Chain Model Of Knowledge Base Of Telecommunication Systems Dielectric Structures

Volodymyr Shulha[1], Dmytro Volokitin[1], Tetiana Prykhodko[1], Ivan Basiuk[1], Denys Nevinskyi[2]

[1] National Aviation University, Kyiv, Ukraine
[2] Lviv Polytechnic National University, Lviv, Ukraine (*nevinskiy90@gmail.com*

***Abstract* — A chain model of an irregular dielectric structure is proposed. This model can serve as a basis for the information technologies creation of the production process supporting and diagnostics of irregular dielectric structures.**

***Keywords* — dielectric structures, frequency, diffraction, Maxwell equations, waves.**

I. INTRODUCTION

Nowadays, dielectric structures (coatings) are used in high-speed telecommunications systems with the help of which it is possible to improve their various characteristics: to reduce the effective scattering area (ESA) [1-3], to increase the frequency and angular selectivity of filtering devices, and to improve the quality of the matching.

In determining the diffraction field, the main difficulty is to determine the tangential component of the field at the diffraction object. This field is determined on the basis of physical considerations or from the solution of integral equations [4,5]. In the first case, due to the errors in physical representations, the accuracy of determining the field in the far zone, and, consequently, in the ESA, can be quite low. When using integral equations, it is impossible, as a rule, to obtain analytical solutions. Therefore, the results obtained by numerical methods are mostly private and do not allow to analyze the scattered field completely.

When solving diffraction problems, when the wavelength is much smaller than the dimensions of the reflecting body, acceptable results are obtained by determining of the tangential component of the field in the approximation of the theory of plane-layered media [4-6]. However, in this case, when the number of layers of the dielectric structure is more than one, the problem of the field determining becomes too cumbersome.

The aim of the article is to determine the chain model of dielectric structures in the approximation of the theory of planar media with an arbitrary number of layers.

The solution of this problem is based on the transformation of Maxwell's equations into a system of telegraph equations of long lines and the use of the four-terminal network theory to determine the various electrical characteristics of a dielectric structure.

II. SURFACE RESISTANCE OF LAMINATED COATING

Suppose that a plane homogeneous wave is incident at an angle φ_0 to the interface between two media (Fig. 1).

Electromagnetic field, varying in time according to the harmonic law $\exp(j\omega t)$, is described by the Maxwell equations [7]:

$$\begin{aligned} rot\,\vec{H} &= j\omega\varepsilon\vec{E} \\ rot\,\vec{E} &= -j\omega\mu\vec{H} \end{aligned} \quad (1)$$

For TE waves ($E_y = E_z = 0$), propagating along the axis y, we have:

$$\begin{aligned} E_x &= U(z)e^{-j\beta y} \\ H_y &= V(z)e^{-j\beta y} \\ H_z &= F(z)e^{-j\beta y} \end{aligned} \quad (2)$$

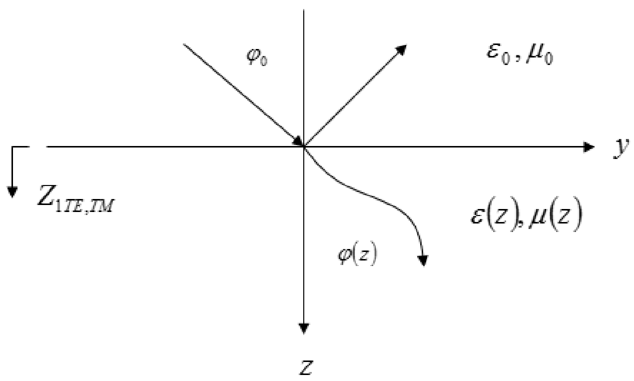

Fig. 1. Passage of a wave through an irregular medium.

Functions $U(z), V(z), F(z)$, as seen from (1), (2), are connected by telegraph equations:

$$\begin{aligned} -\frac{dU}{dz} &= j\omega\mu V \\ -\frac{dV}{dz} &= \left(j\omega\mu + \frac{\beta^2}{j\omega\mu}\right)U \end{aligned} \quad (3)$$

$$\beta U + \omega\mu F = 0 \quad (4)$$

Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 4 Issue 5, May - 2017

These equations can be compared to a distributed circuit in the form of a transmission line [8] with a wave resistance:

$$Z_{\hat{a}TE} = \frac{\omega\mu}{\sqrt{k^2+\beta^2}} = \sqrt{\frac{\mu}{\varepsilon}}\sqrt{1-\frac{\beta^2}{k^2}}^{-1}, k = \omega\sqrt{\varepsilon\mu} \qquad (5)$$

and delay time:

$$\tau_\beta = \frac{1}{\omega}\int_0^Z \sqrt{k^2-\beta^2}dz \qquad (6)$$

When considering a TM wave ($H_y = H_z = 0$) In this case, in all relations for TE waves it is necessary to make a substitution ε for $(-\mu)$, μ for $(-\varepsilon)$ and field components $E(H)$ replace, respectively, with $H(E)$. In this case, replace the functions with $U(z), V(z), F(z)$, is provided by the equations:

$$-\frac{dU}{dz} = j\omega\varepsilon V$$
$$\frac{dV}{dz} = \left(j\omega\mu + \frac{\beta^2}{j\omega\varepsilon}\right)U \qquad (7)$$
$$\beta U - \omega\mu F = 0 \qquad (8)$$

