G.PULLAIAH COLLEGE OF ENGINEERING AND TECHNOLOGY: KURNOOL

DEPT OF ECE

OFC LECTURE NOTES

UNIT-2

BASIC TERMS AND DEFINITIONS:

Attenuation	The loss of optical power, whether caused intrinsically (absorption, scattering, microbends, etc.), or extrinsically by components (connectors, splices, splitters, etc). Expressed as dB or dB/km (with fiber).
Attenuator	A component that incorporates a specific amount of loss into an operational optical network. Attenuators also provide a safety margin in planned networks to allow for electronics degradation over time, or physical changes to the optical component portion of the network. Attenuators come in two styles, fixed and variable. Variable optical attenuators are used for testing systems for dynamic range and quality of signal testing.
Bend loss	Increased attenuation due to macrobends (curvature of fiber) or microbends (small distortions in the fiber) coupling light energy from the fiber core to the cladding.
Connector	Most fiber optic connectors consist of two plugs and one adapter. Connectors can be push/pull types (SC, LC, MPO etc.), bayonet (ST), or threaded (FC). Most use a 2.5-mm ferrule but small form factor types use the smaller 1.25-mm ferrule. Other features include a key and keyway that provide critical alignment for repeatability and for strain relief internally and at the rear boot. Bonding techniques include thermal cure, anaerobic adhesive, and UV adhesive. Splice-on plugs use a prepolished fiber stub and then are mechanically or fusion spliced. Military, industrial, and heavy-duty specialized connectors may use expanded beam lenses and termini contacts (instead of ferrules) based on standard Mil/Aero dimensions. Key specifications for all connectors include attenuation, reflectance, and repeatability.
Dispersion	The cause of bandwidth limitations in fiber. In multimode systems, modal dispersion is caused by differential optical path lengths known as differential path delay. For single-mode systems, chromatic dispersion is a combination of material dispersion (caused by the line width of the laser source) and waveguide dispersion (caused by the difference in the speed of light in the core and the cladding of the fiber). Another type of dispersion is polarization mode dispersion (PMD), which is caused by random vibration, temperature variations, and bending of the fibers known as birefringence.
Fusion splicer	A mechanical device that optically joins optical fibers by discharging voltage between two electrodes. Variations include the single fiber and ribbon fixed V-groove types, the profile alignment splicer (PAS) and the local injection detection (LID), both of which are categorized as core alignment splicers.
Microbending	An effect where small stresses or flaws create attenuation. Mostly an

	extrinsic effect caused by tie wraps and point deformations onto the fiber that allow light to escape. Intrinsic sources are flaws or defects in the core/cladding boundary created during the manufacturing process.
Optical loss	The amount of optical power lost as light is transmitted through fiber, splices, couplers, etc. Also known as attenuation; measured in dB.
Linear scattering	Linear scattering mechanisms cause the transfer of some or all of the optical power contained within one propagating mode to be transferred linearly into a different mode.
non-linear scattering.	Non-linear scattering causes the optical power from one mode to be transferred in either the forward or backward direction to the same or other modes at different frequencies.
Fresnel reflection	When the two joined fiber ends are smooth and perpendicular to the axes, and the two fiber axes are perfectly aligned, the small proportion of the light may be reflected back into the transmitting fiber causing attenuation at joint. This is known as Fresnel reflection.
Beat Length	Beat Length is defined as the period of interference effects in a bi-refringent medium. When two waves with different linear polarization states propagate in a bi-refringent medium, their phases will evolve differently.
Group Velocity Dispersion	Intra-modal dispersion is pulse spreading that occurs within a single mode.The spreading arises from the finite spectral emission width of an optical source. This phenomenon is known as Group Velocity Dispersion.
wave guide dispersion	Wave guide dispersion occurs because of a single mode fiber confines only about 80% of optical power to the core. Dispersion arises since 20% of light propagates in cladding travels faster than the light confined to the core. Amount of wave-guide dispersion depends on fiber design. Other factor for pulse spreading is inter modal delay.
material dispersion	Material dispersion arises from the variation of the refractive index of the core material as a function of wavelength. Material dispersion is also referred to as chromatic dispersion. This causes a wavelength dependence of group velocity of given mode.So it occurs because the index of refraction varies as a function of optical wavelength. Material dispersion is an intra modal dispersion effect and is for particular importance for single mode wave guide.
polarization	Polarization is a fundamental property of an optical signal. It refers to the electric field orientation of a light signal which can vary significantly along the length of a fiber.

