# EXPERIMENTAL STUDY OF NONRADIATIVE DIELECTRIC WAVEGUIDE LEAKY WAVE ANTENNA

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## I. Introduction

A high performance millimeter-wave antenna which is compatible with integrated circuits is a key requirement for developing modern millimeter-wave systems. A leaky wave antenna may certainly be one of promising candidates for such an application because it is not only simple in structure, but also capable of frequency scanning.

This paper is concerned with a novel type of leaky wave antenna which is developed based on the nonradiative dielectric waveguide(NRD-guide)[1]. Since the NRD-guide is inherently nonradiating in nature, some means to emit waves is required. It has been previously suggested that a leaky wave antenna can be realized by locating the dielectric strip in parallel to and in close proximity to the edges of the metal plates[2]. Though such an antenna is simple in structure, it suffers from a large amount of cross polarization in off-axis direction. In addition, the dielectric strip has to be within a distance of less than one millimeter from the edges of the metal plates. This is by no means practical, since the dielectric strip is apt to be damaged externally.

In order to overcome such difficulties of the previously proposed antenna, another principle of operation is introduced. The new leaky wave antenna uses a dielectric strip of trapezoid cross section. Measurements were made at 50GHz to confirm the usefulness of this antenna. Both side lobes and cross polarization were found to be suppressed below -30dB at least provided that the antenna was designed properly. Design principle was also established experimentally.

## II. Structure of Antenna

A cutaway view of the NRD-guide leaky wave antenna to be considered is shown in Fig.1. The dielectric strip is gradually deformed in cross section from a rectangular shape to a trapezoid one, and is excited by a metal waveguide at the end of rectangular cross section. Originally, the electric field of the operating mode of the NRD-guide is predominantly parallel to the metal plates, but the electric field perpendicular to the metal plates is required along the trapezoid dielectric strip to satisfy the continuity condtion at the air-dielectric interfaces. This parastic component of waves leaves the waveguide in the form of leaky wave. To obtain unidirectional radiation, a metal bar of a rectangular cross section was located in parallel to the dielectric strip as a reflector. Spacing between the dielectric strip and the reflector was experimentally optimized to be 2.0mm. The edges of the top and bottom plates were shaped into a two dimensional horn to improve radiation in the vertical plane. Film absorber was attached at the far end of the dielectric strip to remove the remaining waves.

Since measurements were made at 50GHz, the metal plates were separated by

2.7mm(10% reduction of half a wavelength). The trapezoid portion of the dielectric strip was 80mm in length and the transition of 50mm in length was provided between the rectangular and the trapezoid portions.

## III. Radiation characteristics

Widths of the upper and lower sides of the trapezoid strip will be denoted by $b_u$ and $b_l$, respectively, and width of the rectangular portion will be denoted by b in what follows. First of all, the amplitude and phase profile of the leaky wave were measured along the dielectric strip by using a vertical thin unipole antenna. The obtained results for the dielectric strip with $b_u$ = 1.4mm, $b_l$ = 2.2mm and b = 1.8mm are shown in Fig.2(a) and (b). The dotted curve in Fig.2(a) shows the measured amplitude profile which exhibits a sinusoidal growth first and then an exponential decay peculiar to leaky wave. The measured profile can well be approximated by

$$f(z) = \sin(\pi z/2l_0), \qquad 0 < z < l_0, \qquad (1)$$
$$= \exp[-\alpha(z-l_0)], \qquad l_0 < z < l,$$

where $l_0$ and $\alpha$ are parameters to be determined by comparison with measurements. In the present case, $l_0$ = 45mm and $\alpha$ = 0.166dB/mm were obtained. The measured value of $l_0$ is somewhat smaller than 50mm, the actual length of the transition. The solid curve in Fig.2(a) is calculated by substituting these values of parameters into eq.(1).

Fig.2(b) shows the phase profiles at the transition. For the purpose of comparison, data are also presented for the dielectric strip with larger width at the rectangular portion(b = 2.2mm). Comparing the two curves in Fig.2(b) reveals that if

$$b = (b_u + b_l)/2 \qquad (2)$$

holds, the phase profile is almost uniform along the dielectric strip. Since the uniform phase distribution is essential for obtaining a sharp radiation pattern, eq.(2) is the basic design formula for the NRD-guide leaky wave antenna. Radiation pattern can be calculated by using the measured near field distribution as follows:

$$P(\theta) = \int_0^{l} f(z)\exp[-j(\beta - k_0\sin\theta)z]dz, \qquad (3)$$

where $k_0$ is the free space wavenumber, $\theta$ is the azimuth angle, $\beta$ = 0.452rad/mm is the phase constant of the leaky wave, and l = 130mm is the total length of the antenna including the transition.

Measured far field patterns(dotted curves) are compared with those calculated from the near field data(solid curves) in Fig.3(a) and (b). As implied by insertions in the respective figures, the deformation of the dielectric strip in Fig.3(b) is larger in extent than that in Fig.3(a). Naturally, the measured attenuation constant of the former($\alpha$ = 0.270dB/mm) is larger than that of the latter($\alpha$ = 0.166dB/mm). The larger the attenuation constant of leaky wave, the broader the far field pattern and the smaller the ripples superimposed on the pattern, as is inferred from theory. Since the ripples are caused by the field truncation at the far end of the antenna, it is necessary to make the antenna longer to eliminate the ripples in Fig.3(a).

