MICROWAVE NETWORK APPROACH TO DIELECTRIC PERIODIC LEAKY-WAVE ANTENNAS

H.Shigesawa, M.Tsuji and K.Takiyama

Department of Electronics, Doshisha University, Kyoto 602, Japan

ABSTRACT: A network approach is proposed for analyzing the interaction among discontinuities in open dielectric waveguides by taking account of the continuous spectrum accurately. This approach is followed to investigate the effect of finite length of periodic structures on the radiation patterns when a structure is used as a leaky wave antenna.

INTRODUCTION

The step in an open planar dielectric waveguide is a basic discontinuity in various optical and millimeter wave components. However, because of its open nature, unwanted radiation always occurs at the step. To minimize such a radiation, components such as filters and resonators based on periodic structures have been proposed, since large reflection combined with negligible radiation [1] can be expected in their stop bands, corresponding to Bragg reflection. On the other hand, in a different regime of operation, such periodic structures can be positively applied to leaky wave antennas, which positively make use of the radiation effect. If such a structure has a finite extent in its length, one must accurately analyze the interaction of the step discontinuities taking account of the continuous spectrum, as Rozzi et. al.[2] did. Their approach is attractive, but can not be available because of ineffective treatment of the continuous spectrum.

We present an effective method analyzing the interaction among step discontinuities by a Legendre transform of the continuous spectrum. This method is followed to discuss the finite periodic structure as leaky wave antennas.

ANALYSIS

We first analyze a step discontinuity problem. In order to minimize the details, even type TE-mode excitation of a symmetric step is considered as shown in Fig.1. The extension to symmetric steps and to the TM-case present no difficulty [3]. In the analysis of open waveguides, one always encounters a big difficulty, how to discretize the continuous spectrum which usually does not extend in the whole range of spectrum, but in a limited narrow range of it. The well-known Laguerre transform is always not effective to circumvent this difficulty. Our effective approach already discussed [3] 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. This approach is quite adaptive to arbitrary distribution of the continuous spectrum and 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, along with the ports corresponding to the surface waves. Emphasis is on that the definition of terminal ports of the continuous spectrum is perfectly different from that of surface-wave ports: a port of the continuous spectrum does not correspond to a field distribution given by a single eigenvalue like a surface-wave mode, but corresponds to that having the continuous spectrum characterized by one of Legendre functions.

It is important to note that the functional form of the continuous spectrum part changes as a wave propagates (or radiates) along the uniform guide. This results in the continuous change in the amplitude of each Legendre function 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 with different Legendre functions. As a result, it is necessary to introduce the equivalent circuits R_1 and R_2 for the continuous spectrum ports to express a uniform guide section as shown in Fig.3. In contrast, the discrete surface-wave mode can propagate without coupling each other, and the guide can be equivalently expressed by a finite number of uncoupled transmission lines. It is easy to obtain the circuit parameters of Ri by calculating the complex amplitude of each Legendre function at the right (the left) terminal plane of Ri when a wave group with kth Legendre function is inputted from the left (the right) side of Ri. The model shown in Fig.3 is amenable to ordinary microwave network approach, and the antenna characteristics of periodic structures with a finite length can be easily analyzed by the cascaded connection of such networks.

NUMERICAL RESULTS

Fig.4 shows an example of the calculated results. The dimensions of the structure are denoted in the inset of this figure. Each guide in the uniform sections can support only the dominant surface-wave mode. This figure shows the reflection power of the dominant TE surface-wave mode and also the radiation power (backward) for 10 and 20 corrugations as a function of the normalized period d/λ_0 (λ_0 is the wavelength in the free space). It is found that in the first Bragg reflection region at around $d/\lambda_0 = 0.42$, strong reflection occurs with negligible radiation, but in the higher frequency region at around $d/\lambda_0 = 0.45$, the influence of radiation is not negligible because of the effect of the finite length. It is believed that the discussions on such an influence are unprecedented to the best knowledge of the authors. The peak of radiation power at around $d/\lambda_0 = 0.84$ corresponds to the second Bragg reflection region. Fig.4 shows that the leaky wave region starts from about $d/\lambda_0 = 0.45$. Fig.5 shows the radiation patterns in cases of various number of corrugations, calculated at $d/\lambda_0 = 0.48$ by the steepest descent method. The effect of the finite length of the structure is, of course, significant in that the main lobe becomes narrow as the number of corrugations increases.

