LEAKY-WAVE CHARACTERISTICS OF TRAPEZOIDALLY SHAPED NRD-GUIDE SUITABLE FOR DESIGN OF MILLIMETER-WAVE ANTENNA

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ABSTRACT

Leaky-wave characteristics of NRD guide with various shapes of trapezoidal cross section are systematically modeled and analyzed by a method which combines effectively a multimode network theory with a mode-matching technique. Emphasis is laid on the investigation of parametric effect of trapezoidal dimensions on the leakage of NRD guide. Extensive numerical results are given to establish some useful guidelines for the design of new type of NRD-guide leaky-wave antennas.

INTRODUCTION

NRD-guide has been proposed for use in antenna design and applications at millimeter wavelength since it was proposed by Yoneyama and Nishida in 1981 [1]. As we know, waveguide losses increase significantly and usual antenna structures become more difficult to fabricate in view of the reduced size as frequency increases. Leaky NRD waveguide shows a great promise to overcome these problems. In addition, NRD-guide leaky wave antenna is also attractive because of its easy fabrication at millimeter-wave band by simply introducing asymmetry in the cross-section of the guide. Several forms of leaky NRD waveguide structures have been suggested for millimeter-wave use [2]-[3]. Oliner etc. have analyzed leakage properties of NRD-guide with a rectangular profile [3].

In this paper, two new types of leaky-wave NRD-guide with trapezoidal cross section, which will give more flexibility in antenna design, are analyzed in a comprehensive and accurate way. One is full-filled without gap as shown in Fig.1(a) while the other is with gap between the top metal plate and the dielectric strip in NRD-guide, as shown in Fig.1(b). The two new structures provide more degree of freedom for the design of the leaky wave antenna by flexibly changing geometric dimensions of the structures. On the other hand, these antennas may be more practical because keeping an exact rectangular shape during manufacturing sometimes could be very difficult.

Our analysis given here permits one to know the qualitative effects produced by the size *d* and to determine how large of *d* can be permitted before it influences the transmission properties of NRD- guide as a millimeter wave guiding structure. Although the measurements for a leaky wave antenna as shown in Fig.1(a) are available [4], optimization of parameters has not yet been accomplished, and no theory is available to date for the two new NRD-guide leaky-wave antennas.

RESULTS AND DISCUSSION

Let us first consider the leaky-wave antenna structure as shown in Fig.1(a) which may be also used as an array feeder structure. When *d* tends to vanish, the structure becomes a normal uniform NRD-guide, there is no leakage if the design rule of a standard NRD-guide is applied. As *d* increases from zero, an asymmetry is introduced, and a small amount of vertical electric field is thus created, which produces a mode in the parallel plate (air region) akin to a TEM mode. It then propagates at an angle between the parallel plates until it reaches a designated open end and leaks away into space.

The effect of dimension *d* on leakage constant is plotted in Fig.2. We note that there appear three main features as *d* increases. First, when *d* is zero, the structure becomes a normal uniform NRD-guide, no leakage occurs because no coupling between the eigenmodes in the NRD-guide through the dielectric-air interface. When *d* increases from zero, the leakage becomes significant and increases sharply till it reaches to its maximum, then decreases as *d* increases further. This phenomenon is due to the coupling between the LSE and LSM modes through the sloping dielectric-air interface. Second, we observe a dip in the vicinity of d/λ_0=0.45 (for b/λ_0=0.2), it is also physically due to the cancellation effect [5]. The third main feature is that there is a second peek in the leakage curve. This phenomenon is attributed to the fact that when the leakage reaches to the first peek, the coupling between the LSE and LSM modes does not reach its maximum, the decreasing of leakage after the first peek is due completely to the cancellation effect. The second peek is also the synthesis of the maximum coupling and the cancellation effect. As the maximum coupling is near the point where the cancellation effect occurs, the cancellation effect actually reduces the maximum of the leakage. The decreasing of leakage after the second peek is because of the weakening of coupling between modes with *d* increasing further.

Since in the present calculations the sloping line of the structure is geometrically discretized by a staircase approximation. The convergent property of the step number is one of the most important factors in the calculation. Fig.2 also shows the convergence behavior for the calculated results. It is found that as long as the step number is larger than 8, the calculated results are good enough for practical use. For a small dimension of *d*, for instance, in the first peek region, even 4 steps are good enough to obtain accurate results. Fig.2 also indicates that when d/λ_0 is less than 0.09(for b/λ_0=0.2), the leakage can be neglected, and *d* will not influence the performance of NRD-guide as a transmission structure.

Fig.3 presents the variation of $(\beta/\kappa_0)^2$ as a function of d/λ_0. From Fig.3 we can see that β increases as *d* increases. This is because the larger the *d* value, the larger the effective dielectric constant.

