AN ACCURATE ANALYSIS OF DISCONTINUITIES IN DIELECTRIC RECTANGULAR WAVEGUIDE AND ITS APPLICATION TO GRATING FILTERS

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ABSTRACT

An accurate theoretical approach for discontinuity problems in dielectric 3-D (rectangular) waveguides of open type is presented. This approach takes account of the behavior of both surface wave modes and continuous spectral waves, and is successfully applied to design dielectric image guide grating filters. Comparative data are also shown.

INTRODUCTION

Dielectric waveguide is a promising candidate for printed-line type millimeter-wave integrated circuits in the shorter millimeter wavelengths. Dielectric gratings formed on such a guide with periodic notches have wide applications in the circuitries. Discontinuities in various configurations play an extremely important role in such gratings. However, if the waveguides are the structures of open type, the radiation of a part of the transmission power does occur as well as the reflection and transmission of the guided surface wave modes at the discontinuity.

Although such a radiation causes, in some cases, serious problem on the millimeter wave integrated circuit performance, the accurate analysis of such a problem is quite difficult. So, most of the published literatures have discussed on the simplified two dimensional configurations introducing some excessive approximations. Therefore, it is quite difficult to design the practical dielectric grating structures of the 3-D (for example, rectangular) configuration.

In this presentation, we propose an approximate, but rather accurate theoretical method for solving the discontinuity problems in the practical 3-D waveguides of open type. It is believed that the method presented here is unprecedented to the best knowledge of the authors.

THEORETICAL CONSIDERATIONS

We consider here the dielectric image guide (DIG) as a typical example of the 3-D structure of open type, and a typical example of discontinuities to be expected in such a waveguide is shown in Fig. 1. This step discontinuity is the junction of two kinds of waveguide with different widths w_1 and w_2. Here, we assume that each waveguide can support only the fundamental E^Y_{11} surface wave mode (E-field is predominant in the y direction). When the E^Y_{11} surface wave mode is incident from guide 1 to the discontinuity plane, a part of incident power is necessarily radiated in the form of the continuous spectral wave, in addition to the reflection and transmission of the E^Y_{11} surface wave mode in both guides.

To analyze such a radiation, let us here try to alternate the structure of Fig. 1 with an approximate 2-D structure; i.e., a uniform structure in the y direction in this case, as keeping the nature of the original discontinuity as much as possible. If the difference between w_1 and w_2 is not so large, we can assume the field distributions of the E^Y_{11} surface wave mode in the y direction in both guides to be almost same each other. In such a case, it is reasonable to alter the original structure with the structure uniformly extended in the y direction as shown in Fig. 2 (the cross section on an arbitrary xz plane). But, we introduce here a constraint; the phase constants of the original guides 1 and 2 are invariable even in the reduced 2-D guides 1' and 2', respectively. The reason why we have such a constraint is that, if a finite number of discontinuities shown in Fig. 2 are used for devising a grating filter by loading them periodically, the phase constants play an extremely important role for completely theoretical design of it.

The phase constant β_i (i=1 or 2) for the original (DIG) guide with the refractive index n_1 can be accurately calculated by Goell's method [1], while that for the reduced 2-D guide is obtained from the well-known eigenvalue equation for the slab guide with the refractive index n_i' (i=1 or 2). Keeping the width of each guide invariable and equating β_i with β_i' at the specified frequency f, we can solve the necessary n_i' which is usually different from n_1. Then, we may consider that the effect of the slight difference between the field distributions in the y direction in the original 3-D structure is approximately converted into the difference between n_1' and n_2' in the reduced 2-D structure.

