ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Optimization of Electromagnetic Scattering Characteristics on the Objects of Complex Shape Based on the "Ant" Algorithm.

Yakov Evseevich Lvovich[2]*, Igor Yakovlevich Lvovich[1], Andrey Petrovich Preobrazhenskiy[2], and Oleg Nikolaevich Choporov[3].

[1]Paneuropean University, Tomášikova 20 SK-821 02 Bratislava Slovenská republika.
[2]Voronezh Institute of High Technologies, 394043, Russia, Voronezh, Lenina St., 73a
[3]Voronezh State Technical University, 394026, Russia, Voronezh, Moscow Av., 14

ABSTRACT

The issues concerning the construction of objects with extreme average values of scattering characteristics are discussed. Based on the optimization approach using the "ant algorithm", the dimensions dependencies were calculated for a two-dimensional metal cylinder with a lateral wall of complex shape having the maximum average values of the scattering characteristics. Based on the generalization of information concerning the components that represent a cylinder, it is proposed to build CAD subsystems (computer aided design systems) for designing the average characteristics of objects. The object of complex shape is represented as a set of components. The type of components, the observation angles sector, and the required level for the average scattering characteristics are chosen as the input data for subsystems. In this article, a correlation analysis is applied as part of the developed procedure. The correlation makes it possible to determine the component characteristics of the object in question based on the maximum of correlation coefficient.

Keywords: scattering of radio waves, diffraction, optimization, artificial intelligence, design automation.

***Corresponding author**

INTRODUCTION

Modelling the processes of scattering electromagnetic waves on different objects with complex shape is of great practical interest, due to the fact that it requires solving problems relating to radar determination, electromagnetic compatibility, etc. [1-5].

In some cases, if objects of simple shape are studied, it is sufficient to apply analytical formulas allowing for a fairly good estimation of the scattering characteristic values [6].

When using a diffraction approach, the object is treated as a body of complex shape, on which the scattering of radiowaves occurs. At considering the practical application of the integral equations method, it appears to be rather cumbersome and often requires more resources, the same as other numerical methods. However, if we consider the structures, which are the bodies of revolution, the most successful is a combination of methods of integral equations and of eigenfunctions [7], wherein the main role is played by the angular or azimuthal coordinate φ. Along this coordinate, the required fields, the same as when using the method of eigenfunctions, are decomposed into Fourier series, and the fields of individual harmonics become independent due to their orthogonality. Thus, it becomes possible to build a relatively simple integral equation, which is solved numerically, for each azimuthal harmonics [7]. This reduces the degree of the electrodynamic task being solved and the requirements to the volume of computer memory and computer computation time.

There are a number of tasks that require data not only on the angular dependences of scattering characteristics, but also on the average values that can be achieved, especially the maximum ones, for certain sectors of observation angles [8].

Building a fairly simple algorithm for calculating the dimensions of objects with the maximum average values of scattering characteristics in a particular sector of observation angles is of practical interest. For the bodies of simple shape, the dependence of maximum average values of characteristics on the body dimensions can be written down analytically [6]. In this paper, we solved the problem of determining the maximum average values of scattering characteristics of a two-dimensional model of a cylinder. In this case, the analytical dependence of the maximum average values of scattering characteristics on the object dimensions can not be obtained. However, there is a possibility of constructing an approximate function (of an interpolating polynomial), which allows obtaining an approximation of this dependence at a sufficiently small error [9-11].

In this paper, we consider a model for calculating the dimensions of a two-dimensional cylinder, in which the lateral wall has a complex shape, which allows the determination of cylinder dimensions with the maximum average values of scattering characteristics in the given sector of observation angles.

