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Launching and propagation of light in optical fibres

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In recent years, the field of fibre optics has witnessed remarkable progress in the technological aspects of optical communications, with demonstration systems already operational in many countries. These practical advances have indicated the need for increased theoretical effort aimed at quantifying the capabilities of the many aspects of an optical communication system: for example, sources, fibres, joints, measurement techniques. With much of the formalism of fibre analysis now firmly established, the fibre theorist may fruitfully turn to problems of more direct relevance to the systems designer, for example, clarification of the effects of manufacturing imperfections on transmission performance. The work of this thesis follows this aim, by providing quantitative analyses of various facets of the launching and propagation of power in optical fibres.

The thesis begins by reviewing the basic theory of the two formalisms commonly applied in the analysis of optical waveguides: electromagnetic modal theory and geometric optics. The fibre geometry in the cross-sectional plane is assumed to be circularly symmetric, and descriptions of the launching and propagation of light in these structures is given in terms of the alternative representations of modes and rays. In a later chapter, the necessary modifications to the geometric optics analysis caused by the lack of this assumed circular symmetry, are investigated. However, the existing theories are first applied to a variety of problems involving step and graded index fibres of circular cross-section.

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The first such problem concerns the excitation of graded index fibres by obliquely incident parallel beams. General analytical and numerical results are given for the excitation efficiencies of the bound and tunnelling rays. The relevance of these results to fibre excitation by more complicated sources (for example, partially coherent sources), and to the appearance of the fibre output face is discussed. Also, the graded index fibre equivalent of the black-band phenomenon in step index fibres is described, and its application to profile determination considered.

The introduction of a focusing lens in the excitation system is then treated, using the full electromagnetic analysis for step index fibres. Included are the effects on coupling efficiency of transverse, longitudinal and angular misalignment of the lens and fibre axes. The accuracy of various approximations such as geometric optics in multimode fibres, and Gaussian modal fields in monomode fibres is also investigated.

This analysis of lens excitation is applied in a separate chapter, to the visual system of the fly. Numerical results are presented for the effects of the varying focal lengths, tapering photoreceptors, and chromatic aberration that have been experimentally observed. An aim of this chapter is to identify the role of the wave nature of light in the excitation of visual photoreceptors.

The propagation effects considered in this thesis are pulse dispersion, tunnelling attenuation and cladding absorption. Quantitative results are given for the effect on tunnelling power attenuation and impulse response in graded index fibres, of the angular alignment of the collimated beam source. Similar calculations for the effects of cladding absorption are also given for a graded index fibre excited by a Lambertian source. The graded fibres are shown to be far less susceptible to the effect of cladding absorption than step index fibres.

Since the cross-sections of practical optical fibres do not have perfect circular symmetry, the appropriate mathematical representation of a noncircular refractive index profile is discussed. It is shown that the basic power law profile in circular fibres should be replaced by a grading function which is a homogeneous function of the transverse cartesian coordinates x, y . Multimode optical fibres of this type are analysed using geometric optics and general properties of the ray paths described.

The fundamental quantities of interest in fibre optics - power acceptance, ray transit time, impulse response - are shown to depend on the degree of homogeneity of the grading function but not on its specific form. Thus, fibres need not have circular symmetry in order to exhibit,the desirable properties of the circular, power law fibres. Ray paths and classifications are analysed in detail for elliptical, parabolic-index fibres. Splicing losses are examined, and are shown to be not drastically dependent on deviations from circular symmetry.

Finally, the problem of measuring a refractive index probile which is noncircular is discussed. Quantitative results are given for the effect of noncircularity, on a recently proposed method for the measurement of the profile of a fibre preform. Analytical studies show how this method can be simply modified for application to elliptical preforms.