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METHOD OF DISCRETE SOURCES IN THE PROBLEM OF PULSE EXCITATION OF A VIBRATOR IN A LAYERED MEDIUM

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Vibrators are widely used as sources of electromagnetic radio waves. Characteristics of radiation of thin vibrators are typically analyzed by means of reducing the examined problem to Hallen's and Pocklington's integral equations. At the same time, the method of discrete sources which saves computational resources when solving these problems has well been developed to solve external boundary electromagnetic problems. We take advantage of the method of discrete sources to model the radiation field of a vibrator under pulse excitation of a plane stratified media with frequency dispersion.

PROBLEM FORMULATION AND METHOD OF SOLUTION

The geometry of the problem is shown in Fig. 1. The plane $z = 0$ in the Cartesian system of coordinates (x, y, z) coincides with the interface between two half-spaces. The upper half-space $z > 0$ is homogeneous with complex permittivity $\varepsilon_U(\omega)$, and the lower half-space $z < 0$ is a plane-stratified dielectric with $\varepsilon_L(z, \omega)$, where ω is the circular frequency of the electromagnetic field. The layered half-space possesses frequency dispersion. The center of a cylindrical antenna with radius a and length L is at an altitude D from the interface $z = 0$; the antenna is excited at the gap point $(x = 0, y = 0, z = D)$ by a pulse generator, and the field is received at the same altitude in the direction transverse to the antenna axis at the distance $y = y_r$.

The physical model of a thin hollow cylindrical conductor is considered. Unlike [1], the current on the vibrator surface is determined by auxiliary discrete sources (electric dipoles of finite lengths) located on the conductor axis. We assume that the electromagnetic process arbitrarily depending on time is described with the help of the Fourier transform as a superposition of monochromatic components satisfying the Maxwell equations and varying with time as $e^{-i\omega t}$. We express the spectrum of the volume current density of the nth discrete source oriented along the unit vector $\boldsymbol{e}_x$ through the Dirac delta-function:

$$\boldsymbol{j}^e(x, y, z, \omega) = I_n(\omega)\Delta l \cdot \delta(x - x_n)\delta(y)\delta(z - D)\boldsymbol{e}_x, \tag{1}$$

where Δl is the elementary dipole length, and $I_n(\omega)$ is the spectral amplitude of the nth current component. Then the reflected spectral field can be represented in the upper half-space $z > 0$ as a spatial spectrum of plane waves of the form

$$E_{x,n}(x, y, z, \omega) = \frac{1}{8\pi^2}\frac{I_n(\omega)\Delta l}{\omega\varepsilon_0\varepsilon_U}\int\limits_{-\infty}^{\infty} d\alpha_x d\alpha_y e^{i\alpha_x(x-x_n)+i\alpha_y y}\frac{e^{iw(z+D)}}{\alpha_x^2+\alpha_y^2}\left[\alpha_x^2 R_{\parallel}(\alpha,\omega)w - \alpha_y^2\frac{k_0^2\varepsilon_U(\omega)}{w}R_{\perp}(\alpha,\omega)\right], \tag{2}$$

where $w = \sqrt{k_0^2\varepsilon - \alpha_x^2 - \alpha_y^2}$ is the transverse wave number, k_0 is the wave number in vacuum, $\varepsilon_0 = 8.854\cdot 10^{-12}$ s/($\Omega\cdot$m) is the permittivity of vacuum, and $R_{\perp,\parallel}$ are the complex reflection coefficients which in the case of arbitrary layers are numerically calculated by the method of invariant embedding. Summing contributions from each dipole source and satisfying the

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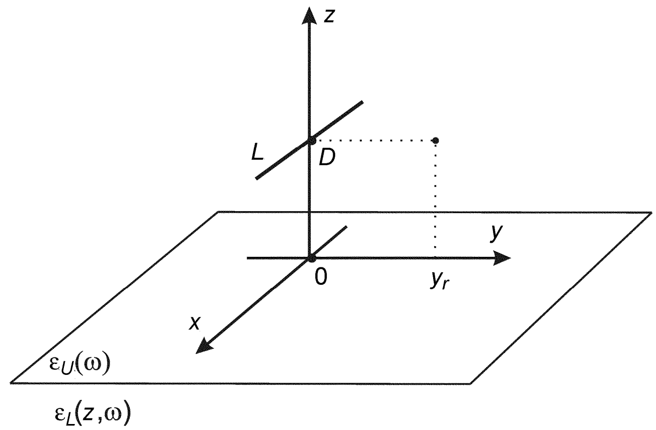

Fig. 1. Geometry of the problem. The vibrator and the receiving point are at the altitude $z = D$ above the layered half-space at points $y = 0$ and $x_r = 0$, $y = y_r$.

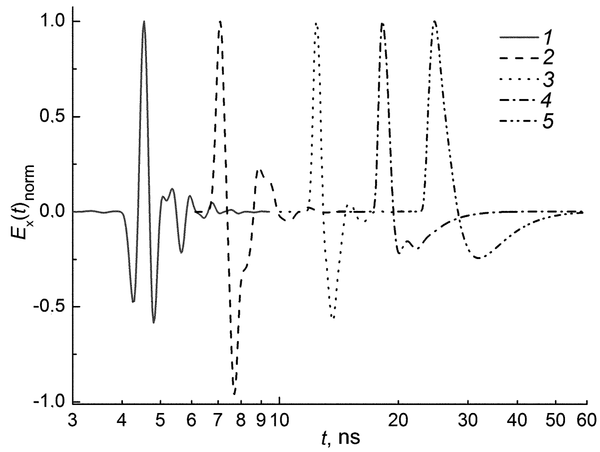

Fig. 2. Time history of the normalized field component E_x. Here curve *1* shows the incident pulse; reflected pulses at the observation point ($x = 0$, $y_r = 0.5$ m, $z = D$) are shown for distances $D = 0.4$ (curve *2*), 0.8 (curve *3*), 1.2 (curve *4*), and 1.6 (curve *5*).

boundary conditions on the ideally conducting conductor surface at collocation points, we derive a system of linear algebraic equations for the unknown currents $I_n(\omega)$.

NUMERICAL RESULTS

Let us use this model for sounding of the interface $z = 0$ between oil- ($z > 0$) and water-bearing layers ($z < 0$) of an oil collector. The complex permittivity of the layers was determined for the refraction model of disperse mixtures [2, 3]. The vibrator was excited by a one-period sine voltage pulse with duration $\tau = 1.0$ ns. 70 point sources and 284 collocation points were used. The antenna length and radius were $L = 0.15$ m and $a = 0.002$ m. Figure 2 shows the reflected pulse waveform for various distances in the oil-bearing medium. A numerical analysis demonstrated that the energy extinction factor P at the receiving point could be approximated by the expression $P = 1.7–71.3D$ [dB] with standard deviation of 4.9. Assuming that the limiting sensitivity of modern georadars is –140 dB [4], we conclude that nanosecond pulses allow the distance to the interface D to be estimated with accuracy of ~1 m.

CONCLUSIONS

In this work, excitation of the cylindrical vibrator by the nanosecond voltage pulse with duration $\tau = 1.0$ ns has been considered. The antenna was located in the layered disperse medium imitating an oil collector. The solution was constructed by the method of discrete sources for nonstationary fields. When propagating, the pulse loses its high-frequency part of the spectrum, acquiring with time an exponential waveform (Fig. 2). Calculations of the total energy flux of the reflected pulse demonstrated that the specific attenuation was about –71.3 dB/m, which allows the reflected signal to be recorded in an oil-bearing medium with modern georadars at distances up to 1 m from the interface.

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