INTERACTION OF EIGENWAVES OF THE INSULATED IMAGE DIELECTRIC WAVEGUIDE WITH SYSTEM OF TRANSVERSE SLOTS IN THE SCREEN

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Abstract

The present work is devoted to the generalisation of operator approach for the solving electromagnetic waves diffraction problems by periodic systems of discontinuities (such transverse slot) in hybrid metal-dielectric structures. The diffraction problem solution of single eigenwave of the hybrid metal-dielectric structure by bounded periodical slot sequences in the metal has been presented. The approach based on the using of semi-infinite periodical structures conception. On the first stage the reflection and propagation coefficients of single slot was found. On the second stage the reflection and propagation coefficients of the semi-infinite sequences of identical discontinuities was found. On the third stage the electrodynamical characteristics of the bounded sequence of identical slot discontinuities was found. By the numerical simulation the dependencies $|S_{11}|$ and $|S_{12}|$ of the structure with single slot and bounded sequences arranged equidistantly was founded. The pattern characteristics are presented.

Keywords:, transverse slot, eigenwave, diffraction problem.

1. INTRODUCTION

At present day in the antenna techniques the radiating structures which are based on various combinations of elements and guides are widely applied. One of such combinations is the hybrid metal-dielectric structure (HMDS) on the basis of the insulated dielectric wave guide (IDW) and slot radiators. Simplicity, rather small dimensions and weight concerns advantages of such antenna systems.

The particular interest to HMDS, which combine periodic sequences of the discontinuities various type (strip, slots, etc.) has detected. It is caused by a number of the important practical applies such as: antennas of leaky waves [1,2], frequency-selective devices [3] and a number of others.

Antennas and antenna gratings on the basis of HMDS are difficult for theoretical electrodynamic analysis. There are a number of factors which cause complexity of a problem by the description of hybrid structures. The main from them are: necessity of consideration of three-dimensional structures; impossibility of use various asymptotic methods, which are correctly at the big or small length of waves in comparison with the linear sizes of radiators; necessity of the account of characteristics of fields near radiator edges; complexity of eigenwave spectrum in a basic line.

The comprehensive information on characteristics of such systems can be received, using numerically-analytical methods of applied electrodynamics. Taking into account multiparametric of problems, the algorithms of calculation even the single slot radiators based on rigorous methods are very difficult, lengthy and, besides, there are difficulties of basic character, for example because of absence now a rigorous analytical method for the decision of a problem diffraction by waves rectangular slot of the finite sizes. Therefore to use rigorous methods for the decision of slot antenna or problem of slot gratings, as a rule, either it is not obviously possible, or it appears not reasonable because of lengthy algorithm and time-taking of procedure even with use of modern computer.

The present work is devoted to the generalisation of operator approach [4] for the solving electromagnetic waves diffraction problems by periodic systems of discontinuities (such transverse slot) in hybrid metal-dielectric structures.

2. FORMULATION AND DECISION PROBLEM

Let's consider a problem of diffraction of one of eigenwaves of the metal-dielectric structure which is presented in Fig. 1, by the bounded sequence of the transverse slots placed equidistantly in the metallized screen. The problem solves in a single mode approach. The approach based on the using of semi-infinite periodical structures conception in some stages.

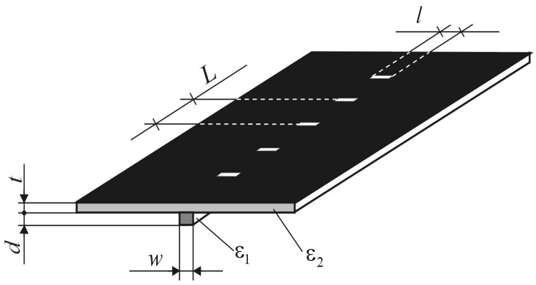

Fig. 1. The metal-dielectric structure.

On the first stage the reflection and propagation coefficients of single slot will be found. On the second stage the reflection and propagation coefficients of the semi-infinite sequences identical discontinuities will be found. On the third stage the electrodynamical characteristics of the bounded identical slot discontinuities will be found.

We assumes that the slot is narrow $l >> t$, and $\lambda >> t$. Hence, the assumption that electric field will be directed across a slot will be competent. We will assume that the screen of hybrid metal-dielectric structure is infinitely thin and ideally connected. Based on these assumptions the expression for the unknown component of a magnetic current M_z on the slot can be presented as follow in a kind $\vec{M} = \vec{z}_0 M_z$, where $M_z = f(z)$.

Considering the sum of the incident E_x^i and scattering E_x^s electric fields, it is possible to receive the integral equation concerning distribution of a magnetic current M_z

$$E_x^i + E_x^s = \psi_s(\alpha, z) + j\omega\mu_0 \int_0^l \left[1 + \frac{1}{k_0^2}\frac{\partial^2}{\partial z^2}\right] G(z,z')M(z')dz', \quad (1)$$

where $\psi_s(\alpha, z)$ – distribution of basic mode at the $y = 0$ $\alpha = a + s + t/2$, $G(z,z')$ – Green's scalar function of eigenmode of image dielectric wave guide. Certainly that for reception of the rigorous decision of the equation (1) the knowledge of a full spectrum of eigenwaves of a image dielectric waveguide is necessary. In a case of single mode Green's function is as follows [5]

$$G(z,z') = \frac{1}{2j}\left[\frac{1}{\beta_s}\psi_s(0,z)\psi_s(0,z') + \int_0^{\infty}\gamma d\gamma \int_0^{\pi/2}\frac{d\theta}{\beta}\psi(0,z)\psi(0,z')\right], \quad (2)$$

