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Dispersion and Losses In Fibers

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ABSTRACT *Modern electronic communication use radio waves and microwaves to carry information over copper wires and co-axial cables. However, the information carrying capacity of these wires is restricted. The main problem of a fiber optic cable is its attenuation and there are different mechanisms which are responsible for the signal attenuation within the fiber and these mechanism lead to material dispersion, material scattering, and micro bending losses.*

KEYWORDS : Attenuation, dispersion and scattering.

1.1.1: INTRODUCTION:

Dispersion in the fiber means the broadening of the signal pulse width due to dependence of the refractive index of the material of the fiber on the wavelength of the carrier. If we send digitized signal pulses in the form of square pulses, they are converted into broadened gaussian pulses due to dispersion. The dispersion leads to the distortian (or) degradation of the signal quality at the output end due to overlapping of the pulses.

There are two kinds of dispersion mechanisms in the fiber: (i) Intramodal dispersion and (ii) Intermodal dispersion.

Intramodal dispersion [3] arises due to the dependence of group velocity on the wavelength. Further it increases with the increase in spectral width of the optical source. This spectral width is the range of wavelengths emitted by the optical source. For example in the case of LED, it has a large spectral width about 40 nm since it emits wavelengths from 830– 870 nm with the peak emission wavelength at 850 nm. In the case of laser diode which has a very narrow spectral width, the spectral width is about 1 or 2 nm only. Thus the intramodal dispersion can be reduced in an optical fiber using single mode laser diode as an optical source. Intramodal dispersion arises due to the dispersive properties of the optical fiber material (material dispersion) and the guidance effects of the optical fiber (waveguide dispersion).

- Material dispersion (or) chromatic dispersion: This dispersion arises due to the variation of the refractive index of the core material with the wavelength or frequency of light. It is directly proportional to the frequency bandwidth of the transmitted pulse. A material exhibits material dispersion when d2n1=d λ 2 6= 0. For pure silica, the material dispersion tends to zero at the wavelength of 1.3 mm. Further by using an optical source with a nar-row spectral width, the material dispersion can be reduced. For shorter wavelengths around 0.6 mm to 0.8 mm, the material dispersion exponentially rises to a higher value[5].

- Waveguide dispersion: This dispersion arises due to the finite frequency bandwidth and the dependence of the mode group velocity on the frequency of light. Higher the frequency bandwidth of the transmitted pulse, higher will be the waveguide dispersion. The amount of waveguide dispersion depends on the fiber design like core radius, since the propagation constant `β ' is a function of a=λ . In the case of single mode fibers, waveguide dispersion arises when d2β =dλ 2 6= 0. In the case of multimode fibers, most of the modes propagate far from the cutoff value. Therefore then all are almost free from waveguide dispersion.

- *Intermodal dispersion* (*or*) *multimode dispersion*: Intermodal dispersion or multimode dispersion arises due to the variation of group velocity for each mode at a single frequency. Different modes arrive at the exit end of the fiber at different times. So there is multimode dispersion and hence there is broadening of the signal pulses.

Dispersion in different fibers :
Among the three dispersions,

multimode dispersion > material dispersion > waveguide dispersion. Based on the dispersion effects, one can get the following results:

1. The multimode step index fibers exhibit a large value of dispersion due to the enor-mous amount of multimode dispersion which gives the greatest pulse broadening. At the same time the multimode graded index fiber exhibits an overall dispersion which is 100 times lesser than the multimode step index fiber's dispersion. This is due to the shaping of the refractive index profile in a parabolic manner[1].
2. In the case of single mode step index fibers, they have only intramodal dispersion. Further among the intramodal dispersions, the waveguide dispersion is the dominant one. The material dispersion in them is almost negligible due to axial ray propaga-tion and small core radius. When we compare it with the dispersion in the multimode graded index fiber, the dispersion in the single mode fiber is negligible. That is why single mode fibers are highly useful in long distance communication systems.

1.1.2: Dispersion-shifted single mode fibers

Generally in single mode fibers, zero dispersion is obtained at a wavelength of about 1.3 mm. Since there is a finite loss in the silica fiber at 1.3 mm, today the fibers are designed such that there is zero dispersion at 1.55 mm with a minimum loss. At 1.55 mm, the ma-terial dispersion in single mode fiber is positive and large, while the waveguide dispersion is negative and small. So to increase the waveguide dispersion equal to that of material dispersion, the relative refractive index difference `Δ' may be slightly increased by adding more Ge O2 in the core (which increases the refractive index of the core) or adding more fluorine in the cladding (which decreases the refractive index of the cladding) or instead of parabolic refractive index profile, a triangular refractive index profile can be designed.

