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MUTUAL INTERFERENCE BETWEEN THE GUIDED WAVE AND THE LEAKY WAVE REGIONS AND ITS EFFECTS ON THE PERFORMANCE OF DIELECTRIC GRATING FILTERS

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ABSTRACT

In an open periodic structure with finite length, a new interaction between the guided-wave and the leaky-wave regions in the ω-β diagram does occur. The effect of such an interaction on the characteristics is investigated rigorously by using our network approach already proposed [1]. Numerical calculations show that the finite length of periodic structures significantly affects the stopband characteristics of the first Bragg reflection region, especially in producing a complicated behavior of the return loss due to radiation. This paper also shows that such a return loss behavior can be easily estimated from the radiation characteristics of only the first step discontinuity of the periodic structure.

INTRODUCTION

The periodic corrugations placed on top of dielectric waveguides are widely applied to various components in the millimeter-wave and optical-wave regions, by employing the Bragg reflection and the leaky-wave phenomena. In a periodic structure with infinite length, the guided-wave region where the Bragg reflection occurs, is non radiative in spite of its open nature, so that components such as filters and resonators based on the design approach in terms of the infinite periodic structure have been proposed. However, if the length of such a structure becomes finite as seen in practical components, the mutual interference between the guided-wave and the leaky-wave regions does occur, so that the radiation always exists even in the stopband corresponding to the Bragg reflection. The influence of such a radiation which has significant effects on practical component design, has not yet been clear because of no effective analytical method for this problem. So the present authors have proposed the unprecedented network approach to solve it [1],[2]. Our approach regards the finite periodic structure as a cascade of the step discontinuities and the uniform guides, and derives its characteristics from the accurate network representation which considers the wave with the continuous spectrum discretized by the Legendre transform, together with the surface wave.

In this paper, we apply our network approach to periodic structures with various step discontinuities and investigate the behavior of radiation wave in the stopband region, which sometimes contributes significantly to the performance of the circuit components.

ANALYSIS

We briefly describe our network approach. It is necessary first to analyze a step discontinuity problem. In order to make the discussions clear, the even type TE-mode excitation of a symmetric step is considered in Fig.1, where the structure is uniform in the y direction. The extension to asymmetric steps or to the TM case presents no difficulty. In the analysis of open waveguides, one always encounters a big difficulty: how to discretize the continuous spectrum which does not extend in the whole range of spectrum, but in a limited narrow range of it in case of usual discontinuities, so that the well-known Lagguere transform [3],[4] is not always effective, especially from the view point of numerical convergence and also cost performance.

To circumvent this difficulty, our approach [5],[6] already discussed successfully for several kinds of step discontinuity problem divides the continuous spectrum into three ranges; one corresponds to the radiation part, the second is an optimally scaled extent of the reactive part, and the third, disregarded here, is the rest of the reactive part. Then, we have only to discretize independently the spectrum in each range by means of the Legendre transform to which the normalized Legendre functions provide the complete set of basis functions in each range.

This approach is quite adaptive to arbitrary distributions of the continuous spectrum and is extremely cost effective yet accurate. Such a discretization makes it possible to derive the equivalent network including radiation phenomena for a junction plane of both guides as shown in Fig.2. In this network, we have the terminal ports corresponding to the radiation part and to the reactive part of the continuous spectrum, together with the ports corresponding to the surface waves. It should be noted here that the definition of terminal ports of the continuous spectrum is different from that of surface-wave ports, that is, each port for the continuous spectrum does not correspond to a field distribution defined by an eigenvalue like the surface wave, but corresponds to a wave group consisting of a continuous spectrum expressed by one of Legendre functions.

