Progress In Electromagnetics Research M, Vol. 12, 205–216, 2010

THREE-DIMENSIONAL ELECTROMAGNETIC DIFFRACTION BY A SLOT SYSTEM WITH PARALLEL PLANE DIELECTRIC INTERFACES

V. M. Serdyuk and J. A. Titovitsky

Institute of Applied Physical Problems
Belarusian State University
Kurchatov St. 7, Minsk 220064, Belarus

Abstract—An efficient method is presented for rigorous description of three-dimensional electromagnetic diffraction fields in slot systems containing several parallel plane interfaces between dielectrics and conductors. For such structures, the method employs the representation of spatial field components in terms of two complex scalar functions. They specify two field polarizations, which reflect and refract on all parallel dielectric interfaces independently, one from the other, which essentially simplify the total solution of diffraction problem. As an example, the application of eigen-function expansions and mode-matching technique solves the specific problem of three-dimensional diffraction of a plane electromagnetic wave by a slot in a thin conducting screen located ahead of a half-infinite dielectric.

1. INTRODUCTION

The three-dimensional diffraction problem for a slot and strip structures with planar stratified media is of interest since its solution is the bases for the theory of slotlines, striplines and another electromagnetic transmission systems [1–6]. However, this case is more complex for computations in comparison with the case of two-dimensional diffraction [7–16], because one cannot consider diffraction fields in terms of two independent polarizations for which the field equations split into two independent subsystems. For example, in the works [3, 4] the three-dimensional diffraction by a slot and strip structures with dielectric layers is described by a system of singular integrodifferential equations for the spatial field components,

Corresponding author: V. M. Serdyuk (serdyukvm@bsu.by).

whose solution is constructed in a matrix form. Another approach employs a representation of these components in term of two scalar functions, which specify two different polarizations, just as proposed in the book [17] for the diffraction by a half-plane. Although these polarizations will not be independent one from the other in the three-dimensional case, such a representation could essentially simplify the problem. Really, this approach provides opportunity to obtain a comparatively simple solution for an unloaded strip line [5, 6]. But in the presence of supplementary planar dielectrics, placed parallel to the line, as well for a simple slotline on dielectric layer without conducting substrate, such an approach does not provide appreciable advantage. The origin for this is the lack of coincidence between the polarizations under consideration, and the polarizations at reflection and refraction on dielectric interfaces are independent [17]. As a result, the equations describing such reflection and refraction do not split into two independent systems, and one should take into account two polarizations at once on every dielectric interface that essentially complicates a solution. It could be more simple for field representation allowing independent reflection and refraction on dielectric interfaces, as it takes place for the ordinary H and E polarizations of a plane wave [17], one of which is orthogonal to its plane of incidence, and the other is parallel to that. In this work, we consider such a representation for three-dimensional diffraction by a slot system with several plane dielectric interfaces parallel one to the other and also parallel to the plane conducting screen containing a diffraction obstacle (slot). Without considerable complications, this representation can be extended to those dielectric media, which are not isotropic and have one optic axis orthogonal to the plane interfaces.

2. GENERAL REPRESENTATION OF ELECTROMAGNETIC FIELDS FOR THREE-DIMENSIONAL DIFFRACTION PROBLEMS

Let us consider Maxwell's equations [17–19] for stationary fields in homogeneous anisotropic medium without sources, assuming their harmonic time-dependence determined by the factor $\exp(-i\omega t)$. We shall suppose that the dielectric tensor of a medium in the rectangular coordinate system (x, y, z) has the diagonal form with the components ε_e, ε_o and ε_o in the x-, y- and z-axes, respectively. For this general case, the spatial components of three-dimensional stationary field can be expressed in terms of two complex scalar functions U and V:

$$E_x = \varepsilon_e V + \frac{\varepsilon_e}{\varepsilon_o k^2} \cdot \frac{\partial^2 V}{\partial x^2} \qquad H_x = \varepsilon_o U + \frac{1}{k^2} \cdot \frac{\partial^2 U}{\partial x^2} \tag{1a}$$

$$E_y = \frac{i}{k} \cdot \frac{\partial U}{\partial z} + \frac{\varepsilon_e}{\varepsilon_o k^2} \cdot \frac{\partial^2 V}{\partial x \partial y} \quad H_y = \frac{1}{k^2} \cdot \frac{\partial^2 U}{\partial x \partial y} - \frac{i\varepsilon_e}{k} \cdot \frac{\partial V}{\partial z} \tag{1b}$$

