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Research of the matching layer influence on the characteristics of scanning antenna based on multilayer dielectric

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The paper presents the results of studying the influence of matching layers on reflection coefficient S_{11} of a scanning antenna based on multilayer dielectric structures. In view of minimizing return losses, the use of different matching layers in the scanning antenna is considered. It is shown that the two-layer structure provides a wider matching bandwidth than the single-layer one (by 7.4% at the S_{11} level no more than -13 dB). The S_{11} level is not higher than -13 dB in the frequency band of 10.7−12.7 GHz for the deflecting structure with two matching layers and not higher than -17 dB for the scanning antenna.

Keywords: antenna system, matching layer, mechanoelectrical scanning, artificial dielectric.

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Nowadays, satellite communication systems are being actively developed and improved with the aid of loworbit, mediumorbit and highelliptical spacecraft. The main part of a satellite-system ground data terminal is a lowprofile , wide-angle scanning antenna. One of the possible ways to create scanning antennas is using antenna systems with wideangle mechanoelectric scanning based on dielectric materials [1]. To steer the beam position in space, in such antennas there are used mechanically rotating dielectric structures with a variable refractive index, which are installed above the antenna aperture. Scanning in the elevation plane is performed by axial rotation of two deflecting structures by the same angle in opposite directions. However, this scanning technique is characterized by the presence of reflections at the interface between the environment and deflecting structure. As for optical lenses, reflection from their surface is commonly reduced by using matching (antireflection) layers [2,3]. The most widely used is the method of interference antireflection coating with one or several layers of antireflection coating [4,5]. The principle of this method is that the minimum thickness of the antireflection layer is $T_i = \lambda_i/4$ (where λ_i is the wavelength in the dielectric material from which the relevant layer is made), as a result of which waves reflected from surfaces of the lens and antireflection layer are summed in antiphase. In this paper we consider the effect of matching layers of different configurations on characteristics of the scanning antenna based on a multilayer dielectric structure

In optical systems, radiation is deflected by using wedge-shaped lenses (prisms). The deflecting system based on a multilayer dielectric with a linearly varying filling coefficient may be regarded as a plane lens. As per the principle of electrodynamic conformability, interference antireflection coatings may be used in the radio range [6–9].

Fig. 1, *a* presents deflecting structure *m* based on triangular dielectric plates with two antireflection layers (*1* and *2*); a simplified model of antenna with a plane output phase front is used as a beam-steering circuit. The radiation pattern (RP) tilt angle is 30°. Fig. 1, *b* presents the model of the scanning antenna system consisting of two identical deflecting structures *m* located one above another; the number of deflecting structure rows depends on the size of the feeder aperture with accounting for the principle of zoning described in [1]. Relative dielectric constant of the deflecting structure material is $\varepsilon_m = 4$.

Using simplification $n = \sqrt{\varepsilon}$ for the media with relative magnetic permeability $\mu = 1$, it is possible to reduce the expression used in the problem of interference antireflection coating for a single matching layer to

$$\varepsilon_1 = \sqrt{\varepsilon_s \varepsilon_m} \Leftarrow n_1 = \sqrt{n_s n_m}, \tag{1}$$

where $\varepsilon_s = 1$ and ε_m are the relative dielectric constants of the environment and deflecting structure material, respectively, n_s and n_m are the refractive indices of the respective media [2]. When the second matching layer is added, the first layer matches the ε_s and ε_2 layers, while the second one matches the ε_1 and ε_m layers. Then, after deriving a set of equations, we can calculate ε_1 and ε_2 as

$$\begin{cases} \varepsilon_1 = \sqrt{\varepsilon_s \varepsilon_2} = \sqrt[3]{\varepsilon_s^2 \varepsilon_m}, \\ \varepsilon_2 = \sqrt{\varepsilon_1 \varepsilon_m} = \sqrt[3]{\varepsilon_s \varepsilon_m^2}. \end{cases} \tag{2}$$

The given formulae are valid for uniform media. The artificial-dielectric deflecting structure in question has different filling coefficients; its effective dielectric constant varies linearly from $\varepsilon_{eff}^{\max}$ to $\varepsilon_{eff}^{\min}$ (from 4 to 1). Hence, reflection will be also different in different regions of such a structure. In addition, the deflecting structures will rotate in the process of scanning. Therefore, ε_m values in (1)

