

## STUDY OF ELECTROMAGNETIC WAVE DIFFRACTION BY A DIELECTRIC COATING AND METAL DIAPHRAGM OVER AN ENDLESS WAVEGUIDE ANTENNA ARRAY

V.I. Magro\*, V.M. Morozov, E.Yu. Trakhtman

*Oles Honchar Dnipro National University, Dnipro, Ukraine*

*\*e-mail: magrov@i.ua*

**A study of the diffraction of an electromagnetic wave on a dielectric coating with a diaphragm over an infinite waveguide antenna array has been carried out. The metal diaphragm is located at some distance from the surface of the antenna array. The influence of the geometric dimensions of a metal diaphragm and its distance from the grating surface on the modulus of the reflection coefficient of the incident wave in waveguides is investigated. Dielectric coatings with different values of the dielectric constant are considered.**

**Keywords:** metal diaphragm, dielectric covering layer, reflection coefficient, dielectric constant.

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### 1. Introduction

The study of the process of diffraction of an electromagnetic wave on a complex structure in the form of a diaphragm in a guiding structure and a dielectric is considered in a number of works. Most often, such works are devoted to the study of metal diaphragms in a rectangular waveguide, which is partially filled with a dielectric. It was shown in [1] that the losses in the dielectric do not shift the resonance frequency of the diaphragm with the slit, which is partially filled with the dielectric, but significantly increases the reflection coefficient from it. The paper [2] considers the effects caused by placing a diaphragm in a rectangular waveguide filled with various frequency-dependent dielectric materials. A waveguide junction is investigated, which is formed by horizontal and vertical diaphragms inside a rectangular waveguide. Areas on either side of the diaphragm are filled with various frequency dependent dielectric materials. The propagation of electromagnetic waves through this inhomogeneity is considered. In [3], thin metal transverse resonant diaphragms with a complex aperture in rectangular waveguides are investigated. Such diaphragms are used to create band-pass filters with improved properties. Resonant diaphragms are manufactured by metallization of a thin dielectric substrate. Such a resonant structure in a rectangular waveguide makes it possible to create compact filters with a bandwidth of 10%.

In [4], a band-pass filter with an inductive diaphragm in the H-plane and a band-pass filter for the millimeter range are considered. Formulas are proposed for calculating such complex electrodynamic structures and methods for manufacturing diaphragms. In paper [5], a general theory of modeling diffraction on antenna arrays is presented, taking into account the peculiarities of diffraction at the sharp edges of scatterers. This paper considers the difference between the exact and optical solution of the wedge diffraction problem. In some works, the analysis of diffraction is carried out by the spectral method [6].

It is quite obvious that a complex metal-dielectric structure (Fig. 1, a), which is located in the "Floquet channel" can significantly change the characteristics of radiation due to the diffraction of the surface wave on this structure [7]. In particular, the magnitude of the modulus of the reflection coefficient of the incident wave in the waveguides can be significantly changed. A partial case of such structure is the completely independent problem of electromagnetic wave diffraction by a dielectric coating with a diaphragm (Fig. 1, b).

### 2. Formulation of the problem

Consider a unit cell of a linear infinite lattice, which is located at the origin of coordinates (Fig. 1, b). Let us conditionally divide the domain of determination of the electromagnetic field in a unit cell into two areas.

Region 1 (waveguide):  $-\infty \leq z \leq 0, -w/2 \leq x \leq w/2$ . Region 2 (spatial waveguide, "Floquet channel"):  $0 \leq z \leq \infty, -f/2 \leq x \leq f/2$ . Based on Green's second formula, the integral representation for the electric field strength in region 2 has the form:

$$E_y^{2d}(x, z) = \int_{-w/2}^{w/2} E_y^{2d}(x, 0) \frac{\partial G^{2d}(x, z, x', z')}{\partial z'} \Big|_{z'=0} dx' - \int_{-f/2}^{-h_{oi}/2} G^{2d}(x, z, x', z') \frac{\partial E_y^{2d}(x', z')}{\partial z'} \Big|_{z'=diz} dx' - \int_{h_{oi}/2}^{f/2} G^{2d}(x, z, x', z') \frac{\partial E_y^{2d}(x', z')}{\partial z'} \Big|_{z'=diz} dx'.$$

