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Radiation Fields of a Printed-Dipole on a Semi-Infinite Substrate

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SUMMARY The printed dipole on a semi-infinite substrate is investigated. The solution is based on the moment method in the Fourier transform domain. We analyze far-field and near-field radiation patterns for a printed dipole. Therefore, we make radiation fields clear.

key words: *far/near-field pattern, printed dipole, stationary phase method, Fourier integral, critical angle*

1. Introduction

It is very important for a radar imaging of an invisible target such as underground. We can investigate the properties of the transient electromagnetic fields transmitted from an antenna. To detect objects buried under the ground by the subsurface radar system, it is necessary to detect objects distant from the interface between air and dielectric. We consider radiation fields when the dipole antenna is located over the interface.

In this paper, we analyze far-field and near-field patterns with the stationary phase method and the Fourier integral respectively.

2. Theory

First case, we show geometry for a dipole on the interface in Fig. 1. We assume that this antenna is a printed dipole and put on the x-axis.

The E-plane which involve the dipole antenna and the H-plane are perpendicular for each other. It is supposed that $z = 0$ plane is the interface separating the two half-spaces. We use the frequency $f = 300\,\mathrm{MHz}$.

Near-field distribution is evaluated by the following discussion. Current distribution on the antenna is determined by the moment method. By using the current distribution, the electric field in the spectrum domain is

$$\tilde{\boldsymbol{E}}(k_x, k_y) = \tilde{\overline{\boldsymbol{K}}}(k_x, k_y) \cdot \tilde{\boldsymbol{J}}(k_x, k_y) \tag{1}$$

where $\overline{\boldsymbol{K}}$ is dyadic Green's function and $\boldsymbol{J}$ is current distribution.

In any position (x, y, z), by inverse Fourier transform of Eq. (1), the electric field is

$$\boldsymbol{E}(\boldsymbol{r}) = \frac{1}{4\pi^2} \int\int_{-\infty}^{\infty} \tilde{\boldsymbol{E}}(k_x, k_y) e^{-j\boldsymbol{kr}} dk_x dk_y \tag{2}$$

where $\boldsymbol{k}$ and $\boldsymbol{r}$ are vector as follows

$$\boldsymbol{k} = k_x \boldsymbol{a}_x + k_y \boldsymbol{a}_y + \gamma_i \boldsymbol{a}_z, \tag{3}$$

$$\boldsymbol{r} = x\boldsymbol{a}_x + y\boldsymbol{a}_y + z\boldsymbol{a}_z. \tag{4}$$

k_x, k_y, γ_i are each propagation constant and $\boldsymbol{a}_x, \boldsymbol{a}_y, \boldsymbol{a}_z$ are each unit vector in x, y, z direction. γ_i are as follows

$$\gamma_i = \begin{cases} \gamma_1 = \sqrt{k_0^2 - k_x^2 - k_y^2} & (z \geq 0) \\ \gamma_2 = \sqrt{\varepsilon_r k_0^2 - k_x^2 - k_y^2} & (z \leq 0). \end{cases} \tag{5}$$

The components γ_1 and γ_2 of the two propagation vectors are related by Snell's law, and we derive the critical angle θ_c from it.

Second case, we consider far-field distribution by approximation of the electric field in Eq. (2), using stationary phase method, and we derive the electric field

$$E_\theta = j\frac{e^{-jk_0R}}{2\pi R} k_0 \left\{ \tilde{E}_x(k_{x0}, k_{y0}) \cos\varphi + \tilde{E}_y(k_{x0}, k_{y0}) \sin\varphi \right\}, \tag{6}$$

$$E_\varphi = j\frac{e^{-jk_0R}}{2\pi R} k_0 \cos\theta \left\{ -\tilde{E}_x(k_{x0}, k_{y0}) \sin\varphi + \tilde{E}_y(k_{x0}, k_{y0}) \cos\varphi \right\}. \tag{7}$$

where R is the distance from the source point.

In any radiation angle (θ, φ), radiation power density P is defined as

$$P(\theta, \varphi) = \frac{1}{2} R^2 \frac{k_0}{\omega\mu_0} \left\{ |E_\theta|^2 + |E_\varphi|^2 \right\}. \tag{8}$$

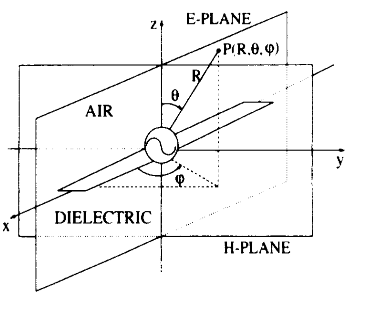

Fig. 1 Geometry for a dipole on a dielectric half-space.