Now the original problem is reduced to that in the 2-D configuration as shown in Fig. 2. The electric field is parallel to the y axis, and the method [2] already developed by the present authors can be successfully applied to such a discontinuity problem in open configuration. Our method is rigorous for the 2-D structures and the key point is to reorganize the wave with continuous spectrum into a set of the newly defined complete-orthonormal modal wave. This reorganization makes it fully possible to allocate the discrete terminal ports even for the continuous wave with the same definition of the terminal parameters as that for the surface wave modes in the actual equivalent network. As a result, each of the isolated-step discontinuity and the intervening dielectric waveguide, constituting a periodic structure with a finite length, can become a building block independently in our network representation [3]. Our approach is then applicable even to any kind of the structure constituted by such a building block connected in tandem, and can easily obtain the wave behavior including the radiation waves by means of the usual microwave network approach. At the oral presentation, we will add a more detailed explanation about the network approach which is omitted here.

NUMERICAL CONSIDERATIONS

Numerical examples are considered for two kinds of the 3-D DIG gratings shown in Fig. 3; one has the shallow notches (w_1 =19 mm, w_2=13 mm, h=12 mm, d=12 mm, d_1/d_2=1, and n_1= 1.52), and the other has the deep notches (w_2=9 mm).

To confirm the validity of reducing the 3-D problem to the 2-D one, we first calculate the field distributions in the x and y directions for the uniform dielectric image guide. Fig. 4 (a) and (b) show the field distributions of the |Hx| component in both directions at 10 GHz, for three guides with the widths w =9, 13, and 19 mm. It is clear that the field distributions in the x direction, of course, strongly depend on and change by the guide width, but those in the y direction are insensitive to it and almost same one another. Therefore, the present 2-D approach can be reasonably applied to the grating filters under consideration, and their reduced 2-D structure is shown in Fig. 5.

Fig. 6 shows the frequency characteristics for the grating filters with (a) the shallow and (b) the deep 30 notches, respectively. The solid lines indicate the results obtained by the present method, while the dotted ones by another approximated method developed by the present authors [4] which solves directly the 3-D problem, but neglects the radiation occurring at the discontinuities. In the case of shallow notch, both results show good agreement, but as increasing the depth of the notch, the simplified approximate method underestimates the insertion loss compared with that obtained by the present method at around the stopband region. The difference may be explained by the radiation power indicated in Fig. 7. It is seen that, in the case of shallow notch, the radiation power level is much lower than that of the insertion loss and both approaches calculate almost the same results. On the other hand, for the deep notch, the radiation power level is comparable to the insertion loss, and the radiation power should be always taken into account for estimating the insertion loss correctly as shown in Fig. 6 (b).

Although interesting experimental data will be shown at the oral presentation, the effectiveness of the present method for the 3-D DIG grating filter is sufficiently discussed.

ACKNOWLEDGEMENT

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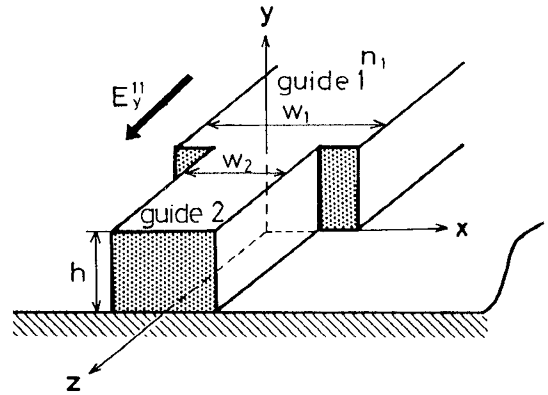

Fig. 1. Step discontinuity consisting of two kinds of dielectric image guide with different widths w_1 and w_2.

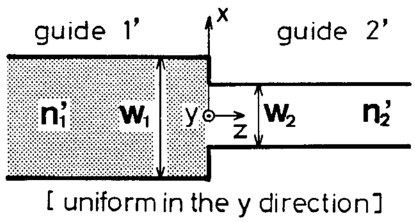

Fig. 2. Reduced 2-D structure uniformly extended in the y direction.