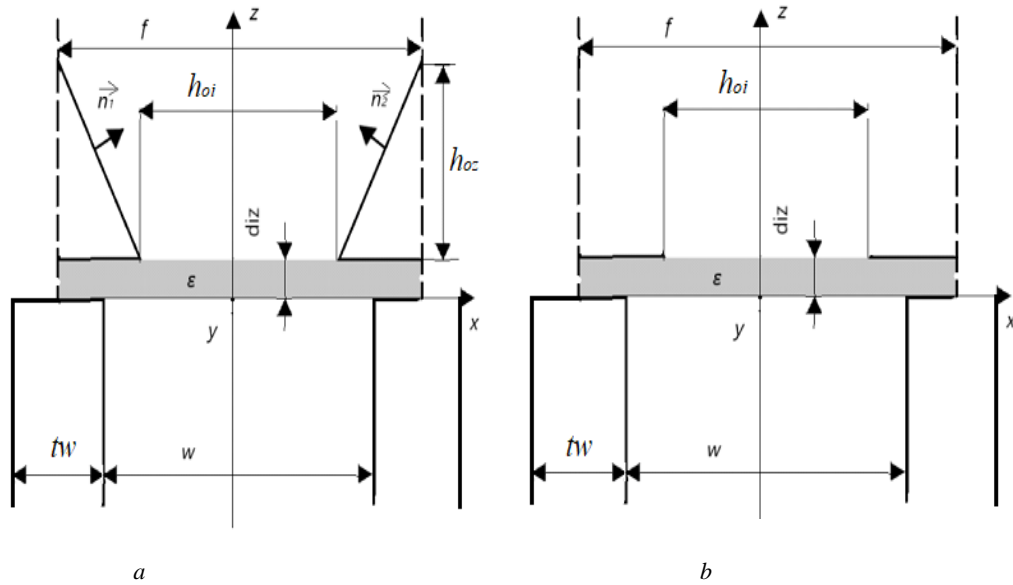


Fig. 1. Metal-dielectric structure in the "Floquet channel" of the antenna array.

The representation for the electric field strengths for the selected regions, the expression for the Green's function of the second region, the boundary conditions for the problem under consideration are given in [7].

### 3. Calculation results

To check the correctness of the developed algorithm for calculating this structure, the limiting case was calculated with the dimensions  $h_i=f, \epsilon=3.0625, diz=\lambda_\epsilon/8; \lambda_\epsilon/4; \lambda_\epsilon/2; \lambda_\epsilon$  (hereafter  $\lambda_\epsilon$  means a wavelength in dielectric medium with permittivity  $\epsilon$ ). Thus, we have an infinite array of open ends of waveguides, in the aperture of which there is a single dielectric layer [8]. The results of the calculation coincide with the graphical accuracy with the results of the work [8]. This confirms the correctness of the developed calculation algorithm.

The diffraction of a surface wave on such a structure is influenced by the geometric dimensions of the metal diaphragm ( $h_{oi}$ ) and its distance from the grating surface ( $diz$ ). The influence of the specified geometric dimensions on the reflection coefficient of

incident waves in waveguides at certain values of the dielectric constant  $\epsilon$  is investigated. A study was conducted for two cases:

1. dielectric-metal structure with a dielectric constant  $\epsilon=1$ ;
2. metal-dielectric structure with dielectric constant values  $\epsilon=1.6$ ; 2; 3.0625.

The study of the reflection coefficient modulus dependence on the scanning angle was carried out at various values of the distance between the diaphragm and the surface of the antenna array (we keep the designation  $\lambda_\epsilon$  for distance measure, though  $\epsilon=1$  (Fig. 2)). It can be seen that the value  $diz = \lambda_\epsilon/8$  should be considered as the optimal distance of the diaphragm from the surface of the antenna array among analyzed ones. Further studies showed that moving the aperture away from the antenna array surface to  $diz = \lambda_\epsilon/16$  provides a general decrease in the value of the reflection coefficient modulus for all scanning angles in comparison with the value  $diz = \lambda_\epsilon/8$ .

