An Efficient Analysis Approach for Inset Dielectric Guide (IDG) Structures and Its Variations

Zhewang Ma, Takahide Ishikawa, and Eikichi Yamashita, *Fellow IEEE*

***Abstract*— Based on a simplified analysis model of the inset dielectric guide (IDG), an efficient mode-matching approach is proposed for the accurate characterization of IDG structures. Formulations of the approach are easy to understand and to perform, and are proved to be accurate, fast convergent, and versatile by a variety of numerical examples.**

I. Introduction

THE INSET dielectric guide (IDG), illustrated in Fig. 1(a), is constituted by a dielectric filled groove on a ground plane. While it retains many of the advantages of dielectric waveguides, it alleviates the radiation loss at bends and corners. The IDG has been shown promise as a low loss transmission line for microwave and millimeter wave circuits and antennas [1]–[4].

Extensive studies on the IDG have been performed by T. Rozzi and his group, using the transverse resonance diffraction (TRD) method in the space domain [1]–[4]. In that approach, the fields in the groove and the upper open regions are expressed by discrete series and continuum integrals, respectively. After employing the boundary conditions, a set of integral equations are formulated. The integral equations are solved by choosing appropriate expansion basis functions and weight functions, which incorporate the field singularity behaviors at the 90 degree metal edges.

In this paper, an alternative mode-matching approach is investigated for accurate analysis of the propagation characteristics of IDG. The treatment is based on the following observation: Since the transmission power of IDG is confined primarily around the groove region, as has been shown previously [1], it is reasonable to consider that if lateral metal walls are placed at some distance away from the groove, as shown in Fig. 1(b), propagation characteristics of the guide will be affected little by the added walls. Then, the guide can be viewed as constituted by parallel-plate-waveguides with widths a and a', respectively, and the fields in both the groove the upper regions can be expanded by discrete parallel-plate-waveguide mode functions. Solving the scattering matrix of the parallel-plate-waveguide step-junction by using the conventional mode-matching procedure, which is well known and easy to perform [5], the characteristic equation of the guide is obtained readily [6].

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The authors are with The University of Electro-communications, Chofu-shi, Tokyo 182, Japan.

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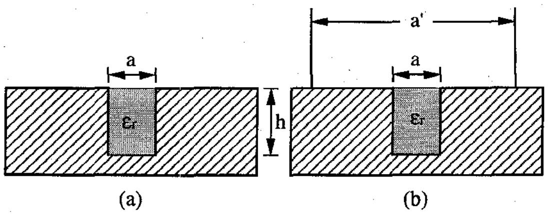

Fig. 1. (a) Cross-section of inset dielectric guide, and (b) the placement of metal sidewalls on an inset dielectric guide.

In the above process, the half open space is approximated by a parallel plate guide, and the formulation is thereby greatly simplified, compared with that of the TRD method. The TRD method is rigorous, and may provide better descriptions of the fields in the half open space and fields at the 90 degree metal edges. For the bound waves of the IDG, however, the present approach describes the essential nature of the fields, yielding the propagation characteristics with high accuracy.

The validity and efficiency of this approach is verified by numerical examples given in the next section. It is found that when the distance a' between the added walls are two or three times larger than that of the groove width a, the influence of the added walls on the solutions becomes negligible. The solutions converge rapidly with the number of mode functions used in the expansion series of the fields, and usually 5 or 10 mode functions in the groove region yield results that are within 1% of those by the TRD methods.

Moreover, the above stated formulations can be applied, with minor modifications, to a variety of IDG structures, including multilayered IDG, coupled IDG's and IDG with complicated groove profile, etc. This is demonstrated by numerical examples in the following section. Finally, it is worth noting that in the present mode-matching analysis, the corner metal edge conditions are satisfied provided that the number of modes in the parallel-plate-guides are determined according to a ratio of their widths, a'/a, and this phenomenon has been verified by many previous publications [5].