fiber birefringence	Imperfections in the fiber are common such as symmetrical lateral stress, non circular imperfect variations of refractive index profile. These imperfections break the circular symmetry of ideal fiber and mode propagate with different phase velocity and the difference between their refractive index is called fiber birefringence.
scattering losses	Scattering losses in glass arise from microscopic variation in the material density from compositional fluctuation and from structural in-homogeneities or defects occurring during fiber manufacture.
macro-bend losses	Macrobend losses are observed when a fiber bend's radius of curvature is large compared to the fiber diameter. Light propagating at the inner side of the bend travels a shorter distance than that on the outer side.

Concepts

Group Delay

Consider a fiber cable carrying optical signal equally with various modes and each mode contains all the spectral components in the wavelength band. All the spectral components travel independently and they observe different **time delay** and **group delay** in the direction of propagation. The velocity at which the energy in a pulse travels along the fiber is known as **group velocity**. Group velocity is given by,

$$V_g = \frac{\partial w}{\partial \beta}$$

Thus different frequency components in a signal will travel at different group velocities and so will arrive at their destination at different times, for digital modulation of carrier, this results in dispersion of pulse, which affects the maximum rate of modulation. Let the difference in propagation times for two side bands is δτ.

$$\delta\tau = \frac{d\tau}{d\lambda} \, x \, \delta\lambda$$

Information Capacity Determination

Dispersion and attenuation of pulse travelling along the fiber is shown in Fig. 2.6.1.

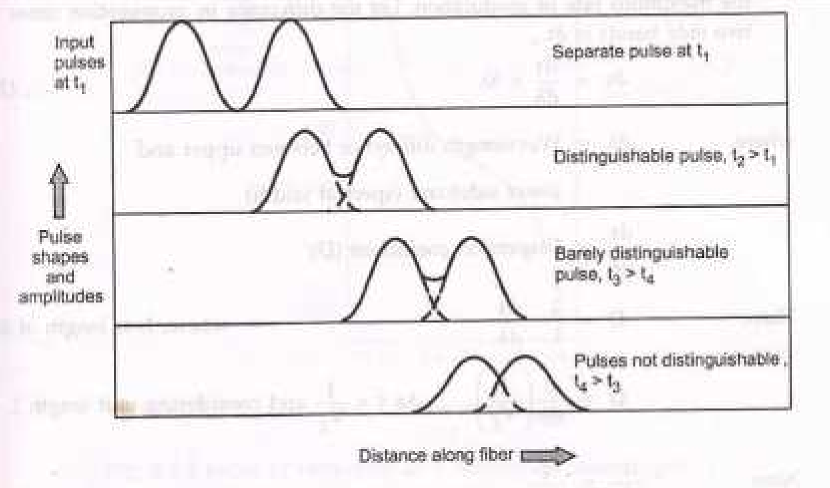


Fig. 2.6.1 Dispersion and attenuation in fiber

Fig. 2.6.1 shows, after travelling some distance, pulse starts broadening and overlap with the neighbouring pulses. At certain distance the pulses are not even distinguishable and error will occur at receiver. Therefore the information capacity is specified by bandwidth- distance product (MHz . km). For step index bandwidth distance product is 20 MHz . km and for graded index it is 2.5 MHz . km.

Absorption

Absorption loss is related to the material composition and fabrication process of fiber. Absorption loss results in dissipation of some optical power as hear in the fiber cable. Although glass fibers are extremely pure, some impurities still remain as residue after purification. The amount of absorption by these impurities depends on their concentration and light wavelength.

Absorption is caused by three different mechanisms.

