B—10—1 ANISOTROPY, BIREFRINGENCE, AND DISPERSION IN THIN OBSTACLE ARTIFICIAL DIELECTRICS

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The search for light weight multiple beam antennas for satellite communications has stimulated a renewed interest in the metallic delay lenses. One type of metallic delay dielectric which is particularly attractive for its low weight and simple construction is the "thin obstacle, artificial dielectric." Such a dielectric is comprised of parallel obstacle planes separated by low density spacers. Each obstacle plane consists of a uniform array of identical and mutually insulated thin metal obstacles printed upon a thin dielectric substrate such as Mylar. An example of this type of dielectric using disk shaped obstacles (hereinafter called a "disk type dielectric") is shown in Figure 1a. A great deal of analysis of this type of artificial dielectric (and many other types as well) may be found in the literature [see bibliographies in 1, 2]. In spite of this there remains a few inadequacies. Some are: (1) The analysis of these dielectrics (with parameters yielding practical values of refractive index) in their dispersive region. (2) The index surfaces of these dielectrics showing the degree of anisotropy and birefringence. (3) The analysis of the staggered structures as illustrated in Figure 2.

In this paper an analysis is made for an artificial dielectric consisting of a hexagonal array of disks as shown in Figure 3. This particular geometry was chosen because of its high symmetry and also the availability of experimental results due to Cohn [3].

The total fields about the structure illuminated by a uniform plane wave at any incident angle were expanded in a set of space harmonics. For frequencies from DC to the first stop band of the structure, only two of these harmonics are propagating. They are proportional to the TE and TM parts of the incident wave itself. The remaining harmonics attenuate away from the obstacle planes and can be ordered according to their rate of attenuation. Thus only the lowest few harmonics interact on adjacent obstacle planes. These are called "accessible" harmonics after Rozzi [4] and the remaining ones may be called "localized" harmonics.

The structure may be modelled by the network analogy shown in Figure 1b. The transmission lines represent the interaction of adjacent obstacle planes through the accessible harmonics while the lumped multi-ports represent the conversion of these harmonics at the obstacle planes. It is within these multi-ports that an account of the interaction between disks on a given obstacle plane is taken. At a given frequency, the multi-port shunt networks are described in terms of a susceptance matrix. The elements of this susceptance matrix are found in terms of stationary expressions involving surface currents due to particular combinations of incident accessible harmonics. These surface currents satisfy integral equations which may be solved approximately be Galerkin's method. Having obtained the susceptance matrix, the refractive indices of the structure are defined in terms of the latent roots of unit amplitude of the transmission matrix between one obstacle plane and its successor in an infinite uniform structure [5,6]. In general, the two sheets of the index surfaces will not be coincident because of the anisotropic nature inherent in thin obstacle dielectrics. Nor will there be even a single ordinary ray for non-normal incidence because of the diamagnetism of these dielectrics.

For normal incidence, a very efficient "wide-band" approximation can be made. The computed results [7] are found in almost perfect agreement with Cohn's measurements, as seen in Figure 4. For all other incidences the results are summarized in Figure 5 which is a plot of the cuts through the two principal planes of symmetry of the structure.

The staggered structure illustrated in Figure 2 is treated in a similar manner to its aligned counterpart of Figure 1 except that a unit cell includes two obstacle planes rather than the one in the latter. The susceptance matrix of the shifted obstacle plane is easily computed from that of the non-shifted plane by the inclusion of appropriately chosen phase shifters between the transmission lines and the multi-port. The staggered dielectric was analyzed and compared with its aligned counterpart the results of which are shown in Figure 6. One notes the greatly reduced dispersion in the staggered dielectric. Thus, for the same refractive index, fewer obstacle planes are required in the staggered dielectric than in the aligned.

1. J. Brown, "Artificial Dielectrics," Progress in Dielectrics, vol. 2, London: Heywood & Company, 1960, pp. 194-225.
2. L. L. Tsai, "Phase-Delay-Type Artificial Dielectrics," Technical Note 1975-4, Massachusetts Institute of Technology Lincoln Laboratory, Lexington, MA, 1975.
3. S. B. Cohn, "Microwave Measurements on Metallic Delay Media," Proc. IRE, pp. 1177-1183, Sept. 1953.
4. T. E. Rozzi, "Network Analysis of Strongly Coupled Transverse Apertures in Waveguides," International Journal of Circuit Theory and Applications, vol. 1, pp. 161-179, 1973.
5. J. Brown, "Propagation in Coupled Transmission Line Systems," Quart. J. Mech. Appl. Math., vol. XI, part 2, pp. 235-243, 1958.
6. J. Brown and J. S. Seeley, "The Fields Associated with an Interface between Free Space and an Artificial Dielectric," Proc. IEE, vol. 105, Part C, pp. 465-471, Sept. 1958.
7. W. F. Richards and Y. T. Lo, "Anisotropy, Birefringence, and Dispersion in Artificial Dielectrics," Technical Report No. 77-17, Electromagnetics Laboratory, University of Illinois, Urbana, IL, 1977.

