Modeling of scattering of electromagnetic waves on the base of multialternative optimization

Yakov Lvovich, Andrew Preobrazhensky, Oleg Choporov

Abstract:

One of the problems arising in management of large systems, is a scattering of electromagnetic waves on complex structures with radio absorbing coatings. In many cases the hollow metallic structures with circular cross section are observed. The modal method was used to estimate the modes in the inner area of the cavity. Tangential components of electric and magnetic fields at the aperture of the cavity excited by a plane electromagnetic wave can be represented in the form of expansions in modes of waveguide with the corresponding unknown modal coefficients. At this stage, the reciprocity theorem of modal coefficients within the relevant cavity modes is determined. Methods of optimization of characteristics of radar absorbing coating are introduced. Determination of the real part of dielectric permeability of radar absorbing coatings in a given thickness of its layer is shown on corresponding figure. Application of absorbing load in the form of the two radar absorbing layers with increasing thickness of one absorbing coating with constant thicknesses of a different radar absorbing coating is introduced. The possibility of achievement of a significant reduction in the level of radar cross section is described.

Keywords:

Simulation modeling, multialternative optimization, scattering of electromagnetic waves, cavity structure.

ACM Computing Classification System:

Equation and inequality solving algorithms, Parallel programming languages, Optimization algorithms.

Introduction

The development of electrodynamic systems of computer-aided design (CAD) allows us to solve a completely new challenge in the field of antenna-feeder equipment, diffraction theory of electromagnetic waves on structures of complex shape that require substantial computing resources and is practically implemented to fulfill many scientific developments, the high degree of complexity of which hindered their practical implementation.

The special class of problems is the study of scattering of electromagnetic waves on the various hollow structures, which can be included in the composition of technical objects of complex shape as elements of design or composition of antenna-feeder devices. The particular interest is in the construction of algorithms of calculation of scattering characteristics of electromagnetic waves of three-dimensional structures. The calculation cannot reduce the dimensionality of the problem (due to the symmetry of an object). The most difficult thing is to research the hollow structure, the dimensions of which correspond to a resonance region.

The calculation of the radar cross section (RCS) of three-dimensional perfectly conducting hollow structures of complex shape with arbitrary cross-section containing radar absorbing materials is a complicated electrodynamic problem. The currently used methods [1-3] to calculate the electrodynamic characteristics of electromagnetis waves is only on hollow structures of some classes, characterized by specific dimensions, shape and cross-sectional hollow structures and methods of placing radar absorbing materials.

At low frequencies, in the resonance region, i.e. when viewed from the hollow structure with aperture size $\sim 1\lambda$, can be used a rigorous method – method of integral equations. For hollow structures with the size of the aperture, comprising several wavelengths, in some cases, it is convenient to use a high frequency approximation [4-6]. There are various high-frequency methods to determine the electromagnetic fields scattered by such structures. One of them is modal method [7].

In practice there are hollow structures, extended in a certain direction and having a uniform cross section along this direction.

In the mathematical modeling of such structures can be represented in the form of a segment of a homogeneous waveguide cross-section. Naturally, this model is one of the simplest models of cavities that are part of real objects. However, such model allows a rigorous modal analysis of the fields inside the hollow structure.

The field inside the structure is represented in the form of an expansion in waveguide modes are known. The unknown modal coefficients are on the basis of the reciprocity theorem [8].

To calculate the RCS of the considered class of structures of hollow rectangular and circular cross section were used modal method. The modern units also include a large number of hollow structures with uniform cross-section, which is close to elliptical (e.g., input and output nozzles, antenna on-Board radio-electronic complexes, the waveguide emitters included in the composition of phased antenna arrays, etc.).

The most fully investigated phased array of waveguides of rectangular and circular cross sections, however, using the well-known advantages of waveguides of more complicated cross-section is elliptical, you can improve range, power and polarization characteristics in a wide angle sector scan.

The parameters describing the shape of the waveguide, give the developer additional degree of freedom for matching the radiator to the space available.

Use in radiators of various absorbing coatings can reduce the reflectance to a sufficiently large sector of the scan when negotiating antenna array with free space.

Thus, due to high incidence of hollow structures of elliptical cross-section the calculation of RCS [9] is an urgent task.

When calculating the RCS three-dimensional hollow structures with elliptical cross-section (unlike, for example, structures with a rectangular cross-section) to reduce the problem to two-dimensional and thus reduce the amount of numerical calculations.

