

**AN ANTENNA SYSTEM WITH COUPLING BETWEEN ELECTRIC AND MAGNETIC CURRENT
SOURCES IN A MULTI-LAYERED MEDIUM**

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I. INTRODUCTION

For analyses of microstrip antennas, the Spectral-Domain Green's functions rather than the Real Space-Domain has been used, because of their planarity. In the Fourier transform Domain or the Spectral Domain, the planarity of the structures makes it possible to derive the Green's function in a compact form for any number of layers. This paper deals with the theoretical analysis of the mutual coupling between slot and dipole antennas embedded in a multilayered medium. The mutual coupling between the slot, that is, a magnetic current antenna, and the dipole, that is, an electric current antenna is very strong. This paper clarifies this concept in the form of a matrix representation[1], by using Galerkin's method applied in the Fourier transform Domain instead of the Space Domain [3],[4].

II. ABSTRACT OF THEORY

The dyadic Green's function can be expressed in terms of TM and TE decoupled field components perpendicular to the grounded multilayered slab. First, by applying a two dimensional Fourier Transform(transformed functions will be denoted by a tilde), the field is decomposed into a plane wave spectrum propagating along the interface with the propagation vector $\bar{k}_t = \hat{x} k_x + \hat{y} k_y$. The ground plane and the dielectric layers have to be extended to infinity in the X-Y direction. Source terms are accounted for in the application of the boundary conditions. The presence of the multilayered medium shown in Fig.1 is characterized by reflection coefficients R^{TM} and R^{TE} for TM and TE waves, respectively. Using the transmission and reflection properties of plane waves, we can find the Z-components of the electric and magnetic fields in any layer. Then the transverse components of the electric and magnetic fields can be readily obtained from E_z and H_z [2]. Therefore a full-wave Green's function completely defining the fields inside a multilayered medium due to a current element arbitrarily placed in any layer is derived in two-dimensional spectral-domain form.

III. FORMULATION

Denoting the space above the ground plane ($Z > 0$) as region + and the space below the ground plane ($Z < 0$) as region -, we assume that two sets of impressed fields $(\tilde{E}^+, \tilde{H}^+)$ and $(\tilde{E}^-, \tilde{H}^-)$ are incident upon the antennas from region $Z > 0$ and $Z < 0$, respectively. The total electric and magnetic fields in each region can be written as a summation of fields due to the various currents in the spectral domain. The boundary conditions ($\bar{E}^{tan} = 0$ on the dipole antenna, and \bar{H}^{tan} is continuous through the slot), are enforced in the Spectral Domain to yield the following equation:

$$\begin{bmatrix} -\tilde{C}^{EJ} & -\tilde{C}^{EM+} \\ -\tilde{C}^{HJ} & -(\tilde{C}^{HM+} + \tilde{C}^{HM-}) \end{bmatrix} \begin{bmatrix} \tilde{J} \\ \tilde{M}_+ \end{bmatrix} = \begin{bmatrix} \tilde{E}^{+^0} \\ \tilde{H}^{+^1} - \tilde{H}^{-^1} \end{bmatrix} + \begin{bmatrix} -\tilde{E}^{+^0} \\ -(\tilde{H}^{+^0} - \tilde{H}^{-^0}) \end{bmatrix} \quad (1)$$

where \tilde{J} electric current density on the printed dipole
 \tilde{M}_+ magnetic current density in the slot
 \tilde{E}^{+^0} electric field on the interface except dipole
 $\tilde{H}^{+^0}, \tilde{H}^{-^0}$ magnetic field on the ground plane except slot
 \tilde{E}^{+^1} incident electric field from region +
 $\tilde{H}^{+^1}, \tilde{H}^{-^1}$ incident magnetic field from region + and -, respectively
 \tilde{C}^{EJ} the dyadic Green's function for \tilde{E} due to \tilde{J} in a multilayer
 $\tilde{C}^{EM+}, \tilde{C}^{HJ}, \tilde{C}^{HM+}$ and \tilde{C}^{HM-} have similar meanings to \tilde{C}^{EJ} .

