A SIMPLE COUPLED-MODE ANALYSIS METHOD FOR MULTIPLE-CORE OPTICAL FIBER AND COUPLED DIELECTRIC WAVEGUIDE STRUCTURES

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ABSTRACT

A simple method is proposed for the coupled-mode analysis of multiple-core optical fiber and coupled dielectric waveguide structures. Total coupled-mode fields are approximately evaluated by using the field of two adjacent cores. The results of numerical calculation are compared with those of a rigorous analysis.

INTRODUCTION

Optical fibers with multiple-core structures are very important in the future application of the high-density optical transmission lines [1][2] and couplers. Useful coupled-mode theory is also required to investigate the characteristics of coupled dielectric waveguides for millimeter wave applications.

In this paper we present a simple coupled-mode analysis method for such structures in which the propagation characteristics of a dual-core fiber are examined to approximately estimate the total coupled-mode fields of multiple-core structures. This procedure corresponds to "Hückel's approximation" in the analysis of molecular orbitals governed by Schrödinger's equation and is applied to dielectric waveguide problems for the first time in this paper.

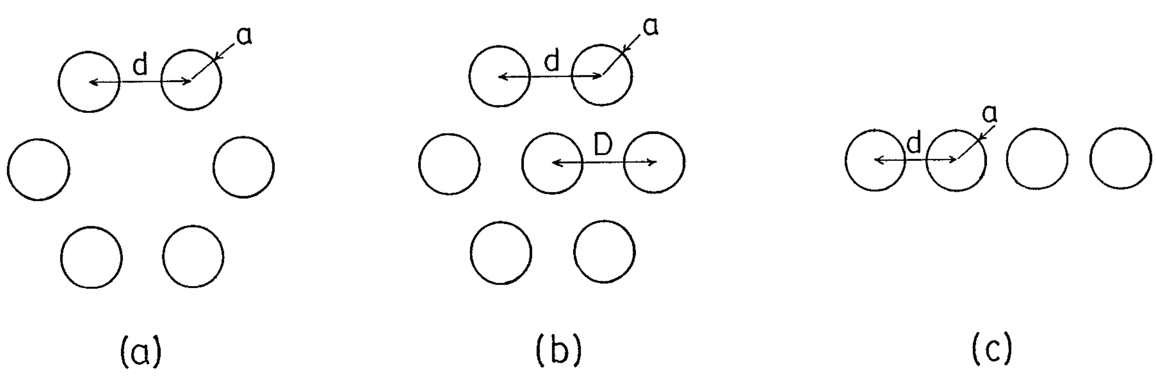

Fig.1. Several multiple-core structures to be considered in this analysis; (a) circularly distributed cores, (b) circularly distributed cores and a central core, and (c) linearly distributed cores.

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ANALYSIS METHOD

Fig.1 shows typical multiple-core structures, i,e., (a) circularly distributed n-cores, (b) circularly distributed n-cores and a central core, and (c) linearly distributed n-cores. The dimension D for the structure (b) is defined by $D=(d/2)/\sin(\pi/n)$. The structure (b) is examined in this paper.

Coupling coefficients between adjacent cores are described based on the differences of the propagation constants of a dual-core structure as shown in Fig.2 whose core separation equals to that of the adjacent two cores of a multiple-core structure. The coupling coefficients of the latter structure have been already analyzed rigorously by the authors [3][4].

The approximation method proposed in this paper is partly based on the conventional coupled-mode analysis and uses the coupled transmission line equations whose matrix elements are coupling coefficients. The coupling coefficients between the adjacent-cores are evaluated from the propagation constants of the even- and odd- modes of the dual-core structure considering the orientation of the transverse electric field vector. The coupling coefficients between the non-adjacent cores are assumed to be negligible.

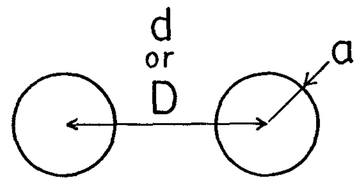

Fig.2 Dual-core Structure.