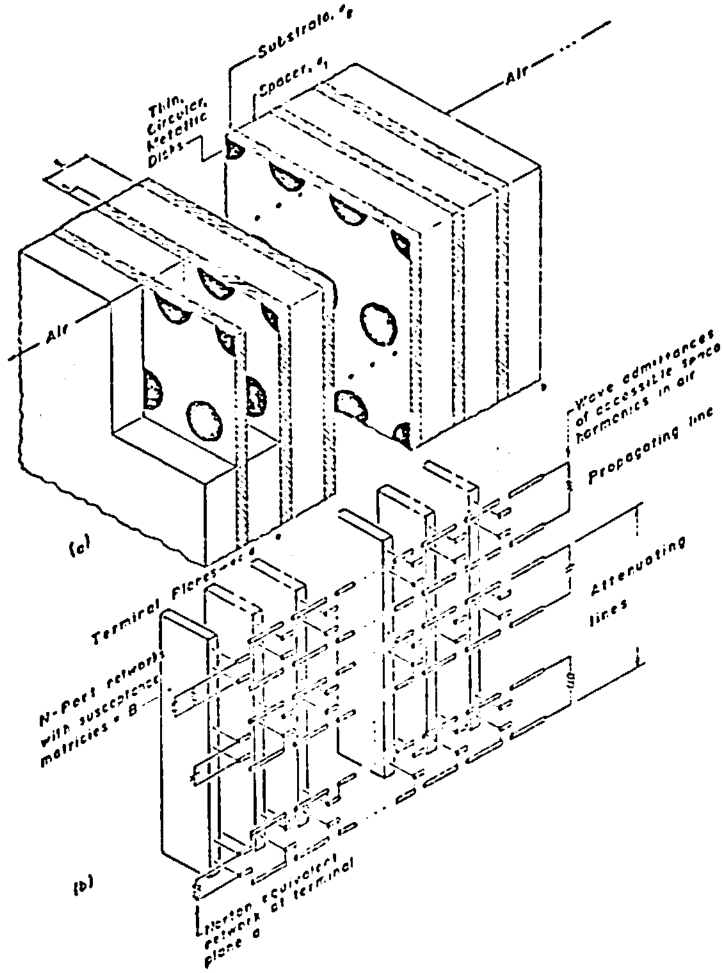


Figure 1. Finite slab of disk dielectric. (a) Physical model. (b) Network model.

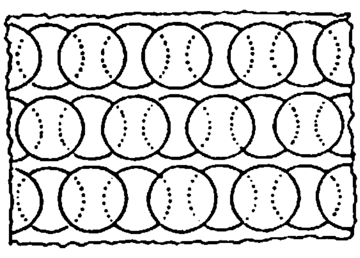


Figure 2. Front view of staggered dielectric. Alternate sheets shifted half a period.

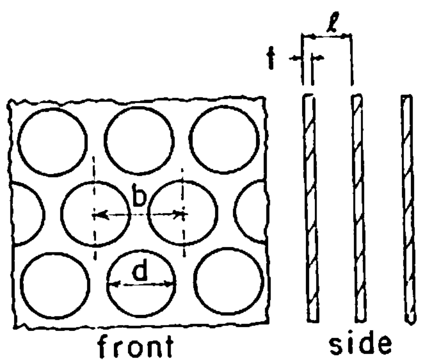


Figure 3. Front and side views of a disk dielectric with hexagonal distribution.

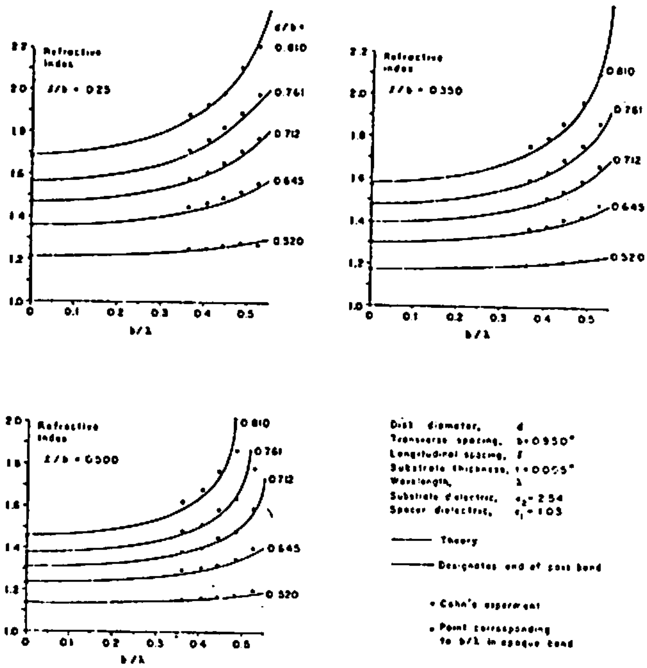
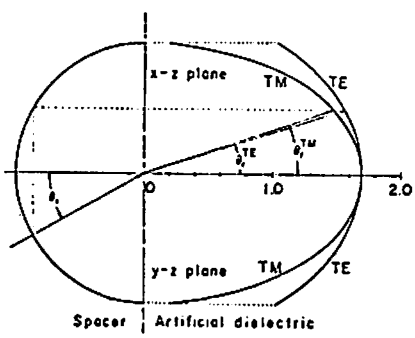


Figure 4. Experimental and theoretical dispersion curves for disk dielectric.



·Figure 5. Index surfaces for $\ell/b = 0.25$, $d/b = 0.810$.

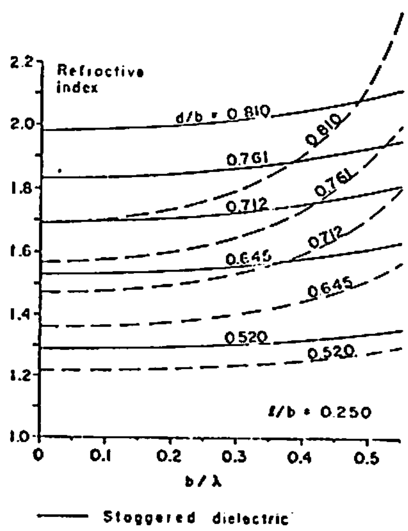


Figure 6. Dispersion curves for staggered and aligned dielectrics; $\ell/b = 0.25$; normal incidence.