Based on the above it is of interest to develop an algorithm of calculation of RCS hollow structures of elliptical cross-section as containing and not containing radar absorbing coatings, enabling the analysis of propagation of electromagnetic waves inside structures with the specified cross-section.

This will provide an opportunity to identify concrete ways to build structures with a given value of the scattering characteristics of electromagnetic waves.

One of the conditions of creating antennas with specified characteristics is the development of adequate mathematical models and algorithms of calculation of complex diffractive structures that are part of the antennas.

The need to study the diffraction of electromagnetic waves on reflective comb with double periodicity, covered with a layer of dielectric because such a structure can be used to create planar microwave antennas of the diffraction type electronically controlled polarization sensitivity.

The basic idea of e-selection on the basis of polarization is that the comb is positioned orthogonal relative to each other grooves, which are polarization-electoral elements: with parallel mutual orientation of the magnetic field lines incident on the structure electromagnetic waves and grooves of a diffraction grating (DG) excited standing waves of significant intensity.

Thus the reaction of grooves located along the other coordinate axis, on the field of the incident wave is negligible (due to their zapredelnoe to the waves of a given polarization).

rrently, there are no scientific simple mathematical model of the process of mutual transformation of bulk and surface waves in two-dimensional periodic metallic PD is covered with a dielectric. In this paper we consider a mathematical model which enables to obtain useful results for practice.

A well known disadvantage of diffraction antennas – escapologist – can significantly offset by the use of polarization decoupling to transmit information. This problem can be solved by the example antennae consisting of diffraction gratings covered with dielectric waveguide. The calculation of the electromagnetic waves on the grid can be carried out using the apparatus of integral equations and theory of periodic structures.

The type of the equation depends on the structure of the antenna. In the case that the antenna contain metal-dielectric materials in their construction, this is taken into account by introducing into the integral equation corresponding members containing characteristics (e.g., surface impedance) of these materials.

The diffraction grating can be used in diffractive antennas with optical excitation type.

It includes a reflector waveguide with grooves of square cross section filled with a homogeneous dielectric. In the evaluation of the directional diagrams can be used approach on the basis of the two-dimensional model that allows to significantly reduce the need for calculations. The calculation is carried out based on the method of integral equations.

As the excitation elements may be used in horn-slotted emitters.

Practically important is the interest of the development of an algorithm that is based on a strict method of the analysis of such structures.

The use of multiple radar absorbing coatings with specific properties (e.g., thickness) allows to achieve the required values of the scattered electromagnetic field in certain sectors of angles.

Consider the characteristics of dispersion (RCS) waveguide cavities of circular cross-section with a flat absorbing load (fig. 1).

