithm.
3. On the basis of these results to make a conclusion on the possibility of using the proposed approach.

The structure of a subsystem for the analysis of the diffraction patterns of the antenna system.

We can ensure to what extent the modelling results are valid and reliable by comparing these results with experimental data. Because there is a limitation on laboratory space, making patterns of objects that have complex geometric shapes can be quite costly. In this regard, computer modelling, the use of computer-aided design (CAD) in many cases seems to be the only possible approach.

Figure 1 provides a subsystem structure 1 of the analysis of the diffraction patterns of the antenna systems. The shape of the diffraction patterns can be quite complex, measures often fall into the resonance area. On this basis, it may be appropriate to apply the method of integral equations in the analysis [8].

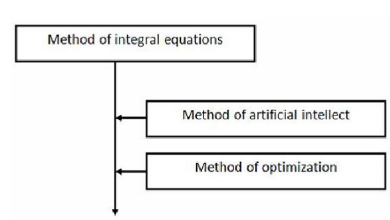

Fig. 1. Subsystem structure of the analysis of the diffraction patterns of antenna systems

To carry out the calculation of RCS objects containing N reflectors, which do not react, it is possible to use an approach associated with the fact that RCS values for each of the reflector σ_i as well as the phase difference in the incident electromagnetic waves are well known [9]:

$$\sigma = \sum_{i=1}^{N} \sigma_i + 2 \cdot \sum_{i>j}^{N} \sqrt{\sigma_i \cdot \sigma_j} \cos \frac{4 \cdot \pi}{\lambda} \cdot \Delta r_{ij} , \quad (1)$$

where $\Delta r_{ij} = r_i - r_j$, r_i is the distance between the center of the i reflector and the observation point. For practical use it should be noted that the advantage of the formula (1) is in analytical methods rather than numerical methods are used for the calculation.

Model

We will use the following calculation model. We select a specific part on the object. Let the total length of the circuit on this part (in the three-dimensional case, we consider the surface area) is L_a. We select a section for this circuit, which has a characteristic size a.

The above approach can be used, e.g., for objects with symmetry [10] or in the case where the analyzed sector of observation angles is close to the normal to the examined sections.

We will carry out constructing a model for calculating the size of the object with maximum average values of the scattering characteristics for the hollow structure. Modern technological items include a large number of hollow structures, and the power of the secondary radiation of such elements can be substantial [6].

We will consider a two-dimensional model. From the literature, it is known that the two-dimensional model of the hollow structure can be used in the evaluation of the scattering characteristics of hollow structures, which have a rectangular cross-section [11].

Suppose the aperture size of the hollow structure is b, the length is L (Figure 2). The load of the hollow structure has the form shown in the figure, we can distinguish the characteristic size of b on it, then the total amount of the load circuit is $L_a = b / \cos(\varphi) + 2 \cdot L$.

As a characteristic parameter, we select the size of the aperture b. It is required to find b and L_a, for which the average RCS in certain sectors of the angles has maximum values. In solving the problem, the angle θ is measured from the normal to the aperture of the hollow structure.

When analyzing the scattering characteristics the sector of the observation angles changed in a large range: 5°≤ $\Delta\theta$ ≤90°, we have considered the area of the front hemisphere. The scattering characteristics were calculated based on the method of integral equations [8].

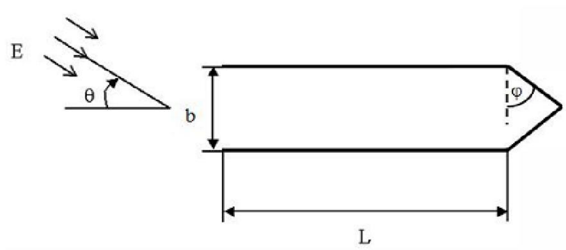

Fig. 2. Schematic scattering of electromagnetic waves on a hollow structure with an aperture size a and a length L, the load has an inclination angle φ

For the Fredholm equation of the first kind, containing an unknown electric current density at E-polarization [12], we can write the following expression:

$$\frac{\omega \cdot \mu}{4} \cdot \int_{\alpha}^{\beta} j(t) \cdot H_0^2[k \cdot L_0(\tau, t)] \cdot \sqrt{\xi'^2(t) + \eta'^2(t)} dt = E_z^0(\tau),$$

$$\alpha \le \tau \le \beta , \quad (2)$$

where

$$L_0(\tau, t) = \sqrt{[\xi(\tau) - \xi(t)]^2 + [\eta(\tau) - \eta(t)]^2}$$

represents the distance between the observation point and the integration point, $E_z^0(\tau)$ denotes the longitudinal component of the primary electric field intensity for the point on the circuit. The circuit is given in a parametric form: $x = \xi(t), y = \eta(t), \alpha \le t \le \beta$, but $\xi'(t), \eta'(t)$ represent the first derivatives of the respective functions, $k = 2 \cdot \pi / \lambda$, λ – length of the incident electromagnetic wave.