$$E_z = -\frac{i}{k} \cdot \frac{\partial U}{\partial y} + \frac{\varepsilon_e}{\varepsilon_o k^2} \cdot \frac{\partial^2 V}{\partial x \partial z} \quad H_z = \frac{1}{k^2} \cdot \frac{\partial^2 U}{\partial x \partial z} + \frac{i\varepsilon_e}{k} \cdot \frac{\partial V}{\partial y} \tag{1c}$$

where $k = \omega/c$. Maxwell's equations [17–19] will be valid for these expressions, if the functions satisfy the following equations:

$$\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2} + \frac{\partial^2 U}{\partial z^2} + k^2 \varepsilon_o U = 0 \quad \frac{\varepsilon_e}{\varepsilon_o} \cdot \frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2} + k^2 \varepsilon_e V = 0 \tag{2}$$

Now let us suppose that the field is harmonically dependent on the z-coordinate:

$$U(x, y, z) = u(x, y)\, e^{ikpz} \quad V(x, y, z) = v(x, y)\, e^{ikpz}$$

where p is the normalized propagation constant of the field along the z-axis. Then the representation (1) takes the form:

$$E_x = \varepsilon_e v + \frac{\varepsilon_e}{\varepsilon_o k^2} \cdot \frac{\partial^2 v}{\partial x^2} \qquad H_x = \varepsilon_o u + \frac{1}{k^2} \cdot \frac{\partial^2 u}{\partial x^2} \tag{3a}$$

$$E_y = -pu + \frac{\varepsilon_e}{\varepsilon_o k^2} \cdot \frac{\partial^2 v}{\partial x \partial y} \qquad H_y = \frac{1}{k^2} \cdot \frac{\partial^2 u}{\partial x \partial y} + \varepsilon_e p v \tag{3b}$$

$$E_z = -\frac{i}{k} \cdot \frac{\partial u}{\partial y} + \frac{i\varepsilon_e p}{\varepsilon_o k} \cdot \frac{\partial v}{\partial x} \qquad H_z = \frac{ip}{k} \cdot \frac{\partial u}{\partial x} + \frac{i\varepsilon_e}{k} \cdot \frac{\partial v}{\partial y} \tag{3c}$$

where the common multiplier $\exp(ikpz)$ of all components is omitted. In this case, Equation (2) becomes

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + k^2(\varepsilon_o - p^2)\, u = 0 \quad \frac{\varepsilon_e}{\varepsilon_o} \cdot \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + k^2(\varepsilon_e - p^2)\, v = 0 \tag{4}$$

The representation (3) is not identical to that of the three-dimensional field in [17]: the latter includes only the first derivatives of the scalar field functions with respect to the spatial coordinates x and y, whereas in (3) the second derivatives are also present. However, the representation (3) is more convenient for the consideration of diffraction structures having parallel interfaces between dielectric and conducting media, if they are orthogonal to the x-axis. Really, the functions u and v will determine the ordinary H and E polarizations with respect to planes of wave incidence, and these polarizations reflect and refract on these interfaces independently one from the other. This circumstance essentially simplifies solution of diffraction problems for such structures, which will be demonstrated in the following section.

3. THREE-DIMENSIONAL DIFFRACTION BY A SLOT IN A THIN CONDUCTING SCREEN SPACED APART FROM HALF-INFINITE DIELECTRIC

By the way of illustration, let us consider the plane-wave diffraction by a slot in an infinitely thin perfectly conducting screen located ahead of the half-infinite dielectric (Figs. 1 and 2), — a simple example of the three-dimensional diffraction by a slot system with dielectric interfaces. This example can be considered as a simplified simulation of a process of photosensitive material exposure through an opaque template with passing openings.

