A CHALLENGE TO THEORETICALLY ZERO-LOSS DESIGN OF 3-D DIELECTRIC WAVEGUIDE Y-BRANCH

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ABSTRACT We present here a new method of designing three-dimensional(3-D) dielectric waveguide Y-branch with theoretical zero-loss due to radiation. In this method, an unprecedented analytical process already developed by us is incorporated along one of the three dimensions in space, so that the 3-D boundary-value problem is effectively reduced to a two-dimensional(2-D) one. The taper section of such a reduced Y-branch is then designed so as to control intentionally the intensive power conversion and reconversion between the surface-wave mode and the radiation wave, thereby transforming the input surface-wave mode only into the desired surface-wave mode on the output waveguide, while suppressing the undesired reflection at the input end. The effectiveness of our approach is confirmed by comparing with some measurements that we took.

1. Introduction

A general configuration of 3-D Y-branch is shown in Fig.1, where each dielectric image guide(DIG) supports only the fundamental E^y_{11} surface-wave mode (polarized in the y direction). Then, there are two problems to be solved: one is to establish a method for analyzing accurately its boundary-value problem and the other is to reduce amazingly the loss due to radiation of 3-D Y-branch. An effective solution to the first problem is derived from an approach to 3-D discontinuous dielectric waveguide circuits developed by us[1], which reduces effectively the essential propagation mechanism of the E^y_{11} surface-wave mode on 3-D structure to a mechanism on 2-D structure. For such a 2-D structure, we can no longer discuss the radiation field itself, but it has been proved that we can estimate enough the amount of the transmission and reflection powers of the surface-wave mode and the radiation power. As a result, this approach is incorporated with a theoretically zero-loss design method of planar dielectric waveguide Y-branch[2] to design an amazingly low-loss DIG Y-branch, in which the radiation wave is intentionally generated along the taper, and is controlled so that it can play an important role to reduce the loss.

2. Theoretical Considerations

Let us first approximate a DIG Y-branch of Fig.1 by a discrete succession of infinitesimal step discontinuities as shown in Fig.2. This structure can be divided into four types of building block: the first is a uniform DIG, the second is a step discontinuity on it, the third is a parallel-coupled uniform DIG, and the last is a step discontinuity on it.

In reducing the problem of 3-D DIG to a 2-D slab waveguide, we must be careful in managing the step discontinuity problem shown in Fig.3. In our approach[1], the E^y_{11} surface-wave mode on a uniform DIG with the width w_i and the height h is first viewed approximately as a pair of TM_0 surface-wave mode(polarized mainly in the y direction) on the conductor-backed slab waveguide, bouncing between the dielectric-air interfaces spaced w_i apart. Next, the phase constant β^{TM} of this TM_0 surface-wave mode is used in the usual EDC method so that the 3-D step discontinuity of Fig.3 is reduced to the approximated 2-D one in Fig.4, which is uniform along the y direction and of which effective refractive index is given by $n_{eff}^{TM} = \beta^{TM}/k_0$. On the other hand, the propagation characteristics of the E^y_{11} surface-wave mode along a uniform DIG is directly solved by Goell's method[3].

The wave behavior on or at each building block mentioned above is now completely expressed by the corresponding generalized network[4] which is effective for waveguides of open type and is still amenable to the usual microwave network approach. Connecting such building-block networks in tandem according to the approximation of Fig.2, we can obtain the over-all network of the DIG Y-branch, of which parameters can be controlled by varying the guide widths w_i, the separation widths d_i, and the segment length Δl_i (i=1,2,..,N).

To obtain a DIG Y-branch with amazingly reduced loss due to radiation, it has been found that the taper shape of Y-branch should be designed so as to control intentionally the intensive power conversion and reconversion between the surface-wave mode and the radiation wave, thereby obtaining only the desired surface-wave mode on the output DIG, while suppressing the undesired reflection at the input end. To control the power conversion and reconversion along the taper, we follow an unprecedented method discussed for 2-D Y-branch, in which the variables expressing the equivalent network parameters are solved by the modified Newton iteration method to fulfill the given conditions of transforming the resultant field only into the desired surface-wave mode on the output DIG and of generating no reflection power at the input end, while keeping constant the total length L of a Y-branch and the separation width D of two waveguides at the output end.

3. Design of Low-Loss Y-Branch and Experiments

In the calculations, we fixed all of the guide widths w_i to W and the separation width D at the output end to $7W$, and varied each of the segment lengths Δl_i. For the sake of experimental convenience, Y-branch was designed at X-band, by using the polyethylene (ε_r=2.25) as a dielectric material.

First, we calculated the insertion loss of DIG Y-branches with a linear taper. Fig.5 shows the calculated and measured characteristics as a function of the normalized taper length L/W. It is seen that the agreement is excellently good. Therefore, it is safe to say that our approach for 3-D discontinuous structures is effective.