1) Absorption by atomtic defects in glass composition.
2) Extrinsic absorption by impurity atoms in glass matts.
3) Intrinsic absorption by basic constituent atom of fiber.

Bending Loss

Losses due to curvature and losses caused by an abrupt change in radius of curvature are referred to as 'bending losses.'

The sharp bend of a fiber causes significant radiative losses and there is also possibility of mechanical failure. This is shown in Fig. 2.4.1.

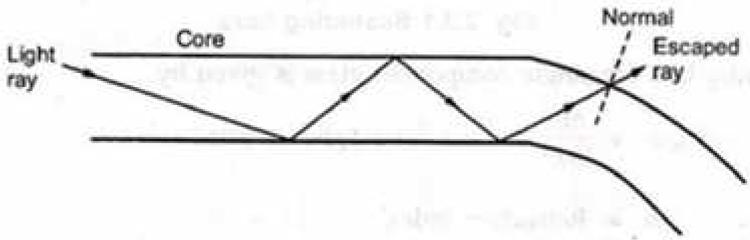


Fig. 2.4.1 Bending loss

As the core bends the normal will follow it and the ray will now find itself on the wrong side of critical angle and will escape. The sharp bends are therefore avoided.

Material Dispersion

Material dispersion is also called as chromatic dispersion. Material dispersion exists due to change in index of refraction for different wavelengths. A light ray contains components of various wavelengths centered at wavelength λ_{10}. The time delay is different for different wavelength components. This results in time dispersion of pulse at receiving end of fiber. Fig. 2.6.2 shows index of refraction as a function of optical wavelength.

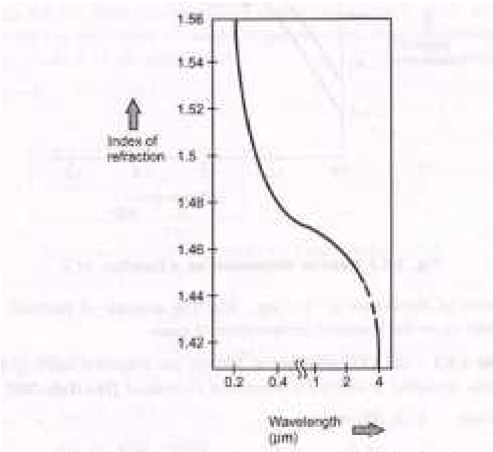


Fig. 2.6.2 Index of refraction as a function of wavelength

The material dispersion for unit length (L = 1) is given by

$$\boxed{D_{mat} = \frac{-\lambda}{c} \times \frac{d^2n}{d\lambda^2}}$$

where, c = Light velocity

λ = Center wavelength

$\frac{d^2n}{d\lambda^2}$ = Second derivative of index of refraction w.r.t wavelength

Negative sign shows that the upper sideband signal (lowest wavelength) arrives before the lower sideband (highest wavelength).

A plot of material dispersion and wavelength is shown in Fig. 2.6.3

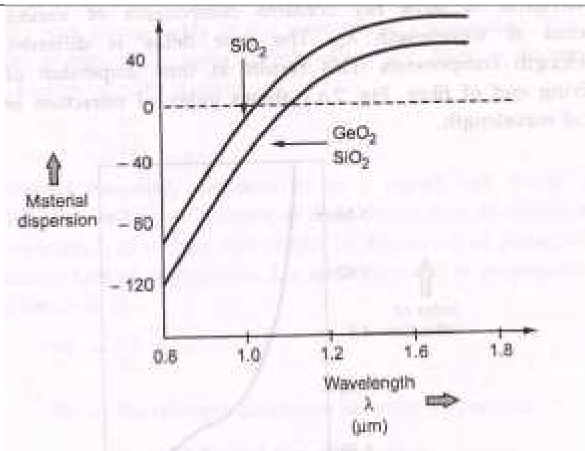


Fig. 2.6.3 Material dispersion as a function of λ

The unit of dispersion is : ps/nm . km. The amount of material dispersion depends upon the chemical composition of glass.

Waveguide Dispersion

Waveguide dispersion is caused by the difference in the index of refraction between the core and cladding, resulting in a 'drag' effect between the core and cladding portions of the power.

