Jour. Ind. Inst. Sc. 61 (A), Sept. 1979, pp. 209–213

Short Communication

Input impedance of spherical dielectric antenna excited in TM symmetric mode

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Received on July 13, 1979.

Abstract

An experimental study of the input impedance of spherical dielectric antenna excited in TM symmetric mode in the X-band has been presented. The spherical antenna has been excited by a coaxial conical feed filled with the same material as the antenna. The experimental input impedance of the sphere has been obtained by finding the impedance transforming property of the conical feed.

Key words: Input impedance, spherical dielectric antenna, TM symmetric mode, conical feed.

1. Introduction

The resonant properties of dielectric spheres have been studied by Gastine *et al*[1], Affolter and Eliasson[2], Van Bladel[3] and Chatterjee and Bhattacharyya[4].

The radiation characteristics of such spheres excited in TM symmetric and hybrid modes have been investigated by Neelakantaswamy and Banerjee[5], Croswell and Chatterjee,[6,7] and Chatterjee and Bhattacharyya[4]. The study of spherical dielectric antenna with the aim of its possible application as a competitor to a conventional horn as the feed for the reflector has been of interest due to its following properties[6,7,4]: (1) the measured gain of the antennas is more (by 6 dB in some cases) than that of optimum horns having same aperture areas, (2) the linearity of polarisation of such antenna is more or less the same as that of an open-ended waveguide radiator, (3) the VSWR in the feeder line can be reduced to a low value over the frequency band of interest by using proper matching network, (4) coupling between individual antennas in an array environment is small by virtue of the poor radiation in the endfire direction. Hence this antenna may find application as primary feed to produce multiple beams in a paraboloid with large f/D ratio. It appears to the author that no information is so far available on the input impedance of such spheres as antennas. But a knowledge of input impedance and its bandwidth is essential in order to match the antenna to its feeder line whether it is used as a primary antenna or as a feed to a reflector. This motivated the study of the impedance characteristics of spherical dielectric antenna. This communication deals with the case of spherical antenna in TM symmetric mode excited by a conical feed.

2. Experimental results and discussion

The input impedances of several structures have been measured by slotted section method using two types of structures (Figs. 1 and 2): (i) hemisphere on large aluminium sheet excited from the back by a coaxial line (A complete sphere can only be simulated in this manner for equatorial excitation). (ii) truncated sphere on cone. Several launching cones (Fig. 3) filled with the same dielectric (perspex; $\epsilon_r = 2\cdot56$; and tan $\delta = 0\cdot005$) as the antenna were constructed. The length, smaller end diameter and wall thickness

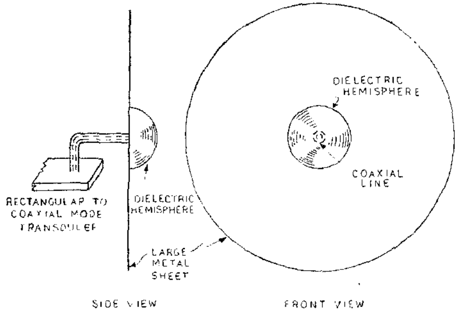

FIG. 1. Hemisphere on large sheet.

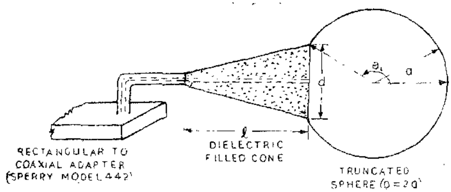

FIG. 2. The launching cone and the truncated spherical dielectric antenna.

were 2, 5/16 and 1/16 inch respectively. Outer diameter at the antenna end varied from 1 inch to $2\frac{1}{4}$ inch in steps of 1/8 inch. This led to a total of 44 cases of truncated spheres on cones, the sphere diameter varying from 1 to $2\frac{1}{4}$ inches in steps of 1/8 inch.

Since the mode changes from TEM in coaxial line with field components E_ρ and H_ϕ to symmetric TM mode with field components E_R, E_θ and H_ϕ in the spherical dielectric antenna (E_ρ in coaxial line gives rise to E_R and E_θ in the antenna), the excitation by the feed open end may be thought of as by a source which has the field components E_R and E_θ.