The idea mentioned above is available for developing a numerical design method of leaky wave antennas based on the periodic structure. Such discussions will be included in the oral presentation.

Acknowledgement: The authors are indebted to Professor A. A. Oliner of Polytechnic Institute of New York for his constant interest and encouragement in this work.

References

[1] H.Shigesawa et al., 1985 IEEE/MTT-S Inter'l Microwave Symp., June 1985.
[2] T.E.Rozzi et al., IEEE Trans. MTT, vol.MTT-27, pp.303-309, Apr. 1979.
[3] H.Shigesawa et al., 1984 IEEE/MTT-S Inter'l Microwave Symp., Digest, 5-3, pp.121-123, May 1984.

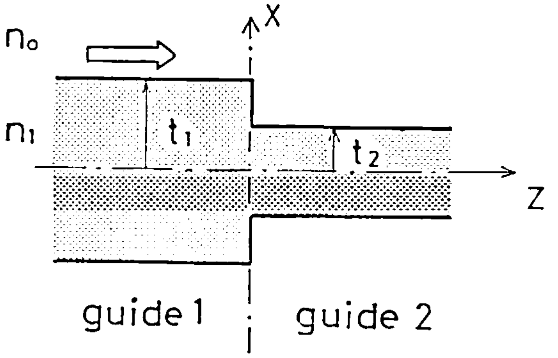

Fig.1. Planar dielectric step discontinuity, where even type TE-mode propagation considered.

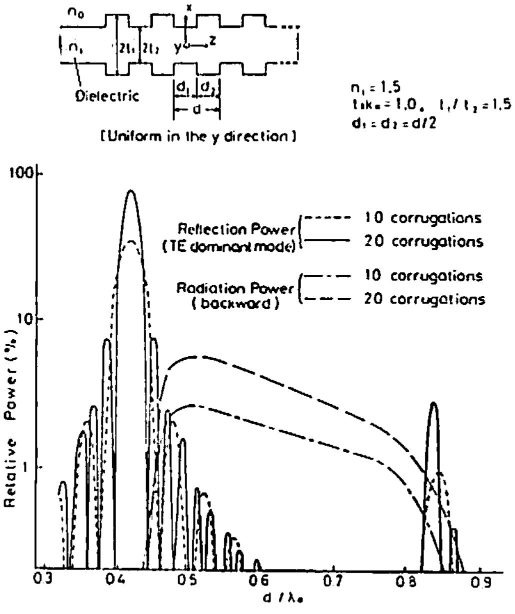

Fig.4 Example of calculated reflection and radiation powers for a periodic structure with a finite length.

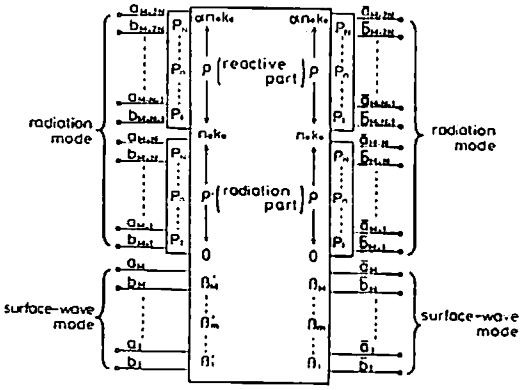

Fig.2. Equivalent network representation for the discontinuity shown in Fig.1, where the wave with continuous spectrum is discretely regrouped by means of the Legendre functions Pn. βm and βm' mean the eigenvalues of surface modes, while ρ means the transverse wave number of continuous wave in the air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

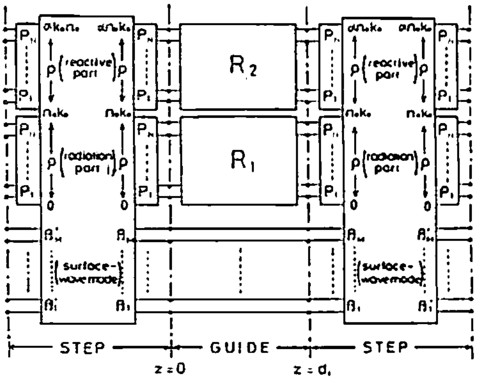

Fig.3. Equivalent network representation for a structure consisting of two step discontinuities connected with a uniform guide. The equivalent circuit Ri is necessary to express the coupling among wave groups characterized by Legendre functions.