Waveguide dispersion is significant only in fibers carrying fewer than 5-10 modes. Since multimode optical fibers carry hundreds of modes, they will not have observable waveguide dispersion.

The group delay (τ_{wg}) arising due to waveguide dispersion.

$$(\tau_{wg}) = \frac{L}{c}\left[n_2 + n_2\,\Delta\,\frac{d\,(kb)}{dk}\right]$$

b = Normalized propagation constant

k = 2π / λ (group velocity)

Normalized frequency V,

$$V = ka(n_1^2 - n_2^2)^{\frac{1}{2}}$$

$$V = k\,a\,n_2\sqrt{2\Delta}\ \text{(For small } \Delta)$$

$$\tau_{wg} = \frac{L}{c}\left[n_2 + n_2\,\Delta\,\frac{d\,(Vb)}{dV}\right]$$

As frequency is a function of wavelength, the group velocity of the energy varies with frequency. The produces additional losses (waveguide dispersion). The propagation constant (b) varies with wavelength, the causes of which are independent of material dispersion.

Signal Distortion in Optical Fibers

One of the important property of optical fiber is signal attenuation. It is also known as fib loss or signal loss. The signal attenuation of fiber determines the maximum distance betwee transmitter and receiver. The attenuation also determines the number of repeaters require maintaining repeater is a costly affair.

Another important property of optical fiber is distortion mechanism. As the signal puls travels along the fiber length it becomes broader. After sufficient length the broad pulse starts over lapping with adjacent pulses. This creates error in the receiver. Hence th distortion limits the information carrying capacity of fiber

Attenuation

Attenuation is a measure of decay of signal strength or loss of light power that occurs as lig pulses propagate through the length of the fiber.

In optical fibers the attenuation is mainly caused by two physical factors absorption ar scattering losses. Absorption is because of fiber material and scattering due to structur imperfections within the fiber. Nearly 90% of total attenuation is caused by Rayleig scattering only. Micro bending of optical fiber also contributes to the attenuation of signal.

Attenuation Units As attenuation leads to a loss of power along the fiber, the output pow is significantly less than the coupled power. Let the coupled optical power is P (0) i.e. origin (z = 0) Then the power at distance z is given by

$$P(Z) = P(0)e^{-\alpha_p Z}$$

Therefore $$\alpha_p = \left(\frac{1}{z}\right)\ln\left[\frac{P(o)}{P(Z)}\right]$$

$$\alpha_{dB/Km} = 10.\left(\frac{1}{z}\right)\ln\left[\frac{P(o)}{P(Z)}\right]$$

This parameter is known as fiber loss or fiber attenuation. Attenuation is also a function wavelength. Optical fiber wavelength as a function of wavelength is shown in fig 5.1

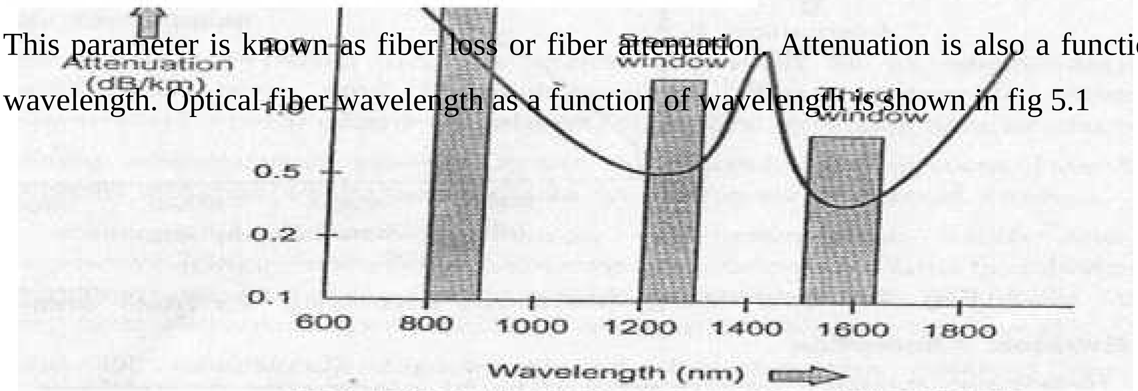


Fig 5.1 Fiber Attenuation As a function of Wave length

A 10 km length of fiber is 100 μW and the average output power is 25 (J.W. Calculate,