Thus the dispersion-shifted fibers have minimum loss and zero dispersion at 1.55 mm.

2.1.1: Result and discussion:

At present the installed fiber optic links are operating at the wavelength of 1.3 mm using conventional single mode fibers. Instead of 1.3 mm wavelength if one wants to use 1.55 mm wavelengths to reduce the transmission loss, then the whole fiber optic link should be replaced with the new dispersion-shifted fibers. This will require an enormous expenditure. To avoid this huge expenditure and to use the old fiber optic links dispersion compensating fibers were evolved[3]. These fibers have a large negative dispersion at 1.55 mm, while the conventional single mode fibers operating at 1.3 mm have positive dispersion at 1.55 mm.

By suitably replacing 1 km length of conventional single mode fiber in the fiber optic link with the dispersion compensating fiber for every 100 km length of conventional single mode fiber optic link, one can achieve minimum loss and zero dispersion also.

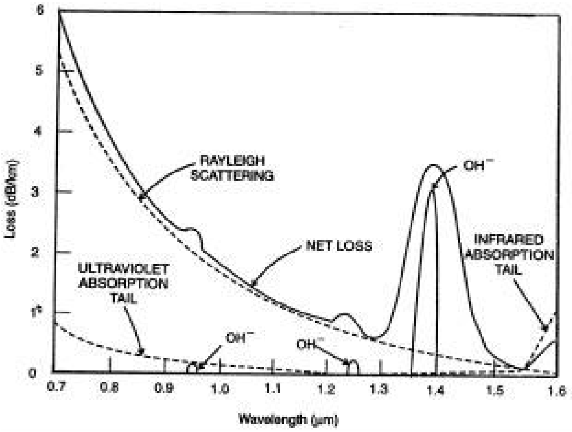

Figure 3. Different intrinsic losses in a pure silica fiber.

2.1.1: Transmission losses in fibers

The transmission loss or attenuation of the signal in an optical fiber is a very important quantity to consider in optical fiber communication[2]. The attenuation of the signal trans-mitting through the fiber results from absorption and scattering and is measured in deci-bel/km and is a function of wavelength as shown in figure 3. The optical communication wavelengths are 0.8, 1.3 and 1.55 mm.

Attenuation can be classified into two types:

(i) Intrinsic losses and (ii) Extrinsic losses.

Mechanisms generating intrinsic losses

- Tail of infrared absorption by Si-O coupling—it is present at higher wavelengths around 1.4 mm to 1.6 mm.
- Tail of ultraviolet absorption due to electron transition—it is present at lower wave-lengths near 0.8 mm. This will produce a loss of 0.3 dB/km.
- Rayleigh scattering due to spatial fluctuation of refractive index and is inversely proportional to λ 4—it produces a maximum loss in the ultraviolet region only. In the wavelength region around 0.8 mm to1 mm, it gives a loss of 0.6 dB/km.
- Absorption by molecular vibration of OH impurity—fundamental absorption due to hydroxyl (OH) ions is present at λ = 2:8 mm. But its harmonics occur at wavelengths 1.38 mm and 0.95 mm respectively. This kind of absorption is almost eliminated by the modified chemical vapor deposition process adopted for the fiber preform production reducing the water content in the fiber to below 10 parts per billion.
- Absorption by transition metal impurities like Cr, V, Fe, Mn and Ni—this absorption produces a loss at wavelengths greater than 0.8 mm. In ultra low loss fibers, this absorption is practically negligible[4].
- Thus it is found that in the case of pure silica fibers the transmission losses are re-duced to a minimum value at 1.55 mm wavelength. At 1.3 mm also, the transmission losses are minimum but the net attenuation is slightly greater with respect to the wavelength 1.55 mm.

Mechanisms generating extrinsic losses:

1. Geometrical non-uniformity at the core-cladding boundary.
2. Imperfect connection or alignment between fibers.
3. Microbending.
4. Radiation of leaky modes.

Conclusion:

At 1.3 mm and 1.55 mm wavelength the intrinsic losses are minimum and extrinsic losses are very small when compared to intrinsic losses and can be minimized by proper care during the manufacturing and installation of the fibers.

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