Fig.4 presents the variations of leakage as a function of d/λ_0, with b/λ_0 as a parameter. The variations are all calculated by discretizing the dielectric sloping line to 9 steps so that the accuracy of the calculation is guaranteed. By comparing the obtained four curves for different *b*, two main features are observed. One is that the first peek decreases rapidly as *b* increases. When b/λ_0=0.33, the first peek even disappears. The other is that the second peek becomes larger as *b* increases, and the dimension *d* where the leakage constant reaches its maximum decreases. These two features can be interpreted by the coupling between modes and the cancellation effect. When *b* increases, the point where the cancellation effect occurs will undergo a shift to the left side, i.e. the larger the *b*, the smaller the *d* where the cancellation effect occurs. However, the effect of changing *b* on the maximum mode coupling is not as significant as that on the cancellation effect. That is why the first peek decreases rapidly while the second peek increases relatively lower. From Fig.4 we can also infer that when *b* is less than $0.2\lambda_0$, the largest leakage will occur in the first peek, and a relatively small increasing of *d* from zero will produce a significant leakage. The smaller the *b*, the smaller the *d* for producing a significant leakage. When *b* is greater than $0.33\lambda_0$, the leakage is negligible if *d* is less than $0.18\lambda_0$. This observation is rather helpful for determining the manufacture tolerance for the transmission waveguide.

In Fig.5 and Fig.6 the leakage and propagation constants are plotted as a function of frequency, where the central frequency is selected to be 37.5GHz. The geometrical parameters are the same given in the inset of Fig.2 and d/λ_0=0.126 is selected in order to obtain a maximum leakage. We can observe that the propagation constant increases linearly as the frequency increases and the leakage decreases slightly as the frequency increases. This is a very desirable feature and it ensures a stable radiation pattern with little distortions as changing frequency is scanning the beam.

The leaky-wave characteristics are given in Fig. 7 for antenna structures with gap. It shows the variations of $\alpha\lambda_0/2\pi$ as a function of b/λ_0 with d/λ_0 as a parameter. When *d* vanishes, we get exactly the same results given in [3], indicated with "●". It can be seen from the curves that there are two main features. One is a general decrease in the value of α as *b* increases. This is because as *b* increases, the modes coupling is reduced, therefore the leakage power decreases. The other is the presence of a dip in the vicinity of certain *b*. It is due to the cancellation effect [5]. When *d* increases, we note that the cancellation will occur at a smaller *b*. This is because the existence of *d* can be viewed as an additional increase of *b*, therefore the larger the *d*, the smaller the *b* where the cancellation occurs.

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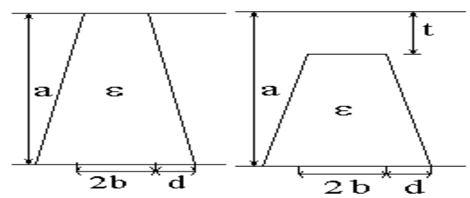

(a) without gap (b) with gap

Fig.1 Trapezoidal cross-sectional view of two new NRD-guide leaky-wave structures.

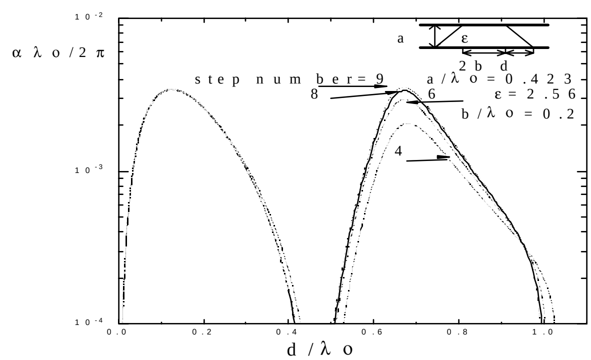

Fig.2 Effect of dimension *d* on leakage constant for the leaky-wave structure without gap.

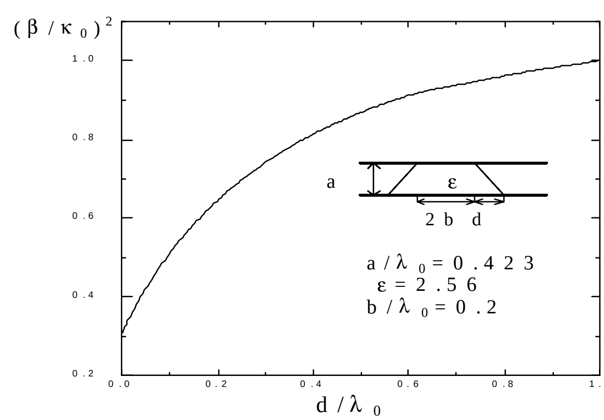

Fig.3 Curve of $(b/k_0)^2$ as a function of d/λ_0 for the structure without gap.