(i) The signal attenuation in dB through the fiber. It is assumed that there are n connectors or splices

(ii) Signal attenuation per km of the fiber

(iii) Overall signal attenuation for the 11 km optical link using the same fiber with splices, each having an attenuation of 0.8 dB

(iv) Numerical value of the ratio between input and output power.

Ans:

Given L=10

Pinput = 100μm

Poutput =25μm

(i) Attenuation

$(\alpha)\ dB = 10 \log_{10}$ (Pinput/Poutput)

$\alpha(dB) = 10 \log_{10}(100*10^{-6}/25*10^{-6})$

α (dB) =6.02 dB

(ii) The signal Attenuation per Km of the fiber is

α (dB) .L =6.02

α (dB) = 6.02/10 $dBKm^{-1}$

= 0.602 $dBKm^{-1}$

(iii) Attenuation per unit length α (dB)

The loss produced along 11Km of the fiber is,

α (dB) .L = 0.602*11(Km* $dBKm^{-1}$)= 6.622dB

The number of splices are 3, each having attenuation of 0.8 dB

Therefore Total loss due t splices is 0.8*3 =2.4

Therefore Total signal attenuation = 6.622 dB + 2.4dB

α (dB) = 9.022dB

(iv) Numerical values of the ratio between input and output power is,

$$\text{Pinput/Poutput} = 10^{\left(\frac{\alpha_{dB}}{10}\right)}$$

$$= 10^{\left(\frac{9.022}{10}\right)} = 7.98$$

Write notes on broadening of pulse in the fiber dispersion?

Ans: The dispersion of the transmitted optical signal causes distortion for both digital ar analog transmission along optical fibers. If we consider the major implementation of optic fiber transmission which involves some form of digital modulation, then the dispersio technique within the fiber causes broadening of the transmitted light pulses as they trav along the channel. This phenomenon is depicted in figure (a), where it may be observed th each pulse broadens and coincides with its neighbors, eventually becoming indistinguishab at the receiver input