Using scattering matrix of the coaxial adapter measured by Deschamps' method (using a coaxial shorting plunger) and A, B, C, D parameters, the impedance seen by the slotted

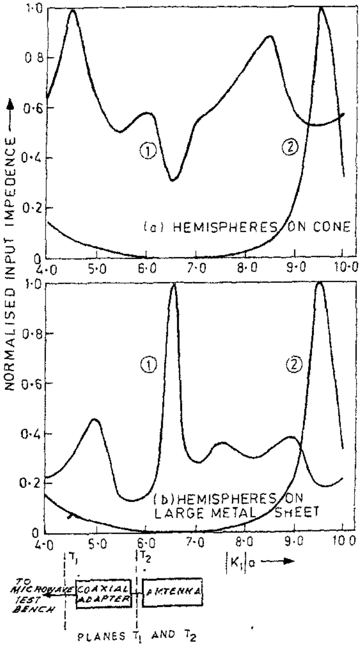

FIG. 3. (*a*) Impedance *vs.* $|k_1|\,a$ for hemispheres on cone. (*b*) Impedance *vs.* $|k_1|\,a$ for hemispheres on large metal sheet. $\epsilon_r = 2\cdot56$; $\tan\delta = 0\cdot005$; $\theta_1 = 90°$. (1) Experimental impedance at plane T_2. (2) Experimental impedance of the dielectric sphere.

line at the input of the adapter is transferred to the junction of the coaxial line of the adapter and the end of the launching cone which fits into the coaxial line. Some of the experimental results are shown in Fig. 3.

The experimental impedance characteristics of the spherical dielectric antenna show a resonating nature. The input impedance was found to be dependent on the mode(s) of excitation which are determined by the values of parameters used. (A typical value of frequency bandwidth for perspex sphere ($\theta_1 = 90°$) with diameter 5·4 cm is 400 MHz at a centre frequency of 9375 MHz). This is in accordance with the known behaviour of a resonator and hence the dielectric sphere acts as an 'open resonator' as reported by other workers.

In order to get the sphere impedance from the experimental values of impedance obtained at plane T_2 (Fig. 3), it is necessary to transfer the experimental values at plane T_2 to the open end of the cone. This was not done experimentally because of the difficulty of construction of a shorting plunger which can run in a dielectric-filled cone. Instead, by using the theory of small reflections in a multisection transformer (see Appendix A) the input impedance seen at plane T_2 has been used to find sphere impedance which is the terminating impedance of the cone. The total number of sections used was 64 for a cone two inches long. Different factors affecting the experimentally obtained values could be the effect of diffraction at the cone-sphere boundary particularly on the inner and outer rim of the open end of the cone, the induced currents on the outer surface of the cone close to the sphere which may also modify the field on and around the sphere and the defect in mechanical fabrication of the structure. Also, the higher order modes, if any, generated in the cone will throw a certain amount of reactance. For the case of experiment with hemisphere on large metal sheet one source of error shall be the leakage from the joint which is supposed to be leak-proof. It may be noted that in a practical case due to finite size of the feeder only a truncated sphere can be excited as a primary antenna. The near- and far-field results show fair agreement with the experiment[4] for $\theta \geqslant 90°$. There is no restriction beyond a limit on the range of ϵ_r. For large ϵ_r, there will be a considerable energy storage in the sphere and loss if $\tan\delta$ is not very small and antenna gets less power to radiate. There is no restriction on 'a' but for large 'a' it becomes an end-fed spherical antenna and becomes a poor radiator. For relatively smaller value of θ_1, the mode numbers 'n' will assume non-integer values[9] as in the case of biconical antennas. A rigorous theory for input impedance taking into account the above factors will be communicated later.

3. Acknowledgement

The author wishes to thank Prof. (Mrs.) R. Chatterjee and Prof. B. Chatterjee for help and encouragement.

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APPENDIX A

Reflection coefficient and input impedance at plane T_2

The overall reflection coefficient Γ at $T_2{}^s = 2\,(\cos(N1 \times \theta) - j \sin(N1 \times \theta))$

$$\times \sum_{N=1}^{N1} ((Z+1) - Z(N)/(Z(N+1) + Z(N)))$$

$$\times \cos((N1\text{-}2N) \times \theta) + (Z_L - Z(N+1))/(Z_L + Z(N+1)). \qquad \text{(A 1)}$$

The first term gives the total input reflection coefficient due to all sections other than the last while the second term gives the contribution due to the last section terminated by the antenna impedance. $\theta = 2\pi/\lambda \times$ length of each section. Subscripted Z denotes the characteristic impedance of the particular section. The input impedance at plane T_2 is given by $Z_{LT_2} = (1+\Gamma)/(1-\Gamma)$. Knowing Γ experimentally, Z_{LT_2} and the sphere impedance Z_L can be obtained. The sphere impedance alone is not of much practical importance since the sphere along with the conical feed is the practical structure.