SOLUTION OF THE RIGOROUS BOUNDARY-VALUE PROBLEMS OF OPEN DIELECTRIC WAVEGUIDE T-BRANCH

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1. Introduction

The widespread use of dielectric waveguide Y-type and T-type branches of open type have stimulated many theoretical studies[1]-[3]. In contrast to Y-type branch, T-type branch has not yet been discussed precisely from the point of view of the boundary-value problem, even if it is two dimensional, because it is impossible to solve its boundary value problem with mathematical completeness. The mathematical difficulties in analyzing T-branch shown in Fig.1 are clear when the power splitting of the input surface-wave mode incident from the waveguide I is considered. As for the input waveguide I, it is well-suited to completely express an arbitrary field on an infinite xy plane transverse to the z axis, in terms of the elementary fields of both the surface-wave modes and the radiation wave on a uniform dielectric slab. Once following this expression, the field on the output waveguide II and II' should be also expressed by using complete field on it from the boundary value point of view. Therefore, it no longer makes rigorous sense to express the field on the waveguides II and II' in terms of the elementary fields defined at an infinite xz plane transverse to the y axis, because the ranges defining the field overlap each other. This paper challenges for the first time to obtain the rigorous solution of T-branch from the boundary value point of view, and clarifies its branching characteristics as precise as possible.

2. Analysis

We divide the T-branch of Fig.1 into three constituents as shown in Fig.2(a): two discontinuities and the homogeneous space of width $2D$ interconnecting these. Then the field on the output waveguides II, II' and its surroundings are expressed only by the radiation wave defined on an infinite xy plane transverse to the z axis. According to our network method[4] for an open dielectric waveguide, which is still amenable to the usual microwave network method, the T-branch can be expressed rigorously by the networks of Fig.2(b), and its characteristics can be easily calculated from this networks.

However, it should be noted that the resultant field obtained from the present method never exhibits the net power flow along the output waveguides II and II'(the y axis) because the elementary fields of radiation wave are expressed by the perfect standing-wave, in order to fulfill the mathematical completeness. Therefore, the problem shown by Fig.2(b) is perfectly different from that under consideration, though the boundary conditions are rigorously solved. Looking, however, this result from the point of view of the excitation condition, we may understand that the problem of Fig.2(b) is same with that the input surface-wave modes corresponding to the incoming wave component of the standing-wave are compulsorily incident from the output waveguides II and II', in addition to the actual input surface-wave mode incident from the waveguide I. Since the actual branching characteristics are obtained when the effect of such compulsory input modes is canceled, we introduce here a possible method to cancel it by considering one more excitation problem in which the surface-wave mode is incident from both the output waveguides II and II', while the input waveguide I is considered as the semi-infinitely extended dielectric layers. In such an analytical process, the microwave network approach based on the non-unitary branch matrix is effectively used. This detail explanation is omitted here, but is presented at our talk.

3. Numerical and experimental Discussions

In Fig.1, we assume n_1=1.5, n_0=1.0 and K_0D=1.0. For this structure, the dielectric waveguides I, II, and II' can support only fundamental surface-wave mode. Fig.3 shows the electric-filed intensity distribution around the junction when the TE_0 surface-wave mode is incident from the waveguide I. We can observe clearly that a part of the incident surface-wave mode is divided into the output waveguides II and II', but the resultant field on these waveguides presents the standing wave because of the compulsory input-wave incidence from the guides II and II'. Figs.4(a) and (b) also show a typical distribution of the continuous spectrum ρ of the radiation wave at $z = 0$. As expected from the physical reasoning, it does not form a line spectrum corresponding to the wavenumber ρ_S of the surface wave on the output waveguide II or II', but extends in the rather wide range around ρ_S. On the other hand, Fig.5 shows the electric-field intensity distribution on the *xz* plane transverse to the output waveguide II or II'(the y axis), where the maximum value in each of curves is normalized to unity. The solid curves indicate the resultant field obtained by the present method, while the dashed ones indicate the modal field of the surface wave on the slab waveguide with thickness $2D$. It is found from this figure that the resultant field gradually converges the modal field of the surface wave as the distance y/D from the junction increases, and both fields become nearly equal at y/D=50. At this distance, the wave impedance of the resultant field is 295.41Ω, while that of the surface-wave mode is 295.43Ω. Therefore, it may be concluded that in the range of y/D>50, the power flow along the output waveguide II or II' can be approximately regarded as the power carried by the surface-wave mode. As a result, we can obtain the quantitative characteristics of the outgoing surface wave on the waveguides I, II, and II'. Finally, introducing another excitation problem mentioned above, the actual divided power and reflected power of the surface-wave mode are determined and the calculated results are given in Table 1. The experiment in the X-band is performed in case of the input surface-wave mode incident only from the waveguide II (only for reason of experimental simplicity). The measured power transmitting to the waveguide II' is 0.43 dB, while the corresponding theoretical one is 0.42 dB. Both results shows an excellent agreement and this proves that the present method is accurate and useful for analyzing the T-branch.