Next, let us consider the interaction with the neighboring discontinuities via uniform guide section. Along such a uniform guide, the discrete surface-wave mode can propagate without coupling each other, and the guide can be expressed by a finite number of uncoupled transmission lines. On the other hand, the functional form of the

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continuous spectrum part changes as the wave radiates from the discontinuity in both forward and backward directions. This radiation phenomenon, if it is viewed from our spectral domain approach of Fig.2, is understood as that the complex amplitude of a wave group expressed by a Legendre function changes continuously along the uniform guide. This change in functional form means that a wave group characterized by a Legendre function continuously couples with other wave groups associated with different Legendre functions. As a result, the equivalent transmission line representation same with that for surface-wave modes makes no sense for the continuous spectrum ports and it is necessary to introduce the equivalent circuits R_1 and R_2 to express a uniform guide section as shown in Fig.3. It is easy to obtain the circuit parameters of R_i by calculating the complex amplitude of each Legendre function at the right (the left) terminal plane of R_i when a group with kth Legendre function is inputted from the left (the right) side of R_i . The model shown in Fig.3 is amenable to ordinary microwave network approach, and the periodic structures with a finite length can be easily analyzed by the cascaded connection of such networks.

NUMERICAL RESULTS

We here concentrates on the effect of the geometric variation of the periodic structures on the characteristics. To make comparison easy, the geometry of such structures is chosen so that the Bragg reflection can occur at the almost same frequency even for different structures. To this end, we have only to consider a unit cell shown in Fig.4, where each guide has the phase constant $\beta_0+\Delta\beta$ and $\beta_0-\Delta\beta$ at the mid-stopband frequency, respectively. Then the average phase constant of the unit cell becomes approximately β_0 for the structures having the various values of $\Delta\beta$.

We assume here a condition of $\beta_0/k_0 = 1.2$, $d_1/d_2 = d/2$ and $n_1 = 1.5$ as shown in Fig.4 and each guide with thickness t_i ($i = 1,2$) can support only the dominant surface-wave mode. In Figs.5(a) and (b), the calculated results of the reflection power of the dominant TE surface-wave mode and the forward radiation power as well as the backward one are indicated for $\Delta\beta/k_0 = 0.04$ ($t_1/t_2 = 1.46$) and $\Delta\beta/k_0 = 0.12$ ($t_1/t_2 = 3.44$), respectively. The results are shown for different number of unit cells Nc (i.e. the length of periodic structure) as a function of the normalized period k_0d. It is found that the Bragg reflection occurs at around $k_0d = 1.3$ in both figures, and the structure with large step, that is, $\Delta\beta/k_0 = 0.12$ has broader stopband than that with small step, $\Delta\beta/k_0 = 0.04$. However, except the width of the stopband and the power level, it seems that the behavior of reflection and radiation characteristics in the stopband region is almost same. So we next pay attenuation to such characteristics for the various values of $\Delta\beta/k_0$ corresponding to thickness ratio of guides t_1/t_2. Fig.6 shows the mid-stopband attenuation for various Nc as a function of t_1/t_2. The attenuation becomes large as Nc and t_1/t_2 increase, and in the case of Fig.5(b), the mid-stopband attenuation attains about 30 dB for Nc = 20. However, it should be noted from Fig.5(b) that the forward and backward radiation powers in the stopband region are not so small that we may neglect it; the return loss of the surface-wave mode has as much as 0.5 dB. Figs.7(a) and (b) show the maximum forward and backward radiation powers within the stopband region. On the other hand, the dotted line in Fig.7(a) indicates the forward radiation power calculated for the isolated step discontinuity of Fig.1 when the surface wave is inputted from the -z direction. It is found from this figure that such a characteristic is quite similar with that indicated by the solid line. This fact gives us an insight that the forward radiation of the finite periodic structure strongly depends on the miss-matching of the impedances of both sides just at the input port, that is, the characteristic of the first step discontinuity of the periodic structure. The dotted line in Fig.7(b) also indicates the forward radiation by the isolated step in case of the wave incidence from another side (i.e. from the +z direction). This assumption is based on the behavior of the reflected wave at the mid-stopband frequency, because most of the incident power returns back to the input port or the first step at that frequency. This result also shows a good agreement with the solid line. Thus we may conclude that both forward and backward radiation powers in the periodic structure with finite length strongly depend on the radiation characteristics of its first step discontinuity even though Nc increases. This is an important problem for designing of the grating filters, antennas and so on.