Note that Eq.(1) contains five unknowns $\tilde{J}, \tilde{M}_+, \tilde{E}^{+^0}, \tilde{H}^{+^0}$ and \tilde{H}^{-^0} . However, $\tilde{E}^{+^0}, \tilde{H}^{+^0}$ and \tilde{H}^{-^0} are eliminated in the process of solution. This spectral domain algebraic equation corresponds to the Pocklington's integral equations in the space domain. It is assumed that the dipole and slot width are very small compared to the wavelength in the free space and dielectric, therefore we consider only the axial components of the currents. The unknown current densities $\tilde{J}(x,y)$ on the printed dipole and $\tilde{M}(x,y)$ in the slot are expanded in N_d and N_s piecewise-sinusoidal basic functions, respectively. Using Galerkin's method in the spectral domain, Eq.(1) reduces to the following matrix equation to be solved for the unknown amplitude, that is, \bar{I} and \bar{V} , of the dipole and slot, respectively. In the expression, we define a suitable inner product for our problem as follows:

$$\langle \tilde{J}, \tilde{E} \rangle = \frac{1}{4\pi^2} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \tilde{J}^t(-k_x, -k_y) \cdot \tilde{E}(k_x, k_y) dk_x dk_y$$

$$\begin{bmatrix} \bar{Z} & \bar{B} \\ \bar{C} & \bar{Y} \end{bmatrix} \begin{bmatrix} \bar{I} \\ \bar{V} \end{bmatrix} = \begin{bmatrix} \bar{V}^i \\ \bar{I}^i \end{bmatrix} \quad \text{where} \quad \begin{aligned} Z_{mn} &= -\langle \tilde{J}_m, \tilde{C}^{EJ} \cdot \tilde{J}_n \rangle \\ B_{mn} &= -\langle \tilde{J}_m, \tilde{C}^{EM+} \cdot \tilde{M}_{n+} \rangle \\ C_{mn} &= -\langle \tilde{M}_{m+}, \tilde{C}^{HJ} \cdot \tilde{J}_n \rangle \\ Y_{mn} &= -\langle \tilde{M}_{m+}, (\tilde{C}^{HM+} + \tilde{C}^{HM-}) \cdot \tilde{M}_{n+} \rangle \end{aligned} \quad (2)$$

Since $\tilde{J}_m, \tilde{M}_{m+}, \tilde{E}^{+^1}$ and $\tilde{H}^{+^1} - \tilde{H}^{-^1}$ are defined on the antenna element and \tilde{E}^{+^0} and $\tilde{H}^{+^0} - \tilde{H}^{-^0}$ are defined outside the element, by using Parseval's relation, \bar{V}^i and \bar{I}^i can be evaluated by $V_m^i = \langle \tilde{J}_m, \tilde{E}^{+^1} \rangle$, $I_m^i = \langle \tilde{M}_{m+}, (\tilde{H}^{+^1} - \tilde{H}^{-^1}) \rangle$. \bar{B} and \bar{C} describe the interaction between the slot and dipole. The reciprocity is reflected to the relation, $\bar{C} = -\bar{B}^t$. In evaluating the elements of Eq.(2) numerically, convergence can be accelerated by using the technique of [3],[4], whereby a term representing the contribution of the current in a homogeneous medium having the same asymptotic behavior is subtracted from the Green's function of the dielectric slab.

For example, Z_{mn} can then be written as

$$Z_{mn} = -[\langle \tilde{J}_m, (\tilde{C}^{EJ} - \tilde{C}^{EJh}) \cdot \tilde{J}_n \rangle + \langle \tilde{J}_m, \tilde{C}^{EJh} \cdot \tilde{J}_n \rangle] \quad (3)$$

where \tilde{C}^{EJh} represents the Green's function of an effective homogeneous medium. In Eq.(3), the second integral can be easily evaluated in closed form, and the first integral will converge relatively quickly.