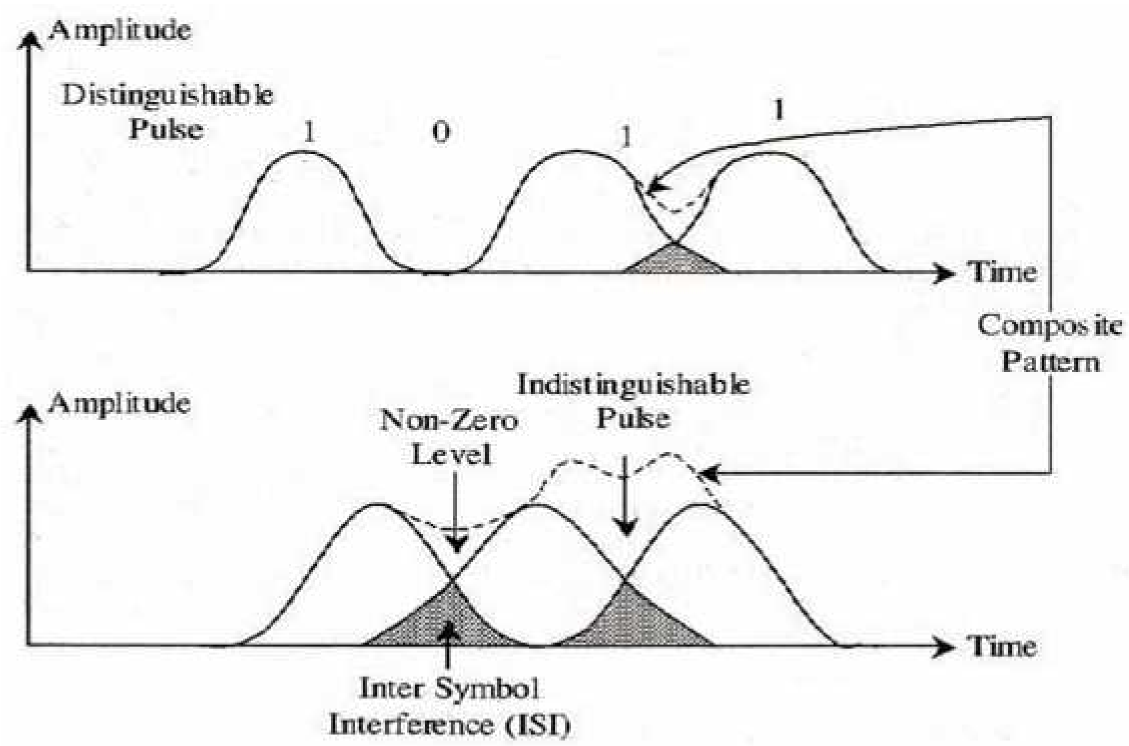


Illustration Of pulse Broading using Digital Bit Pattern 1011

The effect of overlapping of pulses shown in figure (a)' is called Inter Symbol Interferenc (ISI). Thus, ISI becomes more pronounced when increasing numbers of errors a encountered on the digital optical channel. For no overlapping of pulses down on an optic fiber link, the digital bit rate B_T must be less than the reciprocal of the broadened puls duration through dispersion (2τ) and hence,

$B_T \leq 1/2\tau$…………….. (1)

Equation (1) assumes that the pulse broadening due to dispersion on the channel is **T** whic follows the input pulse duration which is also τ. Another more accurate estimate of th maximum bit rate for an optical channel with dispersion may be obtained by considering th light pulses at the output to have a Gaussian shape with an r.m.s. width of τ.

Dispersion Shifted Fiber

Single mode fibers which are designed to offer simultaneously zero dispersion and minimu attenuation at λ = 1.55μ m is called dispersion shifted fibers. The dispersion classifications o various fibers are shown in figure 8.1, which depicts the shifting of zero dispersio wavelength from λ = 1.33 um to λ= 155 mm. This can be achieved by changing the fibe parameters, namely, the refractive index dispersion shifted fiber.

For example, by reducing the fiber core diameter from 8-10μm to 4.5μm and increasing th refractive index difference between core and cladding from 0.003 to greater than 0.01 yield zero dispersion wavelength shifted from 1.33μm to 1.55μm. This may lead to substanti excess loss. Triangular core profile also yields dispersion shifted fibers and moreover solves the above excess loss problem. So, for better results we have to modify the triangula profile. These Profiles are shown in below figure

