E-BAND LEAKY WAVE ANTENNA USING DIELECTRIC IMAGE LINE WITH ETCHED RADIATING ELEMENTS

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ABSTRACT

The design of a dielectric image line leaky wave antenna using etched copper disks on top of the guide as the radiating elements is described together with measurements of the properties of the antenna.

INTRODUCTION

Dielectric image lines like other dielectric waveguides (e.g. strip dielectric- and insular guide) exhibit strong radiation from line discontinuities such as steps in the waveguide dimensions[1] or such as metallic depositions on top of the dielectric guide[2].
Itoh[1] proposed and demonstrated the exploitation of the radiation effect for the design of leaky wave antennas in the millimeterwave range.

In this paper a simple and inexpensive frequency scanned antenna at E-band frequencies is described using a dielectric image line with etched metallic disks on top of the waveguide as the radiating elements. The prperties and the limitations of the design are discussed.

THE EXPERIMENTAL ANTENNA AND ITS THEORY OF OPERATION

In Fig.1 a photograph of the antenna structure to be discussed here is shown. It consists of a dielectric image line of width 2w=3mm and height h=0.8mm. The guide is cut from a copper plated RT/Duroid substrate with small disks etched on one side. The dielectric waveguide is affixed to the copper ground plane using a thin film adhesive*.
The dielectric image line is coupled to a wavesource through a metal waveguide mode launcher, see[2], and is terminated by an absorber load.

Although this kind of antenna structure basically is a leaky wave structure[3], the principle of operation can be described regarding the structure as a linear array of spacing d, illuminated uniformly with a linear phase taper corresponding to the phase constant of the undisturbed dielectric image line[4]. The consequent beam direction is[3]

$$\vartheta = \sin^{-1} (\beta/\beta_0 \ (1 - \lambda_g/d) \ ), \qquad (1)$$

where λ_g is the wavelength and β/β_0 the normalized phase constant of the undisturbed dielectric image line. In the experimental antenna the spacing was chosen to be λ_g at midband (75GHz), corresponding to a broadside beam (with $\vartheta = 0°$).

In Fig.2 the beam direction of the antenna is plotted as a function of the frequency. The broken line was calculated using equ.(1) and the dispersion characteristic of the dielectric image line[5]. The agreement between the calculated and the measured (solid line) beam direction is satisfactory.
Employing a high permittivity dielectric image line in the antenna structure (e.g. silicon), due to the increased dispersion, the frequency scanning can be greatly increased up to about 5°/GHz (instead of only 1.1°/GHz in the low permittivity experimental antenna). This can also be concluded from the experiments, recently published by Jacobs et al.[6]

* Eastman 910 adhesive

Although up to date very few design data are available regarding the radiation properties as a function of the size of the radiating elements, it has been found experimentally that in a certain range of diameters the radiated power increases with the diameter of the disks used as the radiating elements. Thus in a first crude realization of a smooth amplitude taper of the linear array the diameters of the elements were increased from 0.5mm in the 1st disk to 1.2mm in the 8th disk and were decreased from the 15th to the 22nd(last) disk. Thus the diameters of the radiating elements were chosen in a way that the wave power incident from the mode launcher is radiated nearly totally by the disks.

NEAR FIELD MEASUREMENTS

The electric field above the experimental antenna was probed, Fig.3, using an electric field probe technique described earlier[2]. Above the antenna the field of the guided wave on the dielectric image line superimposes with the radiation fields from the radiation elements. To a first approximation the mean value of the probed voltage is proportional to the power propagated in the dielectric image line[2] and the excursion of the probed voltage from the mean value is proportional to the radiated power.

It can be concluded that the power radiated from each element increases from the 1st to the 8th element and decreases to the end of the array. It also can be seen from Fig.3 that the power of the incident wave is radiated nearly totally by the structure.

By choosing a different distribution of the disk sizes a prescribed amplitude taper can be realized, but this requires further investigations of the properties of the radiating elements.

FAR FIELD MEASUREMENTS

In Fig.4 the far field radiation pattern in the plane $\varphi = 0°$ is plotted for three different frequencies in the E-band. The directivity of the antenna is satisfactory with respect to the length of the array. The beam width slightly increases with decreasing frequency. The sidelobe level also is satisfactory, taking into account the amplitude taper realized in this experiment.