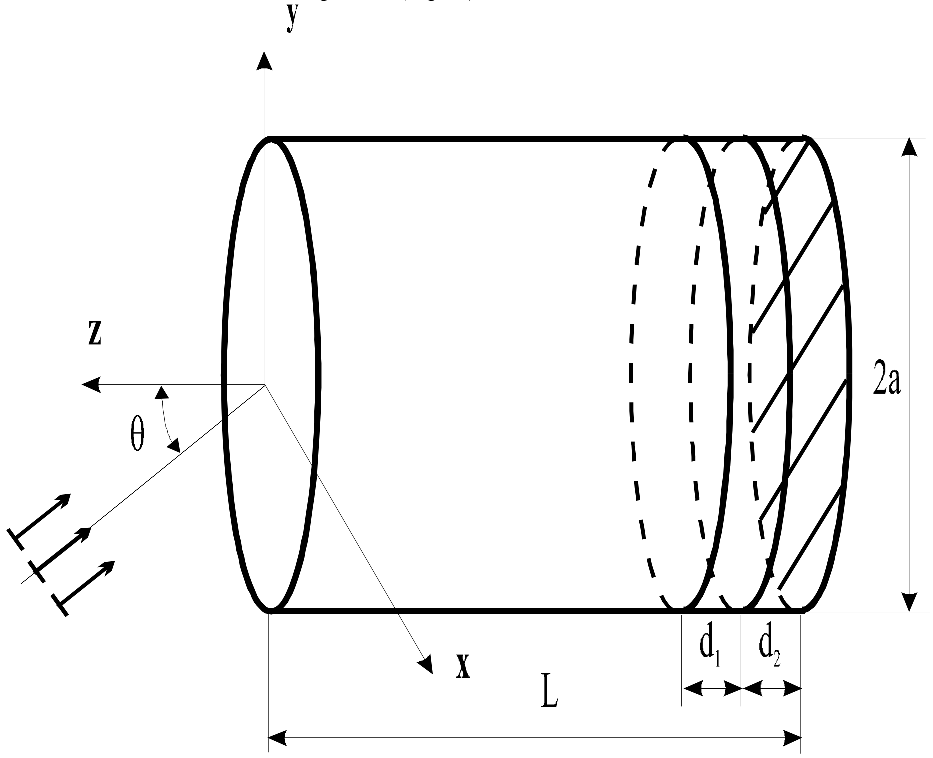

Figure 1. The cavity has a circular cross-section flat with absorptive load

The scattering matrix of a perfectly conducting hollow circular cross-section [10]:

$$S_{\theta\theta} = \sum_m \sum_n \frac{j^{2m+1} m^2 \left(1 + \frac{\gamma_{mn}}{k}\cos\theta\right)^2 J_m^2(ka\sin\theta)}{\gamma_{mn}\varepsilon_m \sin^2\theta\left((\xi'_{mn})^2 - m^2\right)} e^{-2j\gamma_{mn}L} +$$

$$+ \sum_m \sum_n {}' \frac{j^{2m+1}\left(\frac{\tilde{\gamma}_{mn}}{k} + \cos\theta\right)^2 J_m^2(ka\sin\theta)}{\tilde{\gamma}_{mn}\varepsilon_m \sin^2\theta\left(1 - \left(\frac{\xi_{mn}}{ka\sin\theta}\right)^2\right)^2} e^{-2j\tilde{\gamma}_{mn}L}, \qquad (1)$$

где $\gamma_{mn} = (k^2 - (\frac{\xi'_{mn}}{a})^2)^{1/2}$, $\tilde{\gamma}_{mn} = (k^2 - (\frac{\xi_{mn}}{a})^2)^{1/2}$, ξ_{mn}, ξ'_{mn} – the n-th roots of the Bessel function and its derivative, respectively.

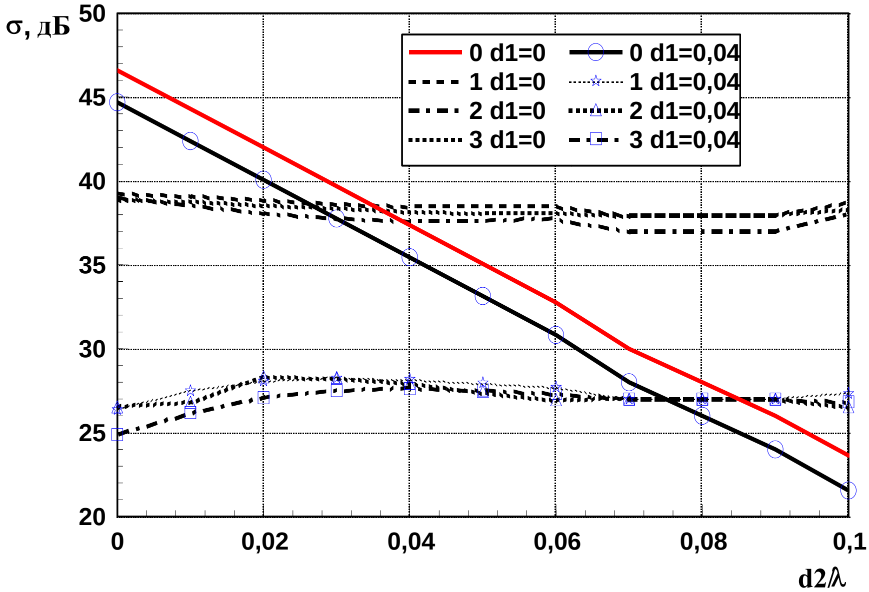

Figure 2. The dependence of RCS of cavity from the change of the thickness of a coating layer at a constant thickness of the other layer coating

Settings: $\varepsilon_1 = 7{,}4$, $\mu_1 = 0{,}92 - j0{,}31$, and $\varepsilon_2 = 13.5 - j \cdot 18{,}1$, $\mu_2 = 1.05$.