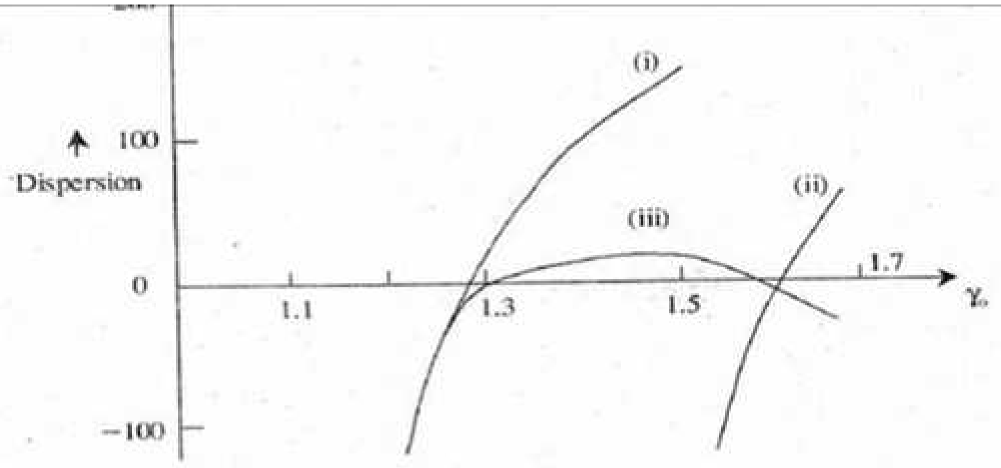
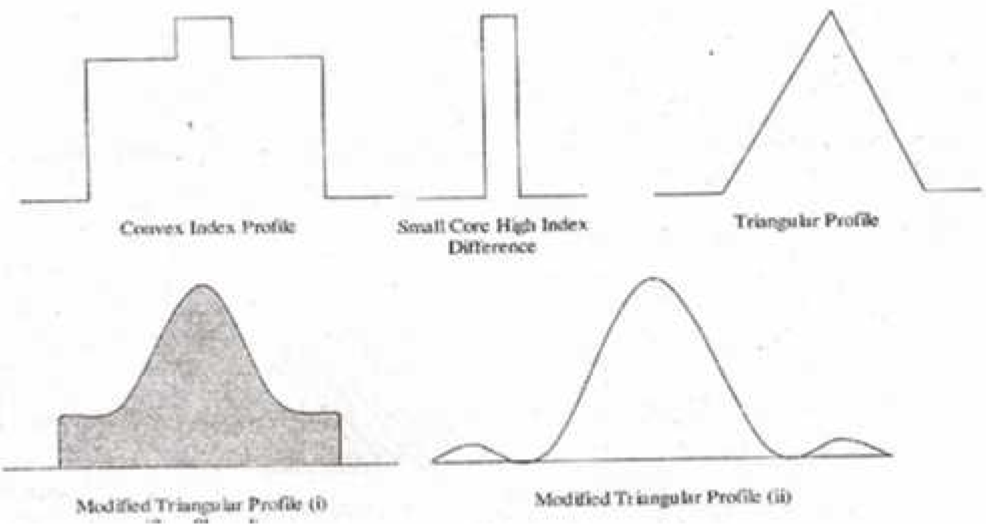


Fig 8.1 (i) Standard fiber (ii) Dispersion shifted fiber (iii)Dispersion Flatted fiber



The above figure shows that the convex index profile also gives the dispersion shifted fiber. Dispersion shifted fibers have the advantage of increased guiding strength, increase in th cut-off wavelength of second order mode and better resistance to bending losses Suc dispersion shifted fibers have been produced by BTRL and others and are now commerciall available from any glass company.

Table (1) compares the characteristics of triangular refractive index profile dispersion shifte fiber with that of simple step index fiber.

