CHAPTER- 3

TRANSMISSION CHARACTERISTICS OF OPTICAL FIBERS

CONTENTS

In this chapter we shall briefly discuss the various transmission characteristics exhibited by optical fiber, when a light signal propagates through it.

3.1 ATTENUATION :

When a light signal propagates through an optical fiber its attenuation occurs due to absorption, scattering and radiative losses of the optical energy in the core and cladding of the optical fiber. The absorption is related to the nature of the fiber material, while the scattering takes place on account of both the nature of the fiber material and the structural imperfections present in it. The attenuation decides the maximum transmission distance between the transmitter and a receiver and hence plays an important role in the design of an optical communication system signal attenuation (or fiber loss) is defined as the ratio of the optical power P_{out} from a fiber of length L to the optical input power P_{in}. It is given in describe per kilometer by the following relation.

$$\alpha = 10 \log \frac{P_{in} / P_{out}}{L} \qquad \ldots\ldots(3.1)$$

For an ideal fiber there will not be any energy loss so that $P_{out} = P_{in}$. this corresponds to a 0-dB attenuation. However, for an actual low loss fiber there can be an average loss of 3 dB/km. This means the input power decreases by 50% over a distance of 1 Km.

Material absorption losses arise due to the following reasons :

1. Absorption by atomic defects in the glass composition.
2. Intrinsic absorption[2] by the basic constituent atoms of the fiber material.
3. Extrinsic absorption by impurity atoms in the glass material. The impurity atoms are mainly the transition metal atoms which are commonly found in the silica glass.

There is Rayleigh scattering which arises due to the microscopic variations in the material density, compositional fluctuations and the structural inhomoginities or defects occuring during the fiber manufacture. There is also mie scattering taking place due to the inhomogeneities which are comparable in size to the guided wavelength. This scattering is mainly in the forward direction. It can be reduced to insignificant levels by reducing the inhomogeneities present in the material.

3.2 DISPERSION[1,2,3] :

When a light signal is travelling through an optical fiber waveform distortion occurs leading to the broadening of the pulse waveform at the receiving end. This affects the transmission capacity of optical fiber as a communication channel. The waveform distortion in the pulse-code modulation (PCM) system arises due to the dispersion of delay-time of various components belonging to the propogating pulse. The time-delay is occuring due to the different group velocities. The amount of pulse broadening depends upon the distance travelled by the pulse within the fiber. In the absence of mode coupling or filtering the pulse broadening increases linearly with the fiber length. The corresponding bandwidth is inversly proportional to the distance. Hence, the information carrying capacity of an optical fiber is measured in terms of band width-length product; which is proved to be an useful parameter.

The intramodal or chromatic dispersion may occur in all the types of optical fibers. It arises due to the finite spectral line-width of the optical source. The pulse broadening due to material dispersion results from the different group velocities of various spectral components belonging to the optical source. The material is said to exhibit material dispersion when $d^2n/d\lambda^2 \neq 0$. In terms of the second derivative of R.I. we can define the material dispersion parameter as below.

$$M = \frac{\lambda}{c} \left| \frac{d^2 n_1}{d \lambda^2} \right|$$

It is expressed in units of Ps nm^{-1} Km^{-1}.

There can be variation in group velocity with wavelength for a particular mode. This leads to the time-delay and hence, to the waveguide dispersion. For single mode whose propagation constant is β , the fiber exhibits waveguide dispersion provided, $d^2\beta/d\lambda^2 \neq 0$. This short of waveguide dispersion is not found practically in the case of multimode fibers.

Pulse broadening may also result due to the intermodal dispersion arising from the propagation delay differences between modes within a multimode fiber. The pulse width at the output depends upon the transmission times of the slowest and fastest modes. A large amount of intermodal dispersion is found in multimode step index fibers there by leading to the greatest pulse broadning. However, this can be reduced by adopting an optimum refractive index profile. In the case of multimode graded index fibers the overall pulse broadening is very much less than that in the multimode step index fibers. Hence, the formar fibers are useful when a large bandwidth is required. In single mode operation the intermodal dispersion is absent and the pulse broadening is entirely due to the infra-modal dispersion.

3.3 PULSE BROADENING[5] :

In a graded index fiber the r.m.s. pulse broadening is given by the relation,

$$\sigma = (\sigma^2_{\text{intermodal}} + \sigma^2_{\text{intramodal}})^{1/2}$$

Here, $\sigma_{\text{intermodal}}$ can be obtained from the r.m.s. pulse width resulting from the intermodal delay distortion, where as $\sigma_{\text{intramodal}}$ is the r.m.s. pulse width resulting from the pulse broadening within each mode.