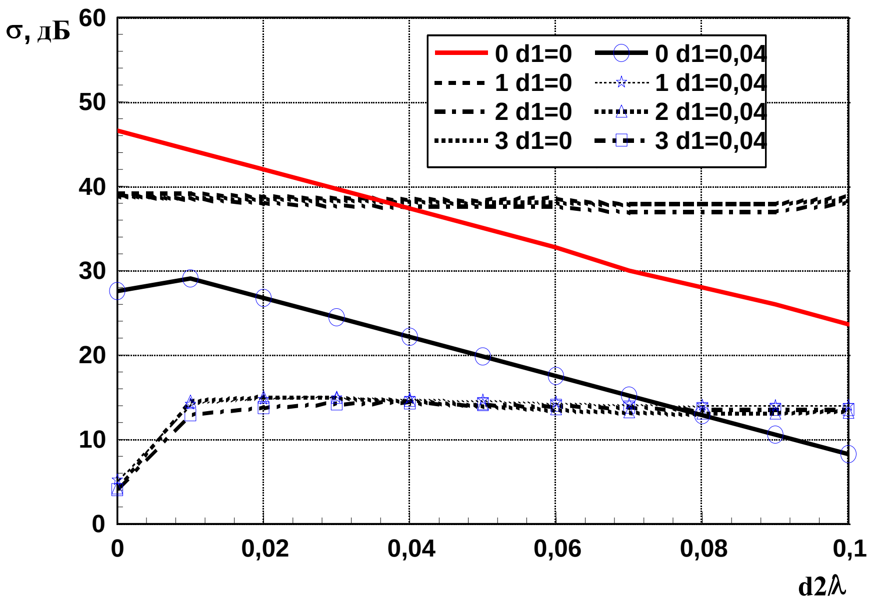

Figure 3. The dependence of RCS cavity from the change of the thickness of a coating layer at a constant thickness of the other coating layer

Parameters: $\varepsilon1=12.1 - j0,124$, $\mu1=1,54 - j3,106$ and $\varepsilon2=13.5 - j\cdot18,1$, $\mu2=1.05$.

The RCS of cavity of circular cross-section is calculated as:

$$\sigma = 4\pi \,|\, S_{\theta\theta} \,|^2 \qquad (2)$$

The scattering matrix of the cavity with radar absorbing coating is determined using the expressions for the generalized scattering matrices of the waveguide of circular cross-section of the waveguide segment and with radar absorbing coating [11].

Far field is calculated in the Kirchhoff approximation for three-dimensional case [12].

The modal calculation of the RCS cavity of a simple form of arbitrary uniform cross-section for the case of E-polarization the incident electromagnetic wave consists of the following steps [13].

1. Tangential components of electric and magnetic fields at the aperture (z = 0) of the cavity excited by a plane electromagnetic wave can be represented in the form of expansions in modes of waveguide with the corresponding unknown modal coefficients. At this stage, using the reciprocity theorem [126, 144], the modal coefficients are determined, within the relevant cavity modes. Calculated modal coefficients corresponding to exiting from the cavity modes, using the well-known expression for the generalized scattering matrix S_{mn} cavity.

2. In the approximation of the Stratton-Chu [279] calculated the secondary stray field of the cavity, due to coming out of the aperture modes. This approach does not take into account the diffraction of electromagnetic waves on the edges of the cavity, it can be taken into account when using the method of boundary waves [225].

3. The field scattered by the cavity is calculated based on the approximations of Stratton-Chu.

From the known values of the RCS cavity of circular cross-section can be synthesized characteristics of radio-absorbing coating, placed on the rear wall of the cavity.

A flat dummy load represents two layers of radar absorbing coating (Fig. 1). For example, as an absorbent load were examined materials$\varepsilon1 = 7,4$, $\mu1 = 0,92 - j0,31$ and $\varepsilon2 = 13.5 - j \cdot 18,1$, $\mu2 = 1.05$ (1st case), as well as materials with $\varepsilon1 = 12.1 - j0,124$, $\mu1 = 1,54 - j3,106$ and $\varepsilon2 = 13.5 - j \cdot 18,1$, $\mu2 = 1.05$ (2nd case) [281]. Consider the cavity had a radius a = 5.5λ, and length L = 15.5λ. The thickness of the layers d1 and d2 of radar absorbing coating is varied from 0 to 0.1λ.