Equation (2) is solved by the method of moments, we find the longitudinal electric currents having a density

$$\vec{j} = \vec{z} \cdot j(t), \ \alpha \le t \le \beta, \quad (3)$$

Two-dimensional RCS of the hollow structure can be found from the following expression

$$\sigma(\varphi) = (60 \cdot \pi)^2 \cdot k \cdot |D(\varphi)|^2 , \quad (4)$$

where

$$D(\varphi) = \int_{\alpha}^{\beta} j(t) \cdot \sqrt{\xi'^2(t) + \eta'^2(t)} \cdot \exp(i \cdot k \cdot d(t, \varphi)) dt,$$

$$d(t, \varphi) = \xi(t) \cdot \cos(\varphi) + \eta(t) \cdot \sin(\varphi) .$$

We calculate the average of the RCS, based on the following expression

$$\bar{\sigma} = \sum_{i=0}^{N} \frac{\sigma(\theta_i)}{N+1}, \quad (5)$$

where $\sigma(\theta_i)$ is the value of RCS for the observation angle θ_i.

The problem of determining b and L_a, which give the maximum average RCS in a given sector of observation angles, we solved as follows. We set the sector value of observation angles $\Delta\theta$. For different values of L_a we determined values of the aperture b. The function $\overline{\sigma} = \overline{\sigma(b, L_a)}$ is multiextremal, and in this regard, in the calculations of L_a we used the grid method [13] with a consistent narrowing of the area of defined values. For each section of the grid, we used the ant algorithm [14, 15].

It uses a transition rule: The ant, which is the point r, is to choose the next point s, based on the following equations:

$$s = \begin{cases} \arg\max\limits_{u \in J_k(r)} \{[\tau(r,u)][\eta(r,u)]\beta\}, & q < q_0 \\ \textit{the choice is} \\ \textit{according to} \\ \textit{the following} \\ \textit{equation} & \textit{otherwise} \end{cases}, \quad (6)$$

here $j_k(r)$ is the set of cells in the grid, which are required for the ant k to visit, it is located on the point r in the grid, $\tau(r,s)$ represents a measure of the pheromone, $\eta(r,u) = 1/\delta(r,u)$, while the weight $\delta(r,u)$ is selected as the distance between the points, we denote the random value as q, q_0 is a parameter $(0 \le q \le 1, 0 \le q_0 \le 1)$.

In the case when $q \ge q_0$, the ant will select the next point in accordance with the following equation:

$$p_k(r,s) = \begin{cases} \dfrac{[\tau(r,s)] \cdot [\eta(r,s)]^\beta}{\sum\limits_{u \in J_k(r)} [\tau(r,u)] \cdot [\eta(r,u)]^\beta}, & \textit{if } s \in J_k(r), \\ 0, & \textit{otherwise} \end{cases} \quad (7)$$

where $p_k(r,s)$ denotes the probability that the point s will be selected by the ant k, which is located at the point r.

The rule of local update is used:

$$\tau(r,s) \leftarrow (1-\rho) \cdot \tau(r,s) + \rho \cdot \Delta\tau(r,s), \quad (8)$$

where ρ is the local parameter, $0 > \rho > 1$, $\Delta\tau(r,s)$ presents a sum of the pheromone that has been left by the ants.

There is a match of the global update rule and the following equation:

$$\tau(r,s) \leftarrow (1-\alpha) \cdot \tau(r,s) + \alpha \cdot \Delta\tau(r,s), \quad (9)$$

where α is the global parameter, $0 > \alpha > 1$, $\Delta\tau(r,s) = 1/(\textit{the best global length})$, in the case if the segment (r,s) belongs to this length.

Results

Fig. 3 shows the dependence of the length of the circuit L_a from the aperture value b of the hollow structure, under which the maximum average RCS $\overline{\sigma} = \overline{\sigma(b, L_a)}$ can be achieved.

We conducted approximation of the obtained dependences L_a from the b by polynomial dependencies within the method of least squares [16].

It was found that the maximum approximation error would occur in the case where there are restrictions on the sector of observation angles: 0°≤ $\Delta\theta$ ≤20°. From the point of view of practical application good approximation (relative error is less than 5%) is obtained for 25°≤ $\Delta\theta$ ≤90° with a degree of approximating polynomial n≥4.

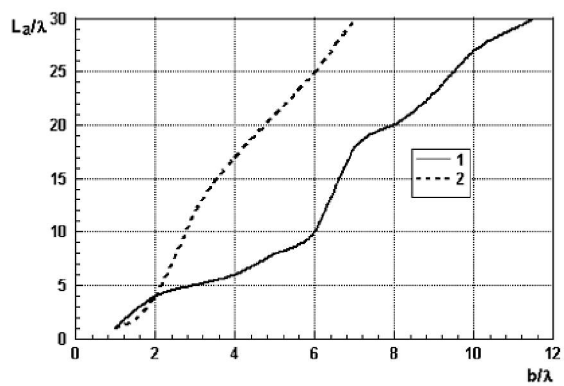

Fig. 3. The dependence of the length of the circuit of the hollow structure (Fig. 2) L_a from the value of sizes of the aperture b under the maximum average RCS in the sector of the angles Δθ =5° (curve 1), Δθ =15° (curve 2) with the angle φ=20°

Findings of the research

The paper shows the structure of the subsystem analysis of diffraction patterns of the antenna system.

On the basis of the examined model we demonstrated the possibility with the example of a hollow structure, having a complex load, of determining the characteristic size of the object, which has the maximum average values of the scattering characteristics.

The characteristics of the approximating polynomial for the size of the hollow structure with the maximum average scattering characteristics are given.

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