STUDIES ON THE PROPAGATION CHARACTERISTICS OF SINGLE MODE OPTICAL WAVEGUIDES

by
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TO

MY

PARENTS

CERTIFICATE

This is to certify that the thesis entitled, "STUDIES ON THE PROPAGATION CHARACTERISTICS OF SINGLE-MODE OPTICAL WAVEGUIDES," being submitted by Mr. Prasanna Kumar Mishra to the Indian Institute of Technology, Delhi for the award of the degree of DOCTOR OF PHILOSOPHY, is a record of bonafide research work carried out by him. Mr. Prasanna Kumar Mishra has worked under our guidance and supervision and has fulfilled the requirements which to our knowledge have 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

Single-mode optical fibers and integrated optical waveguides are finding increasing applications in optical communication, optical signal processing and optical sensing. As a consequence, a larger number of models and methods have been developed to study the propagation characteristics of optical fibers and optical waveguides. We propose a new model - the cosine-exponential (CE) model-which gives moderate to high accuracy for most of the single-mode optical waveguides. Further, this form of the trial function allows one to define an equivalent guiding structure (EGS), which has propagation characteristics very closely similar to those of the actual waveguide. The EGS comprises of homogeneous slab waveguides and hence the evaluation of splice loss, waveguide excitation efficiency, directional coupling characteristics etc, is greatly simplified.

We describe the model and compare its accuracy with that obtained using other methods and establish the superiority of the present model. The method to use the equivalent guiding structure for analysing other characteristics of the waveguide and devices based on them is also discussed. Next, we show the applicability of this model to different types of single-mode waveguides.

In particular, we consider homogeneous rectangular and channel waveguides; inhomogeneous planar and diffused channel waveguides; elliptical-core and circular-core fibers. The model gives better accuracy than the existing approximate methods and models except for the case of circular-core fibers, for which more accurate models are available. However, even in the case of circular-core fibers, the present model gives better accuracy than the widely used Gaussian approximation. Further, the EGS, as defined by the CE-model, is used to study other related problems. For example, the fundamental vector modes of a waveguide are well approximated by the vector modes of its EGS, which are very easy to obtain. The problem of directional coupling between two fibers or integrated optical waveguides reduces to the problem of two parallel slab waveguides (of the EGS) which is almost analytically solvable.

The above model, though it works extremely well for most of the optical waveguides as far as the field distribution propagation constant of the fundamental mode and other related characteristics are concerned, it does not give sufficient accuracy for studying dispersion characteristics in single-mode fibers. Hence, one either uses numerical techniques or makes use of approximate methods.We have developed a numerical method of solving the scalar wave equation for W-type fibers. The method is employed to compute the chromatic dispersion of a graded-core W-type fiber exhibiting two zero dispersion wavelengths, and to study the dependence of chromatic dispersion on various fiber parameters which is essential to design such fibers for Wavelength Division Multiplex (WDM) transmission systems. We also discuss the advantages of a graded-core W-type fiber over a homogeneous-core fiber. The numerical method used above does not provide a closed from expression for the transverse modal field of the W-type fiber. Hence, we approximate the fundamental mode of such fibers by the Gaussian - exponential model (which has been successfully used in the past to study the propagation characteristics of single-clad fibers) and evaluate the various propagation parameters with a considerable good accuracy in comparision to the Gaussian model.

Finally, we give a simple method to estimate propagation constants of modes in absorbing waveguides. The method is based on the transformation of the scalar wave equation into a matrix eigenvalue problem and is applicable to waveguides with arbitrary refractive index profiles, in contrast to earlier methods, which were restricted to step index profiles.

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