For values  $diz = \lambda_\epsilon/8$ ;  $\lambda_\epsilon/16$ , a study of the reflection coefficient modulus dependence on the scanning angle was carried out also for various values of the diaphragm size  $h_{oi} = 0.5714\lambda_\epsilon$ ;  $0.4\lambda_\epsilon$ ;  $0.3\lambda_\epsilon$ ;  $0.2\lambda_\epsilon$  (Fig. 3). The general trend with decreasing  $h_{oi}$  size is a general increase in the value of the reflectance modulus for some values of the scanning angles. In this case, for some scanning angles, it is possible to significantly reduce the value of the reflection coefficient modulus. For example, for  $diz = \lambda_\epsilon/16$  at  $h_{oi} = 0.4\lambda_\epsilon$  it is possible to reduce the value  $|R|$  noticeably in the sector of scanning angles  $\sin\theta = [0.55-0.75]$ ; for  $diz = \lambda_\epsilon/8$  at  $h_{oi} = 0.3\lambda_\epsilon$ , one can significantly reduce the value  $|R|$  in the sector of scanning angles  $\sin\theta = [0.4-0.75]$ . Such reasoning is valid for antenna arrays with a common wall thickness  $t_w=0$  (Fig. 3). With an increase in the thickness of the common wall between the waveguides, an insignificant increase in the incident wave value in the waveguides is observed in comparison with the value  $t_w=0$  (Fig. 4). For the value of the dielectric constant of the coating  $\epsilon=3.0625$ , the dependence  $|R|$  on the scanning angle is shown in Fig. 5. A general increase in the  $|R|$  value is observed here. A significant increase in the  $|R|$  value is observed with an increase in the thickness of the common wall between the waveguides (Fig. 5, b).

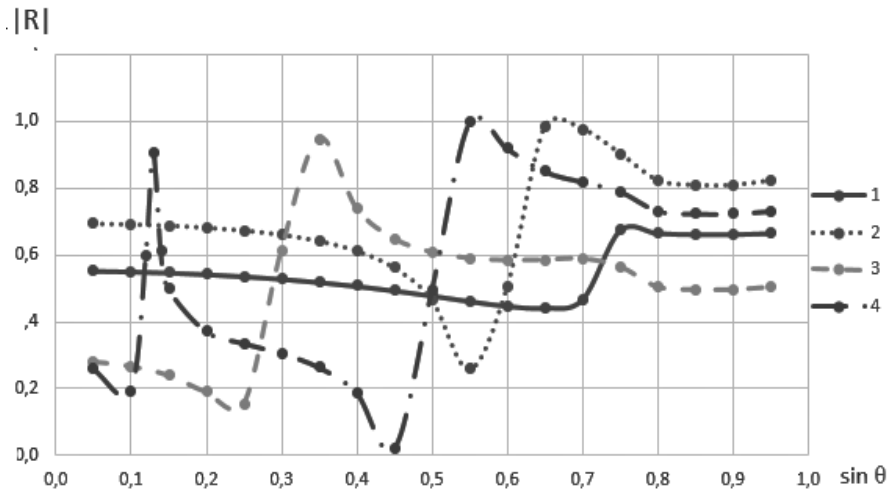
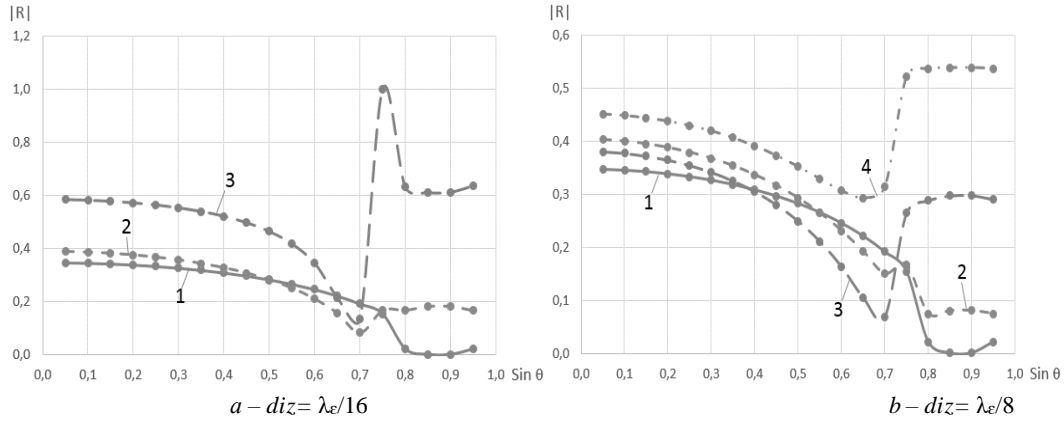
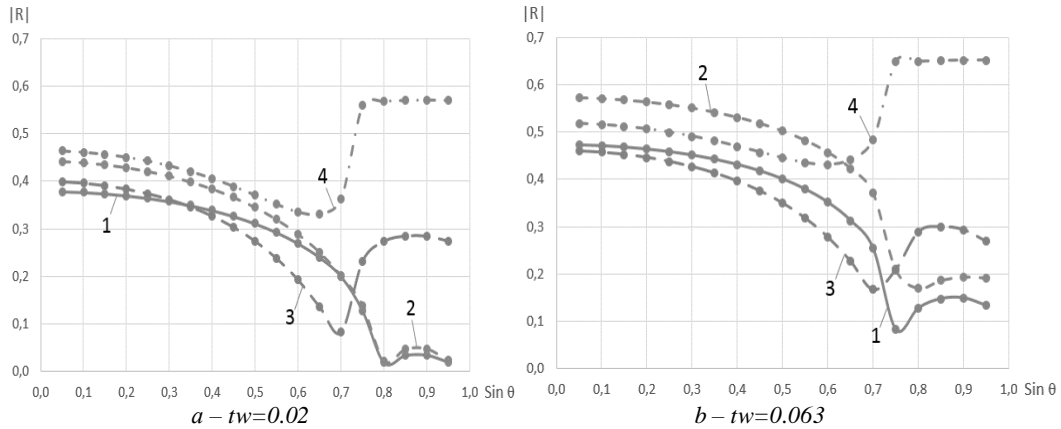