Only the high amount of endfire radiation (near $\vartheta = -90°$) indicates a problem:
The employed mode launcher at the input of the antenna structure directly converts a considerable part of the incident wave power into radiation in the endfire direction. The transmission loss of the simple mode launcher employed here, the largest part of which is due to radiation, has been measured in a seperate experiment to be between 1dB and 1.8dB.

The endfire radiation can be reduced by adding a horn transition to the aperture of the mode launcher (with about 0.5dB transmission loss achievable) or by employing absorber material to absorb the undesired radiation.

In Fig.5 the radiation pattern of the antenna is shown for the plane $\vartheta=0°$ at 76GHz. As was to be expected, the radiation of the antenna is not focused in this plane. The directivity in this plane can be increased e.g. by arranging several identical antennas in parallel or by employing a metallic reflector.

INPUT-VSWR

Another interesting feature of the experimental antenna is shown in Fig.6, where the VSWR, measured at the metal waveguide input port, is plotted versus the frequency. It can be seen that the antenna exhibits a band reject characteristic at about 75GHz (with the beam at broadside). Since at this frequency the array spacing is exactly one wavelength, the incremental reflections from all radiating elements superimpose in phase at the input port.
While this phenomenon also is inherent to the band-reject filter design, described by Itoh[1] (where the spacing d is $\lambda_g/2$), radiation takes place in the antenna structure described here (at $\vartheta=0°$), whereas radiation is suppressed in the band-reject filter.

The high input-VSWR can be overcome by using pairs of radiator elements mutually spaced by $\lambda_g/4$ (thus individually compensating the reflections from the elements), analog to the technique for comb line traveling wave antennas used by James and Wilson[7].

ACKNOWLEDGEMENT

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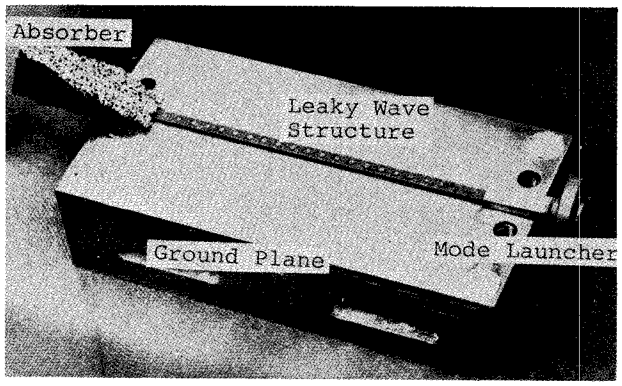

Fig.1: Photograph of the experimental leaky wave antenna.

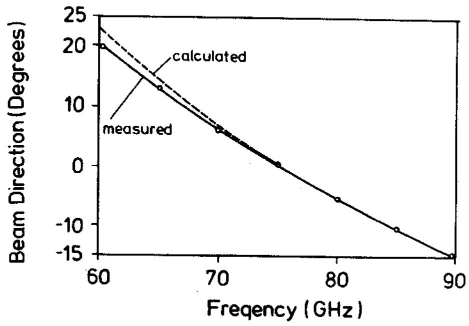

Fig.2: The calculated and the measured main beam direction of the leaky wave antenna.

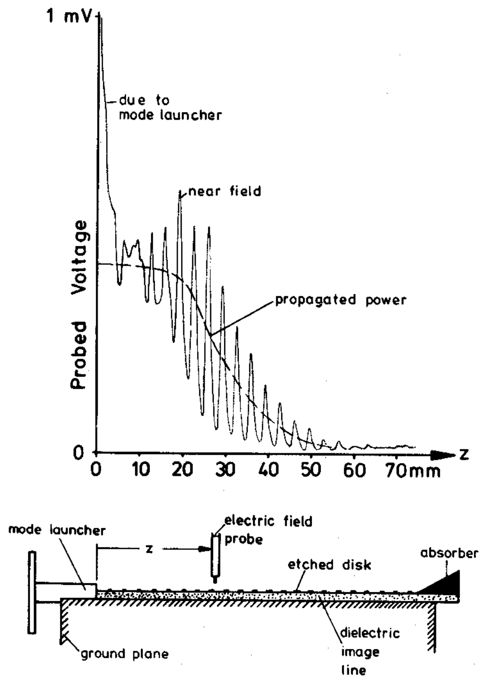

Fig.3: The probed voltage above the leaky wave structure.

