NEW LEAKY WAVE ANTENNAS FOR MILLIMETER WAVES

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1. Introduction

Leaky wave antennas form an important class of scannable antennas. They are created by altering the geometry of a waveguide (closed or open) in such a way that an initially bound mode is converted into a leaky mode, thus permitting power to leak away along the length of the structure. Although the direction of the radiation and the width of the beam can be controlled, the beam is usually narrow and it can be scanned over an angular range of about 50° by varying the frequency or by electronic means. Such antennas for the microwave range were introduced almost 30 years ago, but new problems arise for such antennas in the millimeter wave range, requiring new structures and new techniques for producing the leakage.

Two main problems arise in the millineter wave range. The first relates to the small wavelengths involved, which require small waveguide dimensions and pose fabrication difficulties. The second is the increased waveguide loss at these higher frequencies; for antennas that are many wavelengths long, the leakage (which results in radiation) may compete with the intrinsic waveguide loss, and the antenna design can be adversely affected.

Because of these two problems, new leaky wave antennas have been proposed, analyzed and, in part, measured. To mininize the fabrication difficulties, these structures are made to be longitudinally continuous (in contrast to slot arrays, for example). To reduce the effects of higher loss, these new antennas are based on low-loss waveguides, such as groove guide and nonradiative dielectric (NRD) guide. These low-loss waveguides are open waveguides, although the lowest mode in each is a bound mode. In contrast, most leaky wave antennas for the microwave range were based on closed waveguides that were cut open in some way to produce the leakage. New techniques for obtaining controlled leakage from open waveguides were therefore examined as part of this study. These new ways to produce leakage are (a) introducing asymmetry longitudinally, (b) foreshortening one side of the open waveguide, and (c) employing a leaky higher mode.

In this talk, we describe several of these new leaky wave antennas. Each of the antennas has been analyzed by deriving an accurate transverse equivalent network, from which a dispersion relation for the complex propagation wavenumber ($\beta - j\alpha$) was determined in closed form. The numerical values obtained as a function of frequency and dimensional parameters indicate that these antennas are versatile. Measurements were made on one of these antennas, and they agreed very well with the theoretical values.

Four different antenna structures are presented, two based on groove guide and two on NRD guide. The three ways to produce leakage are included within these four examples. The talk will stress the physical principles of operation and include a few transverse equivalent networks and numerical results.

2. Specific New Leaky Wave Antennas

As mentioned above, these new antennas are based on low-loss open waveguides for which the dominant mode is purely bound. The two waveguides selected are groove guide and NRD guide, and two antennas are presented that are based on each of these low-loss guides.

(a) Antennas Based on Groove Guide

Groove guide is one of several waveguiding structures proposed for millimeter wavelengths about 20 years ago in order to overcome the higher attenuation occurring at these higher frequencies. The cross section of groove guide is shown in Fig. 1(a), together with an indication of the electric field lines present in the dominant mode. One should note that the structure resembles that of rectangular waveguide with most of its top and bottom walls removed; on that basis alone, the attenuation of groove guide must be less than that of rectangular waveguide, which in turn is much less than that of such lines as microstrip line, finline or co-planar line.

The greater width in the middle, or central, region was shown by Nakahara [1,2] to serve as the mechanism that confines the field in the vertical direction. The field thus decays exponentially away from the central region in the narrower regions above and below, causing the dominant mode to be purely bound.

The first leaky wave antenna based on the groove guide was proposed and analyzed by Oliner and Lampariello [3,4]. That structure is shown in Fig. 1(b). It is seen that the structure in Fig. 1(b) differs from that in Fig. 1(a) in that a continuous metal strip of narrow width has been added to the guide in asymmetrical fashion. Without that strip, the field of the basic mode of the symmetrical groove guide is evanescent vertically, so that the field has decayed to negligible values as it reaches the open upper end. The function of the asymmetrically placed metal strip is to produce some amount of net horizontal electric field, which in turn sets up a mode akin to a TEM mode between parallel plates. The field of that mode propagates at an angle all the way to the top of the waveguide, where it leaks away. The value of the phase constant β of the leaky wave (which determines the angle of the radiated beam) is governed primarily by the properties of the original unperturbed groove guide, and the value of the leakage constant α (which determines the beam width) is controlled by the width and location of the perturbing strip.

The leakage mechanism employed in the antenna discussed above is clearly the introduction of asymmetry. Additional antennas can be obtained on recognition that all higher modes in groove guide are leaky [5]. One must then increase the guide width in the central region (in Fig. 1(a)) to accommodate either the first higher odd ($n = 3$) mode or the first higher even ($n = 2$) mode. It can be shown that when the $n = 3$ mode is incident, it becomes leaky with the leakage in the form of the $n = 1$ mode; when the $n = 2$ mode is incident, the leakage is in the form of the TEM mode mentioned above. It follows, therefore, that if horizontal polarization is desired, the $n = 2$

mode incidence should be used, whereas the $n = 3$ mode should be employed for vertical polarization.