Fig. 2. Dependence of the reflection coefficient modulus on the scanning angle for antenna array with a single-layer dielectric covering ( $\epsilon=1$ ): 1 –  $\lambda_\epsilon/8$ ; 2 –  $\lambda_\epsilon/4$ ; 3 –  $\lambda_\epsilon/2$ ; 4 –  $\lambda_\epsilon$ .



**Fig. 3.** Dependence of the reflection coefficient modulus on the scanning angle ( $\varepsilon=1, diz=\lambda_\varepsilon/8; \lambda_\varepsilon/16$ ) for  $h_{oi}$  values: 1 –  $0.5714\lambda_\varepsilon$ ; 2 –  $0.4\lambda_\varepsilon$ ; 3 –  $0.3\lambda_\varepsilon$ ; 4 –  $0.2\lambda_\varepsilon$ .

The study of the structure was under consideration at the value  $\varepsilon=2$ . Considered values were  $diz=\lambda_\varepsilon/4; \lambda_\varepsilon/8$  at  $tw=0$  (Fig. 6). For these two  $diz$  sizes, smaller values of  $|R|$  were observed at  $diz=\lambda_\varepsilon/8$ . With such a thickness of the dielectric, it is possible to reduce the value  $|R|$  in a narrow range of scanning angles for  $h_{oi} = 0.4\lambda_\varepsilon$ . Other sizes  $h_{oi}$  either do not significantly change the considered dependence or lead to an increase of  $|R|$ . For the values  $\varepsilon=1.6, diz=\lambda_\varepsilon/8, tw=0$  decreasing the  $|R|$  value compared the cases discussed above is impossible.



**Fig. 4.** Dependence of the reflection coefficient modulus on the scanning angle ( $\varepsilon=1, diz=\lambda_\varepsilon/8$ ) for  $h_{oi}$  values: 1 –  $0.5714\lambda_\varepsilon$ ; 2 –  $0.4\lambda_\varepsilon$ ; 3 –  $0.3\lambda_\varepsilon$ ; 4 –  $0.2\lambda_\varepsilon$ .

