Optical Fiber Communications

— chapter03—
Transmission characteristics of optical fibers

Attenuation

- The attenuation or transmission loss of optical fibers has proved to be one of the most important factors in bringing about their wide acceptance in telecommunications.
- As channel attenuation largely determined the maximum transmission distance prior to signal restoration,
  - optical fiber communications became especially attractive when the transmission losses of fibers were reduced below those of the competing metallic conductors (less than 5 dB km^{-1})

Attenuation

- Signal attenuation within optical fibers, as with metallic conductors, is usually expressed in the logarithmic unit of the decibel.
- The decibel, which is used for comparing two power levels, may be defined for a particular optical wavelength as the ratio of the input (transmitted) optical power P_i *into a fiber to the output (received) optical power* P_o from the fiber as:

$$\text{Number of decibels (dB)} = 10 \log_{10} \frac{P_i}{P_o}$$

Attenuation

- This logarithmic unit has the advantage that the operations of multiplication and division reduce to addition and subtraction, while powers and roots reduce to multiplication and division.
- However, addition and subtraction require a conversion to numerical values which may be obtained using the relationship:

$$\frac{P_i}{P_o} = 10^{(dB/10)}$$

Attenuation

- In optical fiber communications the attenuation is usually expressed in decibels per unit length (i.e. dB km−1) following:

$$\alpha_{dB} L = 10 \log_{10} \frac{P_i}{P_o}$$

  - where α_{dB} is the signal attenuation per unit length in decibels which is also referred to as the fiber loss parameter and *L is the fiber length.*

Attenuation

- A number of mechanisms are responsible for the signal attenuation within optical fibers.
- These mechanisms are influenced by
  - the material composition ,
  - the preparation and
  - purification technique, and
  - the waveguide structure.

Attenuation

- They may be categorized within several major areas which include
  - material absorption,
  - material scattering (linear and nonlinear scattering),
  - curve and microbending losses,
  - mode coupling radiation losses and
  - Losses due to leaky modes.
- There are also losses at connectors and splices (সংযুক্ত করান), as illustrated in Example 3.1.

Example 3.1

When the mean optical power launched into an 8 km length of fiber is 120 μW, the mean optical power at the fiber output is 3 μW.

Determine:

(a) the overall signal attenuation or loss in decibels through the fiber assuming there are no connectors or splices;

(b) the signal attenuation per kilometer for the fiber.

(c) the overall signal attenuation for a 10 km optical link using the same fiber with splices at 1 km intervals, each giving an attenuation of 1 dB;

(d) the numerical input/output power ratio in (c).

Solution: (a) Using Eq. (3.1), the overall signal attenuation in decibels through the fiber is:

$$\text{Signal attenuation} = 10\log_{10}\frac{P_i}{P_o} = 10\log_{10}\frac{120\times10^{-6}}{3\times10^{-6}}$$

$$= 10\log_{10}40 = 16.0\text{ dB}$$

(b) The signal attenuation per kilometer for the fiber may be simply obtained by dividing the result in (a) by the fiber length which corresponds to it using Eq. (3.3) where:

$$\alpha_{dB}L = 16.0\text{ dB}$$

hence:

$$\alpha_{dB} = \frac{16.0}{8}$$

$$= 2.0\text{ dB km}^{-1}$$

(c) As $\alpha_{dB} = 2$ dB km^{-1}, the loss incurred along 10 km of the fiber is given by:

$$\alpha_{dB} L = 2 \times 10 = 20 \text{ dB}$$

However, the link also has nine splices (at 1 km intervals) each with an attenuation of 1 dB. Therefore, the loss due to the splices is 9 dB.

Hence, the overall signal attenuation for the link is:

$$\begin{aligned} \text{Signal attenuation} &= 20 + 9 \\ &= 29 \text{ dB} \end{aligned}$$

(d) To obtain a numerical value for the input/output power ratio, Eq. (3.2) may be used where:

