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CONTROL OF THE RADIATION CHARACTERISTICS OF A LEAKY-WAVE ANTENNA BY MANIPULATION OF THE GRATING PROFILE

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Abstract

A leaky-wave antenna consisting of a lamellar grating of finite extent fed by a planar dielectric waveguide is considered. The mathematical model of the antenna is improved for calculating of the apertures with large size. The possibilities of the radiation characteristics control by choosing of grating profile with linear variation of the groove depths are investigated.

Keywords: leaky-wave antenna, planar dielectric waveguide, rectangular grooves, Fourier transformation.

1. INTRODUCTION

Development of antennas based on gratings excited by a surface wave of a dielectric waveguide is a perspective direction in the microwave antenna technology. These antennas are widely used in radar and navigation systems with electro-mechanical scanning. In these applications among all possible choices the lamellar grating is one of the most manufacturable solutions [1].

One of the main problems in design of such antennas is due to the difficulties with organization of the required field distribution on the aperture. If a planar dielectric waveguide is parallel to an equidistant grating, the leaky wave in the system “dielectric waveguide – grating” loses its energy propagating along the grating. The resulting field distribution is exponentially decreasing along the grating and characterized by the asymmetric radiation pattern with “covered” zeroes and low directivity.

One of the possible ways to resolve this problem is the use of a bent dielectric waveguide. Selection of the optimum profile of the waveguide allows controlling of the coupling between the waveguide and the grating, and it hereby facilitates organizing of the desired field distribution, for example, such as “cosine on a pedestal” as in [2].

In [3] the accurate two-dimensional mathematical model of such kind of antennas has been built for the case when a planar dielectric waveguide is parallel to a grating (Fig. 1).

In spite of its two-dimensionality the model gives quite accurate description of the real antenna, which size in the direction parallel to lamellas is quite large. The model takes into account the finite extent of a grating and allows calculating the radiation and energy characteristics of the antenna.

The main computational complexity in calculating the antenna with this model is to calculate the Fourier transformation of slowly decreasing functions with poles and branch points. In [3] the deformation of the path of integration was used to bypass all the singularities of the integrand. However, this approach restricted the sizes of calculable apertures up to 30-50 wavelengths depending on the size of the gap between the planar dielectric waveguide and the grating. This problem has been solved by using the other approach to calculate the Fourier transformation, which removed restrictions on the size of the aperture.

This model is suggested to be used for solving of the actual problem of the radiation characteristics control of the antenna by the grating profile optimization. The efficiency of interaction between a groove and a surface wave of a dielectric waveguide depends on groove sizes. Therefore the field distribution on the aperture can be controlled by choosing the grating profile. This approach is more practically feasible compared to bending of a dielectric waveguide. In this paper the radiation and energy characteristics of the antenna with

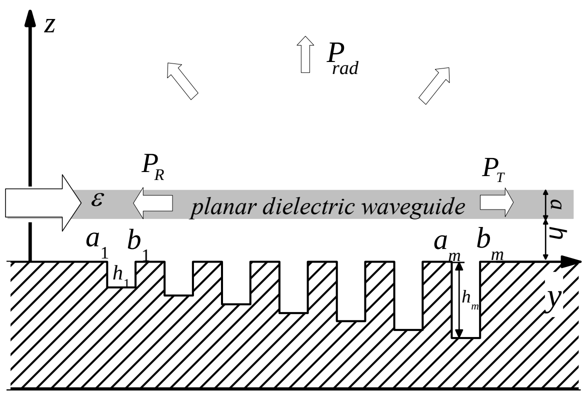

Fig.1. Two-dimensional model of the leaky-wave antenna

linear variation of the groove depths are investigated.

2. Description of the Mathematical Model

Two-dimensional model of the antenna is shown in Fig. 1. It is a waveguide system consisting of a planar dielectric waveguide of the thickness a made of material with dielectric permittivity e and placed above the perfectly conductive surface with finite number of rectangular grooves.

The case of the excitation by a TM surface mode with respect of the propagation direction y is considered.

The problem of the scattering of this wave by a finite number of rectangular grooves is reduced to a singular integral equation with additional integral conditions [3], which are solved numerically by the method of discrete singularities [4]. Taking into account the behavior of the field in the vicinities of the grating edges provides fast convergence of the algorithm.

