Simulation of electromagnetic scattering characteristics of particles with anisotropic surface impedance

A. G. Kyurkchan* and D. B. Demin

Moscow Technical University of Communication and Informatics, Aviamotornaya Street 8A, Moscow, 111024, Russia.

The pattern equation method has been extended to solve the scattering problems of electromagnetic waves on particles with anisotropic surface impedance. The scattering characteristics of axially symmetrical scatterers with artificially soft and hard surfaces and with complicated structures of curves of conductivity on their surfaces are investigated. The comparisons to the results obtained using other methods are discussed.

INTRODUCTION

In this paper, we consider scattering of electromagnetic waves on particles with anisotropic surface impedance. In this case, the surface impedance in the impedance boundary condition, known as Leontovich's boundary condition, is given by a tensor with the components corresponding to appropriate directions of anisotropy.

We extended the pattern equation method (PEM) to solve the abovementioned problem. The PEM has already been applied to solve problems of electromagnetic wave scattering on impedance and dielectric scatterers [1-3]. The PEM is one of the most effective methods for solving scattering problems of electromagnetic waves. It has been earlier established [1-3] that the rate of convergence of the PEM's numerical algorithm is mainly governed by the scatterer size and weakly depends on its geometry.

Under the boundary value problem, we consider the scattering problem of plane waves for axisymmetric scatterers. We investigate the scattering characteristics of these scatterers with artificially soft and hard surfaces [4] using special values of anisotropic impedance. Also, we simulate scattering of circularly polarized plane waves on particles with boundary conditions which correspond to complicated structures of curves of conductivity [5].

PROBLEM STATEMENT

Let us consider the problem of electromagnetic scattering of incident primary monochromatic ($e^{i\omega t}$) field $\vec{E}^0$, $\vec{H}^0$ by an arbitrarily shaped 3D compact obstacle bounded by surface S. Let the following impedance boundary condition be met at S:

$$\left(\vec{n}\times\vec{E}\right)\Big|_S = \hat{Z}\left[\vec{n}\times\left(\vec{n}\times\vec{H}\right)\right]\Big|_S, \qquad (1)$$

* Corresponding author: Alexander G. Kyurkchan (kyurkchan@yandex.ru)

where $\vec{n}$ is the outward unit normal to S; $\hat{Z}$ is a tensor of surface impedance (an anisotropic surface impedance) which is

$$\hat{Z} = \begin{bmatrix} Z_l & Z_{l\varphi} \\ Z_{\varphi l} & Z_\varphi \end{bmatrix} \quad (2)$$

for axially symmetrical bodies; $\vec{E} = \vec{E}^0 + \vec{E}^1$, $\vec{H} = \vec{H}^0 + \vec{H}^1$ is the total field; $\vec{E}^1, \vec{H}^1$ is the secondary (diffracted) field, which satisfies the system of homogeneous Maxwell equations elsewhere outside S and the Sommerfeld radiation condition at infinity.

The component Z_l of tensor $\hat{Z}$ corresponds to the direction of the unit vector $\vec{i}_l$ which is tangential to S and perpendicular to the unit vectors $\vec{i}_\varphi$ (unit vector of a spherical coordinate system (r,θ,φ)) and $\vec{n}$. Thus, the vectors $\vec{i}_l$, $\vec{i}_\varphi$, and $\vec{n}$ form a right-handed orthogonal system.

REDUCTION OF BOUNDARY-VALUE PROBLEM TO SYSTEM OF ALGEBRAIC EQUATIONS

According to the PEM standard scheme [1-3], the initial boundary-value problem for the Maxwell equations is reduced to an infinite system of linear algebraic equations with respect to the unknown coefficients a_{nm}, b_{nm} of expansion of the scattering patterns $\vec{F}^E$, $\vec{F}^H$ of electric and magnetic fields in terms of vector angular spherical harmonics, which compose the orthogonal basis in the spherical coordinates (r,θ,φ).