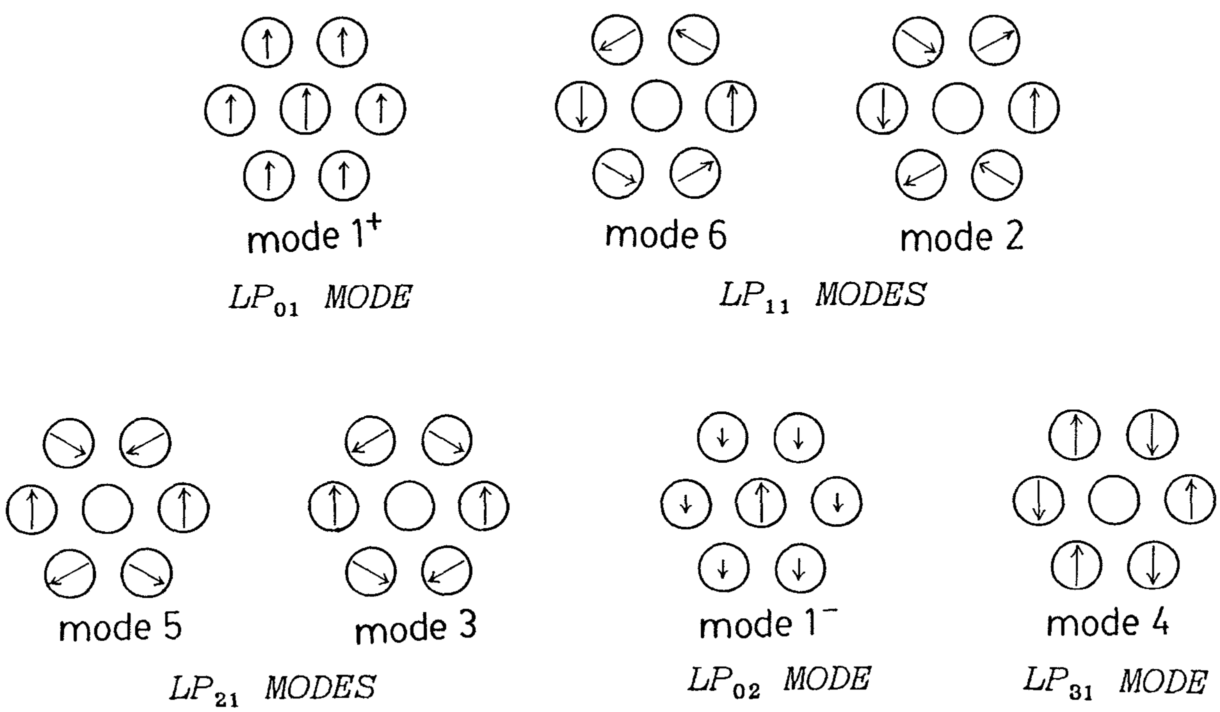

Fig.3. Simplified field patterns of a multiple-core structure calculated by using the present method.