$$\frac{P_i}{P_o} = 10^{29/10} = 794.3$$

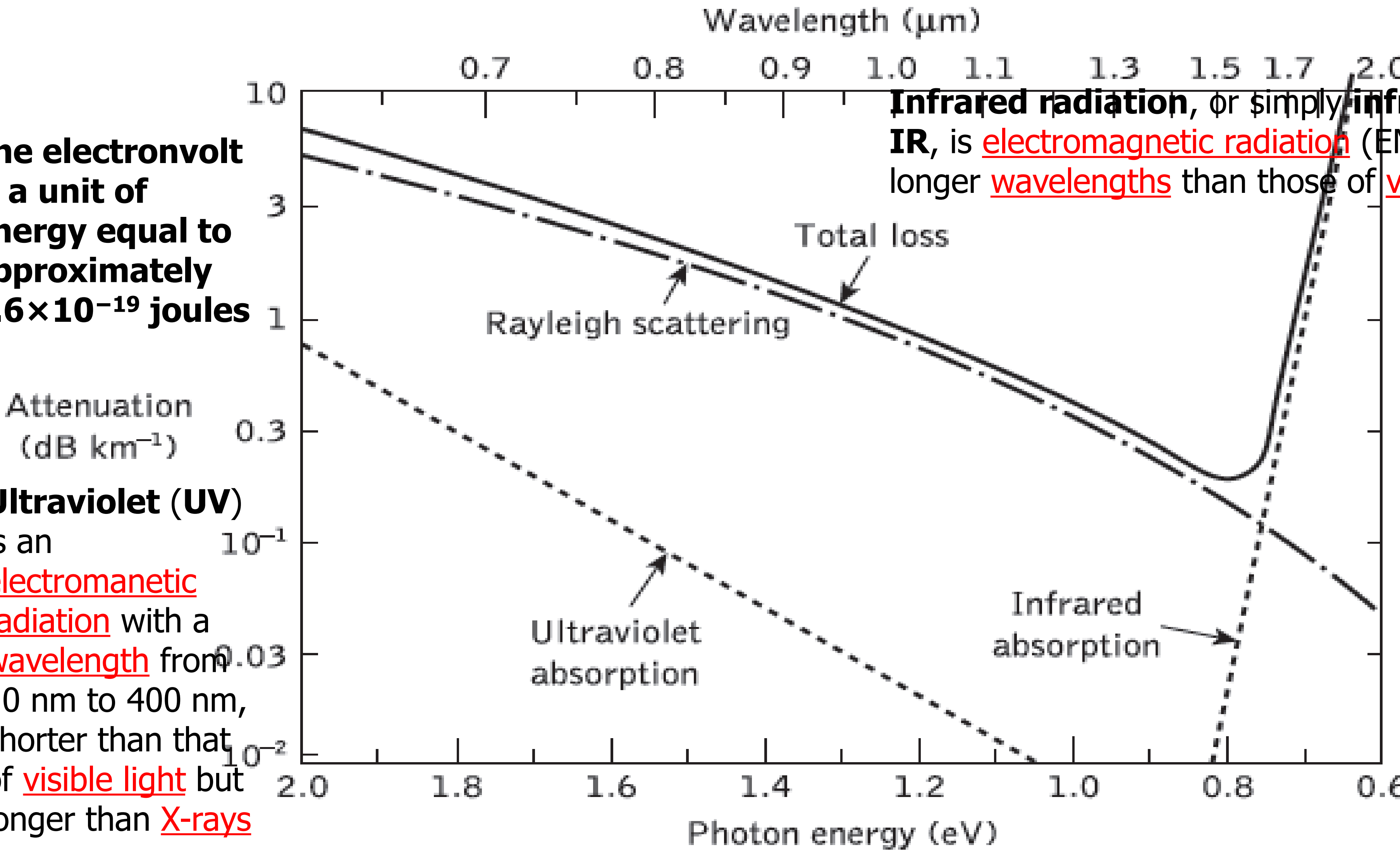
Material absorption losses in silica glass fibers

- Material absorption is a loss mechanism related to the material composition and the fabrication process for the fiber, which results in the dissipation(অপচয়) of some of the transmitted optical power as heat in the waveguide.
- The absorption of the light may be
  - intrinsic (caused by the interaction with one or more of the major components of the glass) or
  - extrinsic (caused by impurities within the glass).

The attenuation spectra for the intrinsic loss mechanisms in pure GeO2–SiO2 glass

The electronvolt is a unit of energy equal to approximately 1.6×10^{-19} joules

Infrared radiation, or simply **infrar** **IR**, is electromagnetic radiation (EMR) longer wavelengths than those of visib



Ultraviolet (**UV**) is an electromanetic radiation with a wavelength from 10 nm to 400 nm, shorter than that of visible light but longer than X-rays

Extrinsic absorption

- In practical optical, fibers prepared by conventional melting techniques
- A major source of signal attenuation is extrinsic absorption from transition metal element impurities.

