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WAVE-GUIDING CHARACTERISTICS OF PARTIALLY CORRUGATED DIELECTRIC WAVEGUIDES

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ABSTRACT

The behavior due to a finite length of periodically corrugated dielectric waveguide is analyzed under the conditions that the TE and TM modes must couple to each other. Excellent agreements between calculated and experimental results are shown not only for the reflected and transmitted powers, but also for the dispersion curves.

INTRODUCTION

A dielectric waveguide with finite corrugation in its length is investigated analytically and experimentally, in case of surface waves propagating at an angle to the corrugation. In analytical considerations, a partially corrugated guide is regarded as consisting of many step discontinuities connected by a length of uniform slab waveguide as shown in Fig.1, and its propagation characteristics in the Bragg interaction region are derived from a cascaded connection of the transmission matrix expressing a step discontinuity[1].

THEORY

For this purpose, it is necessary first to analyze a step discontinuity problem in which the surface wave mode is obliquely incident onto it[2]. The discontinuity that we are concerned with here, has an abrupt change in the waveguide height as shown in Fig.2. When a corrugation is operated in the stopbands corresponding to Bragg reflection, the structure of practical components may be chosen so that the unwanted radiation from such a discontinuity may become small. Then, taking only the lowest TE and TM surface wave modes into account, let us analyze the boundary value problem at the step discontinuity plane by a most simple impedance junction approximation.
As a result, by considering the four cases of surface wave incidence to a discontinuity plane shown in Fig.2, that is, the TE mode incidence from the guide 1 and so on, the step discontinuity can be represented by a transmission matrix with 4x4 elements.

As shown in Fig.1, a periodic rectangular corrugation on the surface of a dielectric slab may be viewed as consisting of many step discontinuities connected by a length of uniform slab waveguide.
Denoting the transmission matrices of nth discontinuity and nth uniform slab guide by T_n and $T_{l.n}$, respectively, one can define a unit cell of a building block constructed by $T^n_{unit} = T_{2n-1} \cdot T_{l.2n-1} \cdot T_{2n} \cdot T_{l.2n}$ shown in Fig.1.
Then the transmission matrix T_{total} for the partially corrugated waveguide consisting of Nc unit cells can be given as follows;

$$T_{total} = \prod_{n=1}^{Nc} T^n_{unit} \qquad (1)$$

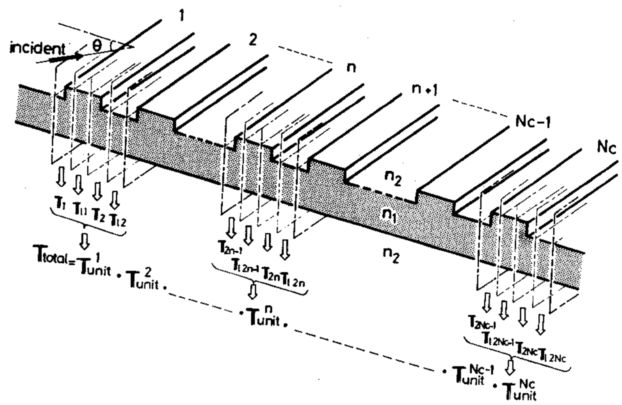


Fig.1. Dielectric slab waveguide with partial corrugation. T^n_{unit} means the transmission matrix of nth unit cell and the finite corrugation in its length is expressed by the cascaded connection of it.

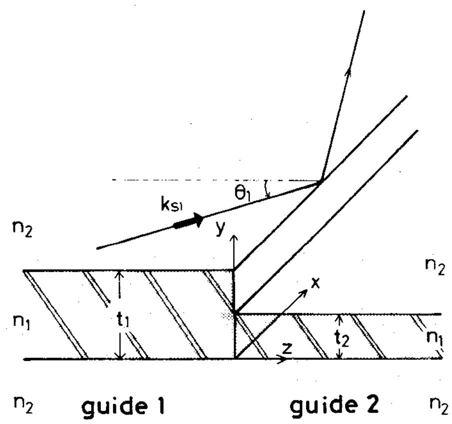


Fig.2. Pictorial representation of the step discontinuity in a dielectric slab waveguide, where a surface wave mode is incident obliquely to the step at an angle θ.

