ANALYSIS OF SCATTERING AND COUPLING PROBLEM OF DIRECTIONAL COUPLER FOR RECTANGULAR DIELECTRIC WAVEGUIDES

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Abstract:In this paper, scattering and coupling problems of the directional coupler for the dielectric rectangular waveguides are analyzed by the mode-matching method in the sense of least squares for the fundamental mode incidence.

1. INTRODUCTION

In optical waveguide used in integrated optics and light transmission circuit and so on, it is often desired to transfer optical power from one to another waveguide. Therefore dielectric rectangular waveguides[1-4] and directional couplers[2],[4] have been presented and studied enthusiastically.

In this paper, scattering and coupling problems of directional couplers for dielectric rectangular waveguides are analyzed by the mode-matching method in the sense of least squares for the fundamental mode incidence. This directional coupler is composed of three parallel waveguide cores with rectangular cross section which are placed at equal space in the dielectric medium. The central rectangular core among them has a periodic groove structure on two surfaces which face each other. In the central waveguide, the fundamental mode is incident from the perfect part toward the periodic structure of this waveguide. The power of the incident mode to the central waveguide is coupled to other two waveguides through periodic groove structure. When the Bragg condition is selected appropriately, the mode which is coupled to other waveguides propagates to the same or opposite direction for the direction of the incident mode.

In this analysis, we shall apply a mode-matching method in the sense of least squares[4-6]. Approximate wave functions of scattered fields in each region of the coupler are described by the Fourier transform with band-limited spectra. These approximate wave functions are determined in such way that the mean-square boundary residual is minimized. This method results in simultaneous integral equations of Fredholm type of the second kind for the unknown spectra. The results of analyses for coupling efficiency and scattered fields are presented on the basis of the first order approximate solutions of the integral equations in this paper.

2. FORMULATION OF THE PROBLEM AND ALGORITHM

The central waveguide core among them has a sinusoidal groove structure of finite extent on the both surfaces of y direction as shown by Fig.1. Fig.1(a) shows the overhead view of the coupler, Fig.1(b) shows the plane figure of it and Fig.1(c) shows the cross figure.

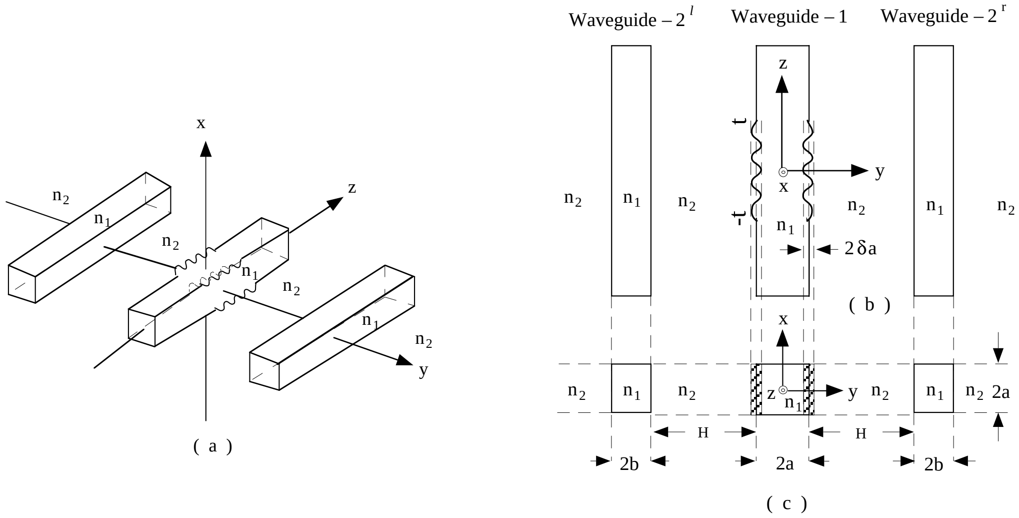

Fig.1 Geometry of directional coupler composed of rectangular dielectric waveguides.
(a) Over head view of the coupler. (b) Plane figure. (c) Cross figure.

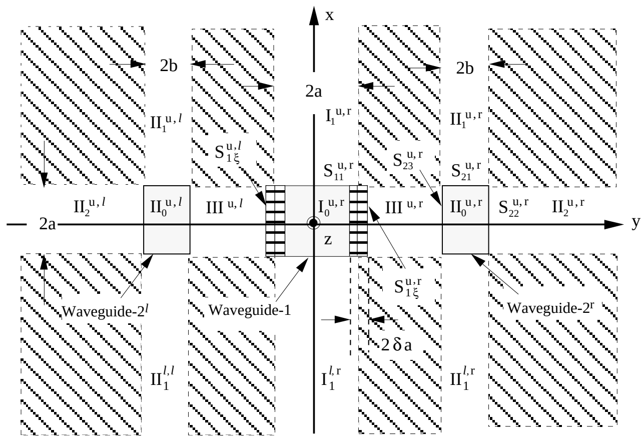

Fig.2 Cross section of directional coupler and its field distribution.