MODEL

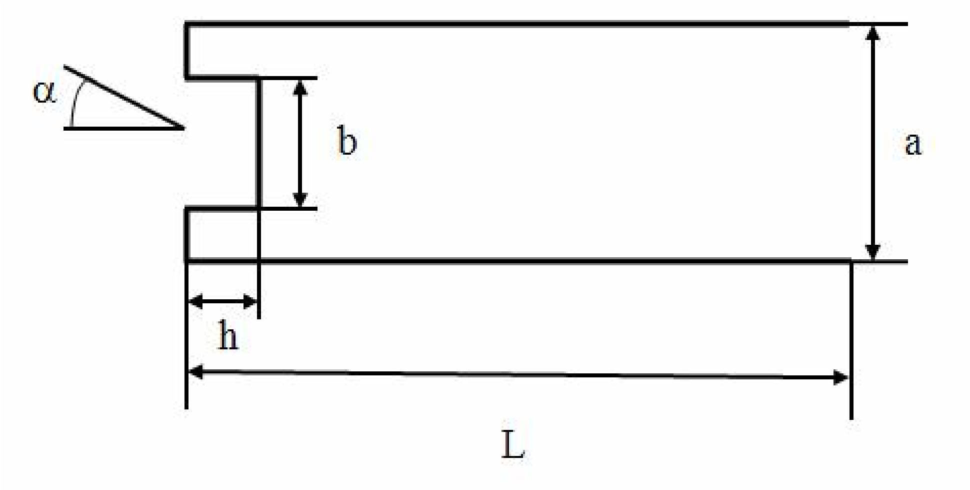
The following calculation model is applied. We distinguish the dimension of a certain cylinder element as a characteristic dimension and build a dependence of the total cylinder contour length on the dimension of this element.

It is significant that the applied method is convenient for using with a cylinder that has a symmetry.

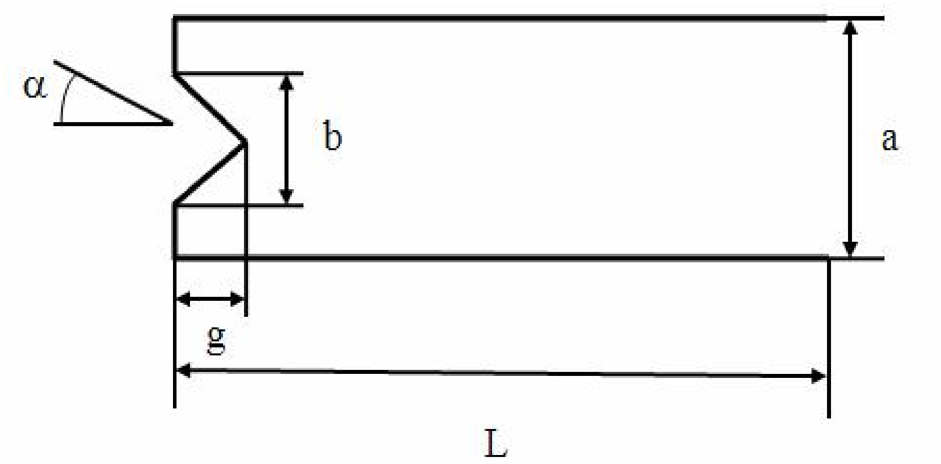
Cylinders form an integral part of many modern technological objects. When taking into account the power of secondary radiation of such structures, it becomes possible to control the power of secondary radiation for the entire object, wherein the value can be changed by several times, and even by dozens of times.

The paper deals with a two-dimensional model. The two-dimensional cylinder models are useful in evaluating scattering characteristics of three-dimensional rectangular metal cylinders [12].

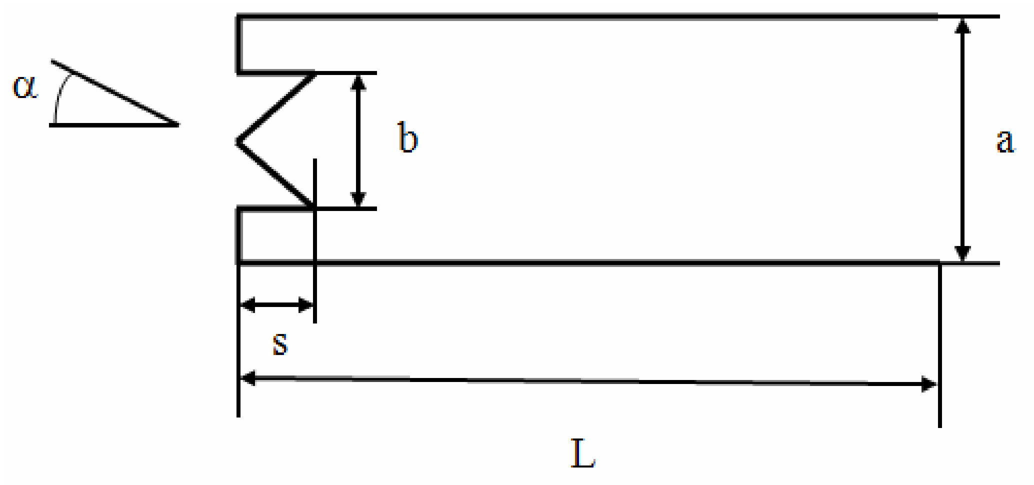
We will assume that the transverse dimension of a cylinder is equal to *a*, length L (Fig. 1). The side wall of the cylinder has a shape which is shown in Fig. 1a, that is, there is a recess with the dimensions h and b. Then the total size of the cylinder contour is *D=a+2h+2L.* Our task is to find *a* and *D*, at which the values of the average scattering cross-section (SCS) in the predetermined sectors of the incidence angles of an electromagnetic wave α give maximum values. The angle α is counted from the direction parallel to the two cylinder walls.