MODE COUPLING :

In actual fiber systems the pulse distortion increases less rapidly after a certain initial length. This is due to a mode coupling and a differential mode loss. The coupling of energy from one mode to the other arises on accountt of structural imperfections.Fiber diameter and the R.I.variations. This mode coupling actually reduces the intermodal dispersion and hence affects the pulse distortion. There is an additional loss h (dB/Km) associated with the mode coupling.

As h increases there is an improvement in the pulse spreading. This h is usually determined experimentally because its calculations are complicated.

3.4 NONLINEAR CHARACTERISTICS[1,4]:

Fiber are usually considered to be completely passive (or linear) media. As the input power is increased, one expects only a proportional increase in the output power. This however, is not strictly true and nonlinear effects can occur which cause strong frequency conversion, optical gain, and many other effects generally associated with strong. Optical intensities and highly nonlinear materials. These nonlinar processes depend on the interaction length as well as intensity. In small-core low-loss fibers high intensities can be maintained over lengths of more than a kilometer. The enhancement lowers the threshold power for nonlinear processes. In a communication fiber this can lead to high attenuation, pulse spreading, and physical damage.

The advantages of fibers for nonlinear optics were pointed out by Ashkin and the first nonlinear effect using such a geometry was observed by Ippen in a liquid core fiber.The long interaction length available in glass fibers was used to observe stimulated Raman scattering, stimulated Brillouin scattering which is the lowest threshold nonlinear process in glass fibers. The long interaction lenngth in fibers enhances spontaneous Raman scattering as well as stimulated scattering and many weak Raman lines have been observed in both liquid and glass fibers.

Recently, devices using fibers have appeared such as tunable Raman oscillators and a fiber generated nanosecond continuum useful for time-resolved spectroscopic studies, SRS,SBS and SPM are of interest because these processes impose limits on the peak power of fiber transmission systems. We consider below the highlights of some of the important nonlinear processes associated with optical fibers.

The stimulated Raman scattering arises due to high photon flux concentrated in a small volume of optical Fiber. This scatttering is undesirable in a transmission fiber, but it is of potential use in an optical amplifier. The Raman gain is found to be greater near the input end of fiber because, inside the fiber the pump power decreases on account of linear absorption. The gain for backward Raman amplification is found to be very large on account of self focusing effect.

Stimulated Brillouin scattering (SBS) can also occur in fibers. It involves acoustic phonons as against high frequency optical phonons involved in SRS. The gain for SBS in glasses is quite large as compared to that for SRS. But SRS is usually a dominent process because of the larger pump line width. In a 10 micron single mode fiber the critical powers for SRS and SBS are found to be respectively equal to 3.3 W and 9.8 mw. The corresponding values for a 50 micron multimode fiber are given by 150 w and 4.46 mw.

In addition to the scattering processes given above, nonlinear effects like optical Kerr effect, self-focusing etc. also arise during the passage of light pulses in optical fibers. These effects arise on account of intensity-dependent R.I. of the optical fiber. The self-focusing effect gives rise to a negligible confinement of the light beam because the propagation it self is taking place on account of multiple internal reflections at the core-cladding boundary. However, small phase shifts cause by the R.I. changes will add up over the entire length of a fiber. In the optical Kerr effect a strong linearly polarized pulse induces briefringence in the fiber core. This pulse is brobed by a weaker signal at a different wavelength with the help of an arrangement shown in Fig. (3.1). The probe is introduced with its polarization making an angle of 45^{0} with that of the pump pulse and the polarizer is set to eliminate the probe light in the absence of the pump. The induced birefringence is then related to the transmission of the polarizer. The birefringence is expressed by the following relation :

$$\delta n_{11} - \delta n_{1} = 1/2 \; n_{2B} \; E^{2}$$

where, $E^{2} = \dfrac{8\pi P}{nc A_{eff}} \quad X \; 10^{7}$

$\delta n_{11} - \delta n_{1}$ = difference between the intensity dependent refractive indices, parallel and pependicular to the pump polarization.

n_{2B} = Kerr coefficient.

A_{eff} = Effective area of the fiber core.

P = Pump power.