Next, we designed a low-loss Y-branch, keeping $L = 10W$ and $h = 0.82W$. Fig.6 shows the top view of the synthesized DIG Y-branch. This configuration consists of the serpentine taper and the abrupt steps at both input and output ends. This result indeed seems to be an unexpected one from the usual design point of view, but is certainly consistent with our original idea as seen in 2-D case[2] from the prudential physical consideration. The calculated result for transmission power agrees excellently with the measured one indicated by the square mark on Fig.5. Incidentally, the insertion loss of the serpentine-taper DIG Y-branch at $L = 10W$ is about 0.5 dB, which is about a half of that of the linear-taper DIG Y-branch.

Only a few examples are given here because of limited available space, but it is obvious that the analytical approach mentioned above will open a new methodology for discontinuous circuit design of 3-D structures.

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References

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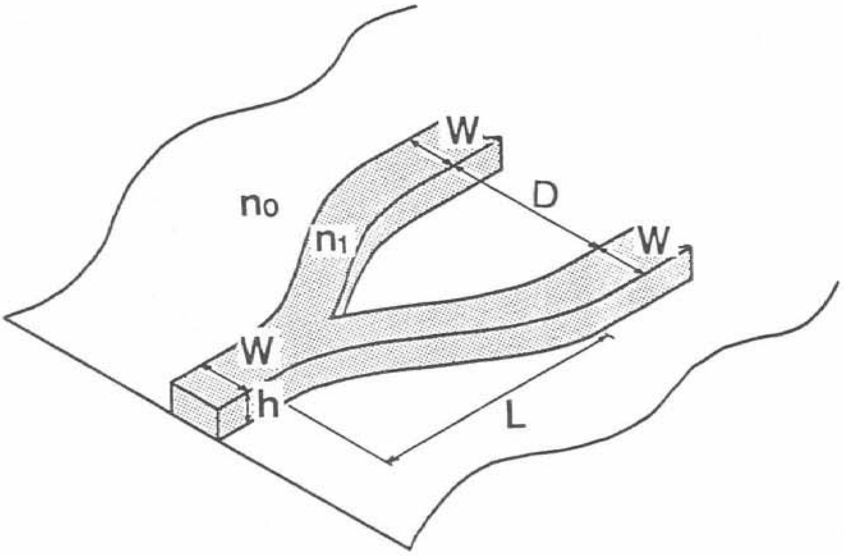

Fig.1. General configuration of 3-D dielectric waveguide Y-branch.

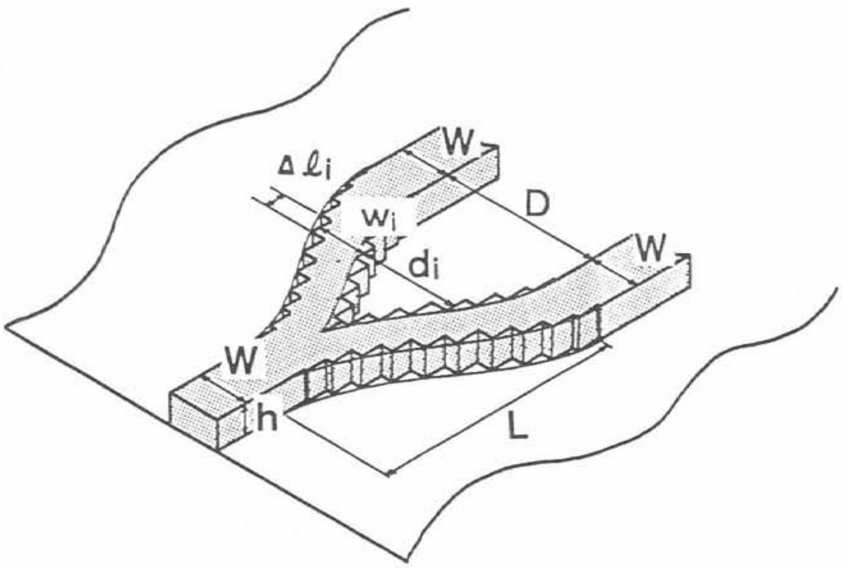

Fig.2. Exaggerated sketch of the step approximation for analyzing a DIG Y-branch.

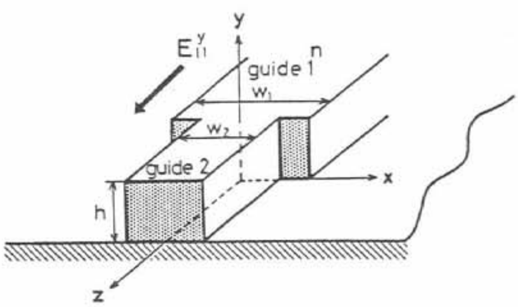

Fig.3. Step discontinuity consisting of two kinds of dielectric image guide.