For the diffracted field $\vec{E}^1, \vec{H}^1$ in the far zone, the following asymptotic relations are met

$$\vec{E}^1, \vec{H}^1 = \frac{\exp(-ikr)}{r} \vec{F}^{E,H}(\theta,\varphi) + O\left(1/(kr)^2\right).$$

Then, using the integral representations for the field $\vec{E}^1, \vec{H}^1$, which could be obtained from the Maxwell equations, and decompositions of these fields in terms of vector spherical harmonics, we have the following system of PEM:

$$\begin{cases} a_{nm} = a_{nm}^0 + \sum_{q=1}^{\infty} \sum_{p=-q}^{q} \left(G_{nm,qp}^{11} a_{qp} + G_{nm,qp}^{12} b_{qp} \right), \\ b_{nm} = b_{nm}^0 + \sum_{q=1}^{\infty} \sum_{p=-q}^{q} \left(G_{nm,qp}^{21} a_{qp} + G_{nm,qp}^{22} b_{qp} \right), \end{cases} \quad n = 1,2,\ldots, \quad |m| \le n, \quad (3)$$

where

$$a^0_{nm} = a^{00}_{nm} + a^{\tilde{z}0}_{nm}; \quad b^0_{nm} = b^{00}_{nm} + b^{\tilde{z}0}_{nm}; \quad G^{ij}_{nm,qp} = G^{0ij}_{nm,qp} + G^{\tilde{z}ij}_{nm,qp}; \; i,j = 1,2. \qquad (4)$$

In Eq. (4), the coefficients with the additional superscript "0" correspond to the perfect conductor ($\hat{Z} = 0$), and the ones marked by "$\tilde{z}$" designate additional terms caused by the anisotropic impedance $\hat{Z}$. The coefficients a^0_{nm}, b^0_{nm} are determined by the incident wave. These coefficients and the matrix elements $G^{ij}_{nm,qp}$, $i,j = 1,2$ in (3) are represented in surface integrals on S, and they are similar to those published in [1-3].

The verification of applicability of the numerical algorithm of PEM has been made earlier (see, for example, [1-3]).

NUMERICAL RESULTS

Consider examples of searching for the scattering patterns for the following axially symmetric scatterers: sphere and spheroid. The z-axis was chosen as the symmetry axis of the scatterers. In all examples, the incident field is a plane wave propagating along the z-axis.

In Fig. 1, the scattering patterns of E-field (with the polarization of the vector $\vec{E}^0$ along the *x*-axis) are shown for the prolate spheroid with the parameters: $ka = 10$ (small semiaxis) and $kc = 20$ (large semiaxis). Curve 1 corresponds to the scattering pattern $|F^E_\theta|$ (in the $\varphi = 0$ plane) of perfectly conducting scatterer ($\hat{Z} = 0$), and curves 2 and 3 correspond to the patterns $|F^E_\theta|$ (in the $\varphi = 0$ plane) and $|F^E_\varphi|$ (in the perpendicular plane) for scatterer with artificially soft surface. The value of anisotropic impedance $\hat{Z}$ of artificially soft surfaces for electromagnetic waves is defined as follows: $|Z_l| = \infty$, $Z_{l\varphi} = Z_{\varphi l} = Z_\varphi$ =0. The value of anisotropic impedance $\hat{Z}$ of artificially hard surfaces is defined as follows: $|Z_\varphi| = \infty$, $Z_l = Z_{l\varphi} = Z_{\varphi l}$ =0 (see [4]). In our calculations, infinity is replaced by the number equal to $1000\zeta_0$ (ζ_0 is the wave impedance of the vacuum). From Fig. 1, it is clear that the patterns $|F^E_\theta|$ and $|F^E_\varphi|$ for soft particle almost coincide with the pattern $|F^E_\theta|$ of perfect conductor for scattering angles corresponding to the illuminated part of the surface. The same result was observed for the artificially hard particle.

