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EFFECTS OF AIR GAP AND FINITE METAL PLATE WIDTH ON NRD GUIDE

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ABSTRACT

A potentially serious problem that may arise with nonradiative dielectric (NRD) guide circuitry is described. First, a small unwanted air gap would generate a leaky hybrid mode that could produce cross talk between components of a circuit, and, second, if the plate width were also finite another type of leaky mode would be created similar to the well-known channel guide leaky mode. Under appropriate circumstances, this additional mode would couple to the leaky NRD guide mode and seriously complicate the performance characteristics of the NRD guide.

INTRODUCTION

Nonradiative dielectric (NRD) guide is a promising candidate of waveguides for millimeter wave use. This guide, first proposed by Yoneyama and Nishida[1], is basically a modification of H-guide[2], where the parallel plate separation is reduced to less than half of a free-space wavelength, and is operated by a TE-like mode with the electric field predominantly parallel to the metal plates (i.e., one of higher order modes in an H-guide). Therefore, any asymmetry and discontinuity convert a part of transmitting power of TE-like mode into that of unwanted modes.

A small air gap between the top metal plate and the dielectric strip expected in fabricating the waveguide can be a typical example of such an asymmetry. An exaggerated example of such a gap is shown in Fig.1, where a metal wall is put at the y-z plane at x = 0 because of the electric field normal to this plane. The effect of the air gap (t) have already been discussed by one of the present authors (A.A.O) [3] only for the case of the infinite width of metal plates ($c = \infty$ in Fig.1). The TE-like mode in NRD guide with air gap consists of both TE and TM wave contents and has all six field components. Each of these constituent surface waves propagates along the waveguide axis successively reflecting at the side of the dielectric strip, but the lowest TM content in the parallel plate region contributes to the power leakage in NRD guide with air gap, and this leakage of energy makes the propagation constant complex. So, we call hereafter this type of leaky mode " NRD guide leaky mode ".

On the other hand, the practical uses of NRD guide truncate the upper and the lower metal plates by a finite width. In such a structure, there is a possibility of the existence of an additional leaky mode; a new type of leaky TEM-like but full hybrid mode, of which predominant field is normal to the metal plates and which propagates at an angle to the axis of the guide and is successively reflected not at the side of diaperture discontinuity at x = (b +c) of parallel plate guide. This type of mode is considered to be almost the same as the well-known channel guide mode. The difference from the original channel guide, which is applied to an empty rectangular guide with a dimension (b + c) x a, is only that there is some dielectric material in the cross section at the end where the electric field of the channel guide mode is weakest, and therefore the dielectric produces only a change in the effective width (b + c). For this reason, such an additional leaky mode is called " channel guide leaky mode " in this paper. This channel guide leaky mode, characterized by the complex propagation constant, of course, are actually independent of the NRD guide leaky mode. However, it is easily understood that, under some dimensional condition, the complex propagation constants of both leaky modes become nearly equal each other, and the necessary mode coupling does occur because of the full hybrid nature of both modes, and they are of course linked together. This coupling complicates the characteristic of NRD guide as shown below, and deteriorates it seriously under some circumstances. This paper will be a first one which discusses these problems in detail.

EFFECTS OF FINITE METAL PLATE WIDTH: THEORY

Because of the presence of the air gap as shown in Fig.1, a modal field in this structure has two kinds of contents; TE and TM wave components. To obtain the network representation transverse to the propagation (z) axis, let us first consider the structure of Fig.1, but the widths of both dielectric strip b and parallel metal plates c are semi-finite in the regions of $x \leq b$ and $x \geq b$, respectively. For such a structure, the fields in the dielectric strip ($x \leq b$) and in the parallel plate region ($x \geq b$) can be expressed in terms of the superposition of the complete set of TE and TM-wave modal functions in each region, respectively. The field components of such the fields tangential to the y-z plane must be continuous at the side of the dielectric strip (y-z plane at x = b). Applying a mode matching method, we finally obtain the equivalent admittance matrix [Y] for the discontinuity at the side of the dielectric strip shown in Fig.2. In the above

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procedures, there are several important points to be considered; the truncation of an infinite series in the field representations, the condition of power conservation across the strip side, the alternative formalism for an equivalent network representation and so on. The readers can find the helpful discussions on these problems, for example, in [4].