Let the plane wave with the unite amplitude

$$\begin{aligned} u(x,y) &= (u_0/\sigma_0)\ \exp\left[ik(\alpha_0 x + \beta_0 y)\right] \\ v(x,y) &= (v_0/\sigma_0)\ \exp\left[ik(\alpha_0 x + \beta_0 y)\right] \end{aligned} \tag{5}$$

is incident upon a slot in a plane infinite conducting screen. Here, $\sigma_0 = (\beta_0^2 + p^2)^{1/2}$, $p = \sin\vartheta\sin\varphi$, $\alpha_0 = \cos\vartheta$ and $\beta_0 = \sin\vartheta\cos\varphi$ are the wave propagation constants along the x- and y-directions, and the scalar parameters u_0, v_0 determine the wave polarization ($u_0^2 + v_0^2 = 1$): when $u_0 = 1$, $v_0 = 0$, the electric vector of the wave is directed orthogonally to its plane of incidence (along the vector $\mathbf{e}_u$, Fig. 2), but at $u_0 = 0$, $v_0 = 1$ it lies in this plane (i.e., it is parallel to the vector $\mathbf{e}_v$).

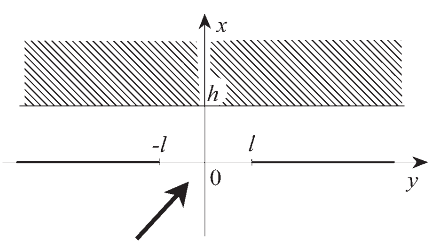

Figure 1. Diffraction by a slot structure with a dielectric interface (a two-dimensional view).

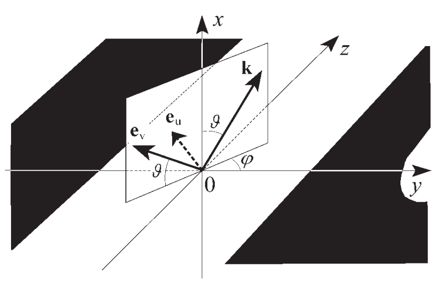

Figure 2. Three-dimensional plane wave diffraction by a slot (a view from the direction of a dielectric).

The diffraction problem will be solved by mode matching technique [20], which employs the division of the field-propagation volume into homogeneous regions of a simple geometry and matching of the fields on their boundaries. Here, it is natural to consider the following three regions: the half-space before the screen ($x \leq 0$) from which the incident plane wave propagates, the region between the screen and a dielectric interface ($0 \leq x \leq h$), and the interior of a dielectric ($x \geq h$). For each of these regions the field will be sought as a Fourier integral on plane waves:
before the slot (for $x \leq 0$, with explicit separation of the incident and reflected plane waves)

$$\begin{aligned} u(x,y) =& \frac{u_0}{\sigma_0}\left(e^{ik\alpha_0 x} - e^{-ik\alpha_0 x}\right) e^{ik\beta_0 y} \\ &+ \int_{-\infty}^{+\infty} A(\beta)\, e^{ik(-\alpha x+\beta y)} d\beta \\ v(x,y) =& \frac{v_0}{\sigma_0}\left(e^{ik\alpha_0 x} + e^{-ik\alpha_0 x}\right) e^{ik\beta_0 y} \\ &- \int_{-\infty}^{+\infty} B(\beta)\, e^{ik(-\alpha x+\beta y)} \frac{d\beta}{\alpha} \end{aligned} \tag{6}$$

before the dielectric interface ($0 \leq x \leq h$)

$$\begin{aligned} u(x,y) &= \int_{-\infty}^{+\infty} A(\beta)\, \frac{e^{ik\alpha x} + R(\beta)\, e^{ik\alpha(2h-x)}}{D(\beta)} e^{ik\beta y} d\beta \\ v(x,y) &= \int_{-\infty}^{+\infty} B(\beta)\, \frac{e^{ik\alpha x} + \bar{R}(\beta)\, e^{ik\alpha(2h-x)}}{\bar{D}(\beta)} e^{ik\beta y} \frac{d\beta}{\alpha} \end{aligned} \tag{7}$$

in a dielectric ($x \geq h$)

$$\begin{aligned} u(x,y) &= \int_{-\infty}^{+\infty} A(\beta)\, \frac{T(\beta)}{D(\beta)} e^{ik\alpha h+ik\gamma(x-h)+ik\beta y} d\beta \\ v(x,y) &= \int_{-\infty}^{+\infty} B(\beta)\, \frac{\bar{T}(\beta)}{\bar{D}(\beta)} e^{ik\alpha h+ik\bar{\gamma}(x-h)+ik\beta y} \frac{d\beta}{\alpha} \end{aligned} \tag{8}$$

