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# A BEAM PROPAGATION ANALYSIS OF OPTICAL WAVEGUIDE BRANCHING STRUCTURES

Miloš Puchta
Institute of Radio Engineering and Electronics
Chaberská 57,182 51Prague 8, Czechoslovakia

## 1 Introduction

Waveguide components play the central role in many elements of integrated optics such as modulators and switches . Coupling and branching of optical signal are widely used in these structures. In the majority of waveguides a single mode regime is established by proper selection of structural and material properties. While the conditions that are required for the single mode regime are easily met in straight longitudinaly uniform structures, a more careful analysis is needed in the inhomogeneous ones. Generaly , any inhomogeneity is strongly connected with the introduction of the continuous spectra. At any abrupt waveguide transition, waveguide bend, branching structure, etc. the continuous part of mode spectra may be excited at the expense of optical signal. Efficient and accurate analysis of longitudinaly varying waveguides has an increasing importance. There is a spectrum of various numerical methods based on the fast Fourier transform (FFT-BPM) [1,2]. New results in finite difference (FD-BPM) methods point to better performance for longer longitudinal step in comparison with the classical FFT-BPM [3]. The problem of reflection of electromagnetic waves at the boundary has been solved by introduction of a transparent boundary condition [4]. Finite difference method [5,6] allow for the greater adaptability by applying inhogeneous sampling of the waveguide structure. For more complex structures the complete vectorial description is inevitable and new semivectotial and vectorial methods [7] were prepared.

## 2 Numerical analysis

Large variety of structures in integrared optics may be described by the slowly varying amplitude approximation (1) in the form of the scalar wave equation (2).

$$|2k_0 n_0 \frac{\partial E}{\partial z}| \gg |\frac{\partial^2 E}{\partial z^2}| \quad (1)$$

$$2jk_0 n_0 \frac{\partial E}{\partial z} = \frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial y^2} + k_0^2 [n^2(x,y,z) - n_0^2] \, E \quad (2)$$

where E is dominant field component, $n_0$ is the reference index of refraction and $k_0$ is wave number in vacuum. Spatial distribution of refractive index is n(x,y,z).

A FFT-BPM (3-6) is based on the exponential operator splitting that is equivalent to the decomposition into the propagation in the free space (operator $\mathcal{P}$) and the lens -like correction factor(operator $\mathcal{C}$).

$$E(z+\Delta z) = \mathcal{PCP}\ E(z) \tag{3}$$

$$\mathcal{P} = exp\,(-j\frac{\Delta z}{4k_0 n_0}\,\frac{\partial^2}{\partial x^2}) \tag{4}$$

$$\mathcal{C} = exp\,(-j\frac{k_0 n_0 \Delta z}{2}\,(\frac{n_{aver}^2}{n_0^2}-1)) \tag{5}$$

$$\frac{\partial^2}{\partial x^2} \rightarrow (\frac{2\pi}{L})^2 k^2 \tag{6}$$

where $n_{aver}$ is an averaged index of refraction on the longitudinal step $\Delta z$. While the FFT-BPM had been implemented with great efficiency in structures where the index of refraction is slowly varying function of spatial coordinates , in rib guide the longitudinal step for the same accuracy is several orders of magnitude lower.

Our numerical model of branching waveguide structures is based on the finite difference method (7-12).

$$\frac{\partial E}{\partial z} \rightarrow \frac{(E_i^m + E_i^{m+1})}{2\Delta z} \tag{7}$$

$$\frac{\partial^2 E}{\partial x^2} \rightarrow \frac{E_{i-1}^m - 2E_{i-1}^m + E_{i+1}^m}{\Delta x^2} \tag{8}$$

$$aE_{i-1}^{m+1} + bE_i^{m+1} + cE_{i+1}^{m+1} = eE_{i-1}^m + fE_i^m + gE_{i+1}^m \tag{9}$$

$$a = c = -e = -g = -\frac{\Delta z}{2\Delta x^2} \tag{10}$$

$$b = 2jk_0 n_0 + \frac{\Delta z}{\Delta x^2} - \frac{\Delta z k_0^2\ ((n_i^{m+1})^2 - n_0^2)}{2} \tag{11}$$

$$f = 2jk_0 n_0 - \frac{\Delta z}{\Delta x^2} + \frac{k_0^2 \Delta z\ ((n_i^m)^2 - n_0^2)}{2} \tag{12}$$

where $E_i^m$ is a sampled field intensity, lower index is equivalent to the transverse coordinate and the upper index describes the longitudinal behaviour. Equations (9-12) are solved by the tridiagonal solver on the PC486.

In any branching structure the optical wave propagation is strongly connected with the reshaping of the wavefront. The symbolic genesis of structure development is depicted on the first picture. The overlap of modes is infinitesimaly small in the first case and no energy transport takes place. The second structure is the subject of this work. The third limiting case is a modified waveguide bend. Obviously the overlap of modes in exciting and receiving waveguides decreases with increasing mutual angle of their axes and the contiuous spectrum is excited as is described on the second picture. In our approach a longitudinal separation between the waveguides is evaluated and local increase of effective index is taken into account. Aspects of detailed analysis will be the main subject of oral presentation.

# 3 Conclusion

A new structure for branching waveguide in asymmetric structures have been analyzed and the impact of inserted longitudinal slit and local increase of effective index are included in numerical model.

# References


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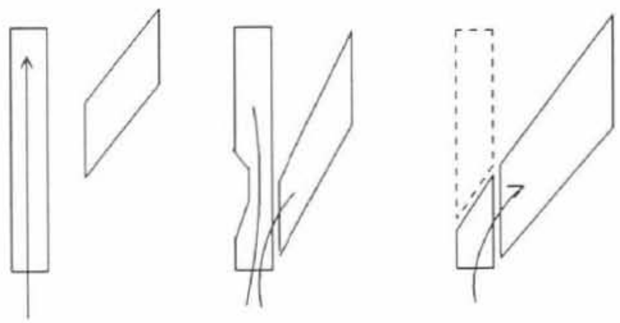
Fig. 1. Symbolic development of structure



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