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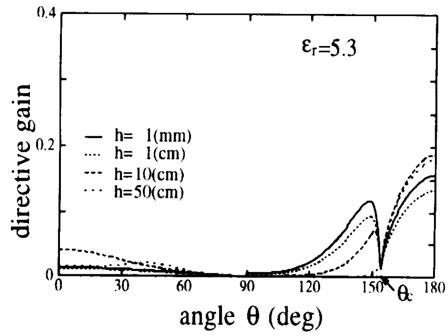
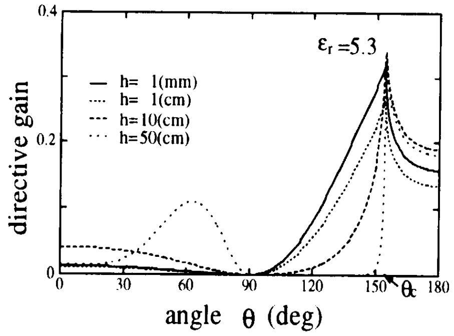


(a) E-plane



(b) H-plane

Fig. 2 Directive gain for dipoles at various heights above interface.

The directive properties of an antenna are described in terms of power gain. The power gain is given by

$$G(\theta, \varphi) = \frac{4\pi P(\theta, \varphi)}{P_{in}} \tag{9}$$

where P_{in} is input power to the element.

In order to compare the power radiating into the dielectric with the power into the air, we consider the power density ratio of the direction $\theta = 0$ to π on the E-and H-plane. When the dipole is on interface [3], we get the ratio

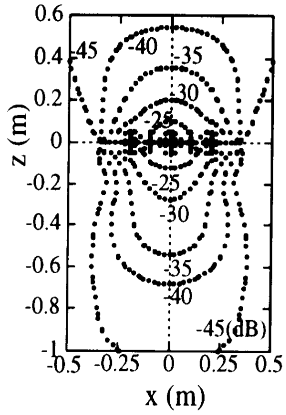
$$\frac{P(\pi, 0)}{P(0, 0)} = \frac{P\left(\pi, \frac{\pi}{2}\right)}{P\left(0, \frac{\pi}{2}\right)} = \varepsilon_r^{3/2}. \tag{10}$$

This indicates that much more power radiates into the dielectric than into the air.

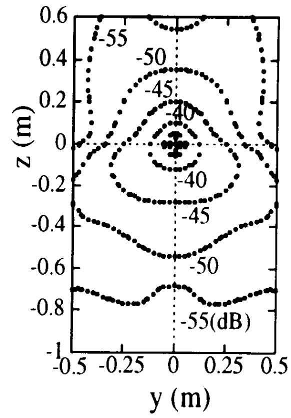
3. Numerical Results

In this section we illustrate the theory numerically using typical values of parameters for a printed-dipole.

In Fig. 2, the far-zone transmitted fields at the angles $0 \leq \theta \leq 90°$, in air, and $\theta_c \leq \theta \leq 180°$, in dielectric, are seen to arise from the refraction of the spectral components for the dipole that represent propagating waves in the direction z, i.e., waves with γ_i a real number. While the far-zone transmitted field at the angles $90° \leq \theta \leq \theta_c$, is seen to arise from the refraction of



(a) E-plane



(b) H-plane

Fig. 3 Near-field distribution.

spectral components of the dipole that represent evanescent waves in the direction z, i.e., γ_2 a pure imaginary number.

As the dipole is raised, heights increased, the amplitudes of the radiation patterns at angles $90° \leq \theta \leq \theta_c$ decrease. Evanescent waves have more exponential dampings as the dipole is raised above the interface. Thus, for large height, the transmitted pattern is significant only within the range of angles $\theta_c \leq \theta \leq 180°$.

Finally, we show near-field distribution. In this case, a dipole is supposed to be on the interface. Dielectric constant $\varepsilon_r = 5.3$. Figure 3 show the near-field distribution on E-plane in (a) and H-plane in (b). The standard of levels is the value of the point 1 mm under interface. Figure 3 (a) shows electric fields in x direction, and Fig. 3 (b) in y direction. From these results it seems that more power radiates into the dielectric than into the air.

4. Conclusion

A numerical method is presented for obtaining far-field and near-field distribution of printed dipole on a semi-infinite substrate. The analysises are based upon the stationary phase method and the Fourier integral.

We investigated that evanescent waves become smaller as antenna heights with larger interface of the two half-spaces.

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