Here, $A(\beta)$ and $B(\beta)$ are the unknown amplitudes of Fourier components,

$$D(\beta) = 1 + R(\beta) e^{2ik\alpha h} \quad \bar{D}(\beta) = 1 - \bar{R}(\beta)\, e^{2ik\alpha h} \tag{9}$$

To ensure validity of Equation (4) for every region, we should set

$$\alpha = \sqrt{1-\sigma^2} \quad \gamma = \sqrt{\varepsilon_0 - \sigma^2} \quad \bar{\gamma} = \sqrt{\varepsilon_0(1-\sigma^2/\varepsilon_\mathrm{e})} \quad \sigma^2 = p^2 + \beta^2 \tag{10}$$

One should choose the branch of the square roots (10) having the nonnegative imaginary parts to provide decrease of diffraction fields moving away from the slot [17–20].

The spatial components of the electric and magnetic fields in various regions can be determined as a result of substitution of the representations (6), (7) or (8) for each region into Equation (3). The unknown Fourier amplitudes in (6)–(8) will be determined through the boundary conditions for these components. If the parameters R, $\bar{R}$ and T, $\bar{T}$ are the corresponding amplitude coefficients of reflection and refraction [17] for two different polarizations on the dielectric interface $x = h$, i.e.,

$$R(\beta) = \frac{\alpha - \gamma}{\alpha + \gamma} \quad \bar{R}(\beta) = \frac{\varepsilon_o \alpha - \bar{\gamma}}{\varepsilon_o \alpha + \bar{\gamma}} \quad T(\beta) = \frac{2\alpha}{\alpha + \gamma} \quad \bar{T}(\beta) = \frac{2\varepsilon_o \alpha}{\varepsilon_e(\varepsilon_o \alpha + \bar{\gamma})} \tag{11}$$

then the continuity conditions for the tangential field components on this interface are satisfied automatically. Thereby, it remains to consider the boundary conditions at the plane of a screen $x = 0$. Here, the tangential electric components should vanish on a conducting surface, but in a slot one should enforce the continuity conditions on the tangential electric and magnetic components:

$$E_y(\pm 0, y) = 0 \text{ for } |y| > l, \quad E_z(\pm 0, y) = 0 \text{ for } |y| \geq l \tag{12a}$$

$$\begin{aligned} &E_y(-0, y) = E_y(+0, y) \text{ for } |y| < l, \\ &E_z(-0, y) = E_z(+0, y) \text{ for } |y| \leq l \end{aligned} \tag{12b}$$

$$\begin{aligned} &H_y(-0, y) = H_y(+0, y) \text{ for } |y| < l, \\ &H_z(-0, y) = H_z(+0, y) \text{ for } |y| \leq l \end{aligned} \tag{12c}$$

where the symbol "0" in the arguments denotes an infinitesimal positive value. As well known [17–21], the electric field component E_z which is parallel to the edges of a slot $y = \pm l$ must be equal to zero. The same condition should be imposed on the difference of the corresponding magnetic components H_z on both sides of a conducting surface to provide zero value of the normal y-component of the surface current on the edges [17–21]. That is why the points $y = \pm l$ are included in the conditions for E_z, H_z and ignored by the conditions for E_y, H_y.

Substitution of the representations (6), (7) into (12) yields the following system of integral equations:

$$\begin{aligned} &\int_{-\infty}^{+\infty} [pA(\beta) + \beta B(\beta)]\, e^{ik\beta y} d\beta = 0 \text{ for } |y| > l \\ &\int_{-\infty}^{+\infty} [\beta A(\beta) - pB(\beta)]\, e^{ik\beta y} d\beta = 0 \text{ for } |y| \geq l \end{aligned} \tag{13}$$

$$\begin{aligned}
&\int_{-\infty}^{+\infty}\left(\frac{\alpha\beta}{D(\beta)}A(\beta)-\frac{p}{\alpha\bar{D}(\beta)}B(\beta)\right)e^{ik\beta y}d\beta=\frac{u_0\alpha_0\beta_0-v_0p}{\sigma_0}e^{ik\beta_0 y}\\
&\hspace{8cm}\text{for } |y|<l\\
&\int_{-\infty}^{+\infty}\left(\frac{p\alpha}{D(\beta)}A(\beta)+\frac{\beta}{\alpha\bar{D}(\beta)}B(\beta)\right)e^{ik\beta y}d\beta=\frac{u_0\alpha_0p+v_0\beta_0}{\sigma_0}e^{ik\beta_0 y}\\
&\hspace{8cm}\text{for } |y|\le l
\end{aligned}\tag{14}$$

We will solve these equations by analogy with the case of two-dimensional diffraction by a slot in a screen of finite thickness [7–10], considering the thin conducting screen having finite but very small thickness compared with the wavelength.

