

# MILLIMETER-WAVE DIELECTRIC LEAKY-WAVE ANTENNAS

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## ABSTRACT

A dielectric leaky-wave antenna with a new perturbation scheme is developed. The attenuation constant with different gap width between metal patches is determined experimentally. The dielectric waveguide used in this paper is an anisotropic Sapphire rod. The conventional effective dielectric constant (EDC) method is modified to calculate the unperturbed propagation constant and then used to predict the main beam position. Experimental data agree quite well with that of simulation.

## I. INTRODUCTION

Dielectric antennas provide superior properties in the low guided-wave loss, simple design, and light weight in the millimeter-wave frequency range. A dielectric leaky-wave antenna also possesses the advantage of electronic scanning of the main beam by simply varying the operating frequency. Directivity or beamwidth of the leaky-wave antenna can be easily controlled by properly designing the antenna length.

The complex propagation constant of a uniform leaky-wave antenna with a finite transverse substrate was analyzed by Mitra and Kastner based on the spectral domain approach [1]. Radiation characteristics of antennas with perturbation strips on either the broad or narrow side of the dielectric rod were studied [2]. The directivity at the transverse plane of an antenna was improved using a pair of metal flares along the longitudinal direction [3]. A series of studies based on a waveguide model for analyzing several dielectric leaky-wave structures was published by Ghomi *et al* [4]-

[7]. The Ritz-Galerkin variational approach was applied to analyze an inset dielectric waveguide antenna [8]. A theory based on a novel multimode transverse equivalent network was proposed by Guglielmi and Oliner to calculate the dispersion behavior of a metal-strip-loaded image leaky-wave antenna [9]. Moreover, mode-matching and point-matching techniques were applied to the analysis of metal-strip-loaded dielectric antennas [10].

It is noticed that metal strips or patches of all pervious references were deposited on the dielectric rod directly. These designs have the advantage of the most antenna elements in the transverse direction if a dense planar array is needed. For applications of a very narrow beamwidth, the dielectric antenna is very long electrically. The attenuation constant of above directly metal-deposited techniques is, however, too high for such a long antenna design. Furthermore, the fabrication process also becomes very difficult for a physically long antenna. In this paper, we use the field coupling mechanism as shown in Fig. 1 to perturb the guided surface wave. Then an appropriate attenuation constant can be obtained for the design of a nearly  $300 \lambda_0$  long leaky-wave antenna.

## II. ANTENNA DESIGN

Fig. 1 depicts a dielectric leaky-wave antenna with the proposed perturbation scheme which is suitable for a very long antenna design. The metal patches are placed on both sides of a high dielectric constant rod so that a proper attenuation constant can be obtained. The dielectric waveguide used here is a low-loss Sapphire rod with an anisotropic dielectric constant tensor,

$$[\epsilon] = \epsilon_0 \begin{bmatrix} 9.3 & 0 & 0 \\ 0 & 9.3 & 0 \\ 0 & 0 & 11.5 \end{bmatrix} \quad (1)$$

where  $\epsilon_0$  is the free space permittivity. The cross dimension of the Sapphire rod is chosen so that only the dominant mode exists in the operating frequency range.

Due to its anisotropy, a rigorous full-wave analysis is necessary to accurately calculate the propagation constant of Fig. 1. However the conventional effective dielectric constant (EDC) method can be modified to quickly give us the approximated but good enough data. In the formulation of the EDC along the y-direction for a multilayered slab waveguide with an anisotropic layer, we assume that only TM modes propagate and there is no x variation. The field is concentrated in the Sapphire region. Derived from Maxwell's equations and compared with the isotropic case, one can have the anisotropic propagation constant as,

$$\beta_{\text{ani}} = \beta_{\text{iso}} \sqrt{\frac{\epsilon_{yy}}{\epsilon_{zz}}} \quad (2)$$

