Design of a Dual Dielectric Rod-Antenna System

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Abstract—**A method is proposed for calculating the coupling coefficient between two dielectric antennas. The numerical solution is carried out by means of the full-wave analysis of the cascaded dielectric waveguides which represent the antenna. The obtained results for the coupling coefficient are in good agreement with the available experimental data. Moreover, the radiation patterns are calculated and presented.**

I. Introduction

Surface-wave dielectric antennas, or rod antennas are widely used in microwave communication systems. This is due to their easy realization given their simple geometry and in particular, because of their compatibility with systems which employ dielectric waveguides [1], [2]. In some systems such as radar, two rod antennas are used, each one being in charge of the emission or reception tasks and the good performance of the whole system depends largely on a minimum interference between the two antennas. Since it is also important to reduce the space occupied by the antennas in such systems, it appears that the distance between the two rods should be optimized in order to have a minimum acceptable coupling between them. In this work, we propose a fast and efficient method for calculating the inter-rod coupling coefficient by means of an optimized model for each antenna in which the mutual and self-admittances are determined. The method allows also to obtain the radiation patterns.

II. Theory

Fig. 1 shows the system of two dielectric tapered rod antennas. The coupling coefficient is defined as the ratio of the power coupled to one of the rods to the input power of the other one. In order to study this coupling, the system should be represented by an equivalent circuit. A single antenna can be considered as a lossy load, represented by a complex admittance and the coupling between the two rods is accounted for by means of the mutual admittance. In this way, the symmetrical coupled-antennas system can be considered as a two-port network, represented by the π-type equivalent circuit of Fig. 2. In this circuit, Y_0 stands for the self admittance of each antenna and Y_1 and Y_2 characterize the coupling effects. The coupling coefficient is deduced from the transfer function of the two-port network, that is

$$C\mathrm{dB} = 20\log\left|\frac{V_{\mathrm{out}}}{V_{\mathrm{in}}}\right| = 20\ \log\left|\frac{Y_1}{Y_0+Y_1+Y_2}\right|. \quad (1)$$

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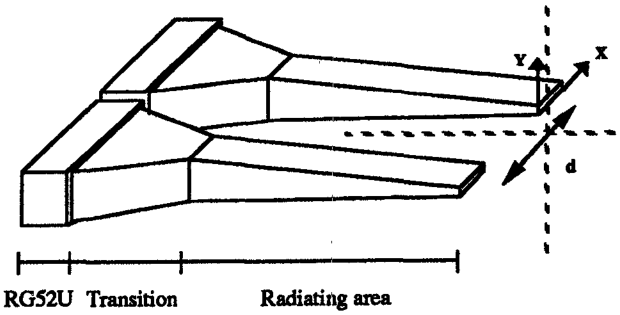

Fig. 1. Coupled rod-antennas system.

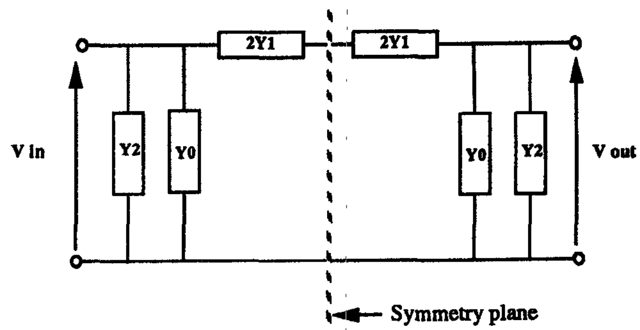

Fig. 2. π-type equivalent circuit Y_0: Self admittance of each antenna Y_1, Y_2: Admittances characterising coupling effects.

As shown in Fig. 1, a symmetry plane separates the structure in two parts. When this symmetry plane is an electric wall, the input equivalent admittance will be the odd admittance given by

$$Y_{\mathrm{odd}} = Y_0 + Y_2 + 2Y_1 \quad (2)$$

and in the case of a magnetic wall, the even admittance will be

$$Y_{\mathrm{even}} = Y_0 + Y_2. \quad (3)$$

The combination of (1), (2), and (3) allows to express the coupling coefficient in terms of Y_{even} and Y_{odd} only

$$C_{\mathrm{dB}} = 20\log\left|\frac{Y_{\mathrm{odd}} - Y_{\mathrm{even}}}{Y_{\mathrm{odd}} + Y_{\mathrm{even}}}\right|. \quad (4)$$

Therefore, the calculation of the even and odd admittances will yield the coupling coefficient. The original approach proposed in this work for the determination of these admittances consists in considering the tapered rod as a succession of cascaded dielectric waveguides of different lengths and cross-sections (Fig. 3). Then the scattering matrix of each discontinuity between two dielectric waveguides, as well as that of the dielectric waveguide/free-space discontinuity, should be calculated as accurately as possible. The overall multimodal

