A PRINTED DIPOLE ELECTROMAGNETICALLY COUPLED TO A MICROSTRIP FEED LINE

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I. INTRODUCTION

Electromagnetically coupled microstrip dipole constitutes a desirable candidate for applications involving one- and two-dimensional antenna arrays [1],[2]. It would be worthwhile to obtain a formulation for an arbitrary location of the printed dipole over the stripline.

In the present work, analysis is carried out to derive an expression for the amplitude of excited current on the printed dipole and the reflection and transmission coefficients for the dominant mode of the stripline. Expression of the dipole current is derived by using the moment method solution with the Green's function [3]. The source current distribution on the stripline required to calculate the reaction integral equation is found from the quasi-static analysis [4]. A comparison between theoretical and experimental results on the equivalent shunt impedance is presented.

II. THEORY

Fig. 1 shows the problem to be considered and the coordinates and notation to be used. The printed dipole is excited by an infinitely long microstrip line embedded in the dielectric substrate.

The method of moment may be used in connection with Richmond's reaction method to determine unknown dipole current [3]. In this method, the current density is expanded in a set of M basis functions,

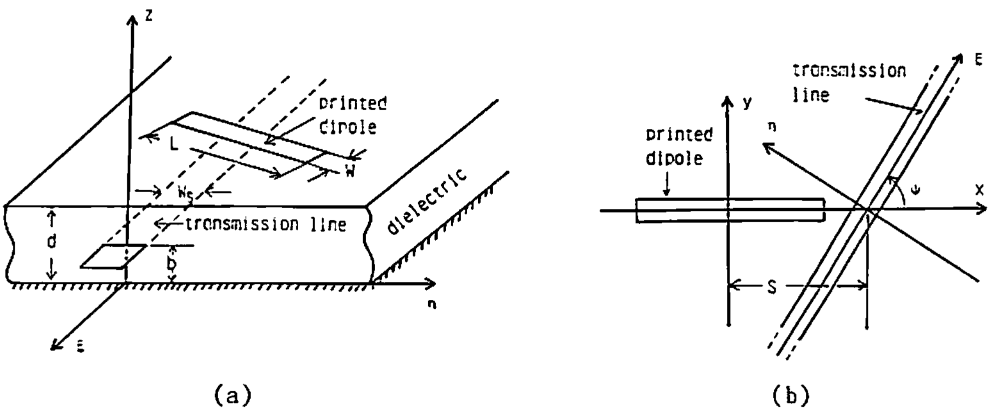

Fig. 1 (a) A printed dipole excited by a transmission line embedded in the dielectric. (b) Coordinate transformation : $\xi=(x-s)\cos\psi+y\sin\psi$, $\eta=-(x-s)\sin\psi+y\cos\psi$.

$$\mathbf{J}_a(x, y) = \sum_{m=1}^{M} I_m \mathbf{J}_m(x, y) \qquad (1)$$

where $\mathbf{J}_m$ is the mth basis function and I_m is its unknown amplitude. The unknown amapltude I_m can be formally obtained in terms of source current by using the simultaneous equation

$$\sum_{m=1}^{M} Z_{nm} I_m = V_n \qquad (n =1, 2, \ldots, M) \qquad (2)$$

where

$$Z_{nm} = - \iint_{dipole} \mathbf{J}_n(x, y)\cdot\mathbf{E}_m(x, y, d)dx\,dy \qquad (3)$$

$$V_n = \iint_{stripline} \mathbf{J}_s(\xi, \eta)\cdot\mathbf{E}_m(x, y, d)d\xi\,d\eta \qquad (4)$$

$$\mathbf{E}_m (x, y, z) = \frac{1}{4\pi^2} \iint_{-\infty}^{\infty} [\mathbf{a}_x \tilde{K}_{xx}(k_x, k_y, z) + \mathbf{a}_y \tilde{K}_{yx}(k_x, k_y, z)] \tilde{J}_m(k_x, k_y)\, e^{-j(k_x x + k_y y)} dk_x dk_y \qquad (5)$$