a)



b)



c)

Fig. 1. Illustration of the electromagnetic waves scattering on a two-dimensional cylinder with a lateral wall of complex shape.

The lateral wall of the cylinder has a shape, which is shown in Fig. 1b, that is, there is a recess with the dimensions g and b. The lateral wall of the cylinder has a shape, which is shown in Fig. 1c, that is, there is a recess with dimensions s and b. When we analyzed the scattering characteristics, the values of the observation angle sectors changed quite significantly (from 5° to 70°), i.e. the angles related to the area of forward hemisphere. The scattering characteristic values were obtained based on the method of integral equations [13].

METHODOLOGY

The Fredholm equation of the first kind, which contains the density of an unknown electric current in the case of E-polarization [13], is recorded, for example, as follows:

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

$$\gamma \le \tau \le \beta, \qquad (1)$$

here $L_0(\tau, t) = \sqrt{[\xi(\tau) - \xi(t)]^2 + [\eta(\tau) - \eta(t)]^2}$ is a distance between the points of observation and integration, $E_z^0(\tau)$ is a longitudinal component of the electric field strength at a point, which is located on the contour. We set the contour on the basis of parametric representation: $x = \xi(t),\ y = \eta(t),\ \gamma \le t \le \beta$, and $\xi'(t),\ \eta'(t)$ are the first derivatives on the respective functions, $k = 2 \cdot \pi / \lambda$, λ is the length of the incident electromagnetic wave.

When solving equation (1) as part of the method of moments, we determine the longitudinal electric currents with a density of

$$j = Z \cdot j(t),\ \gamma \le t \le \beta, \qquad (2)$$

The two-dimensional SCS of a metallic cylinder is calculated based on the following expression

$$\sigma(\alpha) = (60 \cdot \pi)^2 \cdot k \cdot |D(\alpha)|^2, \qquad (3)$$

where

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

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

The average SCS is calculated based on the following expression

$$\bar{\sigma} = \sum_{i=0}^{N} \frac{\sigma(\alpha_i)}{N+1}, \qquad (4)$$

where $\sigma(\theta_i)$ is equal to the SCS value at an observation angle α_i.

The task of determining *a* and *D*, which give the maximum values of an average SCS at certain sectors of observation angles, was solved as follows. We set the value of the sector of observation angles ⍰⍰. At different values of *D*, the values of transverse dimension *a* are determined. The analysis shows that the function $\overline{\sigma} = \overline{\sigma}(a, D)$ will be multiextremal. Therefore, when conducting calculations, we used the grid method [14] at a consequent narrowing of the defined values areas. The ant algorithm was used for each of the grid sections [8, 15-16].

The transition rule is applied thereto:

The ant, which is observed at the point r, will make a choice on the next point s, on the basis of such equations:

$$s = \begin{cases} \arg\max_{u \in J_k(r)} \{[\tau(r,u)][\eta(r,u)]\beta\}, & q < q_0 \\ \textit{choice according to the following equation}, & \textit{otherwise} \end{cases}, \quad (5)$$

here by $j_k(r)$ we marked a set of cells for the grid, which require the ant visit. The ant is in the grid point r, $\tau(r,s)$ is a measure of the pheromone, $\eta(r,u) = 1/\delta(r,u)$, the weight $\delta(r,u)$ is chosen as the distance between points, q denotes a random variable, q_0 represents a parameter ($0 \le q \le 1, 0 \le q_0 \le 1$).