Three parallel waveguide cores with rectangular cross section are placed at equal space H in the dielectric medium. Fig.2 shows cross sections of this, coupler at z=0. The waveguide-1 has a periodic groove structure in the finite region ($|x|\le a, |z|\le t$) on surface of y direction of the core. The boundary surface $S^{u,r}_{1\xi}$ with sinusoidal grooves is giv-en as follows:

$$y=\xi(x,z)=\begin{cases} a+\delta a\,\eta(z)\ , & 0\le x\le a\,,\ |z|\le t \\ a\,, & 0\le x\le a\,,\ |z|>t \end{cases}\ ,\ (1)$$

$$\eta(z)=\cos\left(Kz\right),\ \ t=(N+\frac{1}{4})D\,,\ K=\frac{2\pi}{D}\,,\ (2)$$

and D is the spatial period in the z direction. N is an integer and it denotes the groove number. $2\delta a$ is a depth of the groove and δ is a perturbation parameter. $2t$ is the length of the periodic groove structure in the z direction.

In this paper, Marcatili’s field expression and approach is applied [2-4]. The incident wave to the perfect part of the waveguide-1 is assumed to be the fundamental mode. It is polarized in x direction. In Marcatili's approach, this fundamental mode has mainly E_x, E_z, H_y, and H_z components and H_x,E_y components are neglected. Marcatili's field expression will be valid only if the effect of the shaded areas of Fig.2 may be ignored. Moreover it is assumed that E_x component of this mode and its derivatives in x and y direction are continuous over the entire cross section[3-4]. It is defined that this mode is E_{11}^x mode and above-mentioned continuos conditions with regard to E_x component are boundary conditions in this paper. Scattered field are given by

$$\Psi_V(x,y,z) = \frac{1}{2\pi}\int_{-\infty}^{\infty} \psi_V(h)\,\phi_V(h,x,y)\exp\left(j\,h\,z\right)dh\,,\ (\,V = I_0,I_1,II_0,II_1,II_2,III;\ \ x,y,z \in V\,)\ \ .(3)$$

Both faces of the x direction of the central waveguide-1 and waveguide-2 are perfect. From boundary conditions on those faces, wave numbers of x direction, relations of spectra of regions I_0,$I_1$and II_0,II_1, II_2,III and $\phi_V(h,x,y)$ of all regions are derived to satisfy the boundary conditions. Therefore when spectra $\psi_V(h)$,$(\,V = I_0,III\,)$ are derived, spectra of other regions are obtained. Spectra $\psi_V(h)$,$(\,V = I_0,III\,)$, namely, approximate wave functions $\Psi_V(x,y,z)$, ,$(\,V = I_0,III\,)$ are such way that the mean-square boundary residual is minimized. This method results in simultaneous integral equations of Fredholm type of the second kind for the unknown spectra[4-6]. The results of analyses for coupling efficiency and scattered fields are presented on the basis of the first order approximate solutions of the integral equations in this paper.

3.RESULTS AND DISCUSSION

In Figs.3-4, PBW2 denotes as the normalized power of E_{11}^x mode of the waveguide-2r, which is coupled with the incident mode of the waveguide-1 through the periodic structure and the propagates to negative(backward) z direction. PBW1 is the normalized power of E_{11}^x mode in the waveguide-1 which is reflected by the periodic structure . PRAD is the sum of the normalized powers of radiation fields. PTW1 is the normalized power which is transmitted through periodic structure in the waveguide-1. In Fig.3, It is shown that two times PBW2 has maximum value nearby V=0.6 and its value is about 38%. Fig.4 shows that PBW2 decreases exponentially with increase of space between cores H.

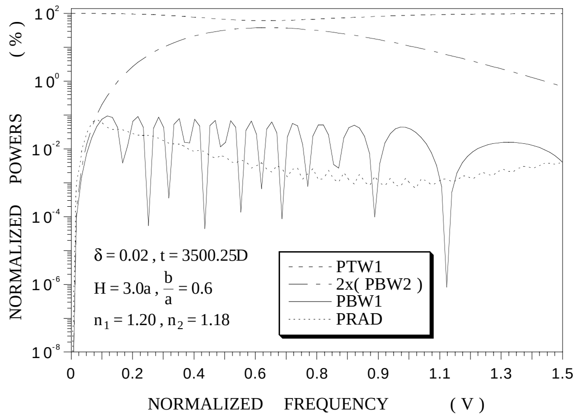

Fig.3 Normalized powers of directional coupler for rectangular waveguides shown by Fig.1 as a function of normalized frequency V under Bragg condition.

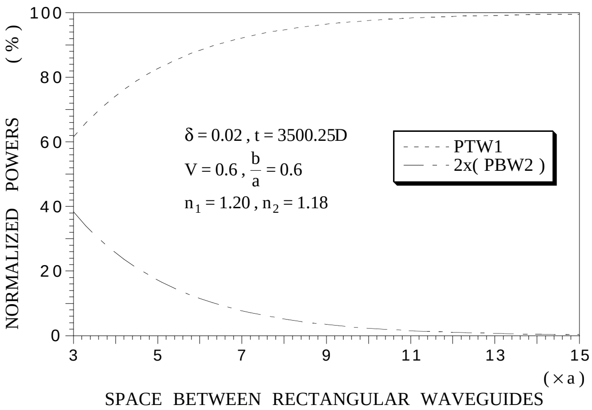

Fig.4 Normalized powers of directional coupler as a function of space between rectangular cores H under Bragg condition.

4. CONCLUSIONS

From results based on the first order approximate solution of the integral equation, it is considered that the structure presented in this paper has function of directional coupler for rectangular waveguides when the Bragg condition is applied appropriately. Moreover it is considered that results of analyses have good agreement with the physical consideration qualitatively.

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