Printed Antenna on Dielectric Substrate with No Ground Plane

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1. INTRODUCTION

Currently there is increasing interest in antenna system with no ground plane such as Optical Control Antenna [1] and Superconducting Antenna [2]. Authors have studied about scattering problem by infinite periodic array [3] and will treat finite array comprised of elements on a substrate. It is important to investigate an element on a dielectric substrate with no ground plane.

This paper presents rigorous solutions for an antenna on ungrounded substrate. Present here is Galerkin's moment method applied in Fourier transform domain. The induced electric current is expanded in piecewise sinusoidal (PWS) basis functions in the direction of current flow to represent arbitrarily shaped conducting elements. The important approach of this paper is to treat the effects of radiation and surface wave separately. From numerical results, we check validity of the present theory and discuss about radiated properties of antenna.

2. THEORY

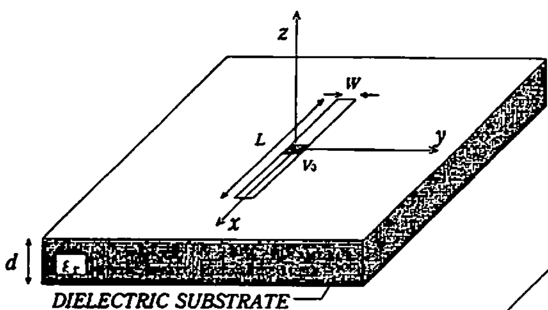

Fig.1 Printed dipole.

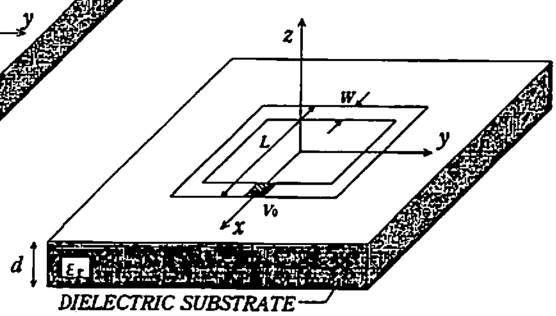

Fig.2 Printed square loop element.

Fig.1 and 2 show printed dipole and square loop element on dielectric substrates with no ground planes. The substrate has a thickness d and relative dielectric constant ε_r.

These elements are center-fed by an ideal delta-gap generator. The delta gap generator is known to yield good numerical results of antennas fed by coaxial and strip lines. At the interface (z=0), the boundary conditions for tangential electric field components have to be satisfied as:

$$(\boldsymbol{E}+\boldsymbol{E}_s)\times \boldsymbol{a}_z = \begin{cases} 0 & \text{(on Conductor)} \\ \boldsymbol{E}_0 \times \boldsymbol{a}_z & \text{(on Substrate).} \end{cases} \tag{1}$$

The moment method solution used here is Galerkin's method applied in Fourier transform domain. The unknown current $\boldsymbol{J}_c$ on a printed antenna is expanded in a set of N piecewise sinusoidal (PWS) basis functions with unknown coefficients I_n in the direction of current flow as follows:

$$\boldsymbol{J}_c(x,y) = \sum_{n=1}^{N} \boldsymbol{J}_n(x,y)\ I_n. \tag{2}$$

By using Galerkin's method in the spectral domain, the following algebraic equation is obtained.

$$\sum_{n=1}^{N} Z_{mn}\ I_n = V_m \qquad (m=1,2,\cdots,N) \tag{3}$$

$$Z_{mn} = \frac{1}{4\pi^2}\iint_{-\infty}^{+\infty} \tilde{\boldsymbol{J}}_m^*(k_x,k_y)\cdot \tilde{\overline{\overline{\boldsymbol{K}}}}(k_x,k_y)\cdot \tilde{\boldsymbol{J}}_n(k_x,k_y)\ dk_x dk_y \tag{4}$$

$$V_m = \begin{cases} V_0 & \text{(on Source)} \\ 0 & \text{(otherwise).} \end{cases} \tag{5}$$