It was shown that when using absorbing load in the form of two radar absorbing layers with increasing thickness one absorbing coating (d2) with constant thicknesses of different radar absorbing coating (d1) it is possible to achieve a significant reduction in the level of RCS in the maximum of the main lobe diagram of the inverse scattering at a constant level of RCS in the field of the first few side lobes (the change of the RCS was not more than 3 dB when changing d2 from 0 to 0.1λ)

In Fig. 2 shows the results of calculations for the 1-st case (when d1 = 0 and d1 = 0,04λ).

In Fig. 2 marked: 0 – level of the main lobe of the diagram of return dispersion, 1, 2, 3 – level first, second and third lobe, respectively.

In Fig. 3 shows the results of calculations for the 2nd case (when d1 = 0 and d1 = 0,045λ). In Fig. 3 marked: 0 – level of the main lobe of the diagram of return dispersion, 1, 2, 3 levels first, second and third lobe, respectively.

It is possible to vary not only the thickness of the PSC, but under the given thicknesses of the radar absorbing coating to determine their dielectric or magnetic permeability. For example, suppose that in the 2nd case the real unknown part ε1, i.e. ε1 = X – j0,124, μ1 = 1,54 – j3,106, where X is the unknown value.

Then asking a certain level of the main or side lobes, it is possible to determine this value. In Fig. 4.34 shows the results of calculations for this case (d1 = 0,055λ and d2 = 0,011λ). In Fig. 4.34 indicated: 0-level of the main lobe of the diagram of return dispersion, 1, 2, 3 levels first, second and third lobe, respectively.

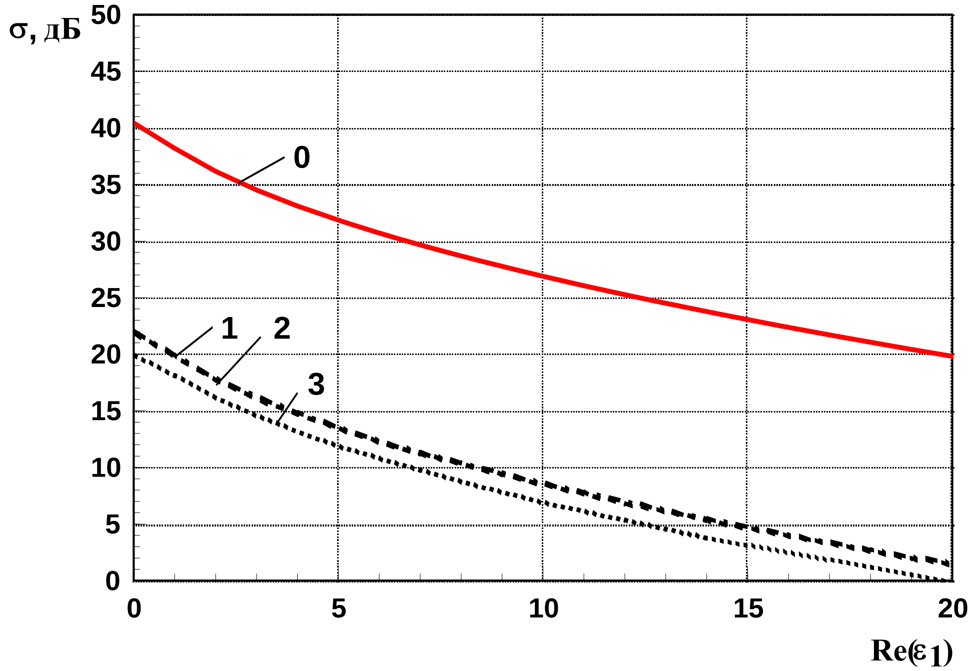

Figure 4. The determination of the real part of the dielectric the permeability of radar absorbing coatings in a given thickness of its layer

It should be noted that with the use of a modal method for modeling the characteristics of scattering of electromagnetic cavity of circular cross section terminating loads of various types. It is only necessary to know the scattering matrix of a waveguide section in which there is a given load.

Its calculation is possible, for example, on the basis of the method of integral equations or finite element method. Using the generalized scattering matrix has several advantages [14-19].

First, the scattering matrix is unique for each configuration, termination resistors and does not require recalculation for different excitations of the cavity (the angles of incidence of a plane electromagnetic wave). Secondly, in the case of symmetry of the load about the axis of symmetry of the cavity a large number of elements in the scattering matrix is equal to zero.