$$\tilde{K}_{xx}(k_x, k_y, z) = -j\frac{\eta_0}{k_0}\sin\gamma_1 z \left[\frac{k_0^2}{T_e} - \frac{k_x^2(\gamma_2\cos\gamma_1 d + j\gamma_1\sin\gamma_1 d)}{T_m T_e}\right] \qquad (6)$$

$$\tilde{K}_{yx}(k_x, k_y, z) = j\frac{\eta_0}{k_0}\sin\gamma_1 z \left[\frac{\gamma_2\cos\gamma_1 d + j\gamma_1\sin\gamma_1 d}{T_e T_m}\right] k_x k_y \qquad (7)$$

$$T_e = \gamma_1\cos\gamma_1 d + j\gamma_2\sin\gamma_1 d \qquad (8)$$

$$T_m = \varepsilon_r\gamma_2\cos\gamma_1 d + j\gamma_1\sin\gamma_1 d \qquad (9)$$

$$\gamma_1^2 = \varepsilon_r k_0^2 - k_x^2 - k_y^2\,, \quad \gamma_1^2 = k_0^2 - k_x^2 - k_y^2 \qquad (10)$$

In order to implement this method, an expression for the source current distribution $\mathbf{J}_s$ is needed. The mode of propagation on microstrip line is almost TEM at lower frequency (below X-band) [4] where the strip width and the substrate thickness are much smaller than the wavelength in the dielectric material. Asuuming that the transmission line supports only the TEM mode, values of characterristic impedance Z_0 and phase constant γ_0 are determined by the variational method in Fourrier tranform domain [4]. The current source due to the dominant TEM mode may be then expressed as

$$\mathbf{J}_s(\xi, \eta) = \mathbf{a}_\xi I(\xi)f(\eta) \qquad (11)$$

where $I(\xi)$ is the mode current and $f(\eta)$ is the current dependence in transeverse direction. The mode current is given by

$$I(\xi) = \begin{cases} e^{-j\gamma_0\xi} - \Gamma e^{j\gamma_0\xi} & (\xi \leqq 0) \\ T\, e^{-j\gamma_0\xi} & (\xi \geqq 0) \end{cases} \qquad (12)$$

where Γ and T are the reflection and transmission coefficients, respectively. Note that the source current $\mathbf{J}_s$ contains these unknown coefficients. The modal vector is given by

$$\mathbf{e}(\eta, z) = \frac{1}{2\pi}\int_{-\infty}^{\infty} [-j\mathbf{a}_\eta \alpha \tilde{\phi}(\alpha, z) + \mathbf{a}_z \frac{\delta \tilde{\phi}(\alpha, z)}{\delta z}] e^{-j\alpha\eta} d\alpha \qquad (13)$$

where

$$\tilde{\phi}(\alpha, z) = \begin{cases} -\dfrac{\tilde{f}(\alpha)}{|\alpha|} e^{-|\alpha| b} \sinh |\alpha| z & (0 \leqq z \leqq b) \\ -\dfrac{\tilde{f}(\alpha)}{|\alpha|} \sinh |\alpha| b \, e^{-|\alpha| z} & (z \geqq b) \end{cases} \qquad (14)$$

and

$$\tilde{f}(\alpha) = 2\left(\frac{\sin \frac{\alpha Ws}{2}}{\frac{\alpha Ws}{2}}\right) - \left(\frac{\sin \frac{\alpha Ws}{4}}{\frac{\alpha Ws}{4}}\right)^2 \qquad (15)$$

Applying the Lorentz reciprocity theorem to the field in the strip line, Γ and T are expressed by

$$\Gamma = -\frac{1}{2I_0} \iint_{dipole} \mathbf{J}_a(x, y) \cdot \mathbf{e}(\eta, d) e^{-j\gamma_0 \xi} dxdy \qquad (16)$$

$$T = 1 - \frac{1}{2I_0} \iint_{dipole} \mathbf{J}_a(x, y) \cdot \mathbf{e}(\eta, d) e^{j\gamma_0 \xi} dxdy \qquad (17)$$

where I_0 is the normalization constant of the modal vector. It is now possible to form a set of simultaneous equations from (2), (16) and (17) for the (M+2) unknown coefficients.

