THEORY AND EXPERIMENT OF MUTUAL COUPLING BETWEEN CYLINDRICAL MICROSTRIP ANTENNAS

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1. Introduction

Theoretical models based on the full-wave approach [1], the cavity-model analysis [2], [3], and the generalized transmission line model (GTLM) method [4], [5] have been recently reported for the mutual coupling computation between cylindrical microstrip antennas. The full-wave approach [1] is rigorous and more accurate theoretical results are expected to be obtained. However, the numerical calculation for the full-wave approach is inefficient and requires more careful programming. On the other hand, the cavity-model analysis and the GTLM method are relatively simpler in the theoretical formulation and more efficient in the numerical calculation. In this article we give a comparison of the calculated mutual coupling coefficients, obtained from the three different theoretical models, with the measured data. The cases of the cylindrical circular and rectangular patches are studied, and both the E-plane and H-plane coupling are considered.

2. Theory and Experimental Techniques

In the configurations shown by Fig. 1, the two rectangular or circular patches are of the same size and mounted on a cylindrical body of radius a. The two patches are here considered as a two-port network with a 2×2 port impedance matrix $[Z]$. Once the elements in the $[Z]$ matrix are determined, the mutual coupling coefficient can be calculated from

$$S_{12} = 2Z_{21} \cdot Z_0 / [(Z_{11} + Z_0)^2 - Z_{21}^{\ 2}], \tag{1}$$

where Z_0 is the characteristic impedance of the feeding coax (selected to be 50 ohms here); Z_{11} is the input impedance of the excited antenna with the presence of the other antenna open circuited, and Z_{21} is the mutual impedance between the two antennas. For the full-wave approach [1], the expressions of Z_{11} and Z_{21} are derived as

$$Z_{i1} = -\int_a^b E_\rho^{(i)}(\rho, \phi_{si}, z_{si})\, d\rho, \qquad i = 1,\ 2, \tag{2}$$

where $E_\rho^{(i)}(\rho, \phi_{si}, z_{si})$ is the ρ component of the total electric field inside the volume of the probe feed, modeled as a unit $\hat{\rho}$-directed line current density, for patch i. The related Green's functions are derived for the expression of $E_\rho^{(i)}$, and numerical results are calculated using Galerkin's moment method.

As for the cavity-model analysis [2], [3], the thin-substrate condition is assumed, and the probe current is modeled as a $\hat{\rho}$-directed current ribbon of effective arc length w_p, about 4.5 times the radius of the actual probe feed. It is also assumed that the mutual interaction does not disturb the interior field distribution inside the cavity below the microstrip patches. In this case Z_{11} is set to be 50 ohms. The mutual impedance Z_{21} between the two patches can be calculated from

$$Z_{21} = \frac{1}{I_1 I_2} \oint \bar{H}_1 \cdot \bar{M}_2 d\ell, \tag{3}$$

where I_1 and I_2 are, respectively, the amplitudes of the feed currents of the two patches, $\bar{H}_1$ is the magnetic field set up by patch 1 on patch 2, and $\bar{M}_2$ is the equivalent magnetic current of patch 2. With Z_{21} evaluated from (3), S_{12} can be readily calculated from

$$S_{12} = 100 Z_{21} / (10^4 - Z_{21}^2). \tag{4}$$

For the GTLM method [5], we use the same assumptions as required for the cavity-model analysis, and the microstrip patch is modeled as a transmission line loaded with a wall admittance at the radiation aperture at the patch edge. By replacing the section of transmission line, between the feed position and the radiation aperture, with an equivalent π network, an equivalent circuit can be derived [4], [5], and Z_{11} has been formulated. By further including the mutual admittance between the radiating edges of the two patches into the equivalent circuit, the mutual impedance Z_{21} can be derived [5], and S_{12} can then be easily calculated from (1).

In the experiment, the microstrip antennas were fabricated using flexible copper-clad laminates (RO3003) and mounted on ground cylinders of different radii. For different cylinder radii, the feed position needs to be adjusted to obtain 50 ohms input impedance. Different edge spacings were achieved by inserting grounded substrates of various sizes, made using the same laminates as the patch substrate, between the two patches, which provides a good approximation of a continuous substrate [6].