Only a few numerical examples are given here because of limited available space, but it is obvious that the precise analysis repeated here is applicable, with appropriate modification, to other types of branch circuits, bends, and so on.

Acknowledgments This work was supported partly the Ministry of Education, Science and Culture of Japan under a Grant-in-Aid for General Science Research(63550261).

References

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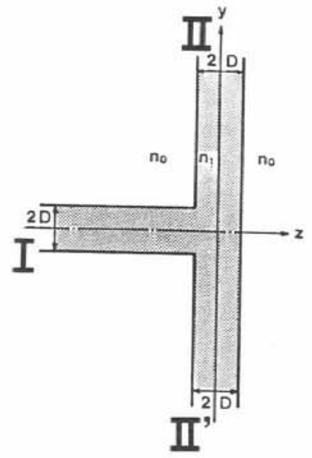

Fig.1. T-branch of open dielectric slab waveguide.

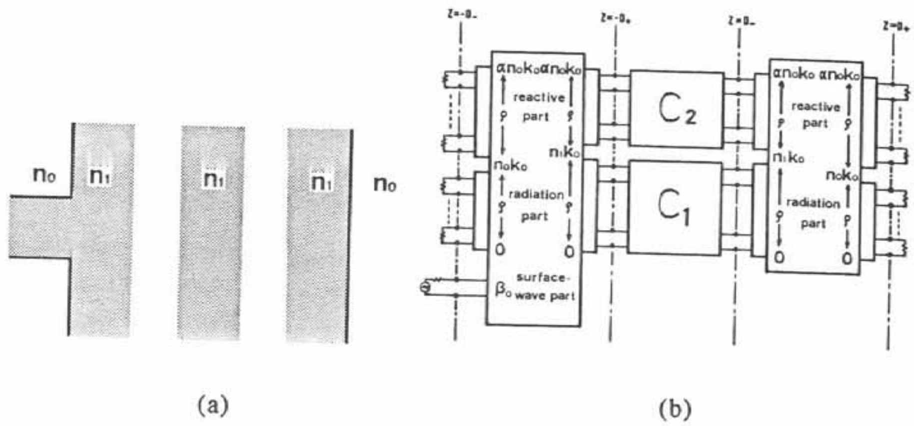

Fig.2. (a)Constitutive blocks of T-branch and (b) its equivalent networks. The large matrices express the discontinuity and the propagation of radiation wave is expressed by the matrices C_1 and C_2.

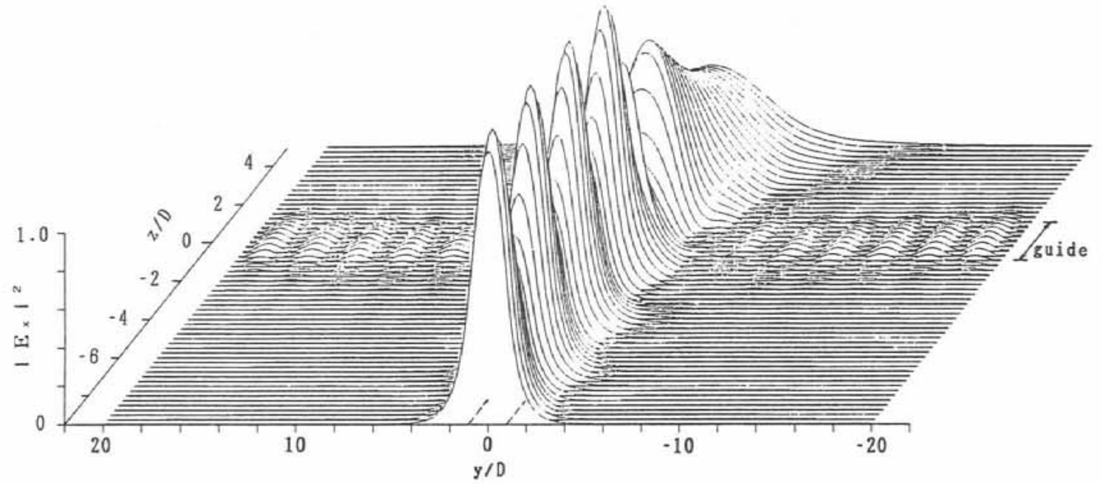

Fig.3. Field intensity distribution around the T-branch.