The kernel of the integral equation contains the Fourier sine transformation

$$I(y)=\int_0^\infty f_0(\gamma)\sin(\gamma y)\,d\gamma. \qquad (1)$$

The function $f_0(g)$ has poles at the propagation constants of eigenmodes of the dielectric waveguide above the perfectly conductive surface g_n. Besides it has a branch point at $g = k_0 = 2p/l$ and behaves as

$$f_0(\gamma)=O\left(\gamma^2-k_0^2\right)^{-1/2}. \qquad (2)$$

in its vicinity. At infinity the function $f_0(g)$ decreases exponentially and velocity of its decreasing depends on the value of the gap h. The smaller value of h, the slower decreasing of the function $f_0(g)$.

To calculate the integral (1) the path of integration was deformed to bypass all singularities of the integrand in [3]. This approach is quite efficient for small values of y. The larger value of y and the smaller the gap value h, the more points for integrand calculation are required. For quite large values of y the Filon's integration formula fails to converge. It restricts the calculable aperture sizes up to 30-50 wavelengths depending on the gap h. However, in practice the apertures of the antennas are measured in hundreds of wavelengths.

It is shown that it is more efficiently to use another approach to calculate (1) for large values of y. The integral (1) can be represented in the form

$$I(y)=\int_0^\infty f_1(\gamma)\sin(\gamma y)\,d\gamma+ \\ +\sum_n\int_0^\infty\frac{\operatorname{res} f_0(\gamma_n)}{\gamma-\gamma_n}\sin(\gamma y)\,d\gamma, \qquad (3)$$

where the function $f_1(g)=f_0(g)-\sum_n\frac{\operatorname{res}f_0(g_n)}{g-g_n}$ has no real poles. The rightmost integrals in (3) can be calculated analytically. The first integral in the right part of (3) can be split into three parts:

$$I(y)=\left(\int_0^{k_0-\Delta}+\int_{k_0-\Delta}^{k_0+\Delta}+\int_{k_0+\Delta}^{\infty}\right)f_1(\gamma)\sin(\gamma y)\,d\gamma. \qquad (4)$$

The first one in (4) is calculated by the Simpson's rule or the Filon's integration formula depending on the number of the integrand oscillations on the interval of integration. The second integral is calculated by the Gauss' formula, which takes into account the behavior of the integrand in the vicinity of the branch point (2). To calculate the third integral the Euler transformation for acceleration of convergence [5] is used. It determines the truncated upper limit of the integral automatically.

It is shown that with this approach to calculation of integral (1) the number of points for integrand calculation increases linearly with the increase of the value y. Moreover the asymptotic estimation of the integral (1) is obtained by the saddle point method. Combined use of the path deformation when y is small, the described approach, and the asymptotic estimation for very large values of y accelerates the convergence significantly and removes the restriction on calculable aperture size.

In Fig. 2 the radiation pattern is shown for an equidistant grating of 333 grooves with the following parameters: the groove width is 1 mm, the lamella width is 5 mm, the groove depth is 2.5 mm, the dielectric waveguide thickness is 3 mm, e = 2.55, the gap is h = 2.5 mm.

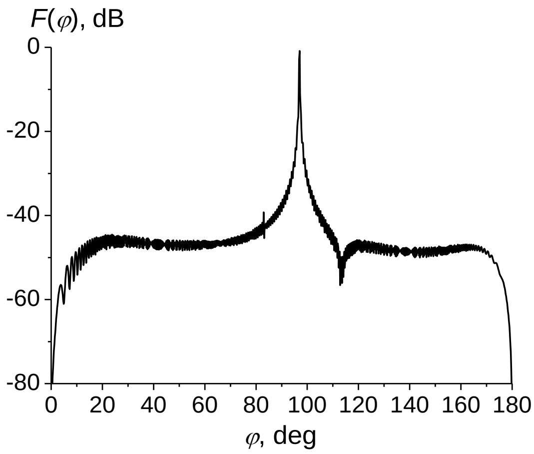

Fig.2. Radiation pattern of the antenna with 333 grooves

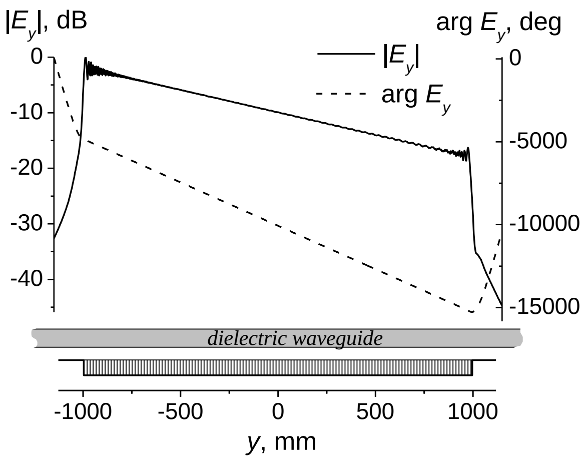

Fig.3. The field distribution at the height 46 mm above the grating for the antenna with 333 grooves