To overcome this problem, it will be necessary that the input portion of the periodic structure is made non uniform with taper section. For such a structure, the published methods are not effective at all, but our approach can perform the analysis theoretically and such discussions will be included in the oral presentation.

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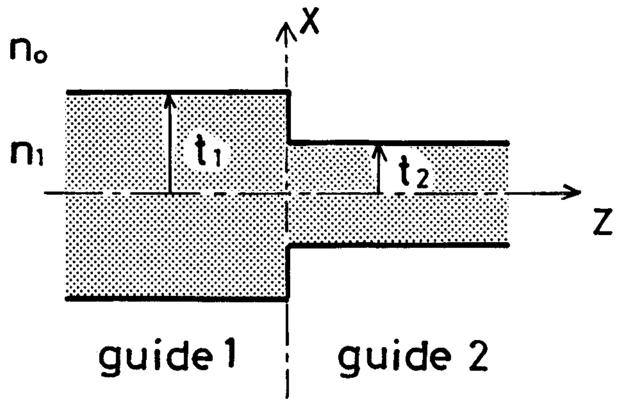


Fig.1. Planar dielectric step discontinuity, where even TE-mode incidence is considered.

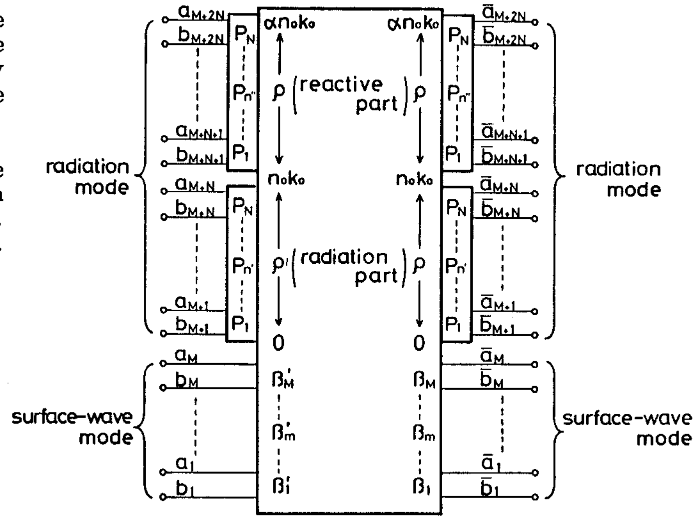


Fig.2. Equivalent network representation for the discontinuity shown in Fig.1, where the wave with continuous spectrum is regrouped discretely in terms of Legendre functions P_N. β_m and β_m' mean the eigenvalues of surface-wave modes, while ρ means the transverse wave number of continuous wave in the air region. α is an arbitrary constant larger than unity.

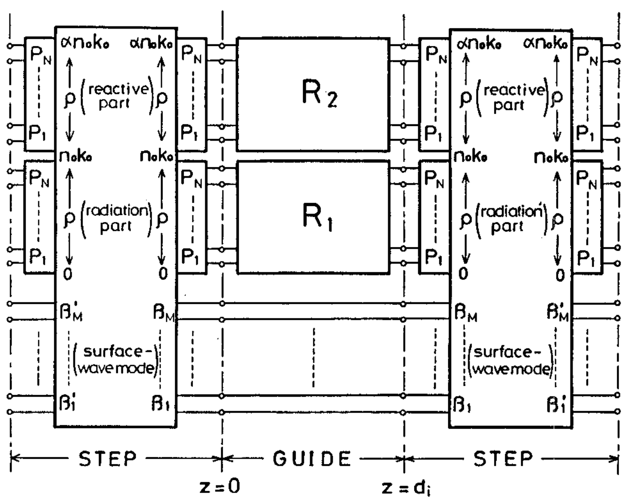


Fig.3. Equivalent network representation for a structure consisting of two step discontinuities connected with a uniform guide. The equivalent circuit R_i is necessary to express the coupling among wave groups characterized by Legendre functions.

