DIELECTRIC ANTENNAS FOR MILLIMETER-WAVE APPLICATIONS

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ABSTRACT

A systematic study of traveling wave dielectric-rod antennas of different types is described. Development of design for several leaky-wave antennas is presented together with experimental results. Existence of surface-wave radiation in end-fire direction is exhibited and methods to suppress it are discussed.

Introduction

The discovery of millimeter-wave dielectric integrated circuits and communication systems has generated an interest in developing front-ends (antennas, lenses, etc.) which are also fabricated from dielectric material so that they can be easily integrated with the remaining system[1-3]. Such radiating elements combine the advantages of low-cost and light-weight with frequency scannability. This paper presents a systematic study of traveling-wave dielectric-rod antennas of two distinct classes: surface-wave and leaky-wave antennas. Design considerations and experimental results are presented for a number of these antennas.

Surface-Wave Antennas

The surface-wave antennas studied were dielectric-rods of rectangular cross-section. In general, the radiation from these structures takes place primarily from the feed region and termination, and produces a fairly broad beam in the end-fire direction. The gain of the antenna increases with length, but only at the expense of enhancing the side lobes, often to an unacceptably high level. However, the radiation characteristics of the antenna can be improved by introducing a longitudinal taper in the rod, which causes the radiation to occur from the entire length of the antenna. Optimal shape and tapering of the rod have been experimentally determined and are shown in Fig. 1 for a dielectric constant of 2.2 at 80 GHz. A comparison of the performance characteristics of the dielectric-rod antenna with other conventional antennas is shown in Table 1. The experimental results summarized in Table 1 lead us to conclude that a surface-wave type antenna has relatively low-gain, large beam width, and moderate side-lobe level. Before leaving this subject, we mention that the efforts to improve this antenna with a variable flare at the feed end did not yield encouraging results and were not pursued further.

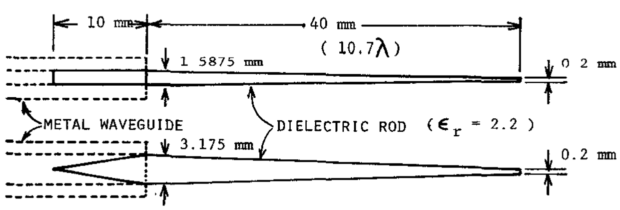

Figure 1: Optimized Surface-Wave Antenna for $f = 80\,GHz$, $\varepsilon_r = 2.2$

TABLE 1 : COMPARISON OF MEASURED CHARACTERISTICS

Antenna type	Aperture & Length	Relative Gain	Beamwidth (3 dB)	Sidelobe Level
Parabolic Reflector	76 mm dia.	0 dB	3.4°	-17 dB
Conical Horn	31 mm dia. 78 mm long	-7 dB	7.4°	-7.5 dB
Rectangular Horn	13 mm x 18mm 40 mm long	-11 dB	14.2°	-11.5 dB
Dielectric Rod	1.6 mm x3.2mm 40 mm long	-17 dB	23.5°	-15.5 dB

Leaky-Wave Antennas

Leaky-wave antennas, which can be regarded as variants of the dielectric-rod surface-wave antennas are derived by introducing periodic discontinuities or perturbations in the same. In contrast to the surface-wave antenna, the leaky-wave version produces a relatively narrow and frequency-scannable beam. The angular direction θ_m of the leaky-wave beam is given by reference 3 and reproduced below:

$$\sin\theta_m = \frac{\lambda_0}{\lambda_g} + m\frac{\lambda_0}{d}, \qquad \left|\frac{\lambda_0}{\lambda_g} + m\frac{\lambda_0}{d}\right| \leq 1$$

where λ_o and λ_g are the free space and guide wavelengths respectively, d is the perturbation spacing and m is the space harmonic $0, \pm 1, \pm 2, \ldots$ Notice that θ_m is a function of frequency; hence, the leaky-wave antenna beam is frequency-scannable. The design studies of leaky-wave antennas proceeded by first investigating a variety of isolated discontinuities in an otherwise uniform dielectric guide. The near-field patterns around a single notch are shown in Fig. 2 for different heights of scan above the plane, whereas the locus of the beam maximum is exhibited in Fig. 3. These plots clearly show that radiation from an isolated notch is directive in nature. The next step in the investigation was to introduce periodic distributions of different kinds in the dielectric rod, and to measure their patterns. The results of the far-field measurements and frequency-dependent scan characteristics of a typical leaky-wave antenna are shown in Figs. 4 and 5. The following conclusions were derived from the experimental design studies of the leaky-wave antennas.

