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A SLOT SUBSURFACE RADAR ANTENNA NEAR THE GROUND SURFACE

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A slot antenna radiating into the ground is placed in close proximity to the ground surface (Fig 1). For the attenuation of the radiation into the air the slot antenna is provided with a flange. Such an antenna is used in subsurface radar systems. For the rapid surveying it is desirable that the antenna should not be in contact with the earth. The spacing (h) between the ground surface and the antenna is much less than the wavelength λ. It is interesting to investigate quantatively how the powers radiated by this antenna into the ground (P_g) and into the air (P_a) vary when the antenna is lifted clear of the ground surface.

The slot antenna is modeled as a thin planar metallic plate of square shape (Fig 2). The rectangular slot is modeled as a surface magnetic current $\bar{J}^m_s$ placed on the bottom side of the plate, as shown in Figs 2,3. The value of $\bar{J}^m_s$ is defined by the electric field transverse to the slot. For the approximation of the electric field in the slot in the direction along the slot a sinusoidal function is used (Fig 3). It is assumed that this disribution of the electric field does not depend on h. We consider the case when the amplitude of the electric field in the center of the slot is maintained at a steady level by a generator and does not depend on the disposition of the antenna over the ground surface.

The analysis of the performance of an analogous antenna placed immediately on the ground surface was made in [1]. Consider in more detail the case when the antenna is lifted clear of the ground surface. We derive a system of integral equations for the unknown tangential electric field on the ground surface and the unknown electric surface currents on the metallic plate $\bar{J}^e$ by matching the boundary conditions $\bar{E}_{tan1}=0$ on the metallic plate and $\bar{E}_{tan1}=\bar{E}_{tan2}$, $\bar{H}_{tan1}=\bar{H}_{tan2}$ on the air-ground interface. $\bar{J}^e$ is equal to $\bar{J}^e_1+\bar{J}^e_2$ where $\bar{J}^e_1, \bar{J}^e_2$ - the electric currents on the top and the bottom sides of the plate (Fig 4). In order to deal with a finite number of unknown expansion coefficients for the electric field on the ground surface we introduce on the air-ground interface an auxiliary metallic plane with a rectangular opening (Fig 2), as it was made in [1]. One should give rather large dimensions of the opening, so that the presence of this plane should not influence appreciably on the antenna performance. We were not be able to do so because of inadequate capabilities of our computer. However we expect that even if the absolute values of the powers P_g, P_a would be changed by the