where $\psi_s(x,z)$ the resulted distribution of the basic wave of an image dielectric waveguide with propagation constant – β_s; $\psi(x,z)$ – the resulted distribution of a continuous component with wave numbers k_x; k_y; where $\gamma^2 = k_x^2 + k_y^2$; $k_x = \gamma\cos\theta$; $k_y = \gamma\sin\theta$; $\beta = \sqrt{k_0^2 - \gamma^2}$. Taking into account Considering slow variations of function $\psi_s(z)$ along a slot, it is possible to receive expression for a scattered field as follow

$$E_s(z) = j\omega\mu_0 \int_0^l G(z,z')M(z')dz \;. \quad (3)$$

For the basic wave of an image dielectric wave guide with single amplitude the equation (3) can be transformed as follow

$$\psi_s(\alpha, z) + j\omega\mu_0 \int_0^l G(z,z')M(z')dz = 0 \quad (4)$$

The equation (4) may be solved with by use of approach for a magnetic current in a kind

$$M(z) = M_0\sqrt{1 - \left(\frac{2z}{l}\right)^2}\,, \quad (5)$$

where M_0 – unknown amplitude.

The required functions M_z and $E_x(z)$ allow to find reflection and propagation coefficients, and also characteristics of radiation of a single slot. Expressions for reflection coefficient r may be presented as follow

$$r = \frac{\omega\mu_0}{2\beta_s}\int_0^l M(z)\psi_s(\alpha, z)dz, \quad (6)$$

where β_s – a propagation constant of mode. The reflection coefficient t may be defined through conductivity of a slot $t = \dfrac{2}{2+Y}$,

where

$$Y = \frac{2}{\beta_s}\frac{\left(\int_0^l M(z)\psi_s(\alpha, z)dz\right)^2}{\int_0^{\infty}\gamma d\gamma\int_0^{\pi/2}\frac{d\theta}{\beta}\left(\int_0^l M(z)\psi(0,z)dz\right)^2}\,. \quad (7)$$

The radiation losses by a single mode can be defined as $L_{rad} = 1 - |r|^2 - |t|^2$.

The required electrodynamic characteristics of a single slot allow to find the coefficients of reflection by semi-infinite sequence of such elements, and also characteristics of the bounded sequence of such elements, following the algorithms resulted in [6].

3. Results of Numerical Modelling and Experiments

The creating model allow to carry out the numerical modeling of characteristics of radiating structure.

The analysis of graphic on Fig. 2 testifies that in enough wide band $|S_{11}|$ does not exceed value 0.25 that corresponds to value of $VSWR \approx 1.66$. The level of $|S_{21}|$ pulsations does not exceed 8 %. Near the frequency of $f = 36$ GHz in both characteristics breaks are observed. The given frequency corresponds to

$\lambda_0 \approx 0.83$ cm that practically coincides with length of a slot $l = 8$ mm and value of the period $L = 8$ mm.

For the comparative analysis the structures with single and three transverse slots were chosen. In Fig. 2 and Fig. 3 the simulation dependences of reflection and propagation factor are presented.

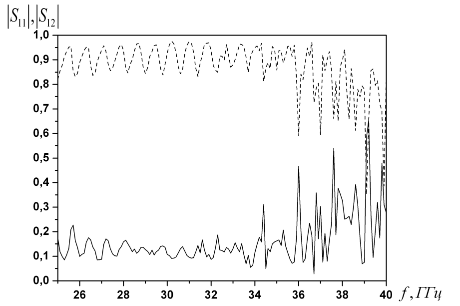

Fig. 2. Simulation dependences of reflection and propagation factor for structure with single transverse slot.

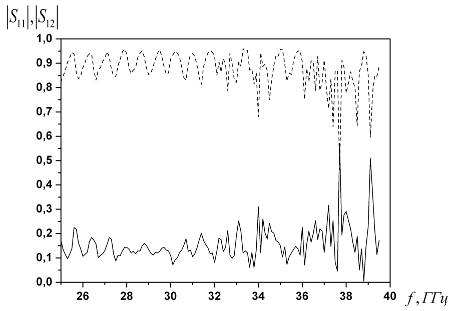

Fig. 3. Simulation dependences of reflection and propagation factor for structure with three transverse slots.

The simulation data allow to design the antenna module with five transverse slots with high level of characteristics. In Fig.4 the four experimental curves corresponding to measurements of electric fields with both side of structure on $f_1 = 28.95$ GHz and $f_2 = 33.2$ GHz.

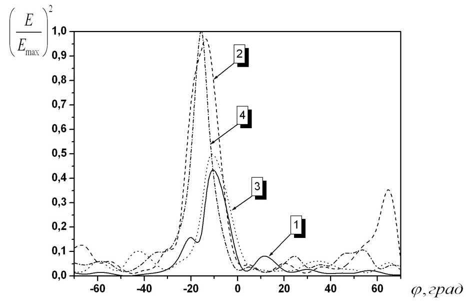

Fig.4. Experimental results.

The curves 1,3 correspond to radiation from dielectric rod side, and 2,4 – correspond to radiation from metallized structure.

By systematic experiments it is established that one can control the level of radiation from both side.

Conclusions

Thus, the constructed mathematical model and the developed numerical algorithms on their basis allow investigating electrodynamic characteristics of the HMDS with slot type discontinuities. This design is adequate to real physical object, and numerical algorithms on its basis allow carrying out simulating of characteristics with sufficient accuracy for practical applications. The further developing of the used approach can be realized by the account a multimode spectrum of eigenwaves in the basic waveguide structure and the account of features of fields near slot edges.

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