The functions of y in the left sides of (13) determine the fields E_y and E_z on a slot. They vanish beyond the interval $-l \le y \le l$, so that these functions can be represented as a Fourier series within this finite interval:

$$\begin{aligned}
&\int_{-\infty}^{+\infty}[pA(\beta)+\beta B(\beta)]e^{ik\beta y}d\beta\\
&=\sum_{m=1}^{\infty}\left(b_m^{(\mathrm{s})}\cos\,(k\eta_m^{(\mathrm{s})}y)+ib_m^{(\mathrm{a})}\sin\,(k\eta_m^{(\mathrm{a})}y)\right)\theta(l^2-y^2)
\end{aligned}\tag{15a}$$

$$\begin{aligned}
&\int_{-\infty}^{+\infty}[\beta A(\beta)-pB(\beta)]\;e^{ik\beta y}d\beta\\
&=\sum_{m=1}^{\infty}\left(a_m^{(\mathrm{s})}\cos\,(k\xi_m^{(\mathrm{s})}y)+ia_m^{(\mathrm{a})}\sin\,(k\xi_m^{(\mathrm{a})}y)\right)\theta(l^2-y^2)
\end{aligned}\tag{15b}$$

where $\theta(x)$ is the step Heaviside's function: $\theta(x) = 1$ if $x \ge 0$ and $\theta(x) = 0$ if $x < 0$, and

$$\xi_m^{(\mathrm{s})}=\frac{\pi}{kl}\left(m-\frac{1}{2}\right)\quad \xi_m^{(\mathrm{a})}=\frac{\pi m}{kl}\quad \eta_m^{(\mathrm{s})}=\frac{\pi}{kl}\,(m-1)\quad \eta_m^{(\mathrm{a})}=\frac{\pi}{kl}\left(m-\frac{1}{2}\right)$$

Such values of spatial Fourier frequencies provide zero values of the function (15b) and of the derivative of the function (15a) on the edges of a slot.

Using the representations (15), one can express the integral Fourier amplitudes in terms of the unknown amplitudes $a_m^{(\mathrm{s,a})}$ and $b_m^{(\mathrm{s,a})}$ of the discrete series (15)

$$\begin{aligned}
A&=A^{(\mathrm{s})}+A^{(\mathrm{a})} \qquad A^{(\mathrm{s,a})}=\frac{1}{\sigma^2}\left(p\bar{P}^{(\mathrm{s,a})}+\beta P^{(\mathrm{a,s})}\right)\\
B&=B^{(\mathrm{s})}+B^{(\mathrm{a})} \qquad B^{(\mathrm{s,a})}=\frac{1}{\sigma^2}\left(\beta\bar{P}^{(\mathrm{a,s})}-pP^{(\mathrm{s,a})}\right)
\end{aligned}\tag{16}$$

where

$$P^{(\mathrm{s,a})} = \frac{kl}{2\pi} \sum_{m=1}^{\infty} a_m^{(\mathrm{s,a})} Q_m^{(\mathrm{s,a})}(\beta) \quad \bar{P}^{(\mathrm{s,a})} = \frac{kl}{2\pi} \sum_{m=1}^{\infty} b_m^{(\mathrm{s,a})} \bar{Q}_m^{(\mathrm{s,a})}(\beta)$$

$$Q_n^{(\mathrm{s})}(\beta) = \frac{1}{l} \int_{-l}^{+l} \cos\,(k\beta y)\,\cos\,(k\xi_n^{(\mathrm{s})} y)\,dy$$

$$Q_n^{(\mathrm{a})}(\beta) = \frac{1}{l} \int_{-l}^{+l} \sin\,(k\beta y)\,\sin\,(k\xi_n^{(\mathrm{a})} y)\,dy$$

$$\bar{Q}_n^{(\mathrm{s})}(\beta) = \frac{1}{l} \int_{-l}^{+l} \cos\,(k\beta y)\,\cos\,(k\bar{\xi}_n^{(\mathrm{s})} y)\,dy$$

$$\bar{Q}_n^{(\mathrm{a})}(\beta) = \frac{1}{l} \int_{-l}^{+l} \sin\,(k\beta y)\,\sin\,(k\bar{\xi}_n^{(\mathrm{a})} y)\,dy$$