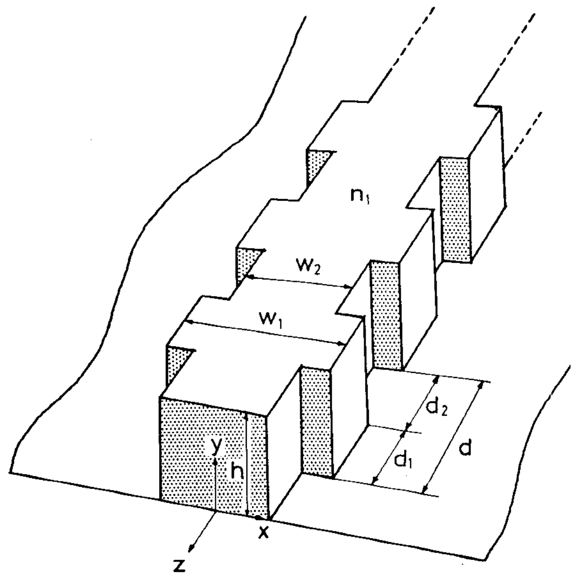

Fig. 3. Dielectric image guide gratings consisting of a finite length of periodic notches.

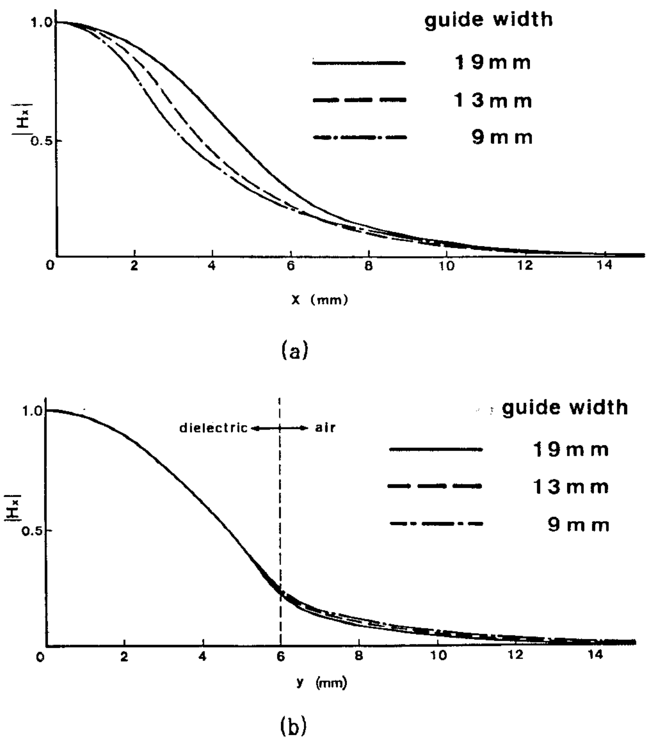

Fig. 4. Field distributions of the |Hx| component for the uniform dielectric image guides with height h=12mm and widths w=9, 13, and 19mm, (a) at y=0 in the x direction and (b) at x=0 in the y direction.

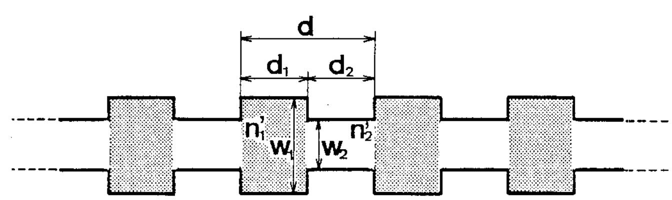

Fig. 5. Reduced 2-D gratings consisting of a finite length of periodic notches.