Equations (7) correspond to a line with a wave impedance:

$$Z_{\hat{a}TM} = \frac{1}{\omega\varepsilon\sqrt{k^2-\beta^2}} = \sqrt{\frac{\mu}{\varepsilon}}\sqrt{1-\frac{\beta^2}{k^2}}^{-1} \qquad (9)$$

The delay time in this case is determined exactly as for TE waves by formula (6). The constant propagation β is determined by Snell's law [7]:

$$\beta = k_0 \sin\varphi_0 = k(z)\sin\varphi(z) = const \qquad (10)$$

To determine the surface resistance of an irregular layer, we represent this layer in the form of a set of homogeneous (regular) layers with a constant wave resistance, as shown in Fig. 2, where $Z_1, Z_2, \dots, Z_M$ - surface resistances on the side of the corresponding layer, Z_i- surface resistance of the boundary medium. In the general case, absolute dielectric and magnetic permeability's ε_i, μ_i are complex quantities.

Since each layer can be represented as a homogeneous segment of the transmission line, it is possible to use the four-terminal network theory [9] to determine the surface resistance of a layered structure, according to which the surface resistance can be calculated from the recurrence formula:

$$Z_i = Z_{i11} - \frac{Z_{i12}^2}{Z_{i22}+Z_{i+2}}, \qquad (11)$$
$$i = 1,2,3,\dots,M$$

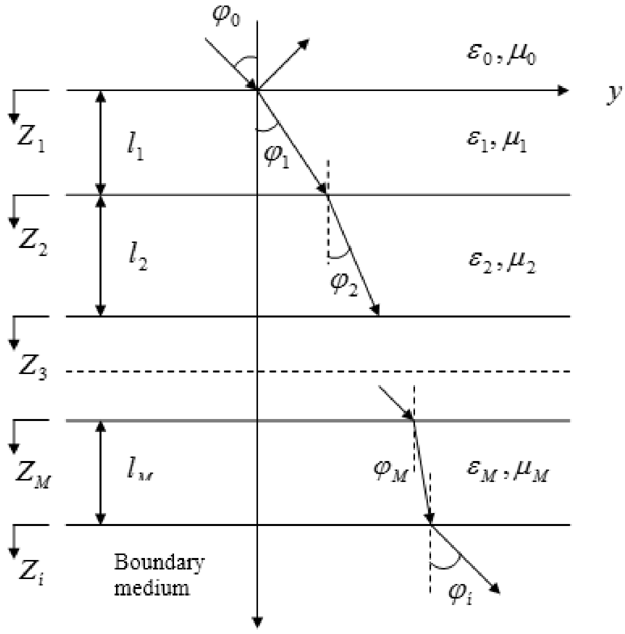

Fig. 2. Layered medium

where Z_i- Surface resistance of layer with number $i = M, M-1, \dots, 2, 1$.

Under the surface impedance when the TE wave fall, according to Equation (3), we perceive the input resistance of the transmission line [8]:

$$Z_{TE} = \frac{U}{V} = \frac{E_x}{H_y}$$

When considering the TM wave, according to equation (7), the input resistance of the transmission line (surface resistance) is:

$$Z_{TM} = -\frac{V}{U} = -\frac{E_y}{H_x}$$

The elements of the matrix of a homogeneous layer resistance are determined by the known expression for regular long lines [8]:

$$Z_{i11} = Z_{i22} = -jZ_{\beta iTE,TM}\,\mathrm{ctg}\,\omega t_{\beta i} \qquad (12)$$
$$Z_{i12} = -jZ_{\beta iTE,TM}\frac{1}{\sin\omega t_{\beta i}} \qquad (13)$$

Wave resistance and delay times of individual layers are calculated according to formulas (5), (6), (9), (10):

$$Z_{\beta iTE} = \sqrt{\frac{\mu_i}{\varepsilon_i}}\sqrt{1-\frac{\varepsilon_0\mu_0}{\varepsilon_i\mu_i}\sin^2\varphi_0}^{-1} \qquad (14)$$

$$Z_{\hat{a}iTM} = \sqrt{\frac{\mu_i}{\varepsilon_i}}\sqrt{1-\frac{\varepsilon_0\mu_0}{\varepsilon_i\mu_i}\sin^2\varphi_0}^{-1} \qquad (15)$$

$$t_{\beta i} = l_i\sqrt{\mu_i\varepsilon_i}\sqrt{1-\frac{\varepsilon_0\mu_0}{\varepsilon_i\mu_i}\sin^2\varphi_0}^{\,-1} \qquad (16)$$

where l_i - layer thickness with number i (Fig. 2). In expression (11) at $i = M$ the value $Z_{M+1} = Z_i$ describes the surface resistance of the boundary medium, and at $i = 1$ function Z_1 is equal to the surface resistance of the irregular layer. Obviously, that at $M \to \infty$ function Z_1 tends to the surface resistance of the smoothly irregular layer from the foregoing it follows that it is necessary to determine the surface resistance starting from the layer with the number M. Further there is the layer with a number $M-1$ etc.