Inserting the representations (16) into integral Equation (14) yields two systems of linear algebraic equations for the amplitudes of the symmetric and antisymmetric Fourier modes (15):

$$\begin{aligned} \sum_{m=1}^{\infty} \left(K_{nm}^{(\mathrm{s,a})} a_m^{(\mathrm{s,a})} + L_{nm}^{(\mathrm{s,a})} b_m^{(\mathrm{a,s})} \right) &= \frac{u_0 \alpha_0 \beta_0 - v_0 p}{\sigma_0}\ Q_n^{(\mathrm{s,a})}(\beta_0) \\ \sum_{m=1}^{\infty} \left(L_{mn}^{(\mathrm{s,a})} a_m^{(\mathrm{s,a})} + M_{nm}^{(\mathrm{s,a})} b_m^{(\mathrm{a,s})} \right) &= \frac{u_0 \alpha_0 p + v_0 \beta_0}{\sigma_0}\ \bar{Q}_n^{(\mathrm{a,s})}(\beta_0) \end{aligned} \tag{17}$$

where

$$K_{nm}^{(\mathrm{s,a})} = \frac{kl}{\pi} \int_0^{+\infty} \left(\frac{\alpha\beta^2}{D(\beta)} + \frac{p^2}{\alpha\bar{D}(\beta)} \right) Q_n^{(\mathrm{s,a})}(\beta)\ Q_m^{(\mathrm{s,a})}(\beta)\ \frac{d\beta}{\sigma^2}$$

$$L_{nm}^{(\mathrm{s,a})} = \frac{kl}{\pi} p \int_0^{+\infty} \left(\frac{\alpha}{D(\beta)} - \frac{1}{\alpha\bar{D}(\beta)} \right) Q_n^{(\mathrm{s,a})}(\beta)\ \bar{Q}_m^{(\mathrm{a,s})}(\beta)\ \frac{d\beta}{\sigma^2}$$

$$M_{nm}^{(\mathrm{s,a})} = \frac{kl}{\pi} \int_0^{+\infty} \left(\frac{\alpha p^2}{D(\beta)} + \frac{\beta^2}{\alpha\bar{D}(\beta)} \right) \bar{Q}_n^{(\mathrm{a,s})}(\beta)\ \bar{Q}_m^{(\mathrm{a,s})}(\beta)\ \frac{d\beta}{\sigma^2}$$

These systems can be solved by the method of reduction [22], restricting ourselves to finite number of unknowns. Using the obtained solution for the field amplitudes $a_m^{(\mathrm{s,a})}$ and $b_m^{(\mathrm{a,s})}$ on a slot, one can compute the integral Fourier amplitudes (16) and the spatial components of the electric and magnetic fields with the help of Equations (6)–(8) and (3). Fig. 3 displays the example of such computation for the following case: the half-width of a slot is $l = 0.382\lambda$ ($kl = 2.40$); the distance between a dielectric and a screen is $h = 0.907$ ($kh = 5.70$); the orientation angles of the diffracting wave

(5) are $\vartheta = 30°$, $\varphi = 20°$; a dielectric is isotropic; its permittivity is the scalar complex value of $1.90 + 2.00 \times 10^{-2}i$, close to the value used in the numerical example of [10]. This figure plots magnitudes of the electric and magnetic field vectors $|E| = (|E_x|^2 + |E_y|^2 + |E_z|^2)^{1/2}$ and $|H| = (|H_x|^2 + |H_y|^2 + |H_z|^2)^{1/2}$ in the same scale. We have considered the cases of two polarizations of the incident plane wave: the so-called U polarization, when $u_0 = 1$, $v_0 = 0$, and the wave (5) is polarized orthogonally to its plane of incidence (parallel to the vector $\mathbf{e}_u$ on Fig. 2) and the V polarization with $u_0 = 0$, $v_0 = 1$, when the electric vector of the wave is parallel to this plane (vector $\mathbf{e}_v$ on Fig. 2). Fig. 3 demonstrates the presence of field singularities on the edges of a slot and the existence of field discontinuities on both sides of a conducting screen, as well as on the dielectric interface, where the discontinuous electric component E_x appreciably differs from zero. Our calculations show that both polarizations are present simultaneously in the diffraction field even if one of them is absent in the incident wave (5), that is the essential feature of three-dimensional diffraction [21]. Really, Equation (17) as well as Equations (13), (14) and the representations (15), are not split into two independent sets of equations for different polarizations.