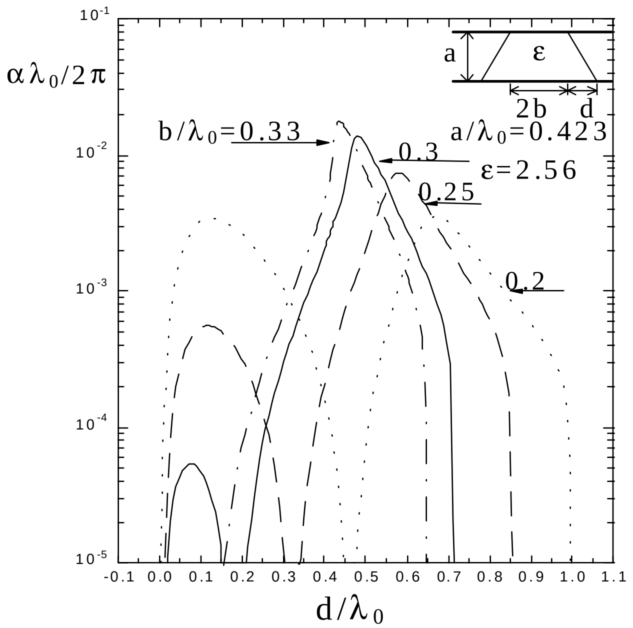

Fig.4 Variations of $a\lambda_0/2\pi$ as a function of d/λ_0, with b/λ_0 as a parameter for the structure without gap.

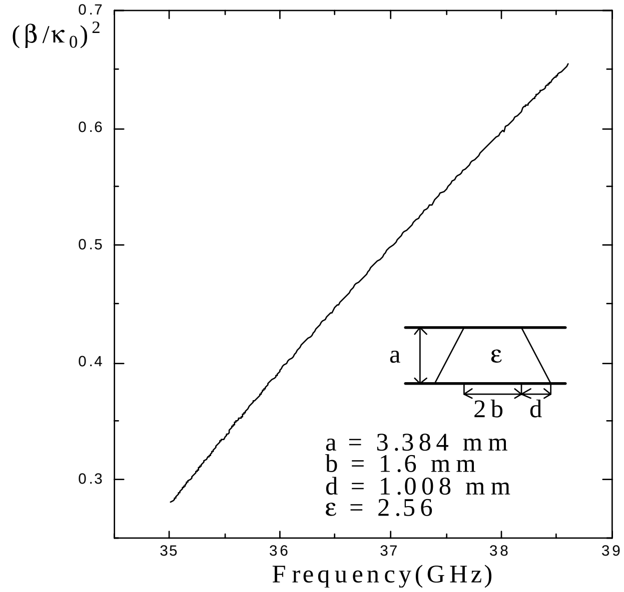

Fig.6 Frequency dependence of $(b/k_0)^2$ for the structure without gap.

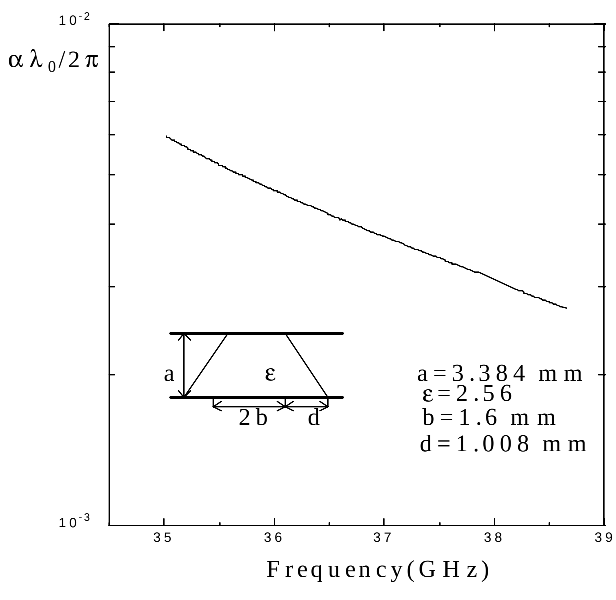

Fig.5 Frequency dependence of the leakage constant for the structure without gap.

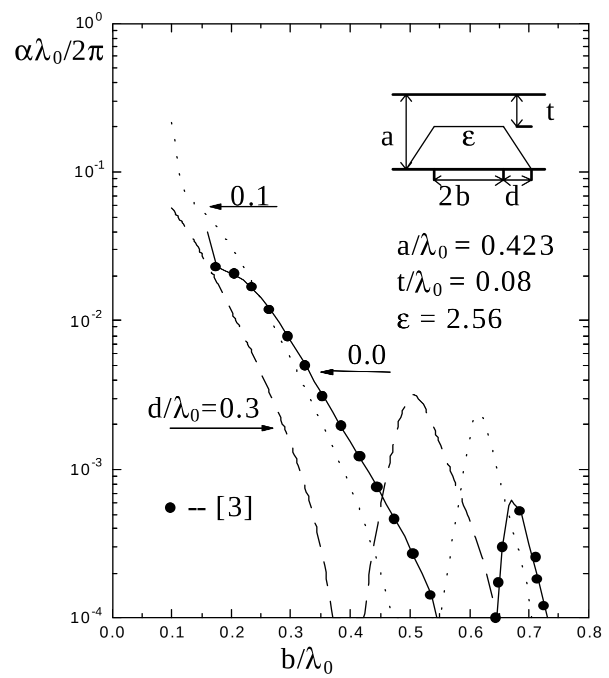

Fig.7 Variations of leakage constant versus b/λ_0 with d/λ_0 as a parameter for the structure with gap.