IV. NUMERICAL RESULTS

In this section, numerical results for a one layer case are discussed. Fig.2 shows the problem to be considered and the coordinates and notation. In this

example, $\epsilon_{r1}=2.6$, $d=0.02\lambda_0$, $L_S=0.30\lambda_0$, $W_d=W_S=0.03\lambda_0$, (λ_0 is the free-space wavelength), and the dipole length L_d is variable. Solving Eq.(2), the current(electric) and voltage distributions for the dipole and slot, respectively can be determined. Radiation fields and power gain patters can be evaluated by the electric and magnetic current distributions on the antennas. Fig.3 shows the calculated radiation patterns, where the slot is waveguide-backed and the dipole is parasitic. From Fig.3, we can make sure that the parasitic dipole functions not only as a director but also as a reflector by varying the dipole length L_d . In the case of free space, this fact has already indicated [1].

V. CONCLUSION

The antenna system composed of the slot and dipole embedded in a multilayered medium has been formulated by using Spectral Domain Approach. The exact Green's functions in spectral domain form are used to find the necessary field components from electric and magnetic currents in a multilayered medium. The concept of the mutual coupling between the slot and the dipole has been grasped clearly as both mutual impedance and admittance in the conventional antenna theory.

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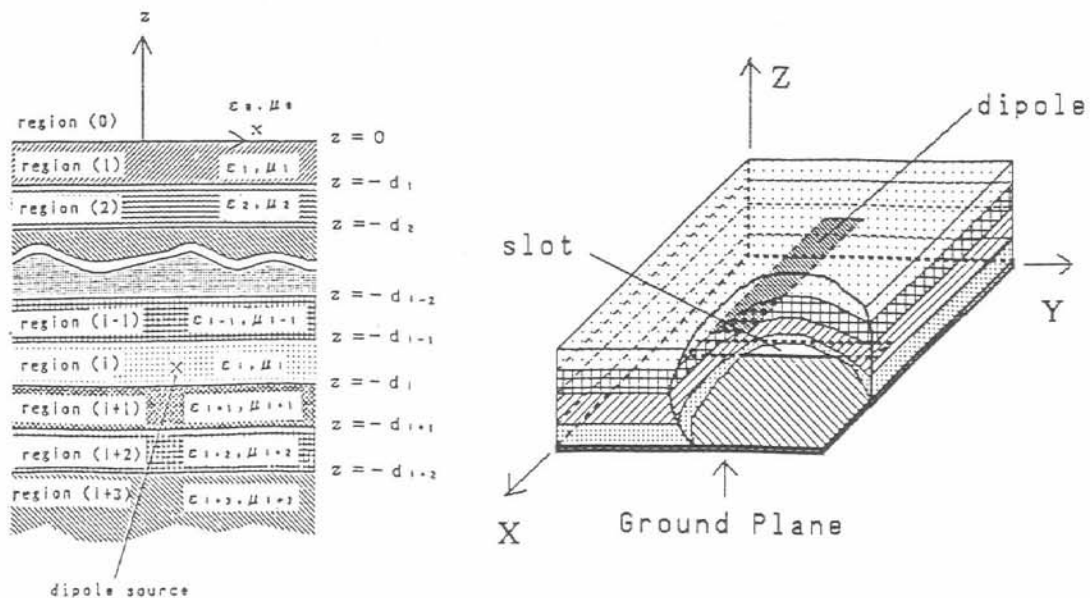


Fig.1-A multilayered medium.