From the foregoing, it follows that plane-layered media can be calculated using the theory of four-poles [9]. In this medium, shown in Fig. 2. Corresponds to the cascade connection of the n four-terminal network in Fig.3

Resistance Z_i and Z_i are from equations:

$$Z_i = \frac{\sqrt{\frac{\mu_0}{\varepsilon_0}}}{\cos\varphi_0}$$
$$Z_i = \sqrt{\frac{\mu_i}{\varepsilon_i}}\sqrt{1-\frac{\varepsilon_0\mu_0}{\varepsilon_i\mu_i}\sin^2\varphi_0}^{\,-1} \qquad (17)$$

For TE waves and expressions:

$$Z_i = \sqrt{\frac{\mu_0}{\varepsilon_0}}\cos\varphi_0$$
$$Z_i = \sqrt{\frac{\mu_i}{\varepsilon_i}}\sqrt{1-\frac{\varepsilon_0\mu_0}{\varepsilon_i\mu_i}\sin^2\varphi_0}^{\,-1} \qquad (18)$$

For TE waves and expressions. Elements of the resistance matrix of individual four-ports are determined according to formulas (12) - (14).

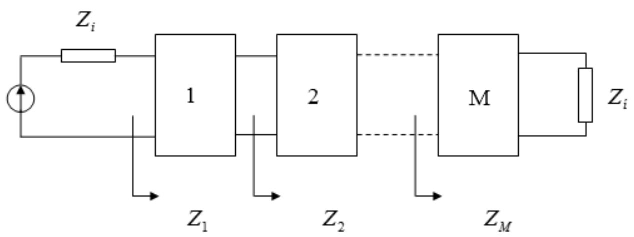

Fig. 3. Chain model of a layered dielectric structure

III. CONCLUSIONS

The main result of the research is the obtaining of analytical expressions for the composite four-terminal networks that determine the parameters of individual layers of a multilayer dielectric structure. The developed chain model can be used in the approximation of physical optics in determining the frequency-angular characteristics of dielectric structures.

The proposed chain model can serve as the basis for the knowledge base in the creation of information technology of the production process supporting and irregular structures diagnosing.

The advantage of the obtained results is the possibility of the methods of a well-developed classical chain theory using [8-11] for the solution of purely electrodynamic problems and the theory of long lines [8]. This circumstance makes it possible to solve the problem of the distributed parameters of the plates layers determining as a synthesis problem. In cases where the limitations of physical optics are not met, the solutions obtained by the theory of circuits can be used as a first approximation for solving integral equations of electrodynamics [5].

REFERENCES

[1] Aviat. Week and Space Technol.-1996.-114-N 6 - p. 26-28.

[2] Aviat. Week and Space Technol.-1996.-144-N 19- p. 57.

[3] Fizicheskiye osnovy diapazonnykh technologiy Stels / Masalov S.A., Ryzhak A.V., Sukharevskyi O.I., Shkil V.M. - Sankt-Peterburg.: VYKU im.Mozhayskoho A.F. -1999.-163p.

[4] Sukharevskyi O.I., Vasylec V.A., Horelyshev S.A., Nechytaylo S.V., Tkachuk K.I. Efektyvnaya ploshchad rasseyaniya (YePR) objektov s neidealno otrazhayushchei poverkhnostiu, imeyushchey izlomy // Zarubezhnaya radioelektronika. - 2001.- N 6.- P.41-47.

[5] Fundamentalniye I prykladniye zadachi teoriyi rasseyaniya elektromahnitnykh voln / Syrenko Yu.K. Sukharevskyi I.V., Sukharevskyi O.I., Yashyna N.P./ Pod red. Syrenko Yu.K. -Kh.: Krok. -2000.- 344p.

[6] Brekhovskykh L.M. Volny v sloyistykh sredakh. - M.: Nauka. -1973. -343p.

[7] Nikolskyi V.V. Elektrodynamika I rasprostraneniye radiovoln.-M.:Nauka, 1973.-607p.

[8] Fusko B. SVCH cepi. Analiz I avtomati-zirovannoye proektirovaniye. - M.: Radio I svyiaz, 1990.- 288 p.

[9] Lykhachov V.L. Elektrotechnika v 2-kh tomakh.-M.: Salon-P, 2001.-1100p.

[10] Kozlovskyy, V., Parkhomey, I., Odarchenko, R., Gnatyuk, S., Zhmurko, T. Method for UAV trajectory parameters estimation using additional radar data. IEEE 4th International Conference Methods and Systems of Navigation and Motion Control, MSNMC 2016 – Proceedings

V.Shulha, I.Basiuk, D.Nevinskyi Construction of the Quick-Acting Integrated Circuits Basic Elements of Telecommunication Means, Journal of Multidisciplinary Engineering Sciences and Technology Vol. 4 Issue 4, April – 2017 p. 7137-7139