H-GUIDE WITH THE PARTIAL CORRUGATION

The above discussions can be applied to a more practical structure, e.g., the partially corrugated H-guide shown in Fig.3. For this structure, it is sufficient to take only TEy$_{11}$ and TMy$_{11}$ modes ** into account in the analysis. If the matal wall separation of the H-guide is properly chosen, each building block with uniform thickness t_1 and t_2 can support these modes only. In this case, the wavenumber in the z direction is fixed to π/a for these modes.

** TEy$_{pq}$ (TMy$_{pq}$) mode denotes TE (TM) mode with respect to the y direction and the subscript p relates to $p\pi/a$, while q indicates the number of extrema of Ey (Hy) component in the y direction.

This situation can be identified with the oblique incidence of the surface wave to the discontinuity at the angle given by $\theta = \sin^{-1}(\pi/a)$ in Fig.2.

On the other hand, if the Floquet's theorem is applied to a unit cell matrix T^{n}_{unit}, the characteristics of an infinite periodic corrugation can be obtained by solving the following eigenvalue equation;

$$| T^{n}_{unit} - exp(-\Gamma d)\cdot I | = 0 \quad , \qquad (2)$$

where $\Gamma = \alpha + j\beta$ means the propagation constant, d indicates the period of corrugation, and I means the unit matrix.
Fig.4 shows a portion of the dispersion curve calculated for the H-guide with the infinite periodic corrugation. It is seen that four stopbands appear here, one due to TEy_{11} - TEy_{11} coulping, another due to TMy_{11}-TMy_{11} coupling and two others due to coupling between TEy_{11} and TMy_{11} modes. Our result shown by the solid curves agrees well with the result calculated by Peng's method [3] indicated by dots.

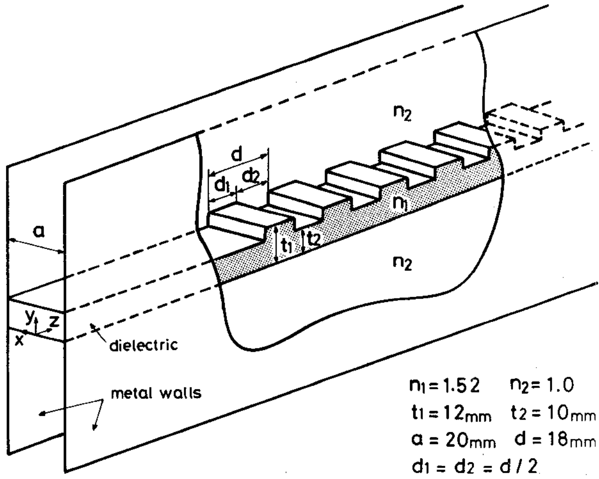


Fig.3. H-guide with the partial corrugation.

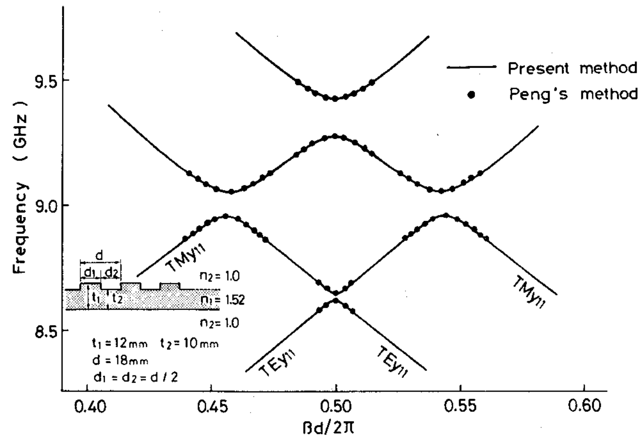


Fig.4. Dispersion characteristics of the H-guide with infinite periodic corrugation in the Bragg interaction region.

EXPERIMENTS

Now let us show the experiments of the H-guide with the partial corrugation. Fig.5(*a*) shows the characteristics of transmitted power of the incident TMy_{11} mode in case of Nc = 20 and 40, where the solid curves indicate the measured values and the dashed curves indicate the theoretical ones.
On the other hand, Fig.5(*b*) shows the characteristics of relative power of the reflected TMy_{11} and TEy_{11} modes in case of Nc = 40. It is obvious from these results that the measured stopband around 9.01 GHz is caused by the TMy_{11}-TEy_{11} modes coupling, while that around 9.35 GHz is caused by the TMy_{11}-TMy_{11} modes coupling.