Let us next consider the practical guide of Fig.1 itself. For representing the dielectric strip region ($0 \leqq x \leqq b$) with an equivalent circuit, it is necessary to connect the short-circuited transmission lines of the length b to the right hand side of the discontinuity matrix [Y]. For the parallel plate region ($b \leqq x \leqq c$), on the other hand, the only leaky wave is the lowest TM wave which see the open end at x = (b + c), and the equivalent transmission line for it should be truncated by a finite length c and is terminated with the aperture admittance ($g_a + jb_a$) which is given in " Waveguide Handbook "[5]. While, the other higher order contents in the parallel plate region do not see the open end. Therefore the ports corresponding to these contents can be terminated by their own transmission line admittances as shown in Fig.2.

By putting the length c (i.e., the metal plate width) infinite, we can calculate the effect of the air gap only, by solving the generalized transverse-resonance relation of Fig.2; the port of TM content is now terminated by its own transmission line admittance for this case. It is also expected that the almost same results can be obtained by using an alternative approximate method[3], and such results for α/k and (β/k_0) as a function of b/λ_0 are presented in [3].

NUMERICAL RESULTS

Our main interest in this paper is the effects of the finite metal plate width of NRD guide. Figs.3 - 6 indicate the calculated results which are obtained for $a = 0.423\ \lambda_0$, $b = 0.25\ \lambda_0$, $\varepsilon_r = 2.56$ and the different values of the air gap t. As mentioned before, the truncation of the upper and the lower metal plates creates a condition for generating a new type of leaky hybrid mode; the channel guide leaky mode. In Fig.3, the nearly horizontal line in the diagram of the phase constant indicates that of the NRD guide leaky mode, while the curves indicated by ① - ⑤ indicate those for the channel guide leaky mode which change significantly as the metal plate width c changes because of its nature like a rectangular waveguide mode. As for the attenuation constants, the NRD guide leaky mode exhibits a lower attenuation than that of the channel guide leaky mode and its attenuation constant changes oscillatory to the metal width c. The points indicated by Ⓐ correspond one another, and at this plate width c, the phase constants of both modes coincide, but there is a large difference between the attenuation constants. Therefore, no coupling or conversion between modes occur. Such a result is usual for quite small air gap (e.g, $t = 0.01\lambda_0$).

On the other hand, important is the case shown in Figs.4 - 6. Fig.4 indicates the results obtained for a rather small air gap $t = 0.03\lambda_0$. In this case, the behavior of the phase constants is almost same with that of Fig.3, but the difference between the attenuation constants becomes so small that both modes interfere each other. Such a mutual interference, depending on the full hybrid natures with complex propagation constants of both modes, is still weak at the point Ⓑ , but the value α of the channel guide leaky mode is slightly affected. As the plate width c increases, the difference between the attenuation constants becomes smaller and the rather strong mutual interference does occur as seen at the point Ⓒ . At the point Ⓓ , such an interference becomes strong enough to make the complex propagation constants of both hybrid modes coincide each other. Then both modes are linked together at around this width of metal plates, and the necessary mode coupling occurs at around this point in the sense as seen in the coupled lossy transmission line system. As a result, the dispersion curve and the corresponding attenuation characteristics exhibit the interesting behaviors as seen at around the point Ⓓ .

As the air gap increases, the difference between the attenuation constants becomes smaller and smaller as indicated in Figs.5 and 6; the mode conversion does occur at many points of c values, and seriously complicates the characteristics of NRD guide. For better understanding of such complicated characteristics, an example of the dispersion curve and the corresponding curve of the attenuation constant are shown by the dotted curves in Fig.5.

In conclusion, the discussions and the calculations presented here make the contributions of finite metal plate width to the leakage from a NRD guide with air gap clear, and justify first the unexpected presence of the additional leaky mode; the channel guide leaky mode, and its coupling to the NRD guide leaky mode. The mode used in a practical NRD guide with an avoidable small air gap is a higher order full-hybrid mode, and the channel guide leaky mode seriously complicates the performance characteristics of the NRD guide. Therefore, for the circuit designs, we should take special care that the mode conversion or coupling produced by the finite metal plate width does not occur.

On the other hand, it was pointed out by one of the present authors (A.A.O) that a reasonably large air gap in a NRD guide could leak the transmission power enough for constructing a new type of leaky wave antanna for millimeter waves[3]. The calculations discussed here strairgtforwadly permit one to determine what air-gap size and metal plate width can be permitted for designing such leaky wave antennas. These will be discussed elsewhwere[6].