In our second example, we consider scattering of a plane wave with circular polarization (left-handed) by a sphere and a prolate spheroid. In Fig. 2, we plot the normalized scattering patterns of particles. Here $Z_{l\varphi} = -\nu(\theta)Z_\varphi$, $Z_l = -\nu(\theta)Z_{\varphi l}$, and $\nu(\theta) = i0.025\sin^2\theta$ that correspond to spiral curves of conductivity on the scatterer with the angle of rise $\psi(\theta)$, $\nu(\theta) = \mathrm{tg}\psi(\theta)$ [5]. The radii of the spheres are equal to $ka = 0.9$ (curve 1), $ka = 1$ (curve 2), $ka = 1.1$ (curve 3). The parameters of the spheroid are as follows: $ka = 0.65$, $kc = 1.6$ (curve 4), that is, the sizes of the particles there are less than the wavelength of the incident field. From Fig. 2, it is visible that, under axial incidence of the circularly-polarized plane wave on particles with spiral curves of conductivity, full absorption is observed, coinciding with the result given in [5]. Let us note that, when $ka > 1.1$, backward scattering grows.

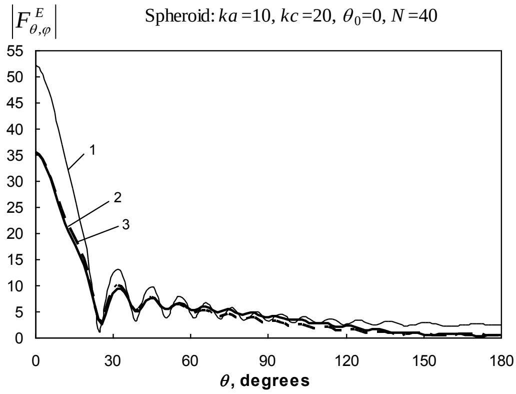

Figure 1. The scattering pattern for a spheroid.

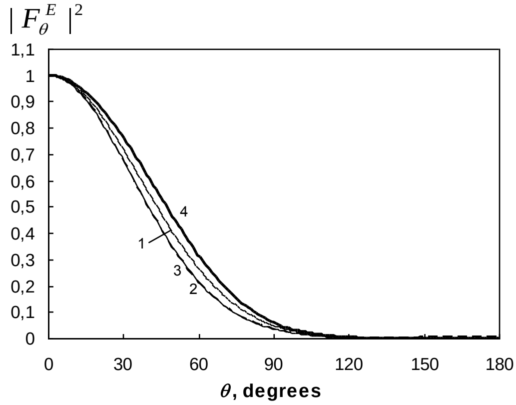

Figure 2. The scattering pattern for a sphere and a spheroid.

CONCLUSION

Thus, we have demonstrated that impedance conditions with anisotropic impedance are applicable in the simulation of scattering characteristics of particles with artificially hard and soft surfaces, and with complicated structures of curves of perfect conductivity.

ACKNOWLEDGMENTS

This work was supported by Russian Foundation for Basic Research, Project no. 09-02-00126.

REFERENCES

[1] A.G. Kyurkchan. Solution of vector scattering problems by the pattern equation method. Journ Comm Tech and Electron. **45** (2000).

[2] A.G. Kyurkchan and D.B. Demin. Electromagnetic wave diffraction from impedance scatterers with piecewise - smooth boundaries. Journ Comm Tech and Electron. **47** (2002).

[3] A. Kyurkchan and D. Demin. Pattern equation method for solving problems of diffraction of electromagnetic waves by axially dielectric scatterers. JQSRT **89** (2004).

[4] P-S. Kildal. Artificially Soft and Hard Surfaces in Electromagnetics. IEEE Transactions on Antennas and Propagation **38**(10) (1990).

[5] E.N. Korshunova, A.N. Sivov, and A.D. Shatrov. Journ Comm Tech and Electron. **45** (2000).