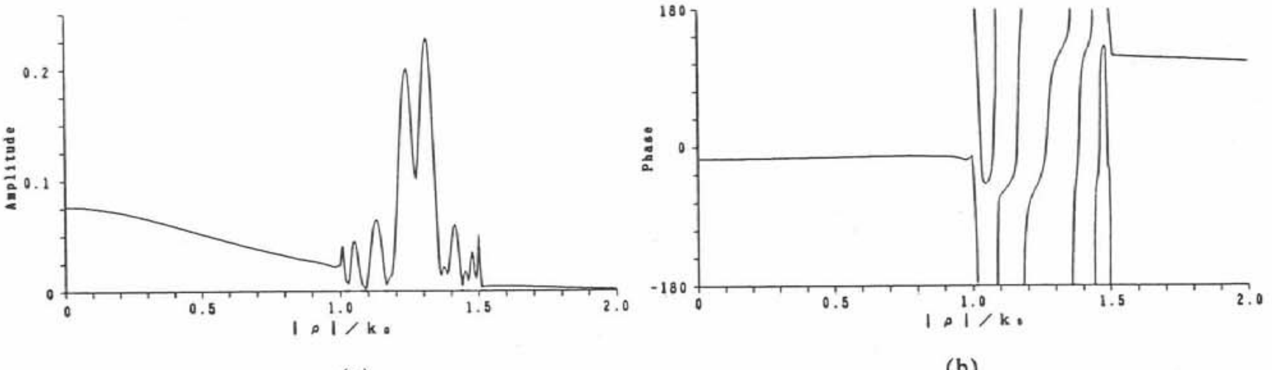

Fig.4. Amplitude and phase distributions of the spectral function ρ.

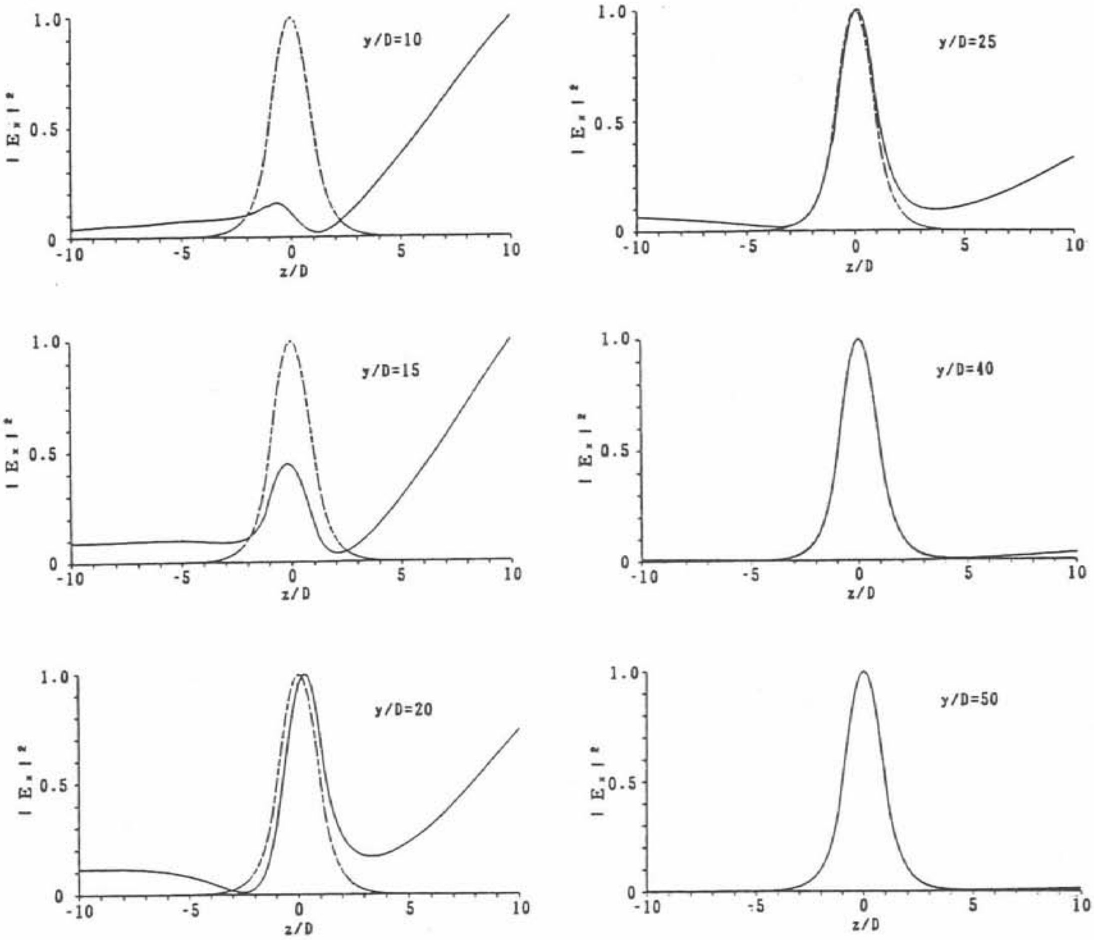

Fig.5. Field intensity distributions on the *xz* plane. The solid curves indicate the solution of the boundary value problem and the dashed ones indicate the modal fields of the TE_0 surface-wave modes.

Table 1. Reflected and divided power of T-branch for the surface-wave mode incident from the waveguide I or II.

(a) Incidence from waveguide I

Reflected power (I) Transmitted power (II or $\overline{\text{II}}$)	2.65% 2.28%
Total surface wave power	7.20%

(b) Incidence from waveguide II

Reflected power (II) Transmitted power (I) Transmitted power ($\overline{\text{II}}$)	0.06% 0.46% 90.8%
Total surface wave power	91.3%