3.5 SUMMARY :

In this chapter we have briefly discribed the different transmission characteristics shown by the optical fiber during the propagation of light signal through it. The attenuation of the light signal is related to various mechanisms like absorption, scattering, radiative loss etc. The pulse broadening observed at the recieving end of the optical fiber is found to be due to the dispersion taking place during the pulse propagation In the intermodal dispersion the basic reason is the time-delay between various modes in a pulse propagating with different group velocities. In the case of waveguide dispersion the variation in group velocity with wavelength for a particular mode is responsible ultimately to the pulse broadening effect. However, in actual fibers the pulse spreading can be improved due to mode coupling and a differential mode loss.

The nonlinear processes occuring in optical fibers are found to be very important in the recent context of the optical communication and the fiber optic devices.

The nonlinear stimulated Raman scattering process is unwanted in a transmission fiber but is useful as an optical amplifier. The intensity dpendent nonlinear effects taking place in optical fibers are found to be significant with reference to the limitations putforth by them in the transmission capacity of the fiber. Most of the studies of nonlinear processes have been so far concentrated only on the step-index silica core fiber due to certain advantages. Various optical devices such as tunable Raman oscillator, four photon parametric Amplifiers, Kérrr modulators and even tunable fiber Raman oscillators are based upon the nonlinear processes. The above observations on the literature study of nonlinear process show that there is a scope for considering such effect with reference to the graded-index type optical fibers. With this view in mind we have considered in the remaining chapters the propagation of isolated HE_{11} and HE_{21} hybrid modes in a step-index fiber which acts like a graded-index fiber on account of the modification of the R.I. profile by the high intensities concentrated in small fiber cross-sections.

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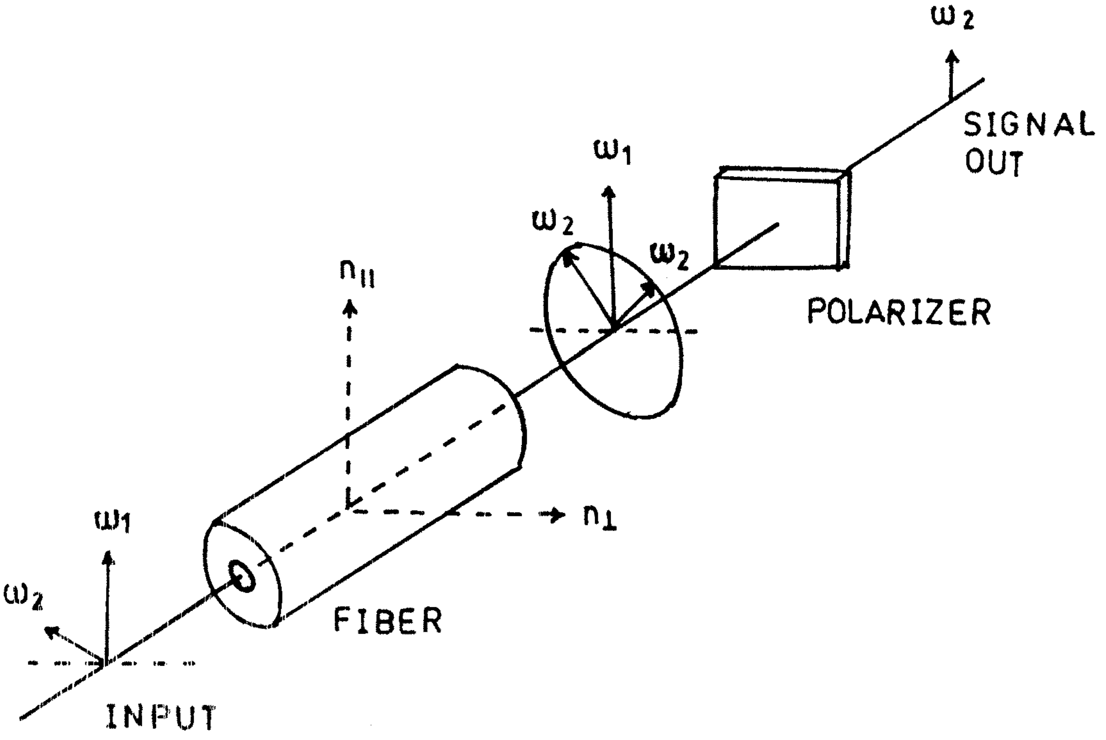

FIG. 3·1 — OPTICAL KERR EFFECT. THE BIREFRINGENCE INDUCED BY A LINEARLY POLARIZED PUMP PULSE AT ω_1 IS PROBED BY A WEAKER SIGNAL AT ω_2.