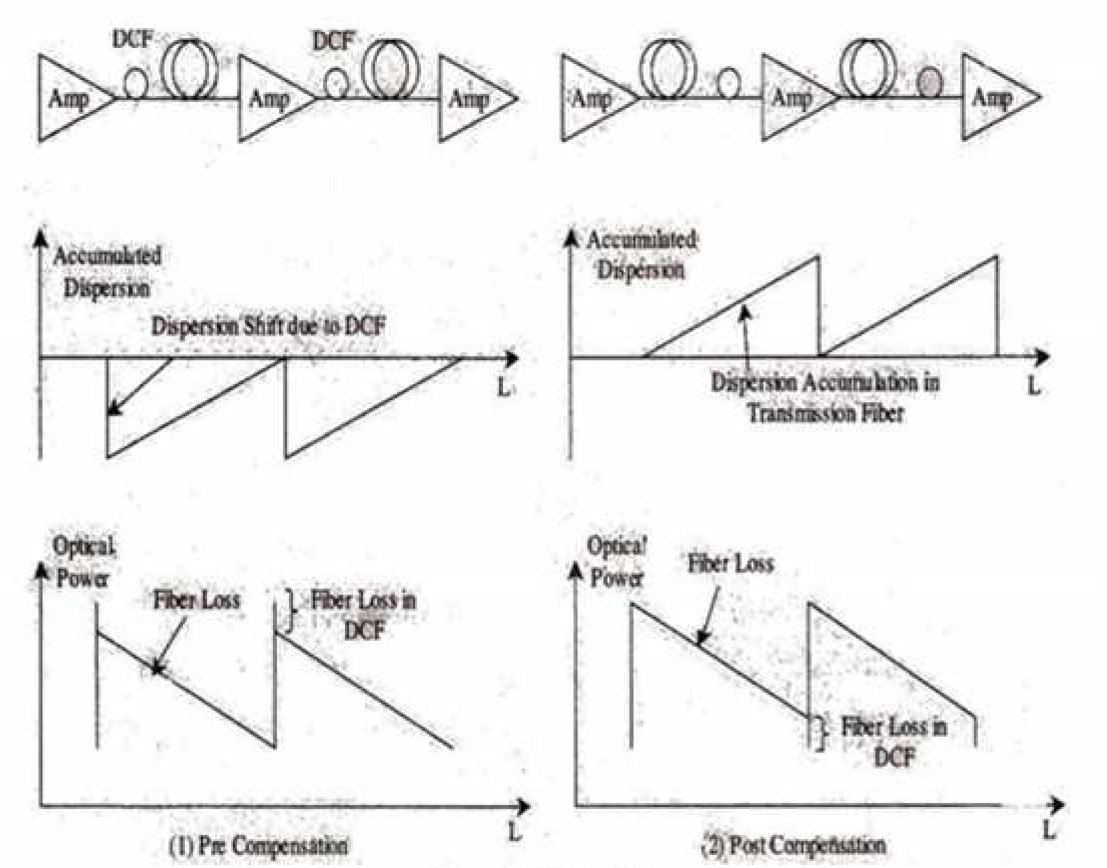
Dispersion Compensating Fiber

The process of dispersion compensation and the fiber loop is referred as dispersio compensating fiber. A large base of dispersion shifted fiber has been installed throughout th world for use in the single wavelength transmission systems. For these kinds of links th complexity arises from Four Wave Mixing (FWM), when one attempt to upgrade them wi high speed dense WDM technology in which the channel spacing is less than 100 GHz ar the bit rates are in excess of 2.5 Gb/s. By using the passive dispersion compensatio technique we can reduce the effect of FWM (four wave mixing). This consists of insertin into the link a loop of fiber having a dispersion characteristic that negates the accumulate dispersion of the transmission fiber. This process is known as dispersion compensation. If th transmission fiber has a low positive dispersion, the dispersion compensating fiber will hav a large negative dispersion. By using this technique, the total accumulated dispersion wi become zero after some distance, but the absolute dispersion per length is non-zero at a points along the fiber.

Figure depicts the Dispersion Compensating Fiber (DCF) which can be inserted at either th starting (or) the end of an installed fiber span between two optical amplifiers. A third optio is to have DCF (Dispersion Compensating Fiber) at both ends.

The above figure shows that the convex index profile also gives the dispersion shifted fiber.

Dispersion shifted fibers have the advantage of increased guiding strength, increase in th cut-off wavelength of second order mode and better resistance to bending losses.



Dispersion and Power Maps

SCATTERING LOSS

The scattering loss is due to the non-uniformity of the refractive index inside the core of the fiber. The refractive index of an optical fiber has fluctuation of the order of 10 ^{4} over spatial scales much smaller than the optical wavelength. These fluctuations act as scattering centers for the light passing through the fiber. The process is, **Rayleigh scattering**. A very tiny fraction of light gets scattered and therefore contributes to the loss.

The Rayleigh scattering is a very strong function of the wavelength. The scattering loss varies as ^{4} . This loss therefore rapidly reduces as the wavelength increases. For each doubling of the wavelength, the scattering loss reduces by a factor of 16. It is then clear that the scattering loss at 1550nm is about factor of 16 lower than that at 800nm. The following Fig. shows the infrared, scattering and the total loss as a function of wavelength.

It is interesting to see that in the presence of various losses, there is a natural window in the optical spectrum where the loss is as low as 0.2-0.3dB/Km. This window is from 1200nm to 1600nm.

There is a local attenuation peak around 1400nm which is due to OH absorption. The low-loss window therefore is divided into sub-windows, one around 1300nm and other around 1550nm. In fact these are the windows which are the II and III generation windows of optical communication.