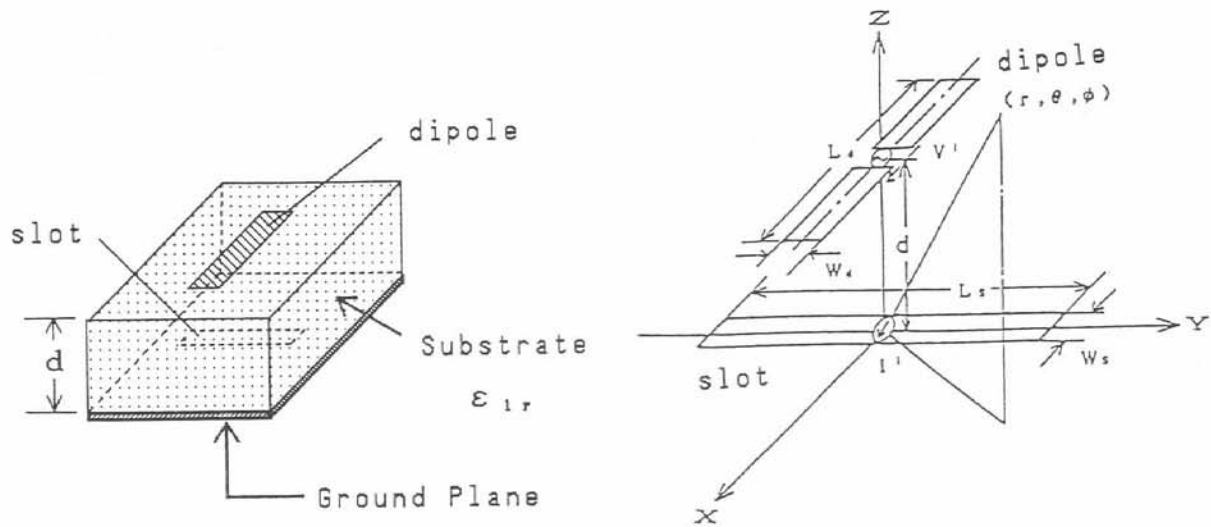


Fig.2-Geometry of the slot and dipole system.

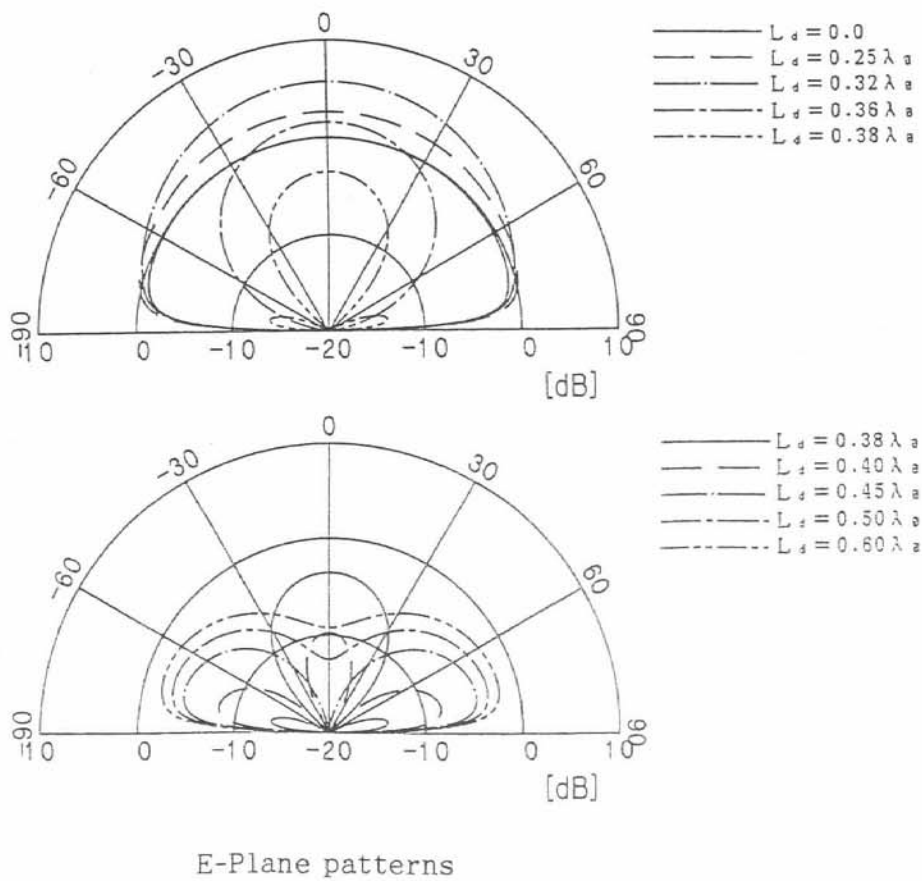


Fig.3-Power gain patterns for various parasitic element length.