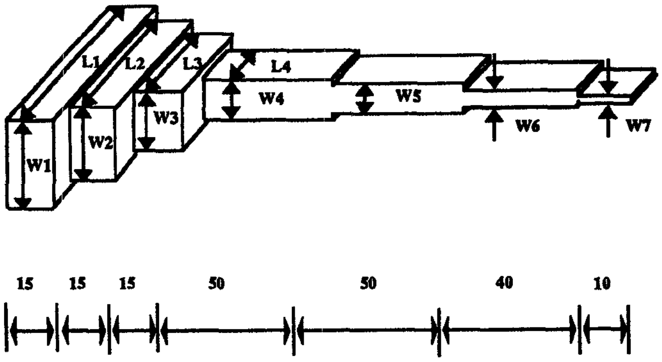

Fig. 3. Modeling of dielectric antenna $w_1 = 10.16$; $w_2 = 9.7$; $w_3 = 9.2$; $w_4 = 8.7$; $w_5 = 7.16$; $w_6 = 5.58$; $w_7 = 4$ $L_1 = 22.86$; $L_2 = 19.07$; $L_3 = 15.29$; $L_4 = 11.5$. Lengths are in mm, Dielectric constant $\varepsilon_r = 2, 5$.

admittance matrices can be deduced from the multimodal scattering matrices:

$$[Y_{\text{odd}}] = ([I] - [S_{\text{odd}})([I] + [S_{\text{odd}}])^{-1}$$
$$[Y_{\text{even}}] = ([I] - [S_{\text{even}})([I] + [S_{\text{even}}])^{-1}, \tag{5}$$

where $[I]$ is the unity matrix. Y_{odd} and Y_{even} will then be the first elements of the multimodal matrices $[Y_{\text{odd}}]$ and $[Y_{\text{even}}]$.

The scattering matrix of each discontinuity is calculated by a multimodal variational method [3], where the propagating modes on either sides of the discontinuity should be known. The corresponding propagation constants are determined by the transverse operator method [4] by placing the antenna in an oversized waveguide. This is supposed not to disturb the main radiation pattern since the guide and the end-fire antenna have the same longitudinal axis.It can be noted that at this stage,the knowledge of the global scattering matrix of the system allows the straightforward calculation of the transverse electric field. By sending a unity wave to the system input when both input and output are matched,the transverse electric field in the aperture is given by the following expression:

$$\vec{E_t} = \sum_{n=1} t_n \, \vec{e_n} \tag{6}$$

in which $\vec{e_n}$ and t_n represent the electric field and transmission coefficient of the nth mode, respectively.

III. Numerical Results

The dimensions of the rod antenna are chosen such that a surface wave can propagate along the dielectric rod. We have therefore taken $k_z = 1.1 \; k_0$, where the condition that the propagation constant k_z be greater than the free-space wave number k_0, guarantees the propagation of a surface wave. In contrast, we should have $k_z/k_0 \leq 1$ near the antenna's end so that a bulk wave is established in this region to ensure the radiation. The number of dielectric waveguide sections is determined on the basis of the convergence of the first element of $[S_{\text{odd}}]$, and in our case, it has been shown that seven sections are sufficient to obtain this convergence. The length of each section is chosen such that the cascaded structure has a form close to the tapered rod antenna. The antenna dimensions as well as top and side views of the cascade model are shown in Fig. 3. The coupling coefficient has been calculated as a function of the distance between the longitudinal axes of the two antennas. Fig. 4 illustrates the results obtained for the coupling coefficient at different operating frequencies. It can be observed that the measured data obtained at 10 GHz by an experimental set-up are in good agreement with the theoretical results. These curves can be used as design curves for the dual-antenna system. Fig. 5 illustrates the distribution of the transverse electric field.

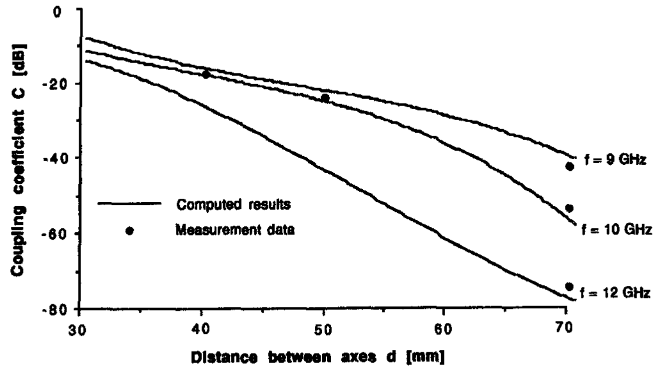

Fig. 4. Coupling coefficient versus inter-axis distance.

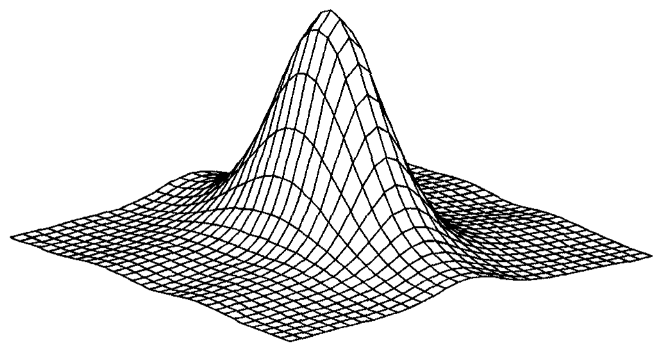

Fig. 5. Transverse field intensity for one rod antenna.

IV. Conclusion

An efficient method has been proposed for the calculation of the coupling coefficient between two dielectric tapered rod antennas. The obtained results can be used for the design of the system through the optimization of the coupling versus the separation distance. The obtained results have been found to be in good agreement with corresponding experimental data. It should be noted that this method can be also applied to other forms of dielectric rod antennas.

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