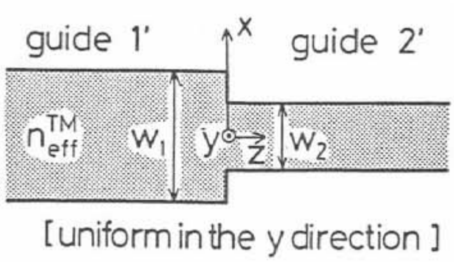

Fig.4. Equivalent 2-D structure of Fig.3.

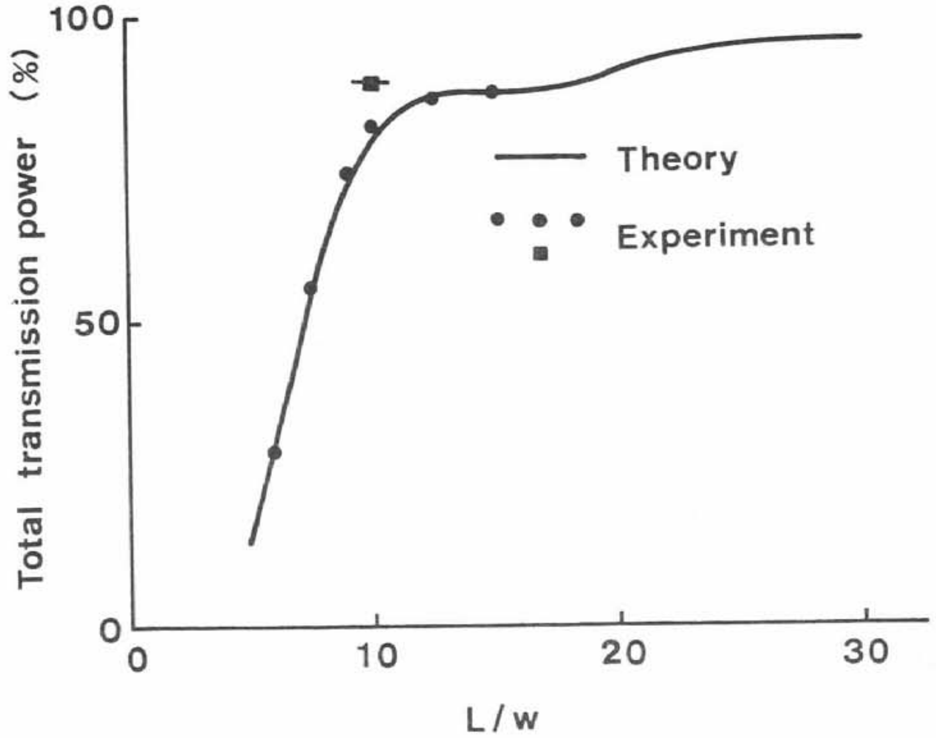

Fig.5. Calculated and measured transmission power as a function of the normalized taper length *L/W* for the linear-taper Y-branch. The square mark on *L/W*=10 indicates the serpentine-taper y-branch.

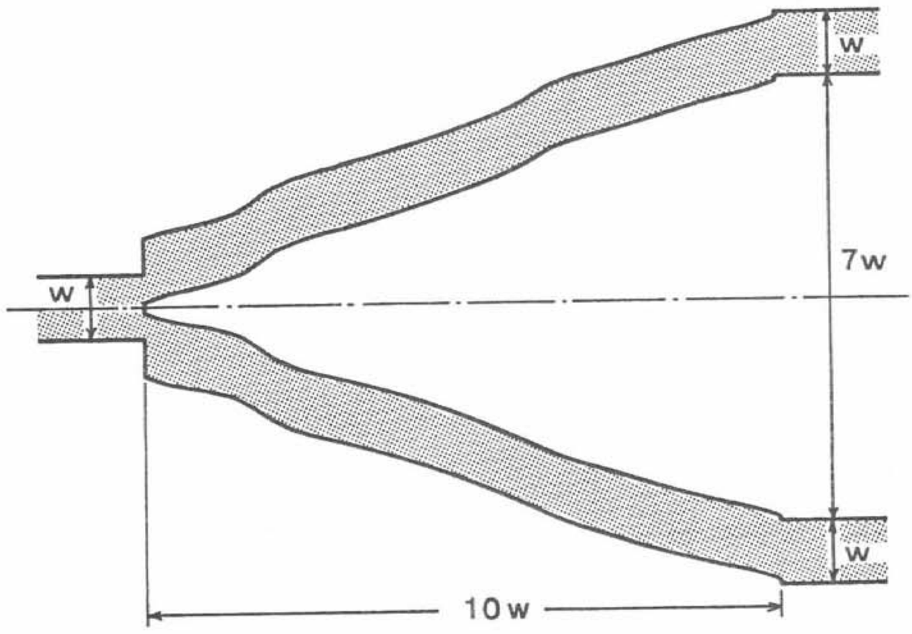

Fig.6. Synthesized low-loss Y-branch of which configuration is characterized by the serpentine taper.