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Theory and application of ray transmission coefficients in multimode optical fibres

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The complete solution of Maxwell's equations for any practical problem even with the simplest geometry is difficult, if not intractable. For more complicated geometries it is essential to develop simple, accurate methods of describing electromagnetic wave phenomena. The emergence of low loss optical fibres as a powerful challenger to coaxial cables for communication purposes has begged a simple but comprehensive theory of electromagnetic wave propagation along dielectric waveguides. This thesis presents a substantial part of the basis of such a theory. Based on considerations of geometric optics and restricted to multimode optical waveguides, wave propagation effects are built into a ray optic analysis to provide an elementary straightforward theory based on simple physical concepts. The approach is an analogue of the well-known theory of geometrical diffraction and provides a powerful analytical tool for the description of losses on multimode dielectric structures. It has direct application to fibres, laser cavities, and a variety of devices known generally as integrated optics.

The role of ray power transmission coefficients in multimode optical guides is described and its relationship to power attenuation coefficients developed. In Chapter 2 the theory is derived for slab and circular dielectric structures with both step and graded refractive index profiles. The mathematical methods used to calculate the ray transmission coefficients are compared, their regions of validity analysed, and the

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reduction to known solutions for these simple structures is observed. Three regions for the ray solution are identified:

(i) bound rays confined to the core of a guiding structure but having associated fields extending indefinitely into the cladding medium;

(ii) refracting leaky rays which lose power rapidly by refraction from the core cladding interface;

(iii) tunnelling leaky rays which undergo electromagnetic tunnelling, slowly losing power from the core of the guide at caustics and points of reflection in a manner analogous to quantum mechanical tunnelling.

As the loss of fibre materials decreases, the role of the very low loss tunnelling leaky rays becomes significantly more important in describing the propagation characteristics of the fibre over large distances. In Chapter 3 an analytic extension of Fresnel's law is developed to describe reflection from within an arbitrarily curved medium with either a step or a continuous refractive index gradation. These generalisations of Fresnel's law are shown to yield solutions corresponding to those of Chapter 2 for skew rays on straight fibres. Chapters 4 and 5 extend the theory to slightly absorbing and multilayered guides using a straightforward building block approach that allows the solution to be written down by inspection.

The result for ray power attenuation using the transmission coefficient theory are compared with exact numerical results of the electromagnetic boundary value problem in Chapter 6. Excellent agreement is shown to within a few percent in most cases.

In Chapter 7 the application of ray transmission coefficients to bent step index and graded index slab and fibre guides is detailed. Some numerical results for each case are quoted for a fibre excited by an incoherent source.

Finally, the application of the theory to guides with a small elliptical deformation is illustrated in Chapter 8, where the solution is also compared with the solution derived from the eigenvalue equation.