Absorption losses caused by some of the more common metallic ion impurities in glasses, together with the absorption peak wavelength

- It may be noted that certain of these impurities, namely chromium and copper, in their worst valence state can cause attenuation in excess of 1 dB km−1 in the near-infrared region
- **Valence** is generally understood to be **the number of chemical bonds that each atom of a given chemical element typically forms.**

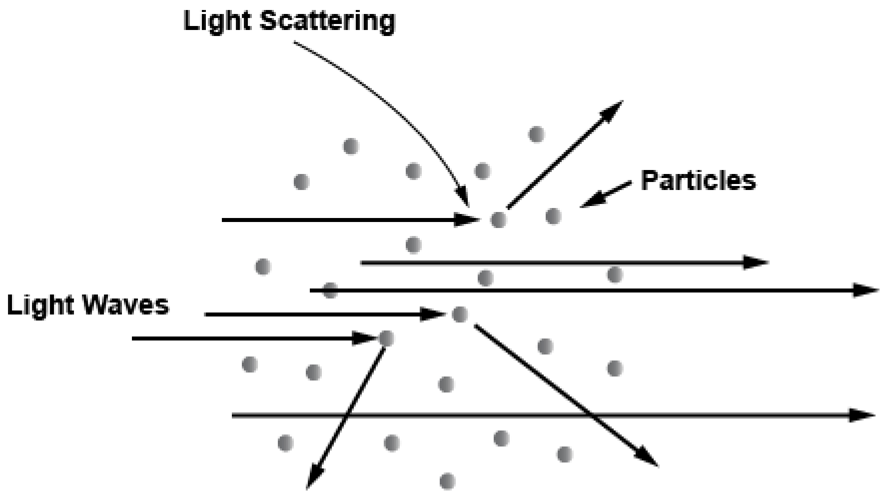
	Peak wavelength (nm)	One part in 10^9 (dB km^{-1})
Cr^{3+}	625	1.6
C^{2+}	685	0.1
Cu^{2+}	850	1.1
Fe^{2+}	1100	0.68
Fe^{3+}	400	0.15
Ni^{2+}	650	0.1
Mn^{3+}	460	0.2
V^{4+}	725	2.7

Extrinsic absorption

- Another major extrinsic loss mechanism is caused by absorption due to water (as the hydroxyl or OH ion) dissolved (দ্রবীভূত) in the glass.
- These hydroxyl groups are bonded into the glass structure and have fundamental stretching vibrations which occur at wavelengths between 2.7 and 4.2 μm depending on group position in the glass network.