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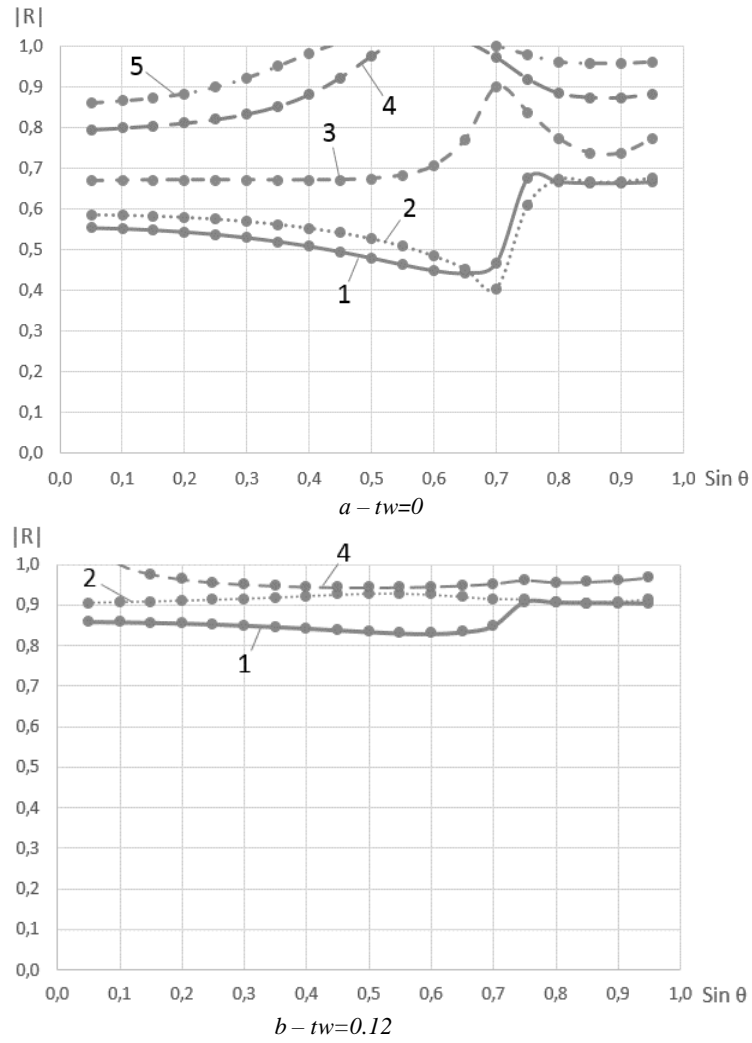


Fig. 5. Dependence of the reflection coefficient modulus on the scanning angle ( $\epsilon=3.0625$ ,  $diz=\lambda_\epsilon/8$ ) for  $h_{oi}$  values: 1 –  $0.5714\lambda_\epsilon$ ; 2 –  $0.4\lambda_\epsilon$ ; 3 –  $0.3\lambda_\epsilon$ ; 4 –  $0.2\lambda_\epsilon$ .

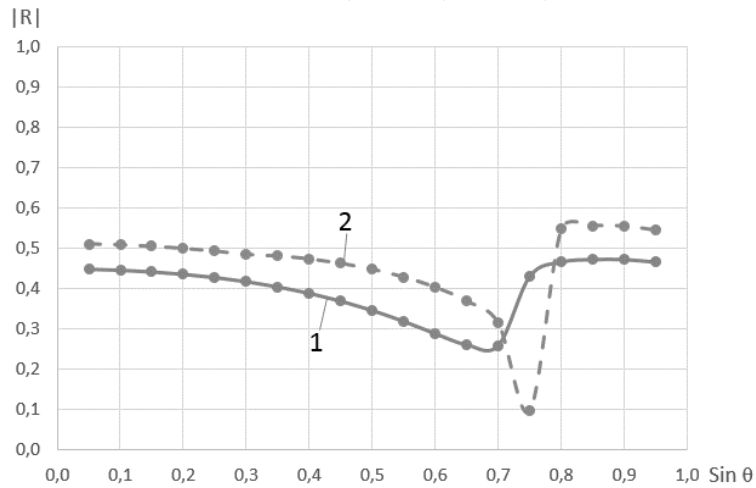


Fig. 6. Dependence of the reflection coefficient modulus on the scanning angle ( $\epsilon=2$ ,  $diz=\lambda/8$ ) for  $h_{oi}$  values: 1 –  $0.5714\lambda_\epsilon$ ; 2 –  $0.4\lambda_\epsilon$ .

#### 4. Conclusions

A study of the diffraction of an electromagnetic wave by a dielectric coating and a diaphragm over an infinite waveguide antenna array has been carried out. Optimizing the geometric dimensions of the aperture according to the criterion of the reflection coefficient minimum shows that for the value of the dielectric constant  $\epsilon=1$ , the dimensions  $diz=\lambda_\epsilon/16$  can be considered as the optimal aperture distance from the surface of the antenna array. Optimization for the value of the dielectric constant  $\epsilon=2$  shows that the optimal distance of the diaphragm from the antenna array surface is  $diz=\lambda_\epsilon/8$ . Scanning angle sectors with a better reflection coefficient reducing are indicated.

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