Notable advantages of using the NRD-guide leaky wave antenna are the extremely low levels of side lobes and cross polization in contrast to ordinary leaky wave antennas, as well as the sharp far field pattern. Indeed, any side lobes and cross polarization in excess of -30dB were not observed as shown in Fig.3(a) and (b). The low side lobe level is due to the smooth growth of the leaky wave at the transition and the low cross polarization level is a direct consequence of the fact that the NRD-guide suppresses radiation whose electric field is parallel to the metal plates. Furthermore, the sharp far field pattern can be explained by taking into account the contribution from the transition.

Measured radiation pattern in the vertical plane is also shown in Fig.4. If a sharper pattern is required, the aperture of the horn has to be made to be larger. Frequency scanning capability of the antenna was also investigated experimentally. Far field patterns measured at different three frequencies are shown in Fig.5. Scanning over an angle of 10° can be achieved by sweeping frequency from 49GHz to 51GHz.

## IV. Conclusions

An experimental study of the NRD-guide leaky wave antenna was made at 50GHz. The antenna exhibits an excellent performance with side lobes and cross polarization below -30dB. A simple, but useful design equation which guarantees a uniform phase distributioin along the length of the dielectric strip is derived. Frequency scanning characteristics were also investigated and proved to be practical. In conclusion, it can be said that the NRD-guide leaky wave antenna is promising as a simple frequency scanning antenna at millimeter wavelengths.

## References


1. T. Yoneyama, "Nonradiative Dielectric Waveguide", in Infrared and Millimeter Waves, vol.11, ed. K. J. Button, Academic Press(New York), 1984.
2. S. Sanchez and A. A. Oliner, "Accurate theory for a new leaky-wave antenna for millimeter waves using nonradiative dielectric waveguide", 1983-URSI International Symposium on Electromagnetic Theory, pp.397-400(Santiago, Aug. 1983).

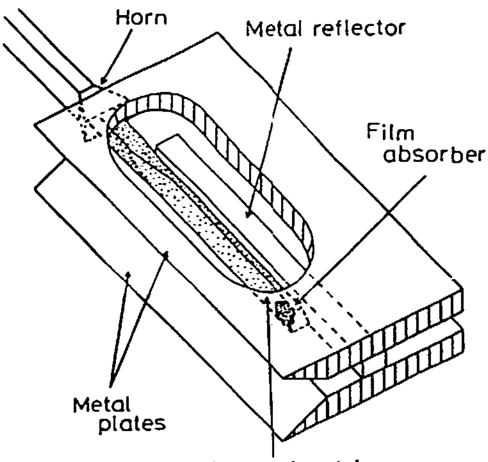
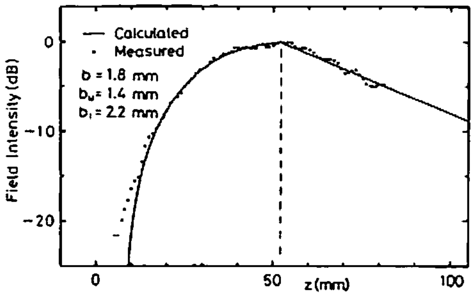
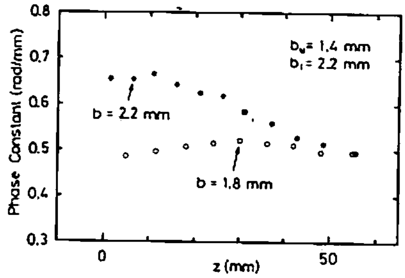




Fig.1 Structure of NRD-guide leaky wave antenna

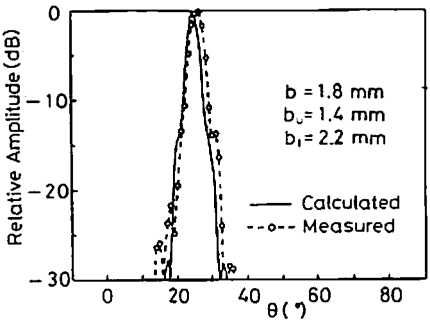



(a) Amplitude

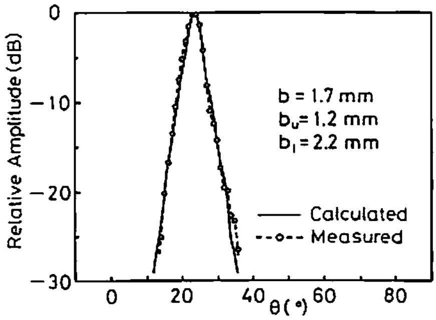



(b) Phase

Fig.2 Field profiles of leaky wave measured at the transition




(a) Small leakage




(b) Large leakage

Fig.3 Far field patterns of the leaky wave antenna. Solid curves are calculated from near field data and dotted curves are measured in the far field region.

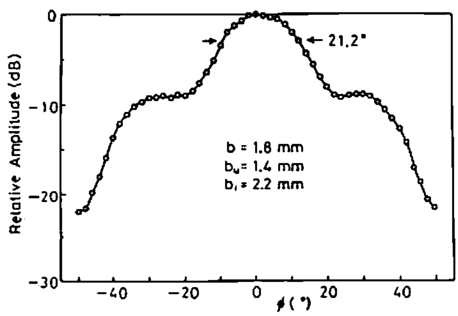



Fig.4 Far field pattern in the vertical plane

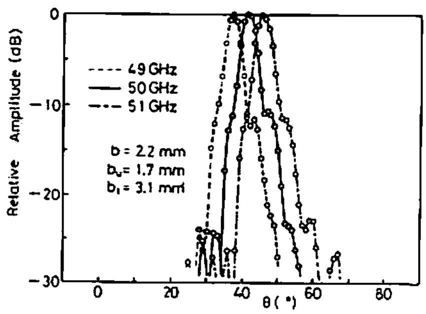



Fig.5 Frequency scanning of radiation pattern