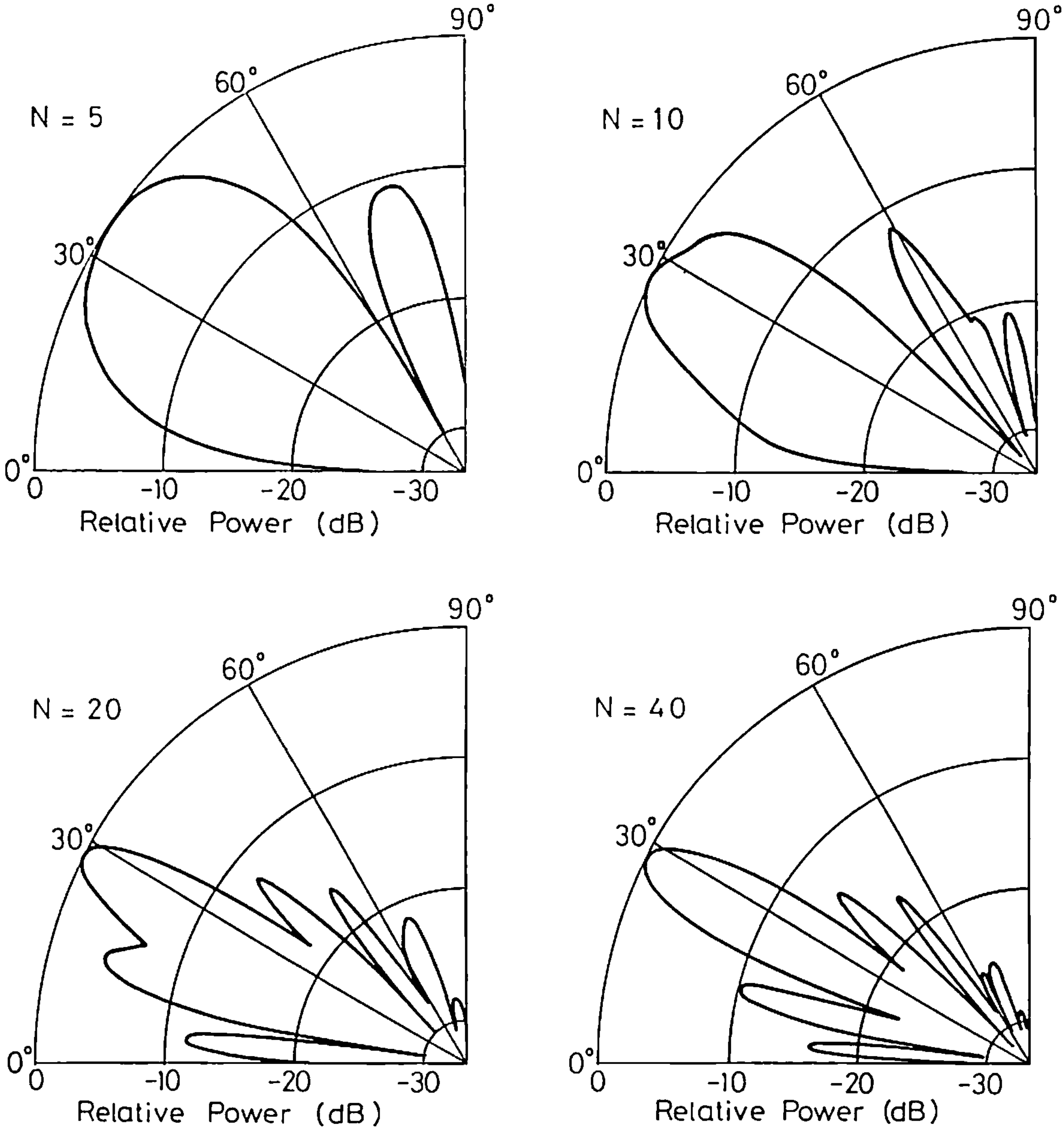

Fig.5. Example of calculated radiation patterns for various number N of corrugations.