Fig.6(*a*) and (*b*) show the measured phase constants of the TMy_{11} mode in the TMy_{11}-TMy_{11} coupling region and in the TMy_{11}-TEy_{11} coupling region, respectively, in case of Nc = 40. The measured values for the finite periodic case show the fairly good agreements with the solid curves calculated by the present method and are found to be different from the dispersion curves for the infinite periodic case indicated by the dashed curves.

From these figures, all of these cases show the good agreements between the theoretical and the experimental values. Small discrepancies may be caused by the influence due to the neglected radiation field.

ANALYSIS OF THE CHIRPED CORRUGATION

The present method may exhibit its straightforward nature in the calculations when a corrugated structure becomes an aperiodic one. An example of such structures is a chirped corrugation. Fig.7 shows the calculated results for an H-guide with the chirped corrugation, where the characteristics are calculated for the TEy_{01} mode which can be identified with the normal incidence to the discontinuity and never couple to other modes. For this example, the average period of the corrugation with Nc = 100 is assumed to be 14.2mm.
The solid curve shows the transmission characteristic of the partially corrugated H-guide with the uniform period of 14.2mm, while the others show the results for the guide having the chirped corrugation with the varying range of Δ = 1.5mm and Δ = 2.0mm in its period. Although experimental investigations remain for this example, these calculated results will be physically understood to be reasonable.

CONCLUSIONS

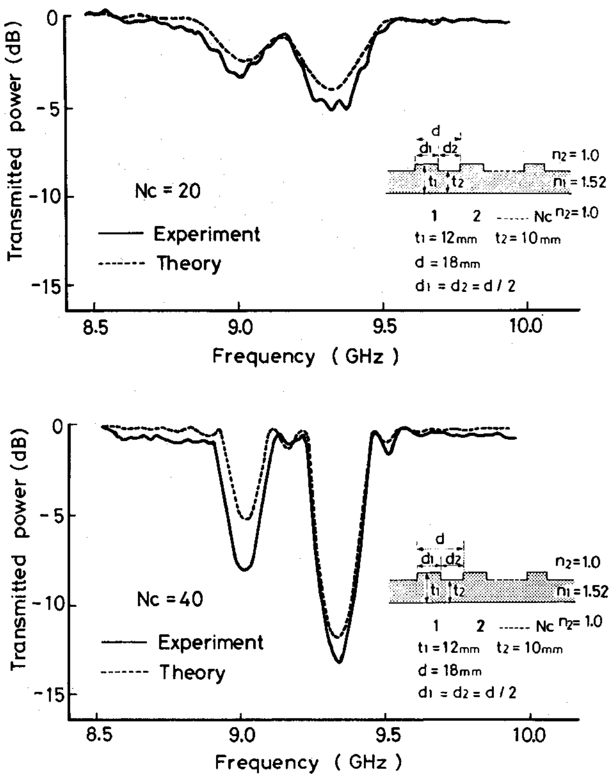
The present method will become one of straightforward and effective method for investigating the propagation characteristics of an open dielectric waveguide with partial corrugation in its length.

REFERENCES

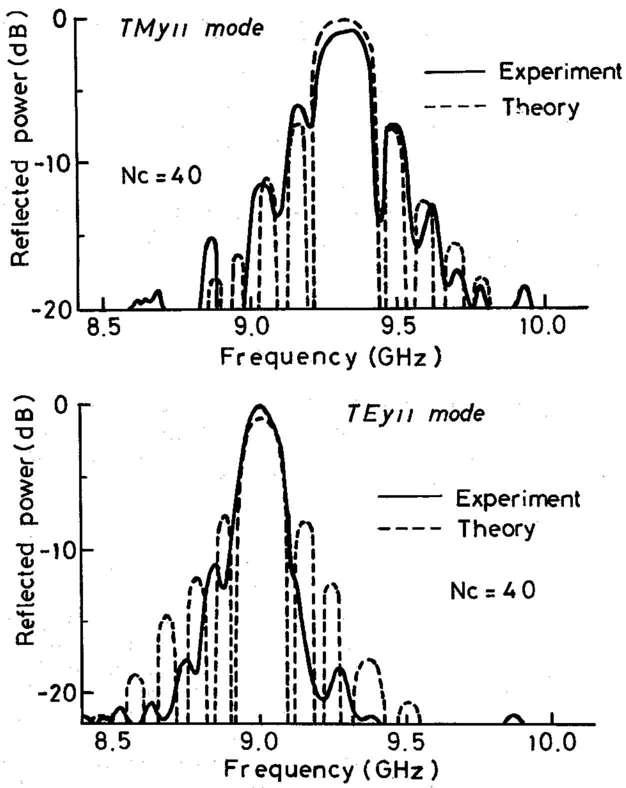
[1] M.Tsuji,S.Matsumoto,H.Shigesawa,and K.Takiyama, "Guided-wave experiments with dielectric waveguides having finite periodic corrugation," IEEE Trans.Microwave Theory Tech.,vol.31,Apr.1983.