where  $\beta_{\text{iso}}$  is calculated from the conventional EDC method by replacing the Sapphire layer with a dielectric constant  $\epsilon_{zz}$  isotropic material. The conventional EDC method is then used to formulate the eigenvalue equation along the x-direction since there is no  $E_x$  component in our assumption. Fig. 2 shows dispersion curves of Fig. 1 without perturbation metal patches and with dimensions:  $w = 24$  mil,  $t = 23.7$  mil, and  $h = 10$  mil. It can be seen that only the dominant mode exists for frequencies less than 100 GHz. The phase constants of Fig. 1 with and without metal patches are assumed to be the same since the leaky constant is usually very small in the leaky-wave antenna design. Therefore, one can use the unperturbed data to predict some important antenna parameters. For example, the main beam position of the -1 space harmonic wave is simply decided by changing the perturbation period  $d$  according to the following equation,

$$\theta = \text{Sin}^{-1} \left( \frac{\beta}{k_0} - \frac{2\pi}{k_0 d} \right) \quad (3)$$

where  $\theta$  is the angle with respect to the broad side direction,  $\beta/k_0$  is the normalized phase constant of the dominant mode.

The attenuation constant of Fig. 1 is studied experimentally by taking the ratio of  $|S_{21}|$  with and without uniformly perturbed patches, respectively. The metal patches are fabricated on a custom-made 10-mil thick Teflon sheet. Each metal patch has the dimension: 20 mil x 50 mil. The parameter used to control radiation is the gap width  $g$  between a pair of patches. The measured attenuation constant versus gap width is shown in Figs. 3 and 4 for two different frequencies. Solid lines are measured data and dash lines are curve-fitting results. Based on these curves, a new tapering method by changing the gap width between patches is employed and a 36-inch long antenna with linearly tapered gap width is designed. The initial gap width is 62 mil and the final one is 40 mil.

### III. ANTENNA PERFORMANCE

The main beam positions of two leaky-wave antennas with different perturbation periods, 80-mil and 50-mil, are assembled and measured. Fig. 5 depicts measured and calculated antenna performance. Although the modified EDC method is an approximated method, this efficient technique can predict the antenna performance quite well. The deviation between theoretical and measured data is about  $5^\circ$  for the 80-mil period antenna and is  $3^\circ$  for the 50-mil one. The measured scanning range from 91 to 97 GHz is about  $16.5^\circ$  and  $24.5^\circ$  for the 80-mil and 50-mil perturbation periods, respectively.

### IV. CONCLUSION

A millimeter-wave leaky-wave antenna with an anisotropic Sapphire rod and a new perturbation scheme is analyzed and designed. The conventional EDC method is modified to include the anisotropy of the Sapphire dielectric waveguide. The calculated main beam position

and the scan range agree well with measured data.

#### ACKNOWLEDGMENT

This work was supported by ThermoTrex Corporation in San Diego, California.

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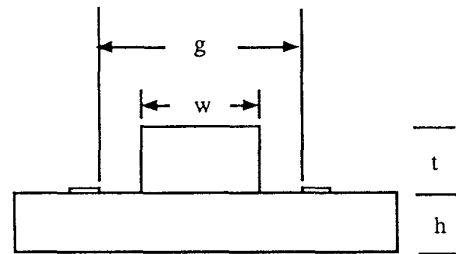
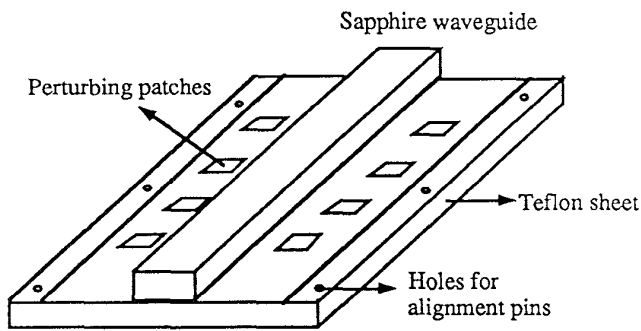


Fig. 1 A dielectric leaky-wave antenna. (a) Schematic plot. (b) Cross dimensions.