For those cases, in which $q \ge q_0$, the ant will choose on the next point on the basis of this equation:

$$p_k(r,s) = \begin{cases} \dfrac{[\tau(r,s)] \cdot [\eta(r,s)]^\beta}{\sum_{u \in J_k(r)} [\tau(r,u)] \cdot [\eta(r,u)]^\beta}, & \text{åñëè } s \in J_k(r) \\ 0, & \text{èíà÷å} \end{cases}, \quad (6)$$

here we marked $p_k(r,s)$ as the probability of choosing the point s by the ant k, which will be in the point r.

We assume fulfilling the following rules, which allows for local update:

$$\tau(r,s) \leftarrow (1-\rho) \cdot \tau(r,s) + \rho \cdot \Delta\tau(r,s), \quad (7)$$

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

There is a correspondence between the global update rule and the following equation:

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

where α is a global parameter, $0 > \alpha > 1$, $\Delta\tau(r,s) = 1/\text{ëó÷øàÿ ãëîáàëüíàÿ äëèíà}$, for those cases, in which there is a membership of segments (r,s) within this length.

RESULTS

Fig. 2 demonstrates the calculated length dependences of the contour *D* on the transverse dimensions of the cylinder a, which make it possible to achieve a maximum average SCS $\overline{\sigma} = \overline{\sigma}(a, D)$. The resulting dependence can be approximated by a linear function.

Fig. 3 provides the calculated length dependences of the contour *D* on the transverse dimensions of the cylinder a, which make it possible to achieve a maximum average SCS $\overline{\sigma} = \overline{\sigma}(a, D)$. The resulting dependence can be approximated by a polynomial of the 4th degree.

Fig. 4 demonstrates the calculated length dependences of the contour *D* on the transverse dimensions of the cylinder a, which make it possible to achieve a maximum average SCS $\overline{\sigma} = \overline{\sigma}(a, D)$. The resulting dependence can be approximated by a polynomial of the 3rd degree.

The achieved approximation error did not exceed 4%.