[2] S.T.Peng and A.A.Oliner,"Guidance and leakage properties of a class of open dielectric waveguide:part 1 - Mathematical formulations," IEEE Trans.Microwave Theory Tech.,vol.MTT-29, pp.843-855, Sept.1981.

[3] S.T.Peng,T.Tamir,and H.L.Bertoni,"Theory of periodic dielectric waveguides," IEEE Trans. Microwave Theory Tech., vol.MTT-23,pp.123-133, Jan.1975.



(a)



(b)

Fig.5. (a) shows the measured transmission characteristics of the TMy*11* mode in case of Nc = 20 and 40 and (b) shows the characteristics of reflected TMy*11* and TEy*11* modes in case of Nc = 40.

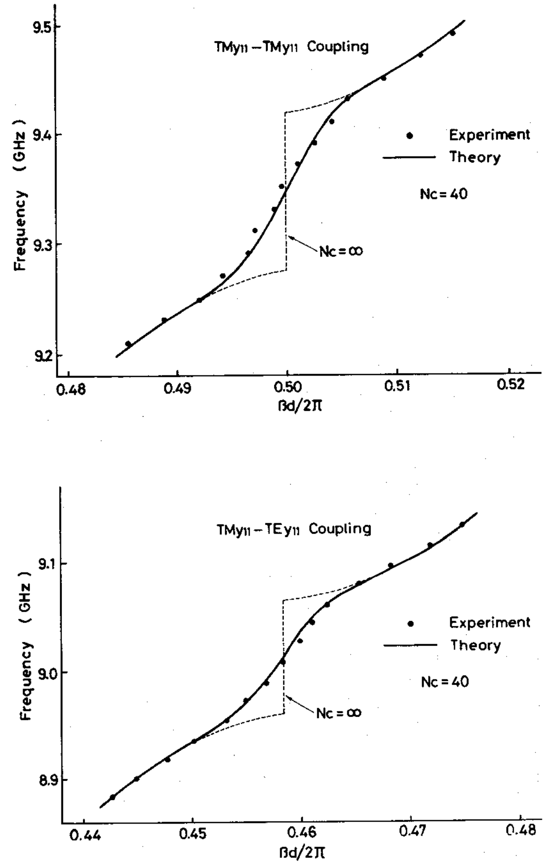


Fig.6. Measured phase constants of the TMy*11* mode in the TMy*11*-TMy*11* coupling region and TMy*11*-TEy*11* coupling region in case of Nc = 40.

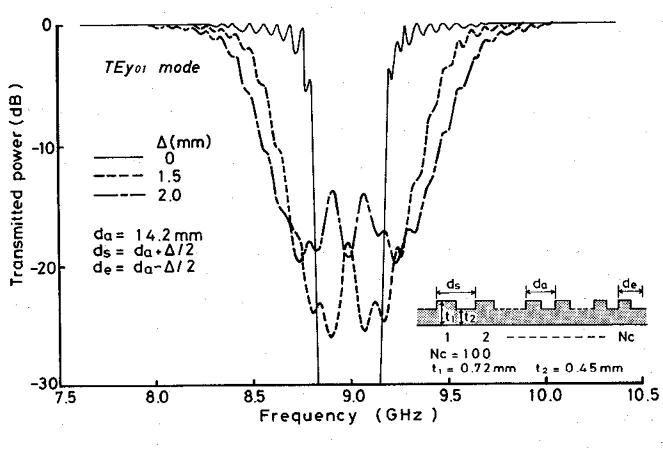


Fig.7. Calculated results for an H-guide with the chirped corrugation operated by the TEy*01* mode.