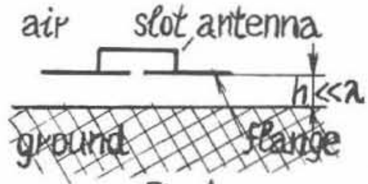

Fig 1

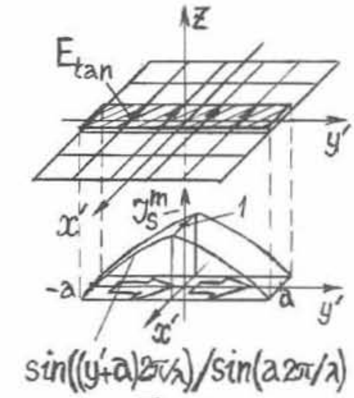

Fig 3

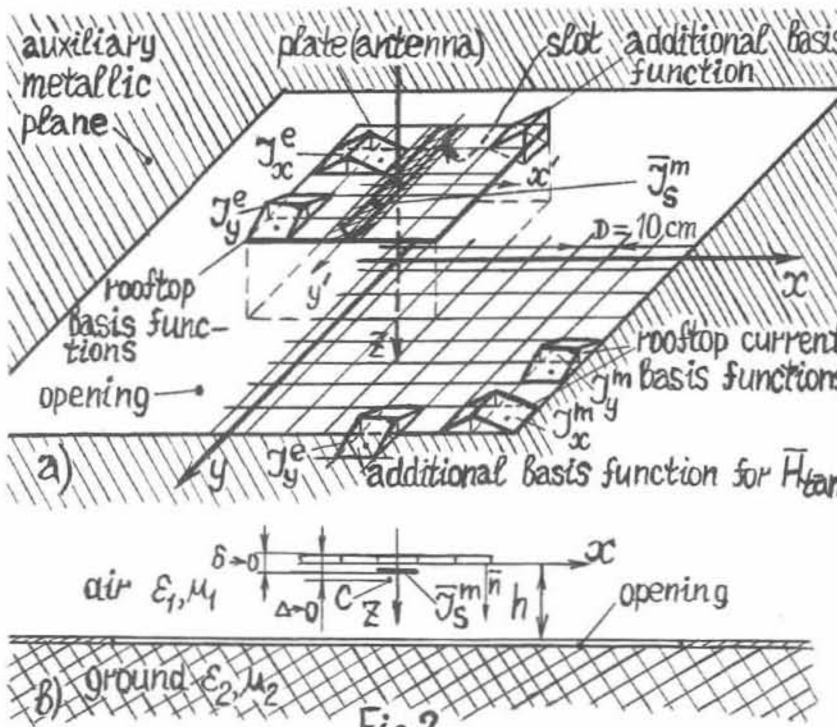

Fig 2

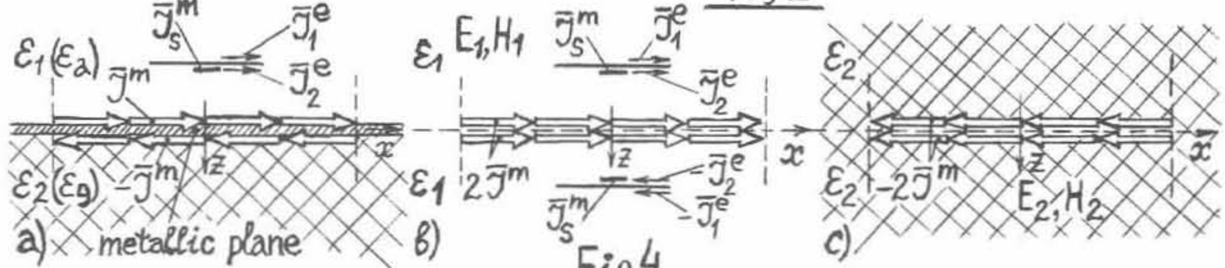

Fig 4

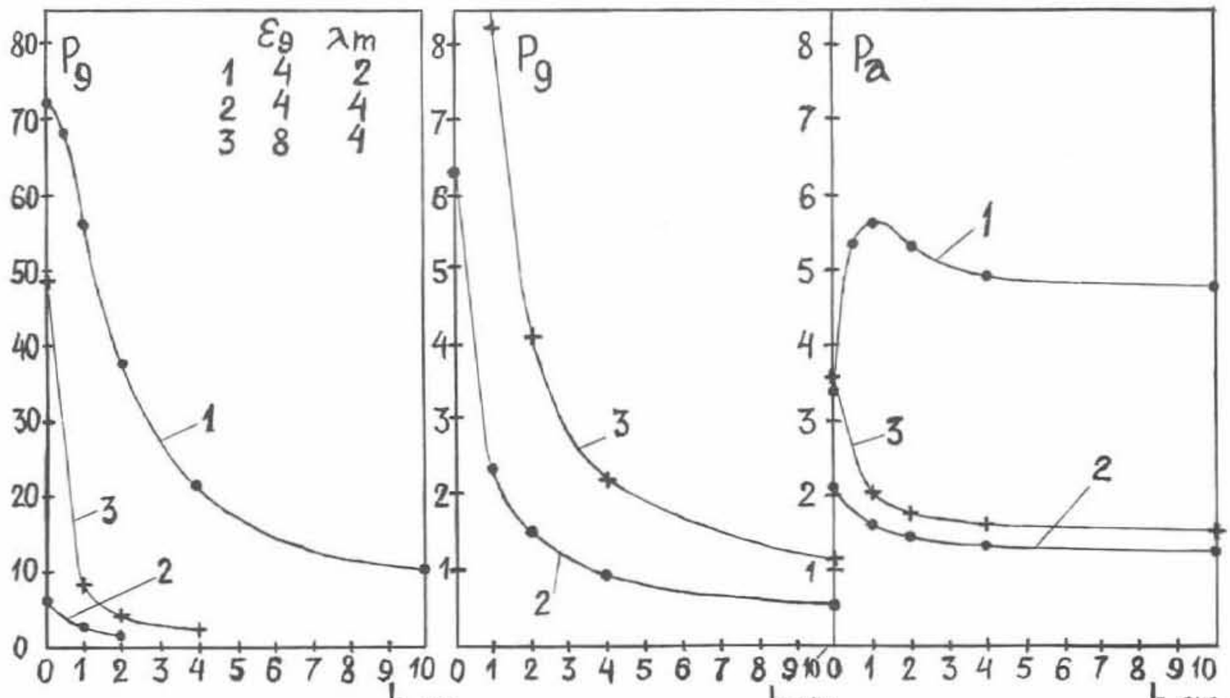

Fig 5

presence of the metallic plane, their comparative values for different dispositions of the antenna over the ground surface and for the same dimensions of the opening would be changed to a lesser extent. One may also average the results (P_g, P_a) over a set of computations for different dimensions of the opening. In this way one may obtain results refered to the infinite ground surface without metallic plane [1]. We find fields $\bar{E}_1, \bar{H}_1$ in the air by using the equivalence theorem. The equivalent electric and magnetic surface currents are introduced on the ground surface in the opening. The equivalent magnetic current $\bar{J}^m = -[\bar{n}, \bar{E}]$ corresponds with unknown tangential electric field in the opening. When the equivalent currents are introduced, the field inside the ground vanishes. Next one may introduce a metallic plane without opening instead of the above metallic plane, with the equivalent currents flowing on the top side of the plane. Next the principle of images is used (Fig 4). In addition the fields $\bar{E}_1, \bar{H}_1$ are expressed in terms of the electric and magnetic vector potentials by routine method. These potentials are expressed through the surface integrals of $\bar{J}^e$ over the plate and its mirror image, of $\bar{J}^m$ over the ground surface and of $\bar{J}^m_s$ over the slot and its mirror image (Fig 4b). The fields $\bar{E}_2, \bar{H}_2$ in the ground are derived by an analogous manner (Fig 4c)). The system of integral equations has a form:

$$\left.\begin{array}{l} [\bar{n}, \bar{E}_1] = \begin{cases} -\bar{J}^m_s & \text{at any point C on the slot as } \Delta \to 0 \text{ (Fig 2b))}, \\ 0 & \text{on the plate except the slot,} \end{cases} \\ \bar{H}_{tan1} = \bar{H}_{tan2} \quad \text{on the ground surface in the opening.} \end{array}\right\} \quad (1)$$

The kernels of the integral operators in the system (1) are of the same type as in the electric field integral equation in the problems of scattering by metallic surfaces. To solve the system (1) numerically we use a method proposed in [2]. The unknown magnetic current $\bar{J}^m$, the unknown electric current $\bar{J}^e$ on the plate are approximated by their expansions in terms of so-called rooftop basis functions [2], shown in Fig 2a). The rooftop basis function is a triangle function along the direction of current flow and is constant in the orthogonal direction. The ground surface in the opening and the surface of the plate were divided into a set of square subdomains, as shown in Fig 2a). The dimension of the subdomain is equal to 10 cm. Each of the rooftop basis finctions is defined on a pair of adjacent subdomains. A testing procedure for the both equations in system (1) consists in integrating the x- and y- components of the tangential fields along piecewise straight-line pathes parallel to the x and y directions respectively from the center to the center of a pair of the adjacent subdomains.