II. Numerical Examples

Fig. 2 illustrates the dispersion characteristics of the fundamental and higher order modes of an IDG calculated by the

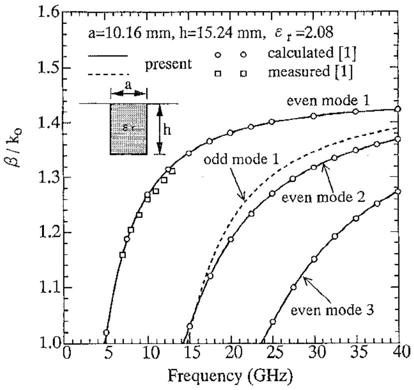

Fig. 2. A comparison between the calculated and measured dispersion characteristics of an IDG.

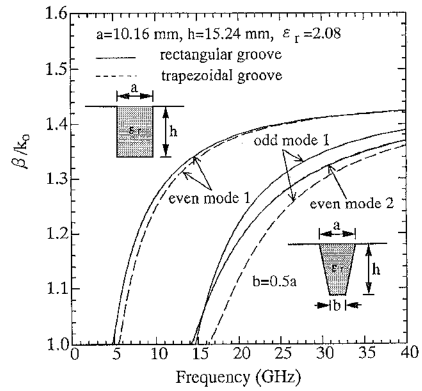

Fig. 3. A comparison of dispersion curves of the IDG's with rectangular and trapezoidal grooves.

TABLE I

CONVERGENCE BEHAVIOR OF SOLUTIONS FOR THE FUNDAMENTAL MODE ON AN IDG WITH PARAMETERS GIVEN BY THE INSET OF FIG. 2

Freq.	N=1	N=5	N=10	N=15	N=20	Ref. [1]	Measured [3]
7	169.617	170.287	170.312	170.317	170.318	170.941	170.056
8	201.514	202.173	202.190	202.204	202.205	202.546	202.008
9	233.290	233.906	233.931	233.936	233.937	234.139	232.297
10	264.990	265.544	265.568	265.572	265.574	265.683	264.138
11	296.633	297.117	297.140	297.144	297.146	297.178	293.914
12	328.225	328.638	328.659	328.663	328.664	328.671	325.806
13	359.764	360.108	360.128	360.131	360.133	360.158	357.388

proposed approach. The measured and calculated results by the TRD method [1] are also indicated, and excellent agreement is found. In Table I, the convergence behavior of solutions with the number of modes N in the groove region is shown, and it is amazing to find that only one mode in the groove region can yield results that are within 1% of those by the TRD method. This reveals that for the fundamental mode, the field of the LSE_0 [6] mode in the groove region is overwhelming.

In Fig. 3, the dispersion characteristics of IDG's with rectangular and trapezoidal grooves are compared. It is seen that while the dispersion curves of the first odd modes of the two guides deviate considerably, the curves of the fundamental modes and the higher even modes vary little. This suggests that the fundamental mode behaviors are not sensitive to the groove profile, therefore, the requirement on the fabrication tolerance of the groove is not strict. We note that in the computation, the trapezoidal groove is approximated by stair cases of 10 layers which give converged results.

A coupled IDG structure is illustrated by the inset of Fig. 4. The coupling coefficient between the guides is calculated by the expression, $Coupling = 20 \log\{\sin[0.5(\beta_{odd} - \beta_{even})L]\}$, where β_{odd} and β_{even} are the propagation constants of the odd and even modes, respectively, and L is the longitudinal length of the coupled IDG's. The measured results of [3] are also illustrated in Fig. 4, and the agreement is found to be favorable too.

III. CONCLUSION

An efficient mode-matching approach is proposed for the analysis of IDG structures, and its accuracy and versatility are justified by a number of numerical examples. Results on a trapezoidal IDG reveal that the requirement of the fabrication tolerance on the groove profile is not critical, and this is of particular importance when the IDG is used at shorter millimeter wavelengths.

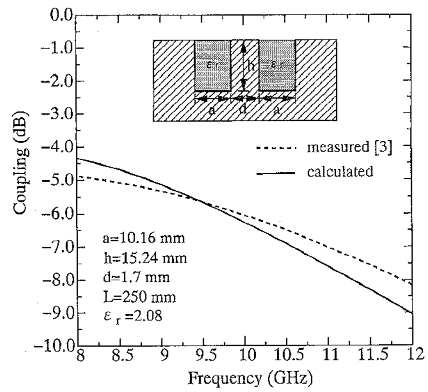

Fig. 4. Calculated and measured coupling characteristics of 250-mm-long coupled IDG's section.

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