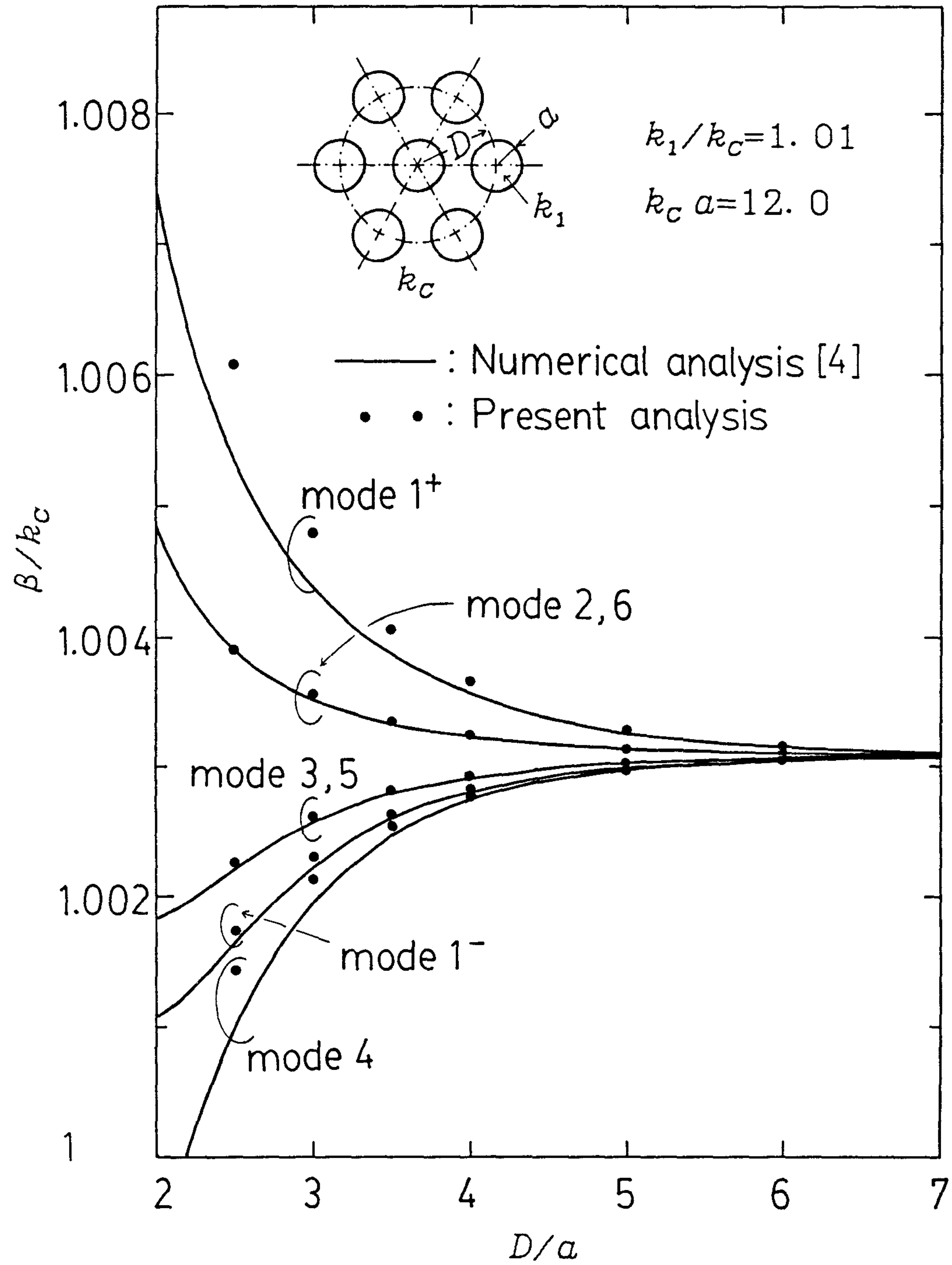

Fig.4. Comparison of the propagation constants obtained from the present method and a rigorous numerical analysis.

NUMERICAL RESULTS

As a result of the above analysis, the propagation constants of the coupled-modes of the structure (b) are given in the form

$$\beta^{(m)} = \begin{cases} \beta_0 + \frac{1}{2}\left\{\Delta\beta_s \pm \sqrt{(\Delta\beta_s)^2 + n(\Delta\beta_c)^2}\right\} & (m=1) \\ \beta_0 + \Delta\beta_s \cdot \cos\frac{2\pi(m-1)}{n} & (m \neq 1) \end{cases}, \quad (n \geq 3)$$

where m is the mode number, β_0 is the propagation constant of a single-core fiber, and $\Delta\beta_s$ and $\Delta\beta_c$ are the differences between the propagation constant of the even- and odd-modes for the core separation d and D, respectively.

The field patterns of this structure can be also drawn from the results of the present coupled-mode analysis. These patterns can be simply depicted from the superposition of fields of individual cores as shown in Fig.3. The state of degeneracy, the order of propagation modes, and the fields patterns can also be given from the present approximation method.

Fig.4 shows the comparison of the propagation constants obtained by this method and that by the past numerical analysis. As the separation between cores is decreased, the effect of coupling between non-adjacent cores naturally become strong and the accuracy of this approximation method is slightly reduced.

In conclusion, the present analysis method is an efficient and practical tool for the coupled-mode characterization of complicated multiple-core fiber structures and coupled dielectric waveguides as related structures.

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