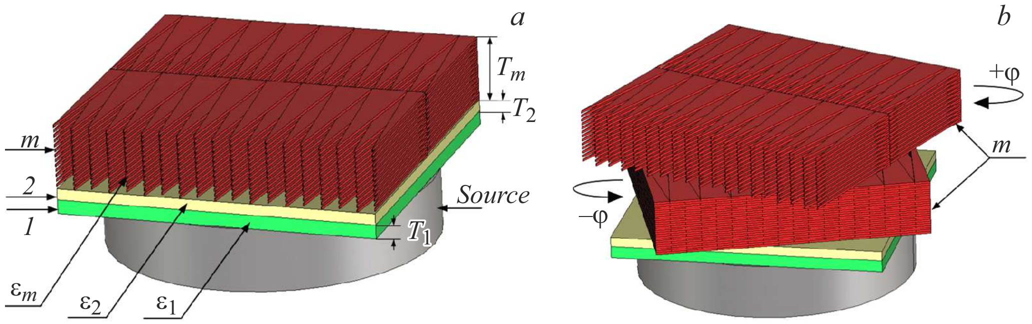

Figure 1. *a* — deflecting structure based on a multilayer dielectric; *b* — scanning system with a two-layer antireflection coating. Relevant comments are given in the text.

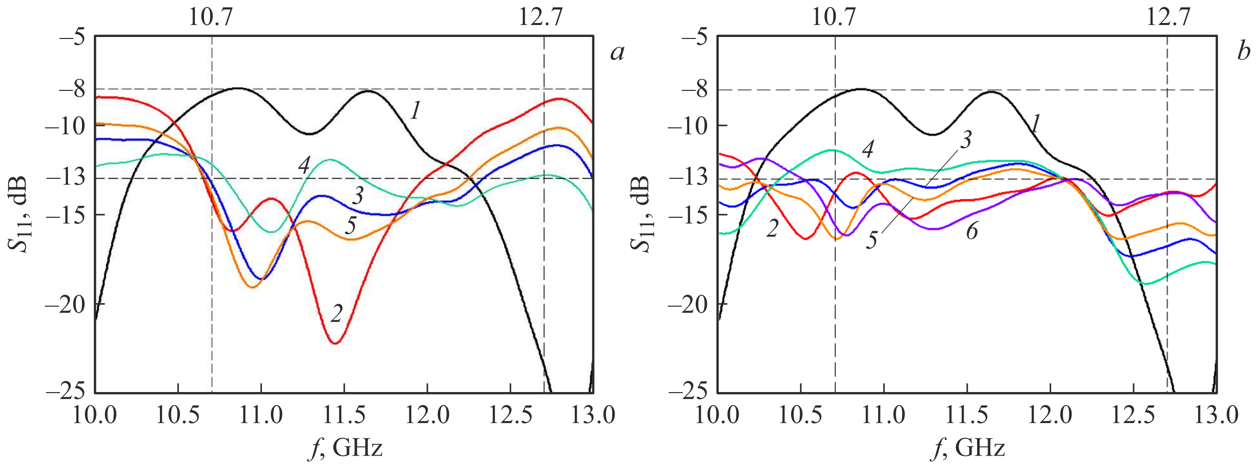

Figure 2. — versus frequency. *a* — at the single-layer antireflection coating, *b* — at the two-layer antireflection coating. The curves are numbered according to the options given in the Table.

Parameters of the matching layers

Option No.	One layer			Two layers			
	ε_{av}	ε_1	T_1, mm	ε_1	T_1, mm	ε_2	T_2, mm
1	–	–	0	–	0	–	0
2	4	2	4.5	1.6	5.1	2.5	4
3	2.5	1.6	5.1	1.36	5.5	1.84	4.7
4	2	1.4	5.4	1.26	5.7	1.6	5.1
5	2.9	1.7	4.9	1.43	5.4	2	4.5
6	2.9	–	–	1.3	5.6	2	4.5

and (2) should be replaced with a certain ε_{av} that is an average of $\varepsilon_{eff}^{\min}$ and $\varepsilon_{eff}^{\max}$. Figs. 2, *a* and *b* present frequency dependences of the deflecting structure reflection coefficient S_{11} for the singlelayer and twolayer antireflection coatings at different ε_{av} and corresponding ε_1, ε_2, T_1 and T_2. Electrodynamic analysis of the proposed structures was performed by using the finite element method. Thereat, open boundary conditions were defined for the boundaries of the counting domain. Parameters of the matching layers are listed in the Table. The following options of the ε_{av} values were used: maximal $\varepsilon_{eff}^{\max}$ (Option 2), arithmetic mean (Option 3), geometric mean (Option 4) and mean-square (Options 5 and 6). To find the optimal configuration of the antireflection layer, we studied the effect of the antireflection layer parameters (thickness, relative dielectric constant, number of layers) on the directional characteristics and matching of the structures under consideration. Option 6 was obtained by optimizing Option 5 based on the criterion of the S_{11} minimization in the frequency band of 10.7–12.7 GHz. The layer *1* thickness was increased by 0.2 mm, while ε_1 was reduced by 0.13 (Fig. 1, *a*). Curves *1* in Fig. 2 (Option 1 in the Table) represent the structure free of a matching layer.