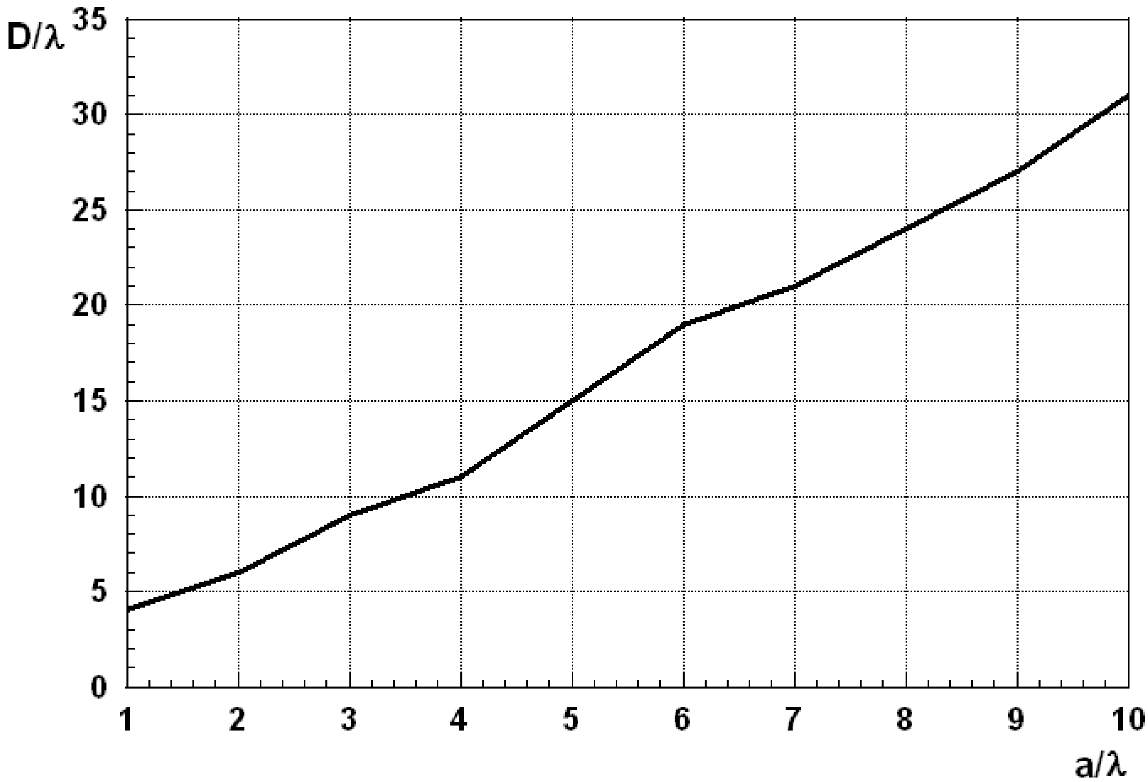


Fig. 2. Dependence of the cylinder contour length (Fig. 1a) *D* on the cross section *a* for the maximum values of an average SCS on the sector of angles ⊗⟨ = 17°, with dimensions b = 0.9L, h = 3L.

The object of complex shape can be represented as a set of separate components, including cylinders [17-18]. To determine the characteristics of the components we use the correlation coefficients. We distinguish the following as the input parameters:

1) type of a component; 2) sector of observation angles; 3) the required level for the average scattering characteristics.

The process of the CAD subsystem functioning, which is used to calculate object components, is shown in Fig. 5.

The output results are the values of the object component characteristics.

The algorithm of the work in a subsystem will be as follows:

1. Entering the input parameters.
2. Calculating the correlation coefficients for each type of object.

3. Choosing the most appropriate component based on the maximum principle of a correlation coefficient.
4. Outputting results.

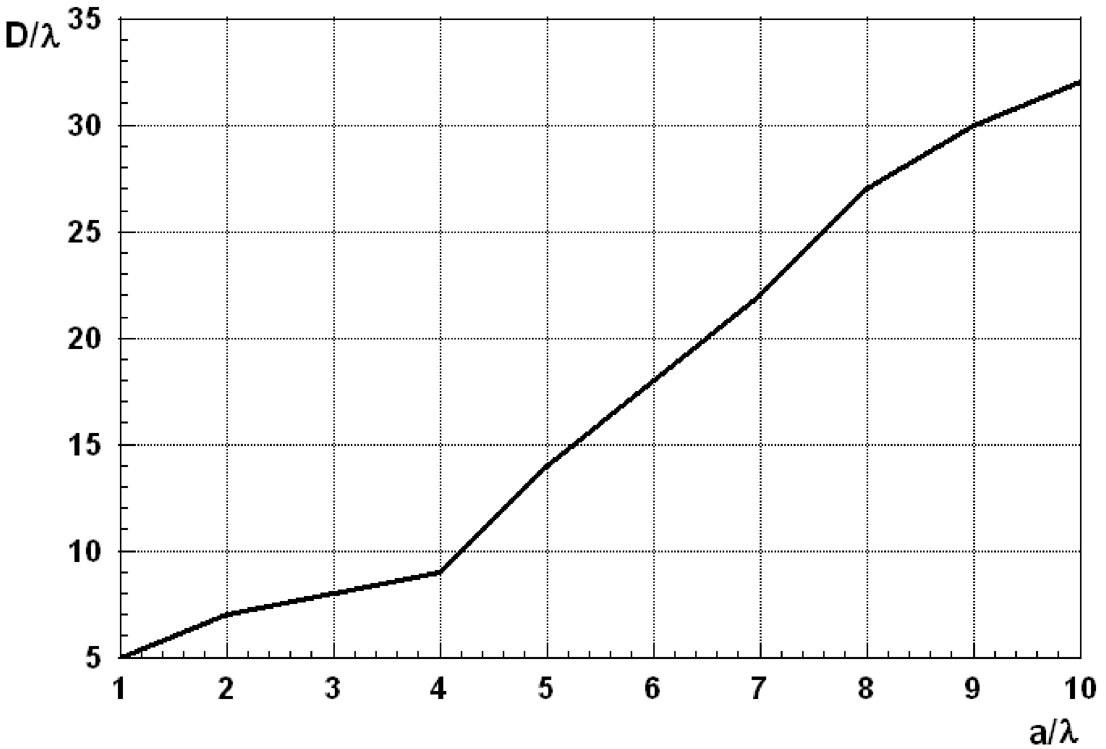


Fig. 3. Dependence of the cylinder contour length (Fig. 1b) *D* on the cross section *a* for the maximum values of an average SCS on the sector of angles ⊗⟨ = 21°, with dimensions b = 0.9⎣, g = 3.5⎣.

