Chapter 4
Modeling of Polymer Optical Fibers

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ABSTRACT
The idea of this chapter is to give a complete overview on a matrix approach to describe light propagation in strongly multimode fibers such as 1-mm diameter plastic optical fibers. These large core fibers accept such a huge number of travelling modes that they can be viewed as a continuum. Thus, light propagation can be described as a power flow by a differential equation that can be more easily solved using matrices. Thus, the key of this method is the propagation matrix that is calculated from the diffusion and attenuation functions characteristic for a given fiber type. The propagation matrix has temporal frequency dependence and can be used to obtain not only angular power distributions but also temporal parameters such as pulse spread or bandwidth. This approach is flexible to introduce localized perturbations of power distribution provided they can be modeled as matrices. Thus, the effect of devices such as scramblers or connectors and also of disturbances such as curvatures and tensions can be introduced at different points in the fiber path to assess their impact on transmission properties. One of the most critical parameters when designing a network is its bandwidth and how it decreases when increasing the link reach. This dependence has been assumed to be linear when both bandwidth and length are represented in logarithms with a slope whose value provides information of the processes underlying propagation. Thus, the authors apply the model to calculate the bandwidth versus length dependence under different conditions analyzing the value of the slope and explaining previous experimental findings.

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INTRODUCTION

Plastic optical fibers (POFs) are being considered for high-performance fiber links at very short distances because of their ductility, light weight and ease of connection as compared to glass optical fibers in spite of their narrower bandwidths. Pulse broadening in multimode fibers is mainly due to modal dispersion, that in PMMA based POFs seems to be related mainly to optical power diffusion. High NA POFs are characterized by propagating a huge number of modes that can be approximated to a continuum of modes, each mode characterized by its propagation angle. Thus, the power exchange between modes can be viewed as power diffusion whose physical origin is either Rayleigh scattering by impurities in the bulk material or Mie scattering produced by irregularities in the core-cladding interface (Bunge et al., 2006). As power propagates through the length of the fiber, diffusion induces power transfer between neighboring angles which is translated as mode mixing, an effect that is much stronger than that occurring in multimode glass fibers. Bends, curvatures and other macroscopic strains also act as diffusive agents transferring power to other further separated angles or modes. All these diffusive effects intrinsic and extrinsic to the fiber have an impact on the fiber’s modal dispersion which consequently determines its temporal response and bandwidth.

Power diffusion changes the angular power distribution as light propagates throughout the fiber by transferring power from some angles towards others. These changes affect the optical paths and produce delays which have an impact on temporal properties and, in particular, on bandwidth. In general, mode coupling tends to reduce modal dispersion in some conditions leading to a dependence of bandwidth with fiber length different from the expected linear rate, which is not necessarily the square-root dependence found for glass fibers after they have reached equilibrium. The strong diffusion in POFs however, does not guarantee a rapid achievement of steady conditions, which can only be reached after 75-100 m propagation (Djordjevich & Savović, 2008). Since the main use of current POFs is in short-range applications, POF links will be mostly working in non-stationary conditions. In these distance ranges, the launching conditions have a strong impact on the fiber performance and localized disturbances such as curvatures, bends and stress have also a strong influence in propagation properties (Losada et al., 2002, Fuster & Kalymnios, 1998). Their effect is not simply power loss but also power transfer from one mode to the others which are further away from their nearest neighbors. These changes in power distribution due to mode mixing also alter the modes’ relative temporal delays and have a direct relation to bandwidth (Kalymnios, 1999). On the other hand, for under-filled launching conditions, the effect of diffusion can increase modal dispersion and, in addition, significantly changes output-field properties that can degrade beam quality with possible consequences for power delivery and sensory systems. Thus, a model that accounts for power transfer among modes is necessary to describe the behavior of the fiber in such conditions.

Another source of changes in the angular power distribution is the differential attenuation, different from the overall attenuation that reduces the whole propagating power as an exponential function of the fiber length. Differential attenuation is a function of the angle, as power following longer paths characterized by higher propagation angles suffer higher losses than power confined near the fiber center. The mechanisms behind attenuation are not so different from those causing diffusion. For attenuation, however, the power that leaves a mode is not transferred to another mode but it is radiated and lost. Both diffusion and attenuation act jointly to change the angular power distribution but their relative influence changes depending on several factors. Usually, diffusion