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Electrodynamic analysis of materials for the antenna elements

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Abstract. The electrodynamic problem of electromagnetic field propagation in a two-layer dielectric structure has been set and solved. A constructive solution is proposed for controlling the propagation conditions of a surface wave in the wall of a controlled radiant cone or antenna cover by introducing an additional dielectric layer between the fairing wall and the contact radiator.

1. Introduction
In the practice of monitoring radio-transparent antenna fairings and shelters, along with far-field methods, increasing use is provided by contact methods using, for example, horn or rod dielectric emitters [1].

In the implementation of contact methods in the wall of the controlled fairing, the excitation of a surface wave is inevitable, the reflection of which from the base, the vertex and other elements that violate the regularity of the propagation of the electromagnetic wave is accompanied by the appearance of additional measurement errors [2].

2. The main provisions
To exclude the measurement errors, it is proposed to place an additional layer between the radiator and the wall of the monitored fairing, the choice of the dielectric permittivity of the material will allow changing the nature of the propagation of the electromagnetic field in the fairing wall [3, 4].

To assess the influence of the surface wave propagating in the dielectric wall of the fairing, consider the structure of the field on the results of measurements of the structural and electrical parameters (figure 1) [5].

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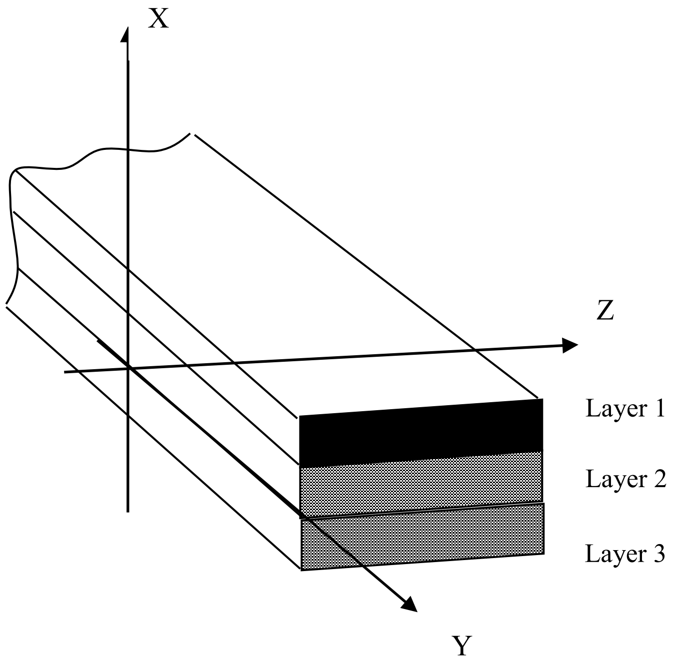

Figure 1. Two-layer dielectric structure "additional dielectric layer 1 (ε_1, μ_1) - wall section of the monitored element 2 (ε_2, μ_2)", located on a metal base-reflector 3.

So for layer 2 it is fair:

$$\begin{cases} E_z = [A_1 \sin(gx) + A_2 \cos(gx)] \times \exp(-jhz), \\ H_y = j\dfrac{\omega\varepsilon_2}{g} \times [A_1 \cos(gx) + A_2 \sin(gx)] \times \exp(-jhz), \\ E_x = -j\dfrac{h}{g} \times [A_1 \cos(gx) + A_2 \sin(gx)] \times \exp(-jhz), \end{cases} \quad (1)$$

where h, g - respectively, longitudinal and transverse wave numbers, the combinations of which determine the spectrum of waves that can propagate in layer 2;

A_1, A_2 - amplitudes of odd and even waves, respectively;

ε_2 - relative permittivity of the material of the product wall.

The wave numbers h, g are related by:

$$h^2 + g^2 = k_0\varepsilon_2. \quad (2)$$

The imposition of the boundary condition for X=0 (Figure 1) suggests that it is possible to distribute only even electric waves in the fairing wall, since $A_1 = 0.$ Hence the solution for the field in the dielectric wall of the fairing takes the form:

$$\begin{cases} E_z = [A_2 \cos(gx)] \times \exp(-jhz), \\ H_y = j\dfrac{\omega\varepsilon_2}{g} \times [A_2 \sin(gx)] \times \exp(-jhz), \\ E_x = -j\dfrac{h}{g} \times [A_2 \sin(gx)] \times \exp(-jhz), \end{cases} \tag{3}$$

Now consider the solution in the additional dielectric layer (layer 1). The field in layer 1 with respect to the field in the dielectric wall of the article, depending on the ratios of the relative permittivities of the materials of which layer 1 and layer 2 are made, can be either accelerated or delayed. For the field in the additional dielectric layer, which is slowed relative to the field in the fairing wall, we write:

$$\begin{aligned} E_z &= Bsh(px+a) \times \exp(-jhz), \\ E_x &= B\frac{jh}{p} ch(px+a) \times \exp(-jhz), \\ H_y &= B\frac{j\omega\varepsilon_1}{p} ch(px+a) \times \exp(-jhz), \end{aligned} \tag{4}$$

$$\begin{aligned} E_z &= Bch(px+a) \times \exp(-jhz), \\ E_x &= B\frac{jh}{p} sh(px+a) \times \exp(-jhz), \\ H_y &= B\frac{j\omega\varepsilon_1}{p} sh(px+a) \times \exp(-jhz), \end{aligned} \tag{5}$$

In the systems of equations (4) and (5), the wave numbers p and h are related by

$$h^2 - p^2 = k_0\varepsilon_1. \tag{6}$$

The description of the field in the additional dielectric layer by the systems of equations (4) and (5) is valid for real values of p and a. In the case of imaginary values p and a upon introducing change of variables

$$p = j\mu, \qquad a = j\phi, \tag{7}$$

and using the known connection between functions of complex and real variables

$$\begin{aligned} sh(px+a) &= L\sin(\mu x + \varphi), \\ ch(px+a) &= \cos(\mu x + \varphi), \end{aligned} \tag{8}$$

the system of equations (4) and (5) reduce to a system analogous to the field in the dielectric wall of the article (3).