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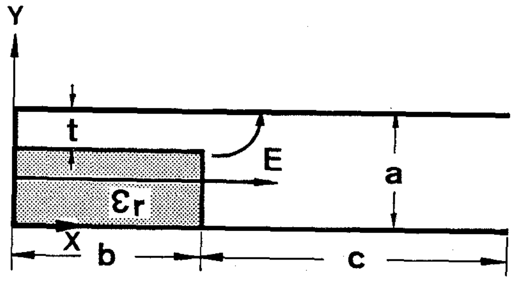

Fig.1. Half section of NRD guide with air gap t, where the upper and lower metal plates are truncated finitely in their widths.

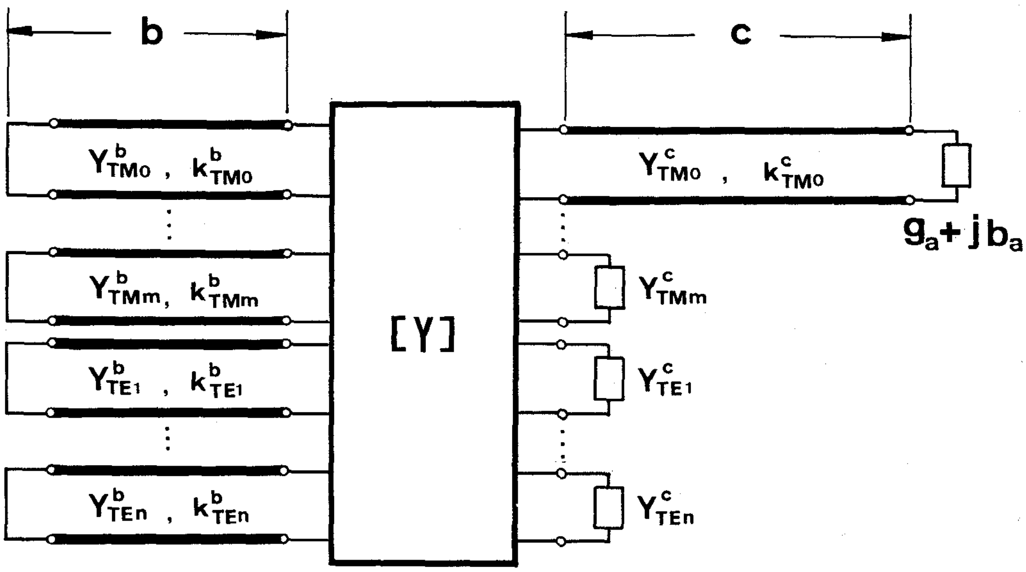

Fig.2. Transverse equivalent network for the structure of which cross section is shown in Fig.1. The admittance matrix [Y] indicates the equivalent network for the discontinuity plane at x = b and the aperture admittance ($g_a + jb_a$) is given in " Waveguide Handbook " [5].

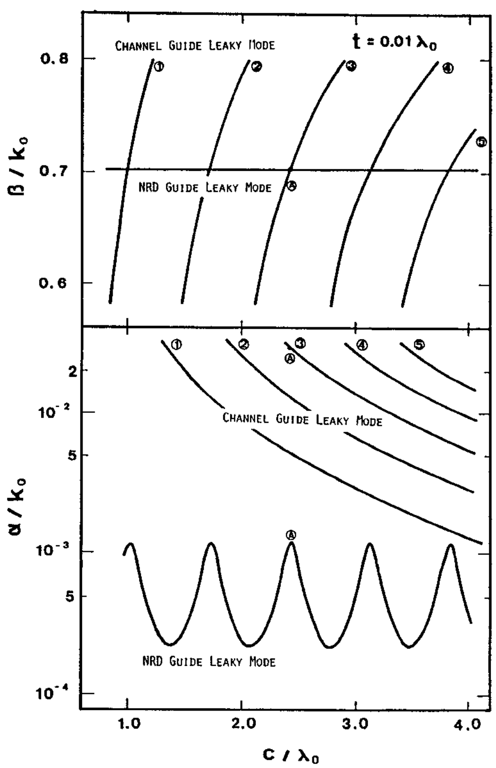

Fig.3. Curves of β/k_0 and α/k_0 as a function of c/λ_0, with $b/\lambda_0 = 0.25$, $\varepsilon_r = 2.56$ and $t/\lambda_0 = 0.01$.