3. Results and Conclusions

Fig. 2 presents the calculated (full-wave solutions) and measured S_{12} between two probe-fed cylindrical rectangular patch antennas. Fig. 3 shows the case for the circular patches, with the calculated results obtained from the GTLM method. Good agreement between the calculated and measured results is observed. The resonant frequency f_{01} for the rectangular patches is at about 1440 MHz, and f_{11} for the circular patches is at about 1560 MHz. The cavity-model solutions are also calculated and found to agree with the full-wave and GTLM solutions. It can be concluded that the mutual coupling solutions obtained from the three different theoretical models show very small differences, although the formulation complexity and the calculation efficiency of the three models vary greatly. More results such as the finite ground plane effects on the mutual coupling and the input impedance results of slot-coupled cylindrical microstrip antennas will be discussed in the presentation.

References

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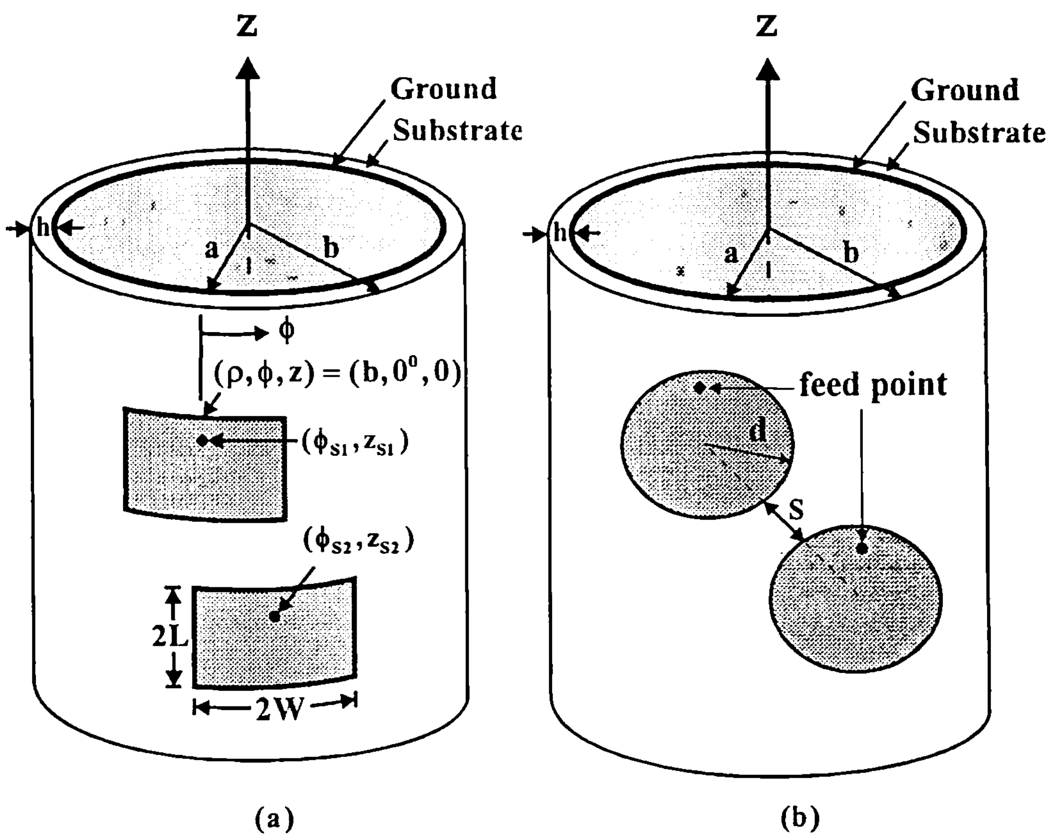

Fig. 1 The configurations of (a) two rectangular and (b) two circular microstrip patch antennas mounted on a cylindrical surface.