In addition to radiating the desired leaky-wave beam, the antenna also sheds considerable energy in the end-fire direction. The end-fire beam can be identified

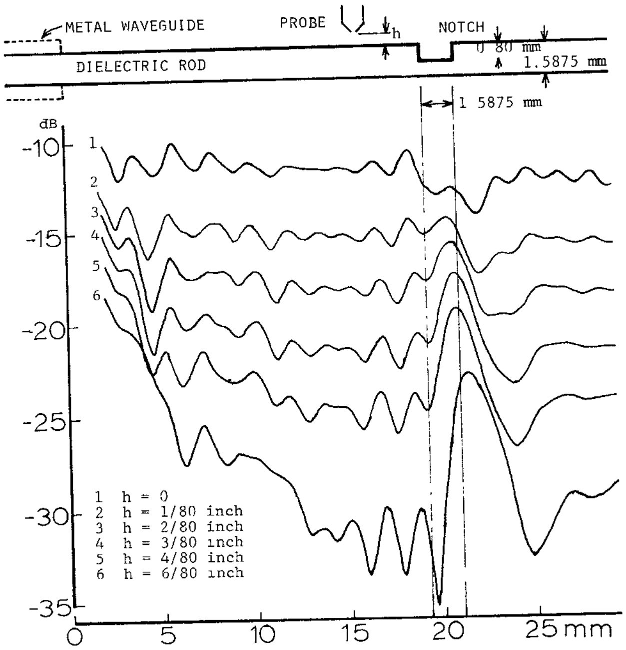

Figure 2: Near field around a notch

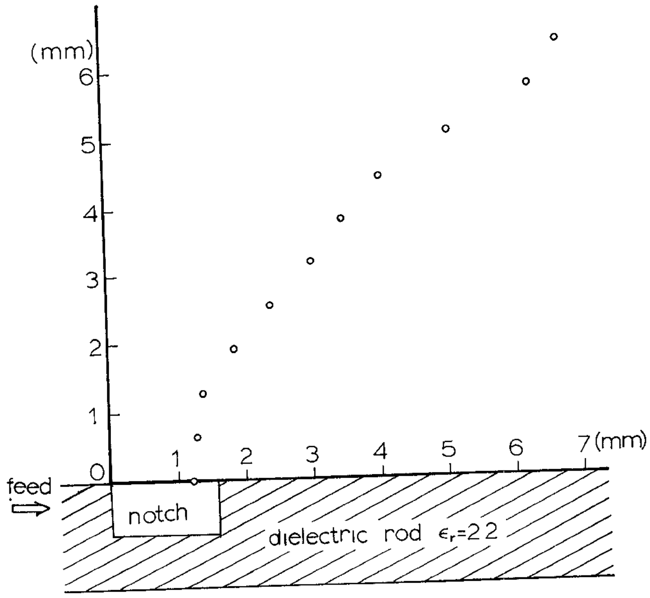

Figure 3: Locus of beam maximum for radiation from a single notch

with the residual surface-wave energy left over from the leaky-wave radiation from the antenna. The relative proportion of the surface-wave and leaky-wave excitations is a function of a number of design parameters of the antenna, which include the geometry of the discontinuity. The design goal is to maximize the power radiated in the leaky-wave beam by suppressing the slow-wave beam in the axial direction. It has been possible to achieve the suppression of the surface-wave beam by at least 12 dB below the leaky-wave beam by manipulating the design parameters of the antenna (see Fig.6). We notice from this figure that it is possible to achieve a narrow beam width using the leaky-wave antenna. The beam-steering characteristics of the leaky-wave antenna are presented in Fig. 5. The plots suggest an agreement between the approximate theoretical result[4] and the experimental result for beam scannability, assuming that the guide wavelength of the rod with notches can be obtained from an equivalent cross-section without notches.

Additional experiments have been carried out with different versions of the leaky-wave antenna, and the potential for beam shaping and manipulating radiation patterns has been explored. These include a combination of dielectric discontinuities and metal deposition on a leaky-wave antenna, which has been investigated in considerable detail. A number of representative results based on these studies are reported.