If a matching layer corresponding to any of the considered options is added, the deflecting structure reflection coefficient S_{11} decreases in the frequency band of 10.7–12.7 GHz. However, in the case of the single-layer coating the matching band is narrower, and S_{11} does not exceed -13 dB in the frequency band of 10.7–12.3 GHz (13.9%). In the case of two-layer antireflection coating, the operating frequency band expands, and S_{11} does not exceed -13 dB in the frequency band of 10.5–13 GHz (21.3%).

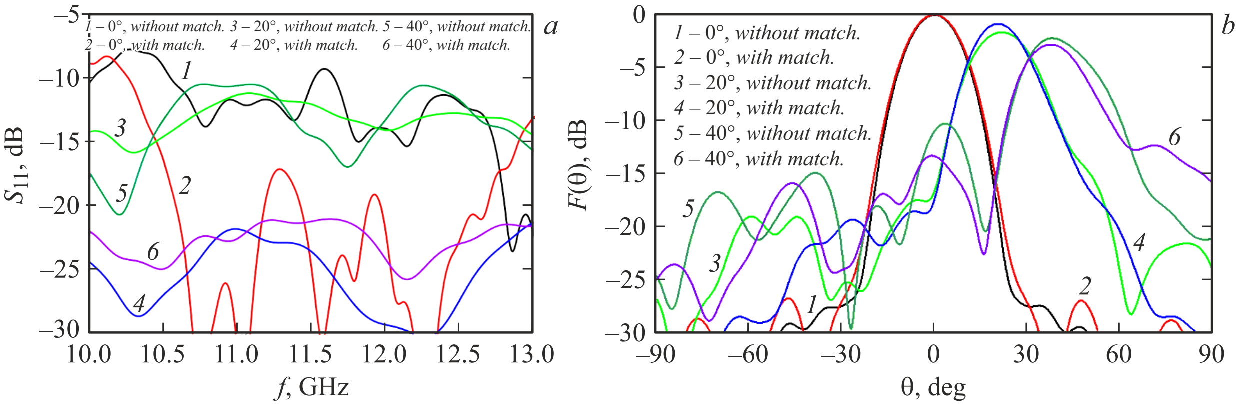

Figure 3. *a* — frequency dependences of the scanning antenna reflection coefficient S_{11} for the parameters corresponding to option 6 in the Table at different pattern tilt angles; *b* — radiation patterns of the scanning antenna.

Fig. 3, *a* demonstrates frequency dependences of reflection coefficient S_{11} for the scanning antennas (Fig. 1, *b*) without matching and with matching (two-layer antireflection coating) at the parameters corresponding to Option 6 (see the Table) at different RP tilt angles. This option has exhibited the possibility of obtaining in the operating frequency band coefficient S_{11} 8 dB less than that of the antenna free of matching layers in the case of non-tilted RP. Fig. 3, *b* presents RPs for the scanning antenna at the positions 0, 20 and 40°. The figure shows that the in the presence of a matching layer the side lobe level decreases by 1.5 dB, while the antenna directive gain (DG) decreases by 0.5 dB. Notice that when RP is tilted to 30°, no decrease in DG is observed.

Thus, the results obtained in this study demonstrate the possibility of improving, by using antireflection layers, the matching characteristics, and, hence, voltage standing wave ratio of the multilayer-dielectric-based scanning antenna. The antireflection layer, as well as the deflecting structure itself, can be realized in the form of planelayered artificial dielectric. In this case, the condition of the geometricmean refractive index of the antireflection layer may be met over the entire lens surface. Extra heat losses arising in the presence of antireflection layers equal 0.0075 dBi and are independent on the deflecting structure rotation angle. If those losses are taken into account, the gain increase may be estimated as approximately 0.3 dBi at the RP tilt angles of up to 30°.

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Conflict of interest

The authors declare that they have no conflict of interests.

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