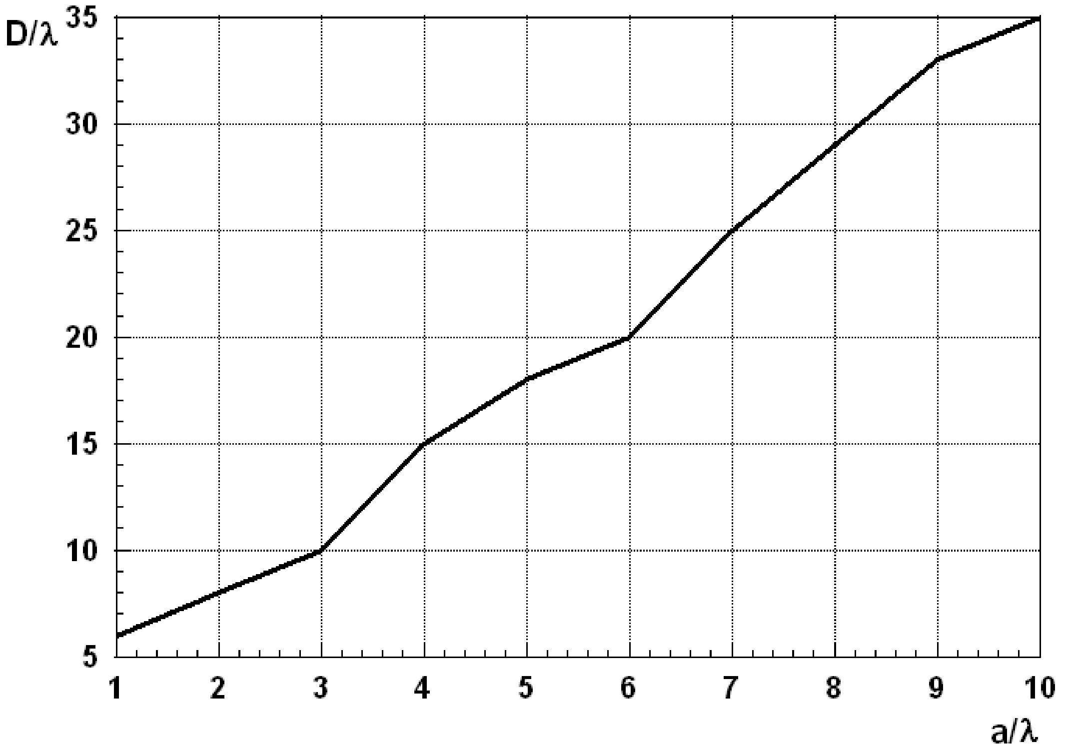


Fig. 4. Dependence of the cylinder contour length (Fig. 1c) *D* on the cross section *a* for the maximum values of an average SCS on the sector of angles ⊗⟨ = 23°, with dimensions b = 0.8⎣, s = 3.8⎣.

