PROPAGATION CHARACTERISTICS OF OPTICAL WAVEGUIDES : DEVELOPMENT OF EFFICIENT NUMERICAL TECHNIQUES

by

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Thesis submitted
in fulfilment of the requirements for
the degree of

DOCTOR OF PHILOSOPHY

DEPARTMENT OF PHYSICS
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
INDIA

September, 1989

CERTIFICATE

This is to certify that this thesis entitled PROPAGATION CHARACTERISTICS OF OPTICAL WAVEGUIDES: DEVELOPMENT OF EFFICIENT NUMERICAL TECHNIQUES by Swagata Banerjee is a record of bonafide research work carried out by her. She has worked under our guidance and supervision and has fulfilled the requirements, which to our knowledge has reached the requisite standard for the submission of this thesis. The results contained in this thesis have not been submitted in part or full to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

Most of the theoretical work in Fiber and Integrated Optics is based on the modal approach. The modal analysis, however, is applicable only to waveguides which are uniform in the direction of propagation. In many cases of interest this is not the case. Many of the coupling techniques that have been developed are based on waveguide tapering. Some slight tapering and other distortions can also be built into the fiber during the process of fabrication. Thus it is important to study the propagation of fields in waveguides nonuniform in the direction of propagation.

Coupled local mode equations have often been employed for the study of z-dependent structures. Local modes are close to the solutions of Maxwell's equations if the non-uniformity in the direction of propagation is relatively slow. For large non-uniformities, the solutions of Maxwell's equations are far from the local modes, which then carry no physical meaning. Further, for single mode waveguides one would have to consider coupling into radiation modes. Such an exercise would be extremely tedious. Hence the need of an accurate numerical method that is general enough to handle any kind of refractive index profile and z-dependence is keenly felt. The Propagating Beam Method (PBM) is one such method which has been used to study a variety of waveguide problems.

In the present thesis an alternative method has been presented for solving similar waveguide problems. The method that has been presented involves no inherent approximations and has been found to be numerically more powerful than the PBM. This has been shown explicitly in a number of cases. The method that has been presented has its starting point in the scalar Helmholtz equation. The orthogonal collocation method has been used to transform the scalar wave equation, which is a partial differential equation into a set of total differential equations. These differential equations can then be solved numerically using standard techniques such as the Runge—Kutta. The basis functions used for the waveguide problem in the present thesis are the Hermite Gauss functions in the planar case and the Laguerre Gauss functions in the case of optical fibers. These functions have been used for the first time in orthogonal collocation.

The present thesis includes a study of planar structures, using both the new method and PBM. Direct comparison shows that for a given accuracy the collocation based method requires much fewer sample points and much less computational effort as compared to PBM. The analysis has been extended to three dimensions. This follows as a natural consequence of the analysis in planar structures. Here a double linear expansion in terms of two sets of Hermite Gauss functions along the two transverse directions of the waveguide has been made for the total field. The degree of complexity introduced while going over from two to three dimensions is found to be of the same order as in the PBM. It has been shown with the help of numerical examples that our method is numerically superior to the PBM even in the case of three dimensional structures.

Next, the case of three-dimensional structures with circular symmetry has been considered. Optical fibers, and fiber based devices, come under this category. In a circularly symmetric structure, if modes of one type of azimuthal dependence are considered at a time, the propagation equation becomes two dimensional. In the collocation based propagation method, this advantage can be exploited using Laguerre-Gauss basis functions and therefore, the computational effort required is of the same order as required in the case of planar structures. On the other hand, in the Propagating Beam Method, one is always restricted to work in Cartesian coordinates and the cylindrical symmetry of the structure cannot be exploited.

For refractive index profiles with a discontinuity in the transverse cross-section, the results obtained using the collocation method show poor convergence. For such structures, the Galerkin method yields better results, but is much more time-consuming. However, for the case of tapers, with a suitable choice of basis functions, simplification is possible and the computational effort is greatly reduced. We have also presented this new approach in the thesis. Propagation of fields through uptapers has been studied using this approach.

The propagation of a pulse in a nonlinear dispersive medium is described by the nonlinear Schrodinger equation, which can be again solved using the collocation method. We have used the collocation method for the propagation of pulses in dispersive media in the presence of third and fifth order nonlinearity. The results have also been presented in the thesis.

Although the method presented in the thesis is aimed at studying the propagation of beams through z-dependent structures, it can be effectively used to obtain modes of uniform waveguides as well. The matrix differential equation in this case reduces to a matrix eigenvalue equation, which yields the propagation constants of the structure. The eigenvalue equation has been solved in a number of cases.

In the present thesis a new technique for the determination of chromatic dispersion has been presented. The analysis is based on the matrix perturbation theory. Treating the change in wavelength as perturbation and using perturbation theory upto second order, dispersion can be obtained easily and accurately. The above method has been used for the computation of dispersion and dispersion slopes in several cases of interest and has been found to yield accurate results.

ACKNOWLEDGEMENTS

This thesis owes its existence to Prof.A.K.Ghatak and Dr.Anurag Sharma whose constant encouragement and unfailing patience beyond the call of duty was much more than this student deserved.

I would like to thank Prof.I.C.Goyal, Dr.B.P.Pal, Dr. K. Thyagarajan, Dr.Arun Kumar and Dr.B.D.Gupta who have contributed to my understanding of fiber optics.

I am grateful to Dr. Ajit Kumar for his valuable suggestions in Non-linear Optics whenever I needed help.

I am thankful to my seniors Dr. Ramanand Tewari, Dr.M.R.Shenoy and Dr.R.K.Varshney on whom I have always relied for moral support and advice.

I would also like to thank Ravindra Sinha, Umesh Das, Vishnu Priye, Supriya Diggavi, Jacintha Kompella, Saeed Pilevar, Saeed Gadreli, Vergheese Paulose, P.C.Subramaniam, Pushpa Bindal, Vrinda Khurana, Anju Taneja, Sukhdev Roy and Ajay Dankar for their company and friendship through the best of times and the worst of times and without whose help the thesis would never have been submitted in time.

Finally I thank Sandipan Deb who also bore the burden of my PhD.

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