The tilde over a quantity designates the Fourier transform of that quantity. If the relative permitivity of homogeneous medium is selected as ε_e=(1+ε_r)/2, the Green's function $\tilde{\overline{\overline{\boldsymbol{K}}}}(k_x,k_y)$ will approach the Green's function $\tilde{\overline{\overline{\boldsymbol{K}}}}^h(k_x,k_y)$ in homogeneous medium for large values of $\beta(=\sqrt{k_x^2+k_y^2})$ [4]. The Green's function is given by reference [3]. The integral Z_{mn} of eqn.(4) is split into two parts as follows:

$$Z_{mn} = Z_{mn}^h + \Delta Z_{mn} \tag{6}$$

$$Z_{mn}^h = \frac{1}{4\pi^2}\iint_{-\infty}^{+\infty} \tilde{\boldsymbol{J}}_m^*(k_x,k_y)\cdot \tilde{\overline{\overline{\boldsymbol{K}}}}^h(k_x,k_y)\cdot \tilde{\boldsymbol{J}}_n(k_x,k_y)\ dk_x dk_y \tag{7}$$

$$\Delta Z_{mn} = \frac{1}{4\pi^2}\iint_{-\infty}^{+\infty} \tilde{\boldsymbol{J}}_m^*(k_x,k_y)\cdot \{\tilde{\overline{\overline{\boldsymbol{K}}}}(k_x,k_y) - \tilde{\overline{\overline{\boldsymbol{K}}}}^h(k_x,k_y)\}\cdot \tilde{\boldsymbol{J}}_n(k_x,k_y)\ dk_x dk_y \tag{8}$$

The first integral Z_{mn}^h is equal to the impedance matrix element of an antenna in homogeneous medium and is known as closed form. The second integral ΔZ_{mn} converges rapidly for large β.

Surface waves can be excited on a dielectric substrate and determined by the poles of the Green's functions. Since surface wave power P_{sw} launched in a substrate will not contribute to radiated power P_{rad}, the total power P_{tot} can be expressed by

$$P_{tot} = P_{rad} + P_{sw} \tag{9}$$

with

$$P_{tot} = \frac{1}{2} Re \sum_{m=1}^{N} \sum_{n=1}^{N} I_m^* Z_{mn} I_n \tag{10}$$

$$P_{rad} = \frac{1}{2} Re \sum_{m=1}^{N} \sum_{n=1}^{N} I_m^* Z_{mn}^{rad} I_n \tag{11}$$

$$P_{sw} = \frac{1}{2} Re \sum_{m=1}^{N} \sum_{n=1}^{N} I_m^* Z_{mn}^{sw} I_n \tag{12}$$

where Z_{mn} represents the matrix using the total field and Z_{mn}^{rad} and Z_{mn}^{sw} represent the radiation and surface wave contributions, respectively. The elements can be broken up and the impedance matrix are

$$Z_{mn} = Z_{mn}^{rad} + Z_{mn}^{sw}. \tag{13}$$

3. NUMERICAL RESULTS

Figure 3 shows the input admittance ($Y = G + jB$) of printed dipole (length L=39.0 mm, width W=0.86 mm) on a dielectric substrate (ε_r= 2.53, d= 0.76 mm) against frequency. To check the accuracy of the present method, numerical results are compared with measured results. These results are in good agreement, the present method is valid.

Dielectric substrate (ε_r=2.53, 5.0 and 10.0, d= 0.76 mm) are selected for comparison in Fig.4. From this figure, when ε_r is larger, resonant frequency becomes small. We find that the wave-length reduction appears.

Next we calculate the properties of square loop element (length L= 19.5 mm, width W= 0.86 mm) on a substrate (ε_r= 2.53, d= 0.76 mm) as shown in Fig.5. The resonant frequencies are different between square loop and dipole. Square loop element shows sharp resonant band.

4. CONCLUSIONS

A moment method for the printed antenna on no grounded dielectric substrate is formulated. From measured and numerical results, we show the validity of present theory. The input admittance properties of dipole and square loop element on substrates are calculated.

We will apply this method to scattering problem of antenna with no ground plane and develop it to finite array.