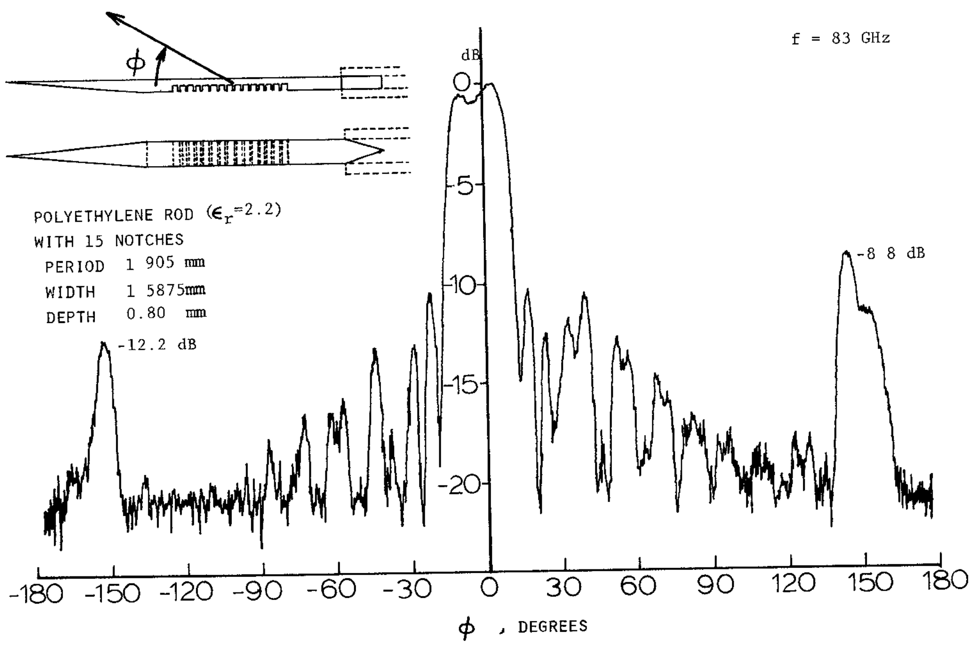

Figure 4 : Example of radiation pattern of Leaky-wave antenna

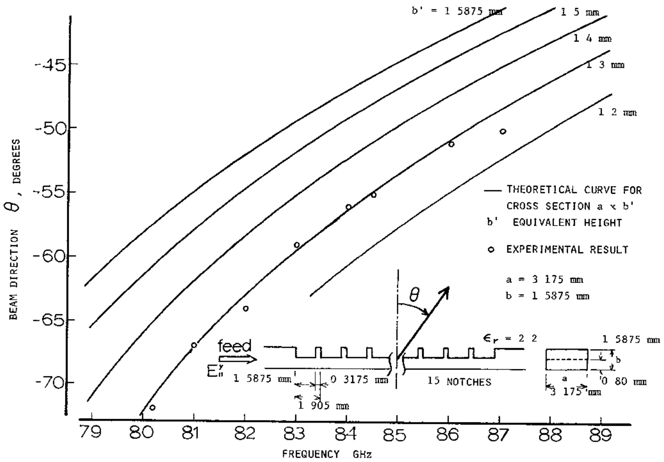

Figure 5. Beam Steering by Frequency Scan

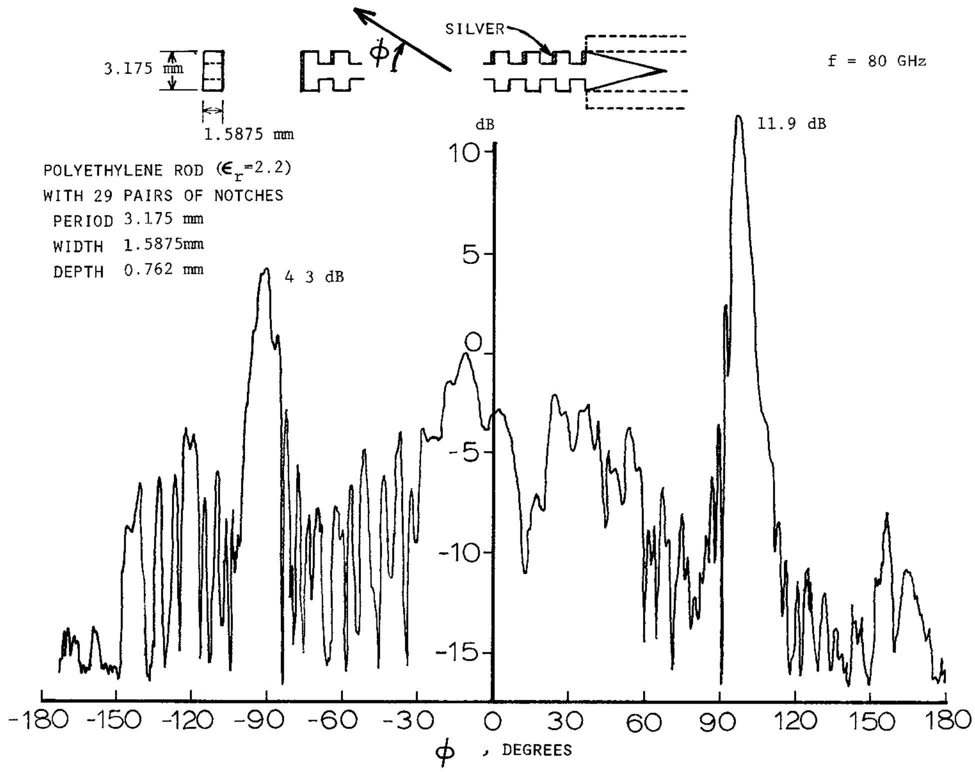

Figure 6. Example of Radiation Pattern of Leaky-Wave Antenna

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