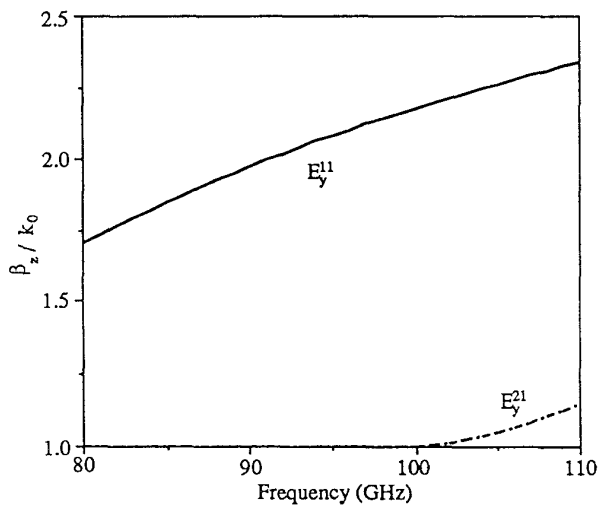


Fig. 2 Dispersion curves of Fig. 1 without perturbation metal patches.

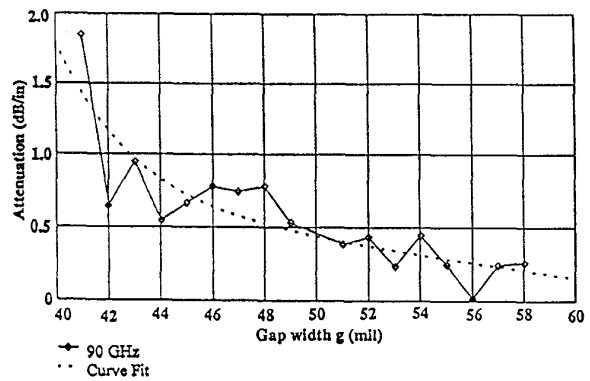


Fig. 3 Attenuation constant versus gap width at 90 GHz.

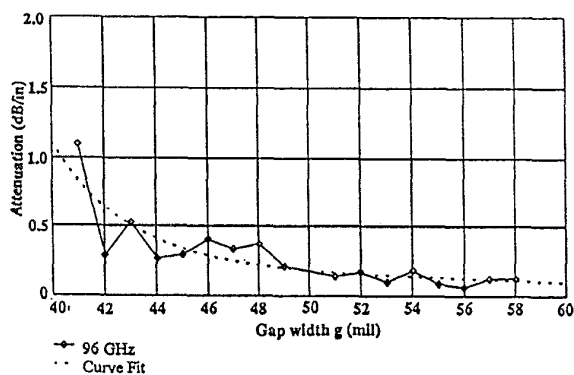


Fig. 4 Attenuation constant versus gap width at 96 GHz.

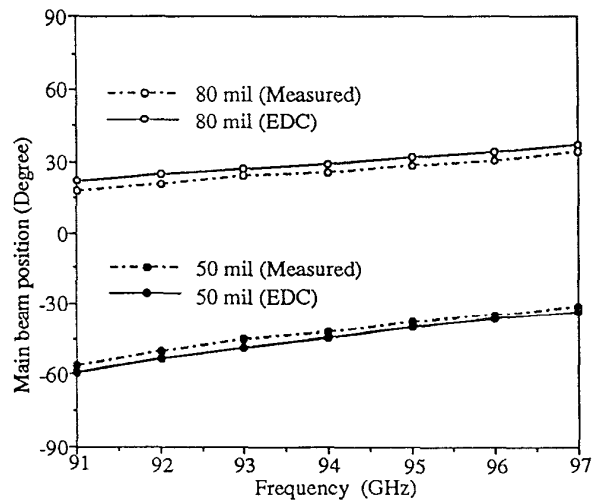


Fig. 5 Measured and calculated main beam position of antennas with different perturbation periods.