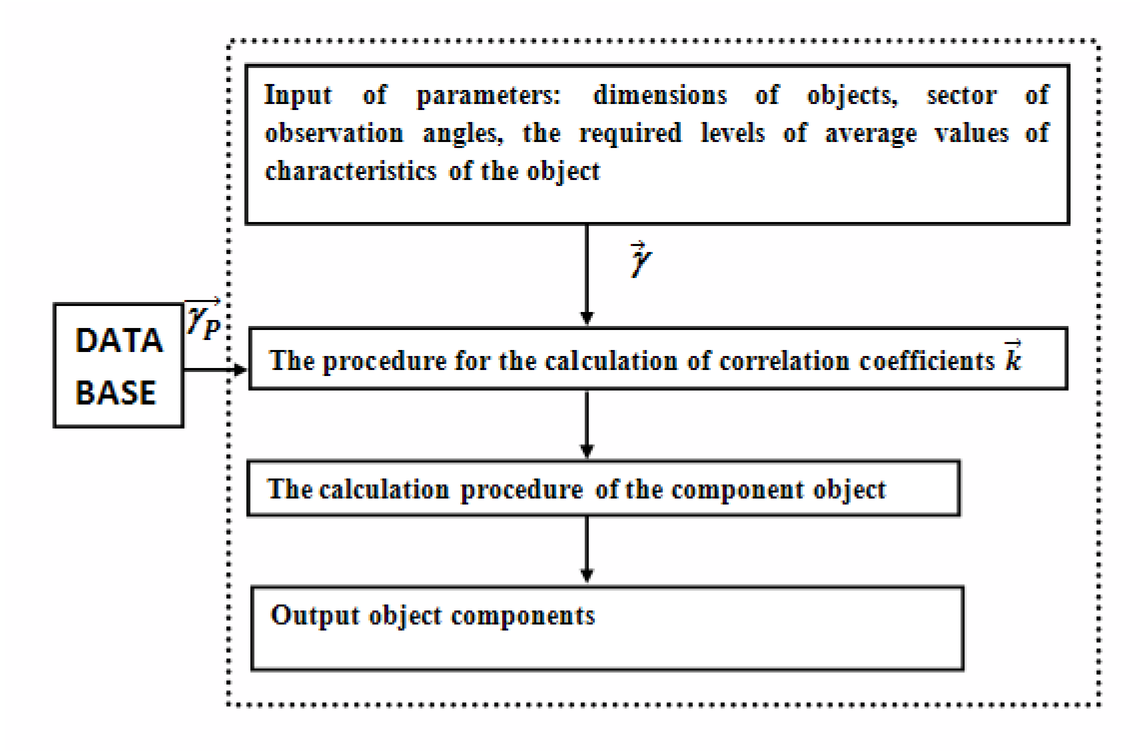


Fig. 5. The process of the CAD subsystem functioning for the average object characteristics.

The following abbreviations are used: $\vec{\gamma}_{VP}$ is a vector, each element of which is the respective input parameter; $\vec{\gamma}_P$ is a vector containing the appropriate dependences in the DB; $\vec{k}$ is a vector comprising the correlation coefficient [19-20].

The process of determining the characteristics of components is reduced to performing the following procedure of determining the maximum of the correlation coefficient.

$$\vec{k} = \frac{\int\limits_{S_1S_2...S_L} \vec{\gamma}_P(\eta_1,\eta_2..\eta_L)\vec{\gamma}_{VP}(\eta_1,\eta_2..\eta_L)\,d\eta_1 d\eta_2...d\eta_L}{\sqrt{\int\limits_{S_1S_2...S_L} \vec{\gamma}_P(\eta_1,\eta_2..\eta_L)^2\,d\eta_1 d\eta_2...d\eta_L \times \int\limits_{S_1S_2...S_L} \vec{\gamma}_{VP}(\eta_1,\eta_2..\eta_L)^2\,d\eta_1 d\eta_2...d\eta_L}}, \qquad (3)$$

where $S_1, S_2, ..., S_L$ are the areas of parameter changes $(\eta_1, \eta_2, ..., \eta_L)$.

For the vector of correlation coefficients, using the standard procedure, the maximal elements are determined, the numbers of which correspond to the required components in accordance with the input parameters.

CONCLUSIONS

Based on the above-mentioned model, we demonstrated the possibility of determining the characteristic dimensions of a two-dimensional cylinder, which provide the maximum average SCS values. The obtained results can be used when designing objects, on which the requirements to reduce the level of secondary electromagnetic radiation are imposed.

REFERENCES

[1] Preobrazhenskiy, A.P., & Yaroslavtsev, N.P. (2005). Sovremennye radiolokatsionnye kompleksy dlya izmereniya radiolokatsionnykh kharakteristik [Modern Radar Systems for Measuring the Radar Characteristics]. *Vestnik Voronezhskogo gosudarstvennogo tekhnicheskogo universiteta, 1*(8), 29-32.

[2] Lvovich, I., & Preobrazhenskiy, A. (2015). The Possibilities of Improvement Wireless Coverage Inside Buildings. *Information Technology Applications, 1*, 124-130.

[3] Lvovich, Ya.Ye., Lvovich, I.Y., Preobrazhenskiy, A.P., & Choporov, O.N. (2014). The Use of "Ant" Algorithm in Constructing Models of Objects That Have Maximum Average Values of the Scattering Characteristics. *Life Science Journal, 11*(12), 463-466.