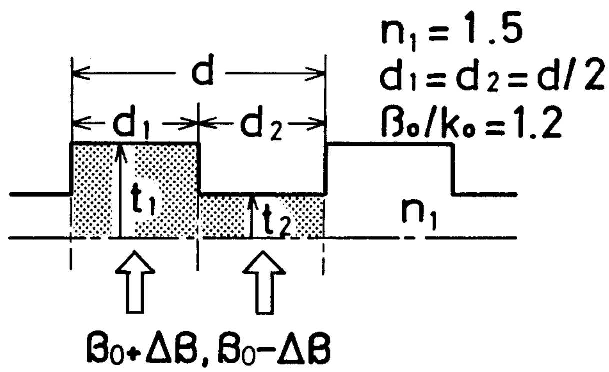
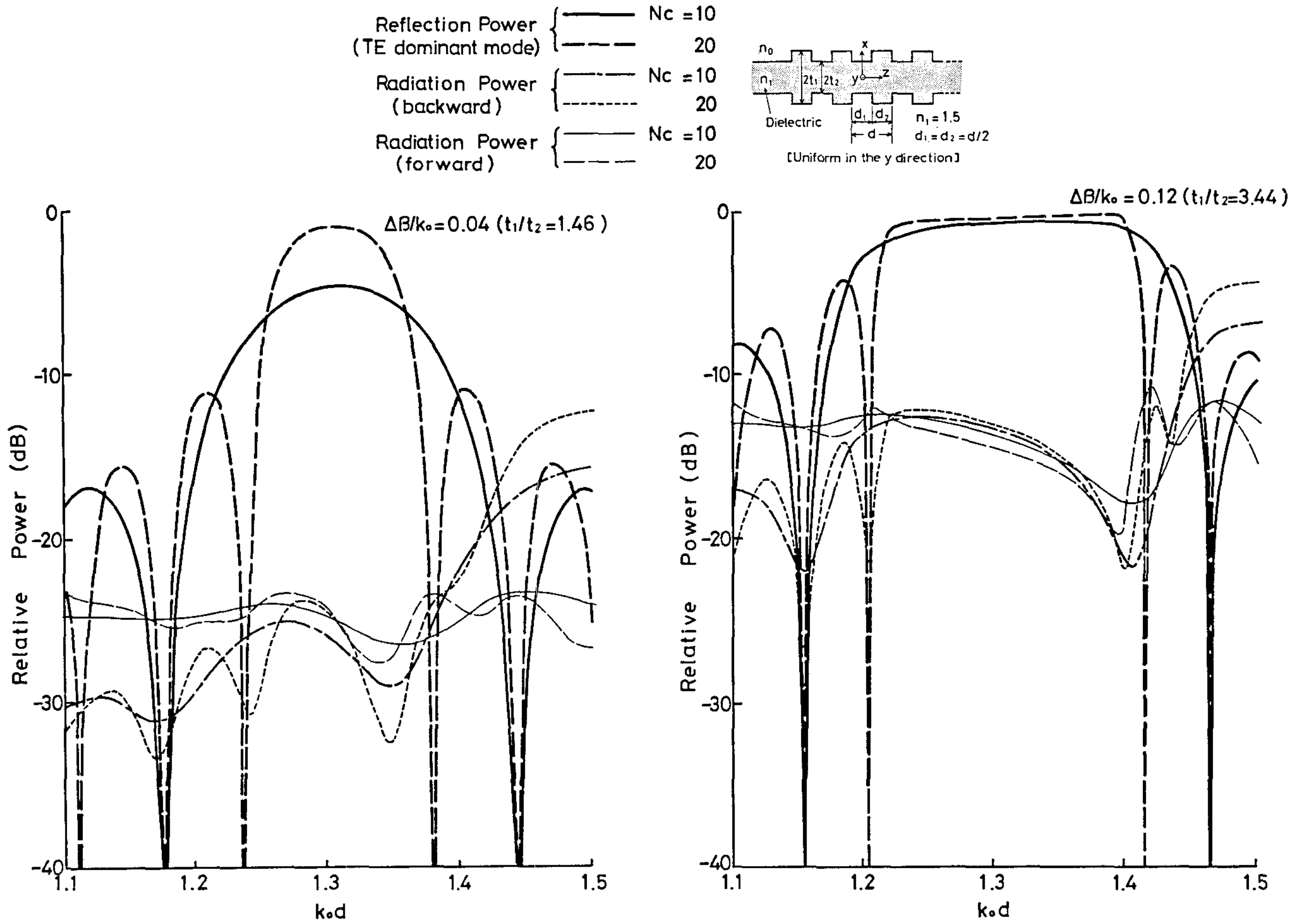