The obtained solution can be generalized on the case of multilayer dielectric placed behind the screen, if coefficients R and $\bar{R}$ in (7) and (9), determined here for one interface, will be replaced with appropriate reflection coefficients computed for a multilayer dielectric structure as a whole.

4. CONCLUSION

We have considered the equations describing three-dimensional fields in diffraction systems containing multilayer dielectric structures and have solved a simple example of diffraction problem for such a system with a slot in a thin conducting screen. These equations can be used for rigorous simulation of various diffraction systems with several parallel plane dielectric interfaces such as slot and strip transmission lines.

The presented approach to three-dimensional diffraction is based on the representation of the spatial field components in terms of two scalar complex functions. They specify two different field polarizations, which can be identified as the well-known H and E polarizations, if they are considered with reference to the plane of incidence for every plane-wave component in composition of a total diffraction field. Owing to this fact the field propagation through a multilayer dielectric structure with parallel plane interfaces can be described easily, because such propagation occurs independently for these polarizations. In essence, under these conditions the solution is reduced to solving the problem of field propagation through a diffracting obstacle (slot, slit or aperture), just as one solves a two-dimensional problem. However, in contrast to this simpler case, the orientation of planes of incidence for various plane-wave field components under three-dimensional diffraction is varied. That is why one needs two polarizations simultaneously for simulation of diffraction problems in this case, even if an incident field has only one polarization.

ACKNOWLEDGMENT

The authors are grateful to the reviewers for useful comments.

This work was supported by the National Academy of Sciences of Belarus under the State Integrated Program of Scientific Research "Technical diagnostics".

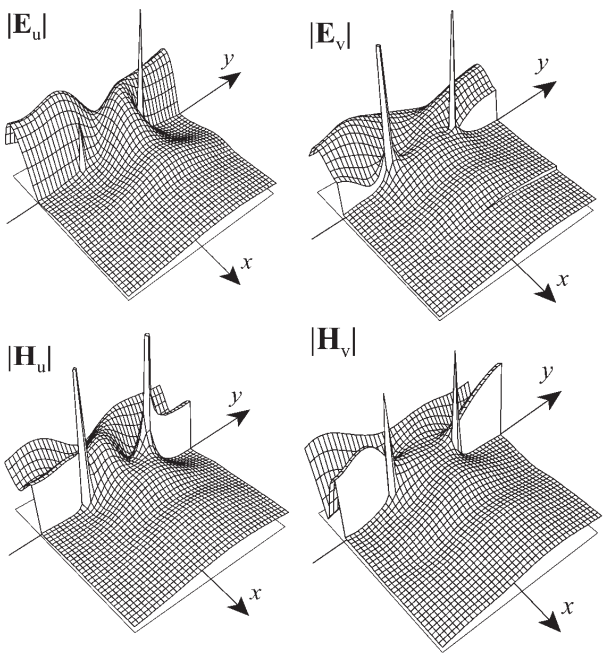

Figure 3. Spatial distribution of the electric (top) and magnetic (bottom) field magnitude for the diffraction of a plane electromagnetic wave by a slot in a thin conducting screen spaced apart from a half-infinite dielectric in the cases of the U-polarized incident wave (left) and the V-polarized one (right).