[4] Golovinov, S.O., Preobrazhenskii, A.P., & Lvovich, I.Y. (2013). Modeling the Millimeter Wave Propagation in Urbanized Areas Based on a Combined Algorithm. *Telecommunications and Radio Engineering, 72*(2), 139-145.

[5] Lvovich, I.Ya., Preobrazhensky, A.P., & Choporov, O.N. (2013). Analysis of Potential of Error-Correcting Capabilities of Codes. *Life Science Journal, 10*(4), 830-834.

[6] Kobak, V.O. (1975). *Radiolokatsionnye otrazhateli* [Radar Reflectors]. Moscow: Sovetskoe radio.

[7] Vasil'ev, E.N. (1987). *Vozbuzhdenie tel vrashcheniya* [Excitation of the Bodies of Revolution]. Moscow: Radio i svyaz'.

[8] Lvovich, I.Ya., Preobrazhensky, A.P., & Choporov, O.N. (2015). The Use of "Ant" Algorithm for Construction of Models of Objects with Maximum Average Values of Scattering Characteristics. In O.Ja. Kravets (Ed.), *Modeling and Information Technologies: Selected Papers of the International Scientific School "Paradigma" (Summer-2015, Varna, Bulgaria)* (pp. 67-72). Yelm, WA, USA: Science Book Publishing House.

[9] Lvovich, I.Ya., Preobrazhensky, A.P., & Savchenko, V.E. (2015). The Possibility of Developing the CAD Subsystem for the Analysis of Scattering Characteristics of Hollow Structures. *Global Scientific Potential, 9*(54), 66-68.

[10] Lvovich, I.Ya., Preobrazhensky, A.P., & Savchenko, V.E. (2015). The Possibility of Developing the CAD Subsystem for Analysis of Scattering Characteristics of Hollow Structures. *Components of Scientific and Technological Progress, 3*(25), 10-13.

[11] Golovinov, S.O., Preobrazhenskii, A.P., & Lvovich, I.Y. (2013). Modeling the Millimeter Wave Propagation in Urbanized Areas Based on a Combined Algorithm. *Telecommunications and Radio Engineering, 72*(2), 139-145.

[12] Ling, H. (1990). RCS of Waveguide Cavities: A Hybrid Boundary-Integral/Modal Approach. *IEEE Transactions on Antennas and Propagation, AP-38*(9), 1413-1420.

[13] Zakharov, Ye.V., & Pimenov, Yu.V. (1986). *Chislennyy analiz difraktsii radiovoln* [Numerical Analysis of the Radio Waves Diffraction]. Moscow: Nauka.

[14] Lvovich, Ya.Ye. (2006). *Mnogoal'ternativnaya optimizatsiya: Teoriya i prilozheniya* [Multialternative Optimization: Theory and Applications]. Voronezh: Kvarta.

[15] Botee, H.M., & Bonabeau, E. (1998). Evolving Ant Colony Optimization. *Advances in Complex Systems, 1*, 149-159.

[16] Doringo, M., Maniezo, V., & Colorni, A. (1996). The Ant System: Optimization by a Colony of Cooperating Agents. *IEEE Transactions on Systems, Man, and Cybernetics – Part B, 26*(1), pp.29-41.

[17] Lvovich, I.Ya., Preobrazhenskiy, A.P., Choporov, O.N., & Kaydakova, K.V. (2015). The Analysis of Scattering Electromagnetic Waves with Use of Parallel Computing. In *Proceedings of the 2015 International Siberian Conference on Control and Communications, SIBCON 2015* (pp. 1-6).

[18] Preobrazhensky, A.P. (2015). The Principles and Approaches of the Assessment of the State of WNANA Environment. *Vestnik Voronezhskogo instituta vysokikh tekhnologiy, 15*, 29-31.

[19] Shirman, Ya.D., Gorshkov, S.A., Leshchenko, S.P., Bratchenko, G.D., & Orlenko, V.M. (1996). Metody radiolokatsionnogo raspoznavaniya i ikh modelirovanie [Methods of Radar Detection and Their Simulation]. *Zarubezhnaya radioelektronika, 11*, 3-63.

[20] Shtager, Ye.A, & Chayevskiy, Ye.N. (1974). *Rasseyanie voln na telakh slozhnoy formy* [Scattering of Waves on the Bodies of Complex Shape]. Moscow: Sovetskoe radio.