From (16) and (17) we find that $1 + \Gamma = T$ for a printed dipole perpendicularly or symmetrically placed, so the dipole behaves like a shunt element in the dominant TEM mode transmission line. The impedance of the dipole is given by

$$Z = \frac{T Z_0}{2(1 + T)} \qquad (18)$$

III. NUMERICAL AND EXPERIMENTAL RESULTS

In this section numerical results using the above-described method are compared with measurements of impedance for stripline fed printed dipole. Three PWS expansion modes were used in the moment solution. The measurements were made with electromagnetically coupled printed dipole on a grounded dielectric substrate of size 12 x 12 cm^2. Impedance of the coupled dipole is experimentally measured using the network analyzer which enables the determination of the complex transmission coefficient [5].

Fig. 2 compare measured and calculated impedance for the printed dipole perpendicularly placed over the microstrip line. In this example the dipole is of length L=35 mm, width W=1 mm. The substrate is of thickness d=3.02 mm, dielectric constant ϵ_r=2.53, $\tan\delta$=0.002 and embedding distance b=1.51 mm.

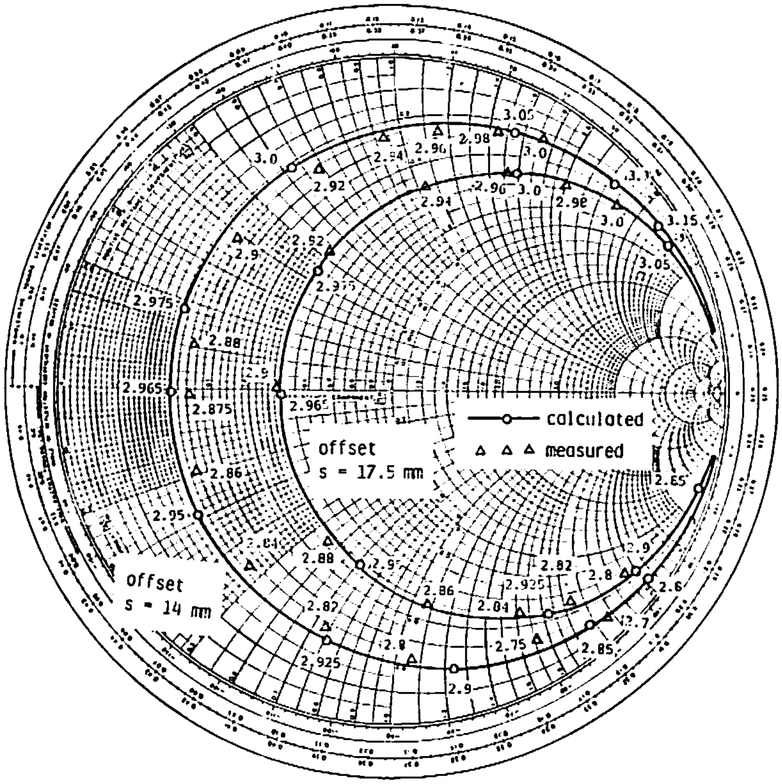

Fig. 2 Measured and calculated impedance of a perpendicularly located dipole.

IV. CONCLUSION

An moment method solution for the electromagnetically coupled printed dipole is presented which properly accounts for the effects of substrate thickness, surface wave, offset and dipole length. The present method gives agreement with the measured data for perpendicularly displaced dipole over the frequency range of interest.

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