It should also be noted that from symmetry the $n = 2$ mode fields correspond to an electric wall at the midplane, so that the structure can be bisected with a metal wall, as shown in Fig. 1(c), without disturbing the fields. (In this form the leakage mechanism can again be viewed as asymmetry.) We have as a result a leaky wave antenna of particularly simple configuration. We have analyzed this structure accurately by viewing it as a tee stub on a parallel plate guide, and the numerical results show that this antenna is capable of yielding narrow or wide beam widths, as desired. These results have not as yet been published.

(b) Antennas Based on NRD Guide

Nonradiative dielectric (NRD) guide is a recent modification of H guide, which was a low-loss guide introduced many years ago by Tischer. The modification made by Yoneyama and Nishida [6] was to reduce the width between the plates to less than a half wavelength, thereby causing all discontinuities that maintain symmetry to become reactive, and to make the guide a practical candidate for low-loss millimeter-wave integrated circuits. The basic NRD guide is shown in Fig. 2(a).

The first antenna based on NRD guide is the one shown in Fig. 2(b), where the leakage mechanism is that obtained by foreshortening one side of the guide. When the distance d in Fig. 2(b) is small, the fields have not yet decayed to negligible values at the upper open end, and therefore some power leaks away. The upper open end forms the antenna aperture, and the polarization is seen to be vertical. The antenna is furthermore very simple in structure.

This antenna type has been analyzed accurately recently by Sanchez and Oliner [7], who showed that a wide range of performance possibilities are available. Measurements taken by Han, Oliner and Sanchez, not yet published, show very good agreement with the theoretical values.

Another type of antenna based on NRD guide depends on the asymmetry leakage mechanism, and is shown in Fig. 2(c). Recent accurate analysis, not yet published, shows that the asymmetry produces a net horizontal electric field that creates a TEM mode in the air region, so that power can leak away, and that changing the air gap or the dielectric width permits substantial flexibility in antenna design.

In summary, the problems facing leaky wave antennas at millimeter wavelengths are overcome in this study by devising structures of simple configuration based on low loss open waveguides, and by examining some new leakage mechanisms. Four new antenna structures are discussed; accurate analyses have been performed for all four, and measurements have been made on one of them.

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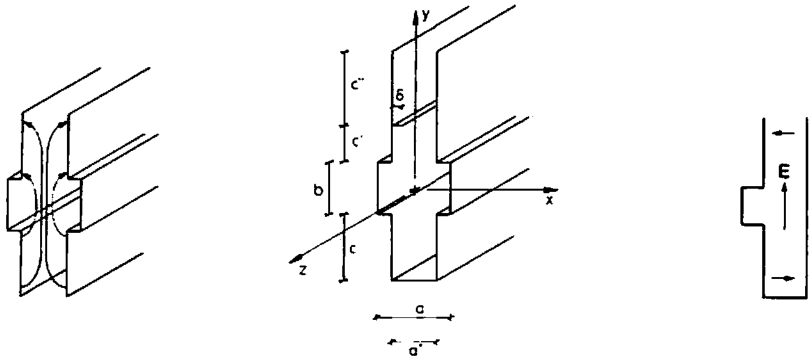
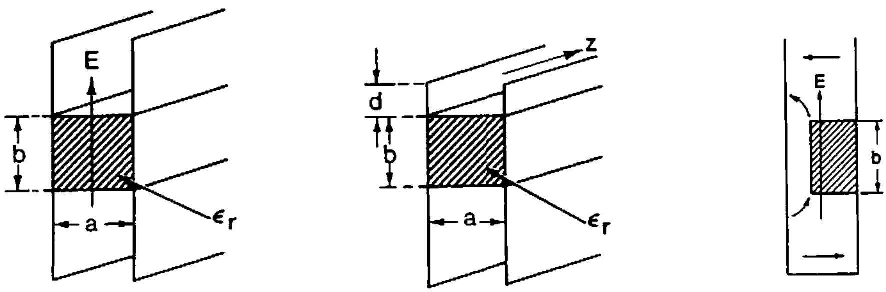


(a) (b) (c)

Fig. 1 Leaky wave antennas based on groove guide. (a) Nonradiating groove guide, (b) Asymmetric strip antenna, (c) Bisected groove guide antenna.



(a) (b) (c)

Fig. 2 Leaky wave antennas based on nonradiative dielectric (NRD) guide. (a) Nonradiating NRD guide, (b) Antenna using foreshortened side, (c) Antenna using asymmetric air gap.