Fig.4. Unit cell composing the periodic structure. The guides with thickness t_1 and t_2 have the phase constants $\beta_0+\Delta\beta$ and $\beta_0-\Delta\beta$, respectively.



(a) (b)

Fig.5. Calculated reflection and radiation powers for a periodic structure with a finite length. (a) $\Delta\beta/k_0$ = 0.04, (b) $\Delta\beta/k_0$ = 0.12.

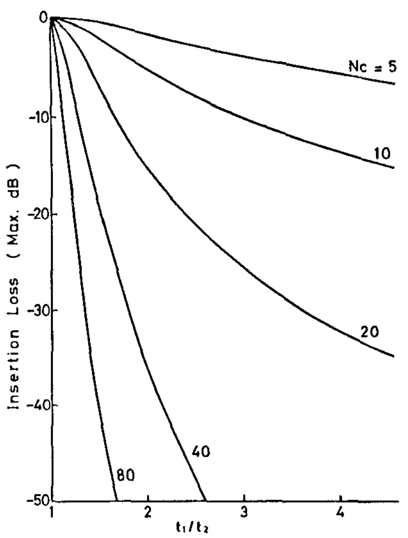
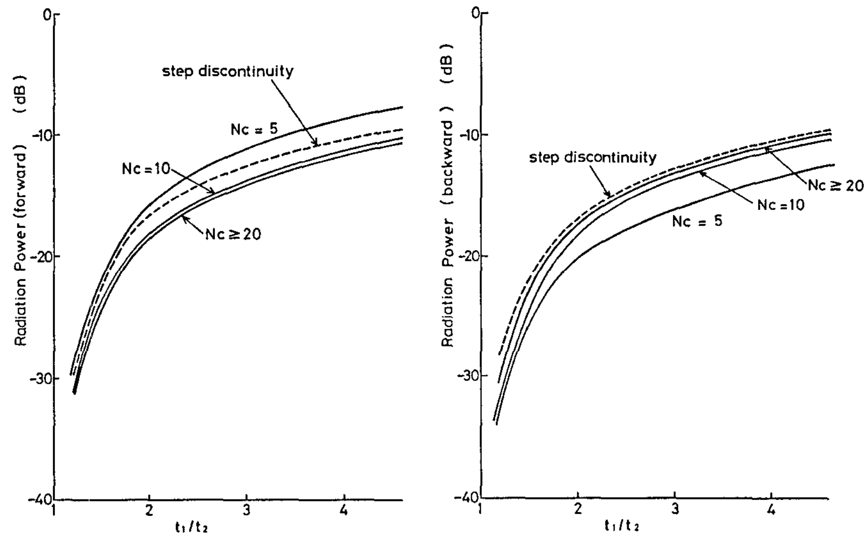


Fig.6. Mid-stopband attenuation for various numbers of unit cell Nc.



(a) (b)

Fig.7. Maximum (a) forward and (b) backward radiation powers within the stopband region for various numbers of unit cell Nc.