References

[1] KOSZYKOWA C. Diffraction by a plane-parallel waveguide inhomogeneities with a three-layer dielectric filling. / S. Koshikava,

T. Momoze // International electronics. The success of modern electronics, 1996. – P. 10-37.
[2] MARKOV G. T. Mathematical Methods Applied Electromagnetics / G. Markov, E. Vasiliev. – M.: Sov. radio, 1970. – 120 p.
[3] NOBLE D. Method of Wiener-Hopf / D. Noble. – M.: Publishing House of Foreign. lit-ry, 1962. – 279 p.
[4] KNOTT YF Development of methods of calculation of the effective area of he reflection of radar targets // Proc, 1985. – V. 73. – № 2. – P. 90-105.
[5] BURKHOLDER R. J. High-frequency asymptotic methods for analyzing the EM scattering by open-ended waveguide cavities / R. J. Burkholder – Ph.D. dissertation, The Ohio State University, Columbus, OH, 1989.
[6] PATHAK P. H. Modal, ray and beam techniques for analysing the EM scattering by open-ended waveguide cavities / P. H. Pathak, R. J. Burkholder // IEEE Trans. Antennas Propagat., 1989, vol. AP-37, №. 5. – P. 635-647.
[7] ALTINTAS A. A selective modal scheme for the analysis of EM coupling into or radiation from large open-ended waveguides. / A. Altintas, P. H. Pathak, M. C. Liang // IEEE Trans. Antennas Propagat, 1988. – Vol. AP-36. – No. 1. – P. 84-96.
[8] SAZONOV, D. M. Microwave Devices / D. M. Sazonov, A. N. Gridin, B. A. Mishustin. – M: Executive. School, 1981. – 295 p.
[9] ALHOVSKY E. A. Flexible waveguides in the art of microwave / E. A. Alhovsky, G. S. Golovchenko, Il'inskii etc. – M.: Radio and Communications, 1986.
[10] LING H. High-frequency RCS of open cavities with rectangular and circular cross sections. / H. Ling, S. W. Lee, R. C. Chou // IEEE Trans. Antennas Propagat., 1989, vol. AP-37, №. 5. – P. 648-654.
[11] NICHOLAS V. Electrodynamics and Propagation / V. V. Nikolsky. – M.: Nauka, 1978. – 543 p.
[12] Numerical methods in electrodynamics / Ed. R. Mitra. – M.: Mir, 1977. – 485 p.
[13] LING H. RCS of waveguide cavities: a hybrid boundary-integral / Modal approach / H. Ling // IEEE Trans. Antennas Propagat., 1990, vol. AP-38, no. 9. – p. 1413-1420.
[14] MISHIN J. A. About the computer-aided design systems in wireless networks / Y. A. Mishin // Herald of the Voronezh Institute of High Technologies. 2013. – № 10. – p. 153-156.
[15] MILOSHENKO O. V. Methods for evaluating propagation characteristics in mobile radio communication systems / O. V. Miloshenko // Herald of the Voronezh Institute of High Technologies. – 2012. – № 9. – P. 60-62.
[16] GOLOVINOV S. O. Management problems of mobile communication systems / S. O. Golovinov, A. A. Hromyh // Herald of the Voronezh Institute of High Technologies. – 2012. – № 9. – P. 13-14.
[17] LVOVICH I. J. Application of methodological analysis in the safety

study / I. Ya. Lvovich, A. A. Voronov // Information and Security. 2011. – T. 14. – № 3. – S. 469-470.

[18] ERASOV S. V. Optimising processes in the electrodynamic problems / S. V. Erasov // Herald of the Voronezh Institute of High Technologies. – 2013. – № 10. – P. 20-26.

[19] BOLUCHEVSKAYA O. A. The properties of the scattering characteristics of the evaluation methods of electromagnetic waves / O. A. Boluchevskaya, O. N. Gorbenko // Simulation, optimization and information technology. – 2013. – № 3. – P. 4.

……………………………………………………………………………………

Prof. Yakov Lvovich, D. Sc.
the honored scientist of the Russian Academy of Natural Sciences
President of Voronezh Institute of High Technologies
office@vivt.ru

Doc. Andrew Preobrazhensky
Voronezh Institute of High Technologies
app@vivt.ru

Prof. Oleg Choporov, D. Sc.
Voronezh Institute of High Technologies
Choporov_oleg@mail.ru