REFERENCES

1. K.Nishimura and M.Tsutsumi, "Optical Control of the Printed Dipole Antenna" Trans. IEICE Vol.J78-C-I, No.3, pp.173-179, March 1995.
2. D.Zhang, M.Matlobian, T.W.Kim, H.R.Fetterman, K.Chou, S.Prakash, C.V.Deshpandey, R.F.Bunshah and K.Daly, "Quasi-Optical Millimeter-Wave Band-Pass Filters using High-T_c Superconductors", IEEE Trans. Microwave Theory and Tech., MTT-39, 9, pp.1493-1497, Sept. 1991.
3. H.Wakabayashi, M.Kominami, H.Kusaka and H.Nakashima, "Numerical Simulations for FSSs with Complementary Elements", IEE Microw. Antennas Propag., 141, 6, pp.477-482, Dec. 1994.
4. M.Kominami, D.M.Pozar and D.H.Schaubert, "Dipole and Slot Elements and Arrays on Semi-Infinite Substrates", IEEE Trans., Antennas Propagat., AP-33, 6, pp.600-607, June 1985.

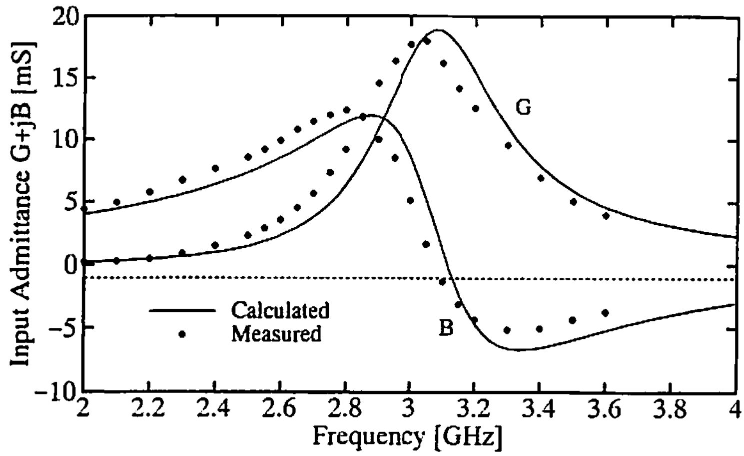

Fig.3 Comparison of measured and numerical results.

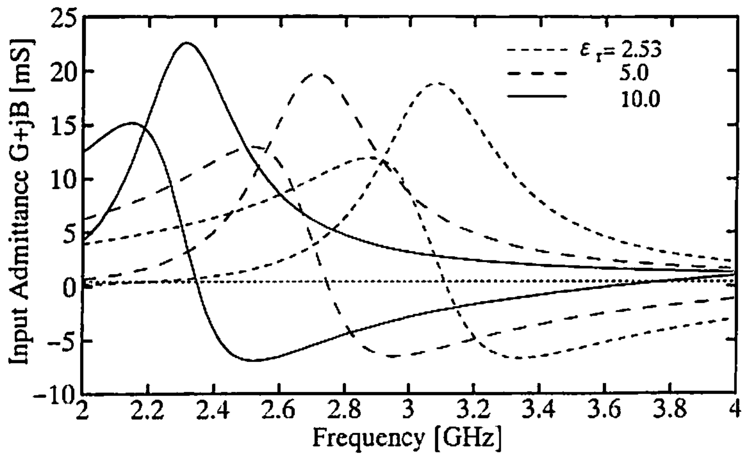

Fig.4 Input admittance of dipoles on dielectric substrates.

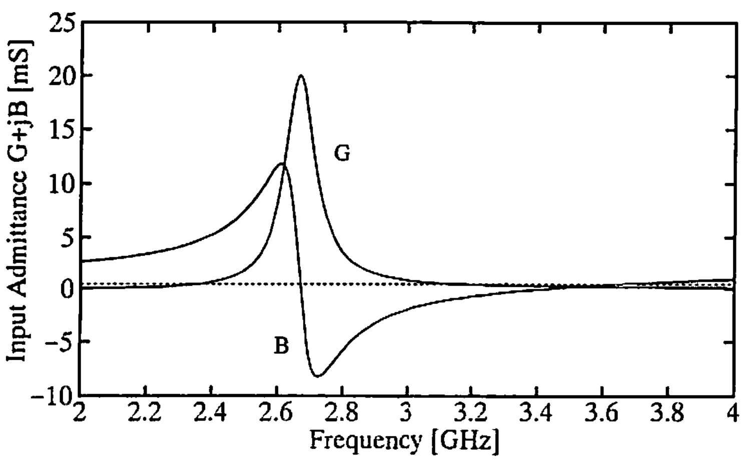

Fig.5 Input admittance of square loop element on a dielectric substrate.