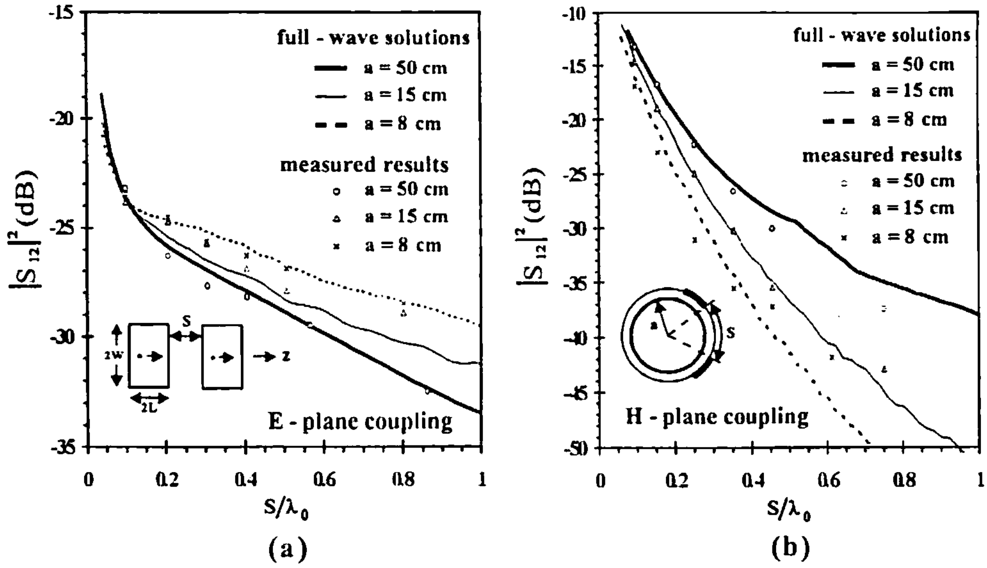

Fig. 2 Mutual coupling between two probe-fed cylindrical rectangular patch antennas (TM_{01} mode excitation); $\varepsilon_r = 3.0$, $h = 0.762$ mm, $2L = 6$ cm, $2W = 4$ cm. (a) E-plane coupling case. (b) H-plane coupling case. The calculated data are full-wave solutions.

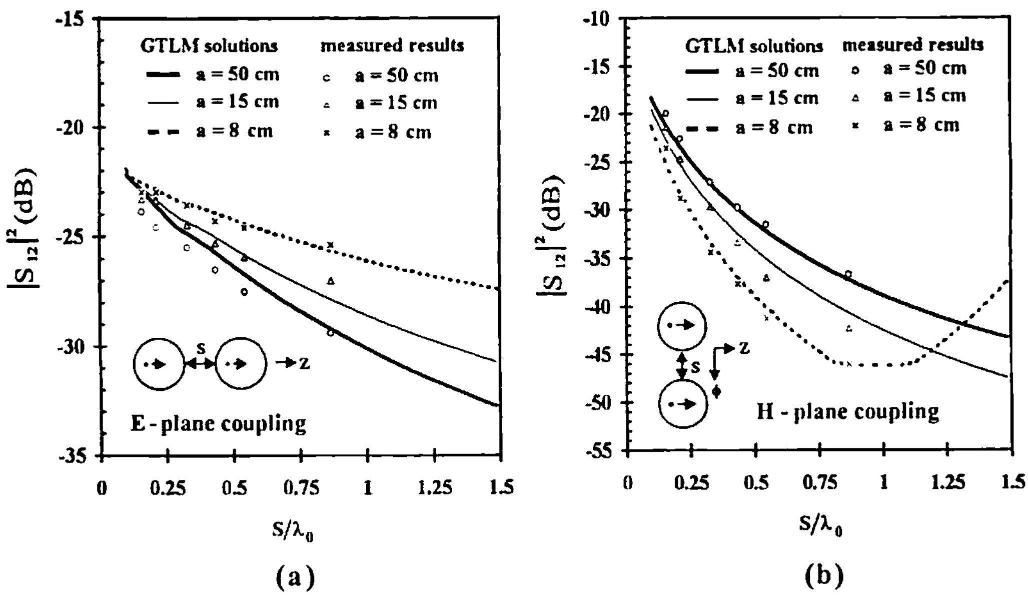

Fig. 3 Mutual coupling between two probe-fed cylindrical circular patch antennas (TM_{11} mode excitation); $\varepsilon_r = 3.0$, $h = 0.762$ mm, $d = 3.2$ cm. (a) E-plane coupling case. (b) H-plane coupling case. The calculated data are GTLM solutions.