The evaluation of the powers P_g and P_a was carried out by two different approaches: by integrating the radiated power in the farzone and directly, by integrating the normal component of the Poynting's vector over the ground surface and over the slot. For the both approaches the results were approximately the same. When determining the Poynting's vector in the second approach the tangential magnetic field on the ground surface and the electric current $\bar{J}_2^e$ (and $\bar{J}_1^e$) are approximated by their expansions in terms of the rooftop basis functions. Besides it is necessary to introduce additional basis functions on the plate (to approximate the currents flowing from one side of the plate to another) and on the opening (Fig 2a)). For the latter basis functions the common edge of the two subdomains lies on the edge of the opening. $\bar{J}_2^e$ is obtained from the difference $\bar{J}_2^e-\bar{J}_1^e$ and $\bar{J}^e$. The difference $\bar{J}_2^e-\bar{J}_1^e$ may be found by matching the boundary condition $H_{tan1}=0$ at points inside the plate (between $\bar{J}_1^e$ and $\bar{J}_2^e$). To find the coefficient of a basis function in the expansions of $\bar{J}_2^e\bar{J}_1^e$ or $\bar{H}_{tan1(2)}$ (which corresponds with an equivalent electric current) on the ground surface we integrate a magnetic field component parallel to the common edge of the pair of adjacent subdomains (on which this basis function is defined) along this edge. It was found that this procedure yields more accurate results than when the magnetic field is evaluated at the centers of the edges.

Fig 5 shows the computed values of the powers P_g, P_a versus the spacing h. (In the case when h=0 an integral equation was derived for the unknown tangential electric field on the ground surface and solved by the same numerical method). Three cases for different dielectric permittivities of the ground and different wavelengths are considered (Fig 5): 1 - $\varepsilon_g=4$, $\lambda=2$ m; 2 - $\varepsilon_g=4$, $\lambda=4$ m; 3 - $\varepsilon_g=8$, $\lambda=4$ m. The powers are expressed in per unit, but the scale of ordinate is the same for all three cases. Let h_0 denotes the spacing between the ground surface and the antenna for which power P_g is half as much as the power P_g radiated by the antenna placed immediately on the ground surface. From Fig 5 one can see that for the cases 1,2,3 h_0 is about 2, 0.8, 0.6 cm respectively. One can expect that h_0 is expressed as $h_0 \approx const/(\lambda\sqrt{\varepsilon_g})$. One can see also that P_g significantly depends on λ and ε_g. The greater the frequency, the greater P_g and the greater ε_g, the greater P_g. To obtain more accurate quantative data one should make computations for greater dimensions of the opening in the auxiliary metallic plane. All deductions made above are for the case when the electric field in the slot is maintained at a steady level by a generator.

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