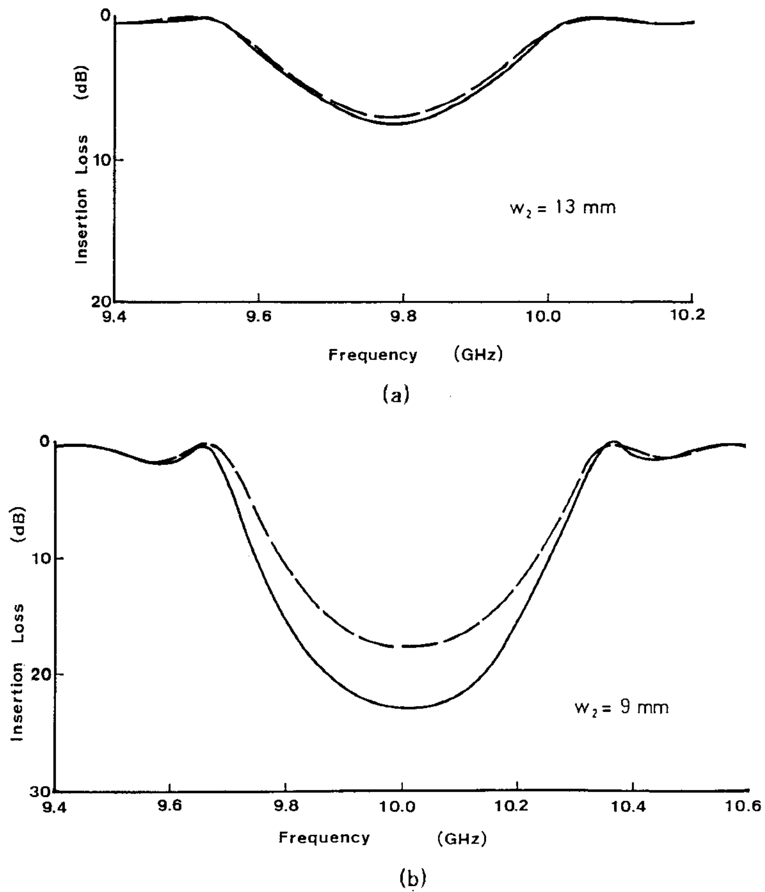

Fig. 6. Transmission characteristics of the DIG gratings with (a) shallow notch (w_2=13mm) and (b) deep notch (w_2=9mm). The solid lines indicate the results obtained by the present method, and the dotted ones by another approximated method which solves directly the 3-D problem, but neglects the radiation occurring on the discontinuities.

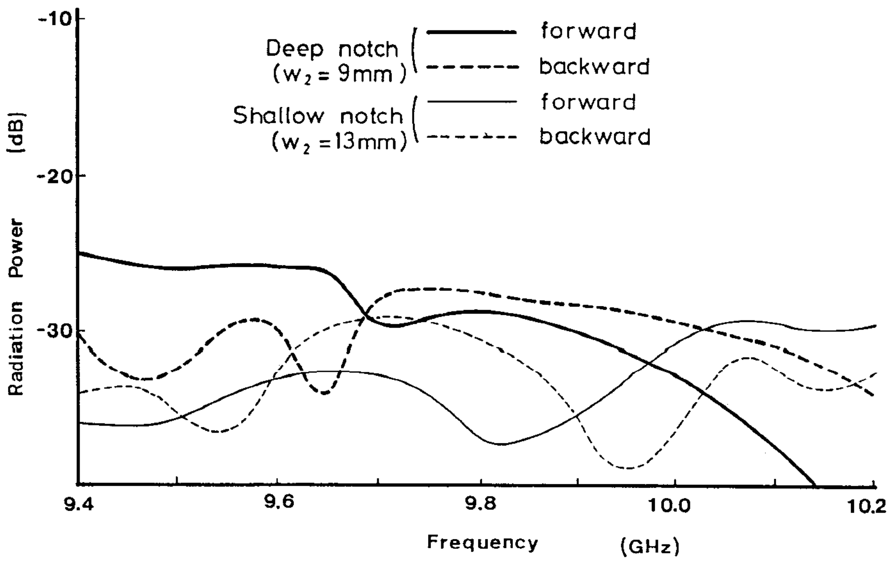

Fig. 7. Radiation characteristics of the DIG gratings with shallow and deep notches.