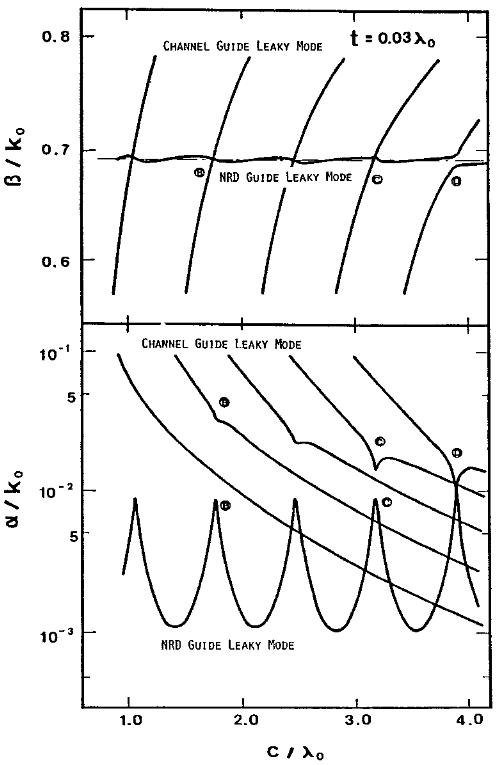

Fig.4. Curves of β/k_0 and α/k_0 as a function of c/λ_0, with $t/\lambda_0 = 0.03$.

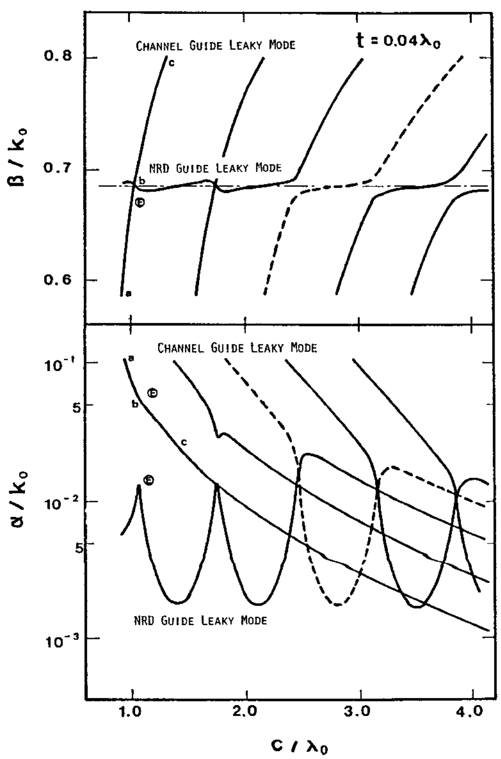

Fig. 5. Curves of β/k_0 and α/k_0 as a function of c/λ_0, with $t/\lambda_0 = 0.04$.

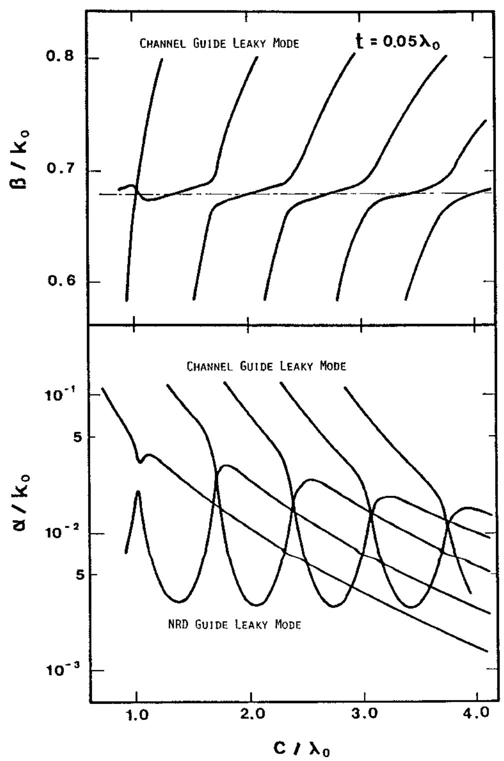

Fig.6. Curves of β/k_0 and α/k_0 as a function of c/λ_0, with $t/\lambda_0 = 0.05$.