For a field in free space in front of a two-layer dielectric structure, i.e. at $x > t_{об}$, where $t_{об} = t_{Г1} + t_{Г2}$, the solution is an electromagnetic wave damped exponentially in the direction of the x axis:

$$
\begin{aligned}
&E_z = C\exp(-qx)\exp(-jhz),\\
&H_y = -j\frac{\omega\varepsilon_0}{q}C\exp(-qx)\exp(-jhz),\\
&E_x = -j\frac{h}{q}C\exp(-qx)\exp(-jhz),
\end{aligned} \tag{9}
$$

with wave numbers satisfying the condition

$$h^2 - q^2 = k_0. \tag{10}$$

Applying the boundary conditions at the interface $x = t_{\Gamma 2}$, we obtain the first equation for the calculation of wave numbers:

$$-\frac{g}{\varepsilon_2}tg(gt_{\Gamma 2}) = \frac{p}{\varepsilon_1}th(pt_{\Gamma 2} + a), \tag{11}$$

similarly at the interface $x = t_{об}$:

$$\frac{p}{\varepsilon_1}th(pt_{об} + a) = -q, \tag{12}$$

in addition, we take into account that the longitudinal wave number must be constant for all partial layers. Hence additional equations are formed:

$$h^2 + g^2 = k_2; \quad h^2 - p^2 = k_1; \quad h^2 - q^2 = k_0, \tag{13}$$

where $k_1^2 = k_0^2\varepsilon_1; \quad k_2^2 = k_0^2\varepsilon_2.$ (14)

Thus, the application of boundary conditions makes it possible to form a system of five equations for calculating unknown wave numbers g, p, q, h, a, necessary for determining the amplitude and phase characteristics of the field in the two-layer dielectric structure "additional dielectric layer - the dielectric wall of the controlled article" located on the metal base - reflector:

$$
\begin{cases}
-\frac{g}{\varepsilon_2}tg(gt_{\Gamma 2}) = \frac{p}{\varepsilon_1}th(pt_{\Gamma 2} + a),\\
\frac{p}{\varepsilon}th(pt_{об} + a) = -q,\\
h^2 + g^2 = k_2^2, \quad h^2 - p^2 = k_1^2, \quad h^2 - q^2 = k_0^2.
\end{cases} \tag{15}
$$

The solution of this system is carried out in the following order.

1. Setting the values h, λ determine g, q, p on the equations

$$
\begin{aligned}
&g = \sqrt{(2\pi/\lambda)^2 - h^2};\\
&q = \sqrt{(h \ \ - (2\pi/\lambda)^2};\\
&p = \sqrt{h \ \ - \varepsilon_1(2\pi/\lambda)^2}.
\end{aligned} \tag{16}
$$

2. Setting the values g, q, p into equation

$$-\frac{q\varepsilon_1}{p\varepsilon_2} tg(gt_{\Gamma 2}) = \frac{th(pt_{\Gamma 1}) + (q\varepsilon_1)/p|}{1-(\varepsilon_1/p)th(pt_{\Gamma 1})}, \tag{17}$$

and in the case of non-equality, correct the value of *h* until the equation turns into an identity.
3. Determine the value a from equation

$$a = arcth\left[\frac{q\varepsilon_1}{p\varepsilon_2} tg\left(gt_{\Gamma 2}\right)\right] - pt_{\Gamma 2}. \tag{18}$$

When solving the system of equations (15), the quantities g, q, h are taken to be real and positive, and the quantity a is real. It is obvious that the values of *h* belong to the interval

$$h \in \left\lfloor k_0\sqrt{\varepsilon_1}, ... k_0\sqrt{\varepsilon_2} \right\rfloor. \tag{19}$$

In this case, the solution for the field in the additional dielectric layer (layer 1) is described by the systems of equations (4) and (5), the condition for the applicability of such a solution has the form

$$\varepsilon_1 < \varepsilon_2. \tag{20}$$

The use of system (3) as a solution for the field in an additional dielectric layer leads to an interval of possible values of *h*:

$$k_0 < h < k_0\sqrt{\varepsilon_0}; \quad k_0 < h < k_0\sqrt{\varepsilon_1}. \tag{21}$$

3. Conclusion

The variation of the wave numbers for the two-layer dielectric structure "an additional dielectric layer - the dielectric wall of the controlled fairing" by changing the characteristic parameters of the partial layers allows to control the propagating surface wave in the structure, to redistribute it between the layers and, thereby, to control the resulting error in measuring the parameters of the dielectric wall of the fairing. The considered electrodynamic structure can be realized in a new constructive solution of a microwave sensor for radio wave inspection of antenna fairings.

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