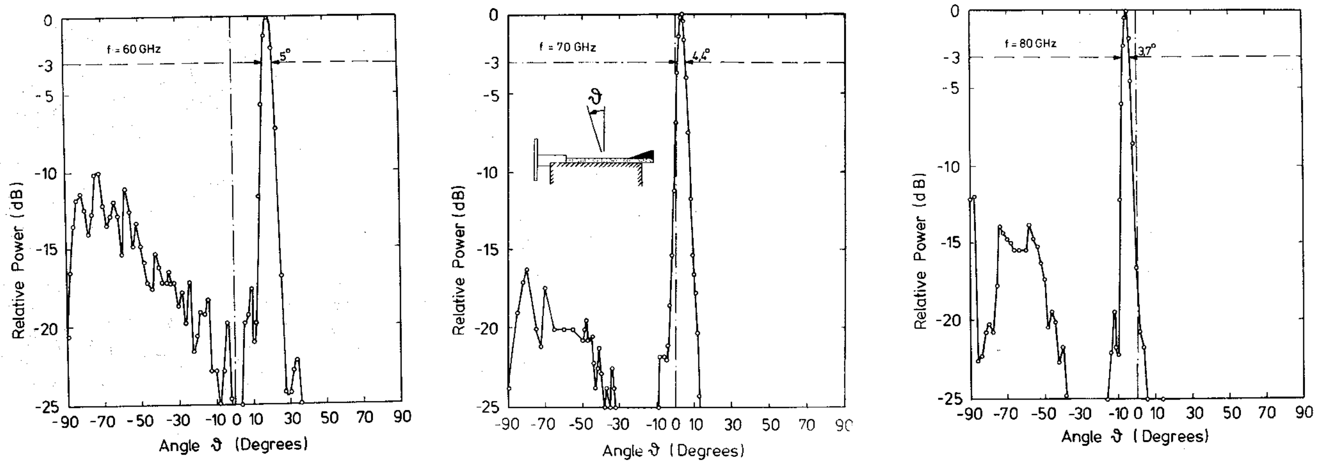

Fig.4: The far field radiation pattern of the leaky wave antenna for the plane $\varphi = 0°$ at three different frequencies in the E-band.

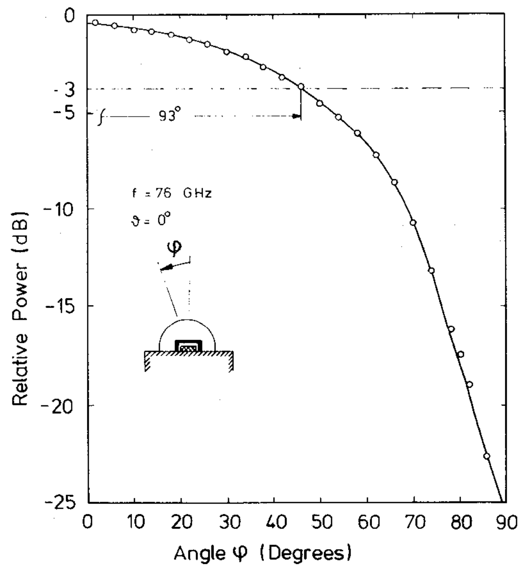

Fig.5: The far field radiation pattern of the leaky wave antenna for the plane $\vartheta = 0°$.

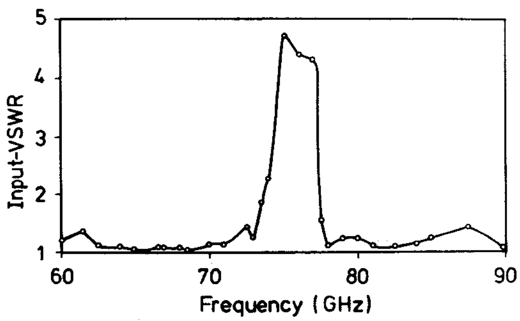

Fig.6: The input-VSWR of the leaky wave antenna as a function of the frequency.