REFERENCES

1. Baranchugov, E. A., P. M. Zatsepin, and S. A. Komarov, "Quasi-three-dimensional problem of diffraction of a planar electromagnetic wave by an impedance strip," *Journ. of Communications Technology & Electronics*, Vol. 43, No. 11, 1199–1203, 1998.
2. Slade, G. W. and K. J. Webb, "Computation of characteristic impedance for multiple microstrip transmission lines using a vector finite element method," *IEEE Trans. Microwave Theory Tech.*, Vol. 40, No. 1, 34–40, 1992.
3. Tsalamengas, J. L., "Scattering of arbitrarily polarized plane waves obliquely incident on infinite slots or strips in a planar-stratified medium," *IEEE Trans. Antennas Propag.*, Vol. 46, No. 11, 1634–1640, 1998.
4. Tsalamengas, J. L., "Direct singular integral equation methods in scattering and propagation in strip- or slot-loaded structures," *IEEE Trans. Antennas Propag.*, Vol. 46, No. 10, 1560–1570, 1998.
5. Janaswamy, R., "Wiener-Hopf analysis of the asymmetric slotline," *Radio Sci.*, Vol. 25, No. 5, 699–706, 1990.
6. Itoh, T. and R. Mittra, "Spectral-domain approach for calculating the dispersion characteristics of microstrip lines," *IEEE Trans. Microwave Theory Tech.*, Vol. 21, No. 7, 496–499, 1973.
7. Kashyap, S. C. and M. A. Hamid, "Diffraction characteristics of a slit in a thick conducting screen," *IEEE Trans. Antennas Propag.*, Vol. 19, No. 4, 499–507, 1971.
8. Litvinenko, L. N., S. L. Prosvirnin, and V. P. Shestopalov, "Diffraction of a plane H-polarized electromagnetic wave by a slot in a conducting screen of finite thickness," *Radiotechn. & Electron.*, Vol. 22, No. 3, 474–484, 1977 (in Russian).
9. Serdyuk, V. M., "Diffraction of a plane electromagnetic wave by a slot in a conducting screen of arbitrary thickness," *Technical Physics*, Vol. 50, No. 8, 1076−1083, 2005.
10. Rudnitsky, A. S. and V. M. Serdyuk, "Diffraction of a plane electromagnetic wave by a slot in a conducting screen of finite thickness placed in front of a half-infinite dielectric," *Progress In Electromagnetics Research*, PIER 86, 277–290, 2008.
11. Kim, J. H. and H. J. Eom, "Radiation from multiple annular slots on a circular cylindrical cavity," *Journal of Electromagnetic Waves and Applications*, Vol. 21, No. 1, 47–56, 2007.
12. Nesterenko, M. V., V. A. Katrich, Y. M. Penkin, and S. L. Berdnik, "Analytical methods in theory of slot-hole coupling

of electrodynamics volumes," *Progress In Electromagnetics Research*, PIER 70, 79–174, 2007.

13. Zhao, X. W., X. J. Dang, Y. Zhang, and C. H. Liang, "MLFMA analysis of waveguide arrays with narrow-wall slots," *Journal of Electromagnetic Waves and Applications*, Vol. 21, No. 8, 1063–1078, 2007.
14. Al-Zoulbi, A. S., A. A. Kishk, and A. W. Glisson, "Analysis and design of a rectangular dielectric resonator antenna FED by dielectric image line through narrow slots," *Progress In Electromagnetics Research*, PIER 77, 379–390, 2007.
15. Veliev, E. I., M. V. Ivakhnychenko, and T. M. Ahmedov, "Fractional boundary conditions in plane wave diffraction on a strip," *Progress In Electromagnetics Research*, PIER 79, 443–462, 2008.
16. Imran, A., Q. A. Naqvi, and K. Hongo, "Diffraction of electromagnetic plane wave from a slit in PEMC plane," *Progress In Electromagnetics Research M*, Vol. 8, 67–77, 2009.
17. Born, M. and E. Wolf, *Principles of Optics*, Pergamon, Oxford, 1969.
18. Stratton, J. A., *Electromagnetic Theory*, McGraw-Hill, New York, 1941.
19. Jones, D. S., *Acoustic and Electromagnetic Waves*, Clarendon Press, Oxford, 1989.
20. Mittra, R. and S. W. Lee, *Analytical Techniques in the Theory of Guided Waves*, Macmillan, New York, 1971.
21. Weinstein, L. A., *The Theory of Diffraction and the Factorization Method*, Golem, Boulder, 1969.
22. Kantorovich, L. V. and V. I. Krylov, *Approximate Methods of Higher Analysis*, Wiley, New York, 1964.