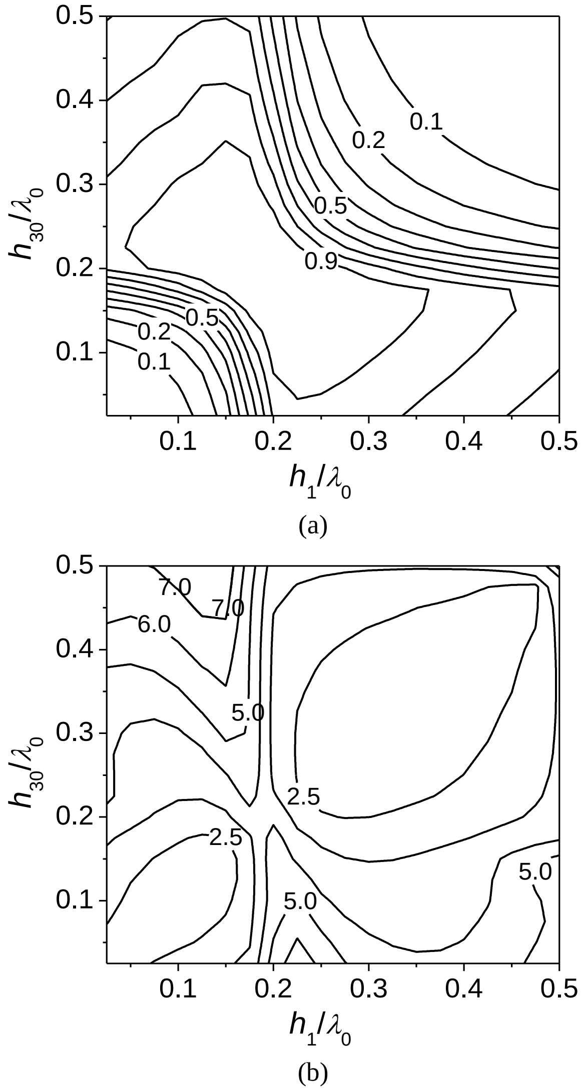

Fig.4. The level lines for: a – the efficiency of radiation, b – the beam width at the level of –3dB in degrees

The antenna is considered at the wavelength λ_0 = 8.33 mm. The size of its aperture is 239 wavelengths. The efficiency of radiation is 97.5%. The beam width at the level of –3 dB is 0.24°. The form of radiation pattern in Fig. 2 is typical for the leaky-wave antennas with exponential decrease of the field along the aperture (Fig. 3). Its radiation characteristics can be improved by choosing of the grating profile.

3. Characteristics of the Antenna with Linear Variation of the Groove Depths

Consider a grating of 30 grooves with linear variation of the groove depths along the aperture:

$$h_i = h_1 + (i - 1)(h_{30} - h_1)/29, \quad i = 1, 2, \ldots, 30.$$

All the other parameters are fixed as described above.

The level lines for the radiation efficiency and the beam width at the level of –3 dB depending on the depths of the first and the last groove h_1 and h_{30} are shown in Fig. 4.

The radiation pattern with good characteristics of directivity can be formed by equidistant gratings and gratings with the grooves of different depths.

The different linear laws of the depth variation correspond to the regions of maximum efficiency and of the narrower radiation pattern. Therefore in the case under consideration a reasonable compromise should be found between energy characteristics and the characteristics of directivity of antenna.

The next planned step is to solve practically important problems of the optimization of the required field distribution by the choosing of the optimum grating profile.

References

1. Yevdokimov A.P., Krizhanovsky V.V. 1996, ‘New direction in the antenna array engineering’, *Izv. VUZov. Radioelectronika* **39**, 54-60.
2. Melezhik P.N., Sidorenko Y.B., Provalov S.A., et al. ‘Flat antenna of diffraction radiation of radar complex of millimeter range’, *Izv. VUZov: Radioelectronika* (in print).
3. Steshenko S.O., Kirilenko A.A. 2005, ‘The accurate two-dimensional model of the effect of the surface waves transformation into the spatial modes’, *Radiofizika i electronika* **10**, 30-38.
4. Gandel Y.V. 1986, ‘The method of discrete singularities in the problems of electrodynamics.’ In: Voprosy kibernetiki. Ed. AS of USSR, Moscow, 166-183.
5. Sauter T. 2000, ‘Computation of irregularly oscillating integrals’, *Appl. Numerical Math.*, 245–264.