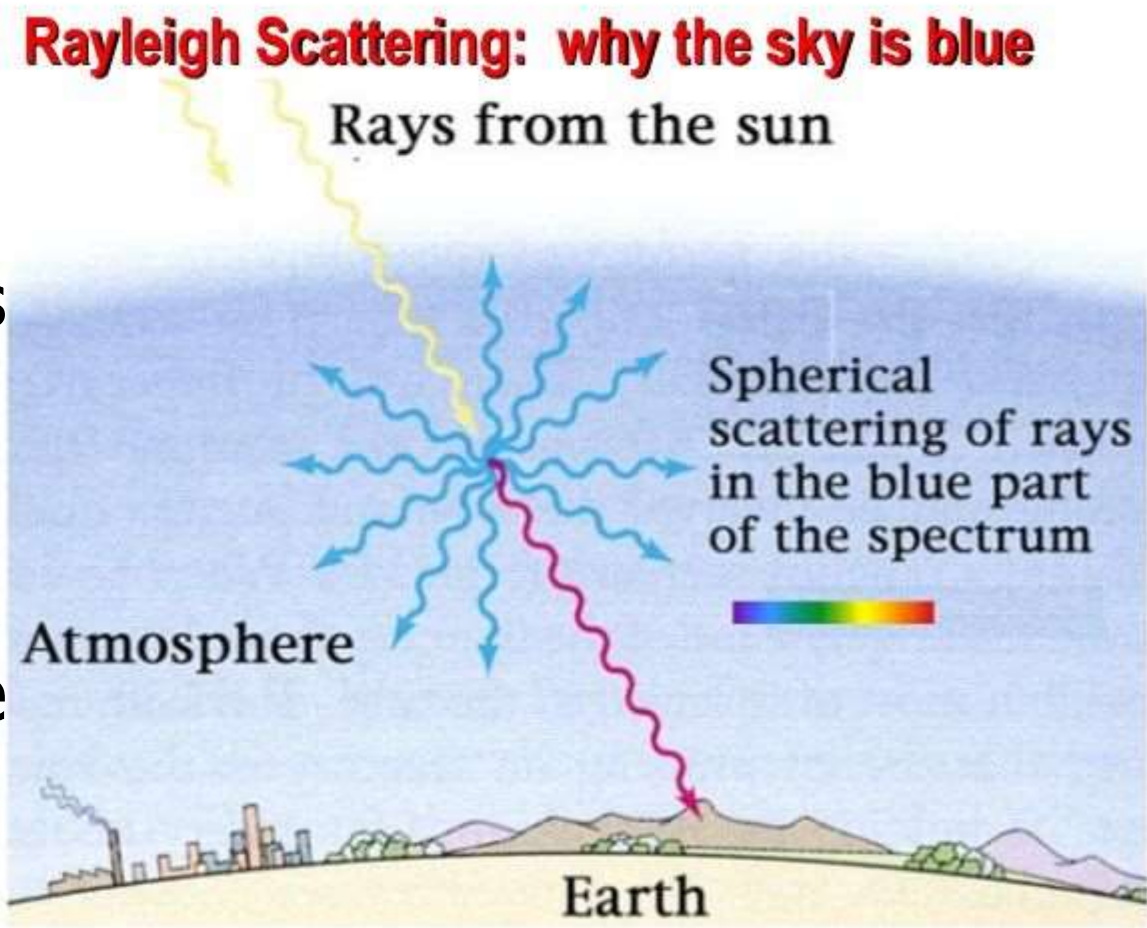
Linear scattering losses

- 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.
- This process tends to result in attenuation of the transmitted light as the transfer may be to a leaky or radiation mode which does not continue to propagate within the fiber core, but is radiated from the fiber.



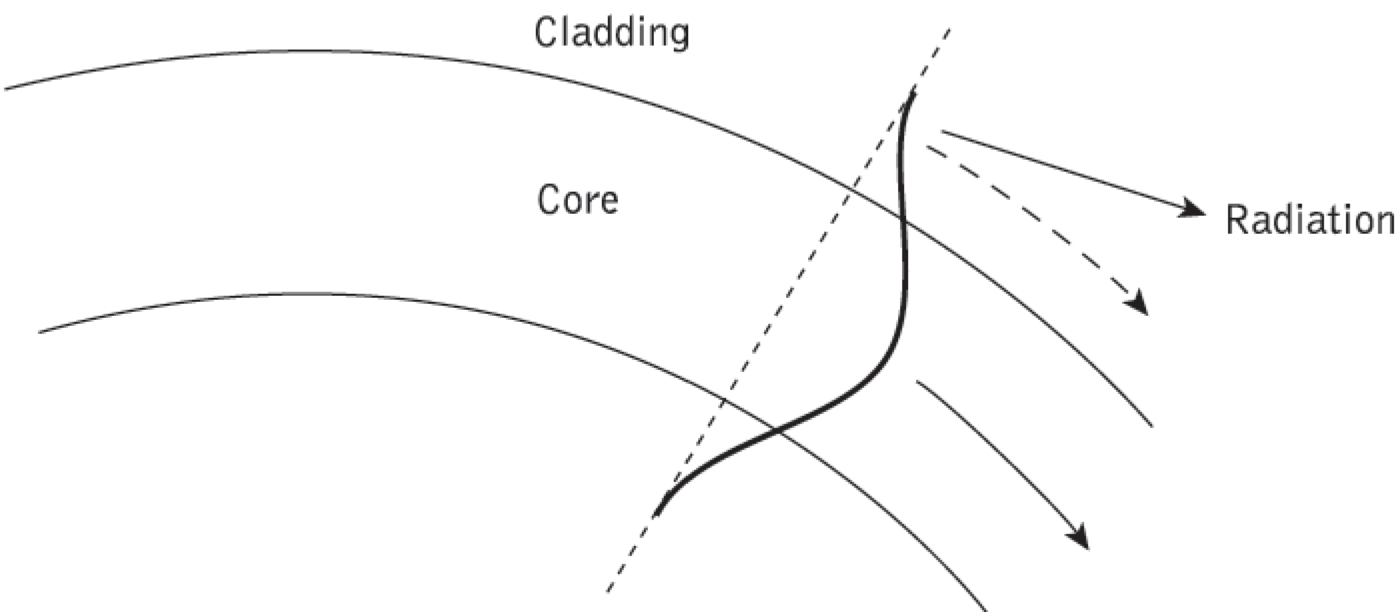
Rayleigh scattering

- **Rayleigh** is the elastic scattering of light or other electromagnetic radiation by particles much smaller than the wavelength of the radiation.
- The particles may be individual atoms or molecules

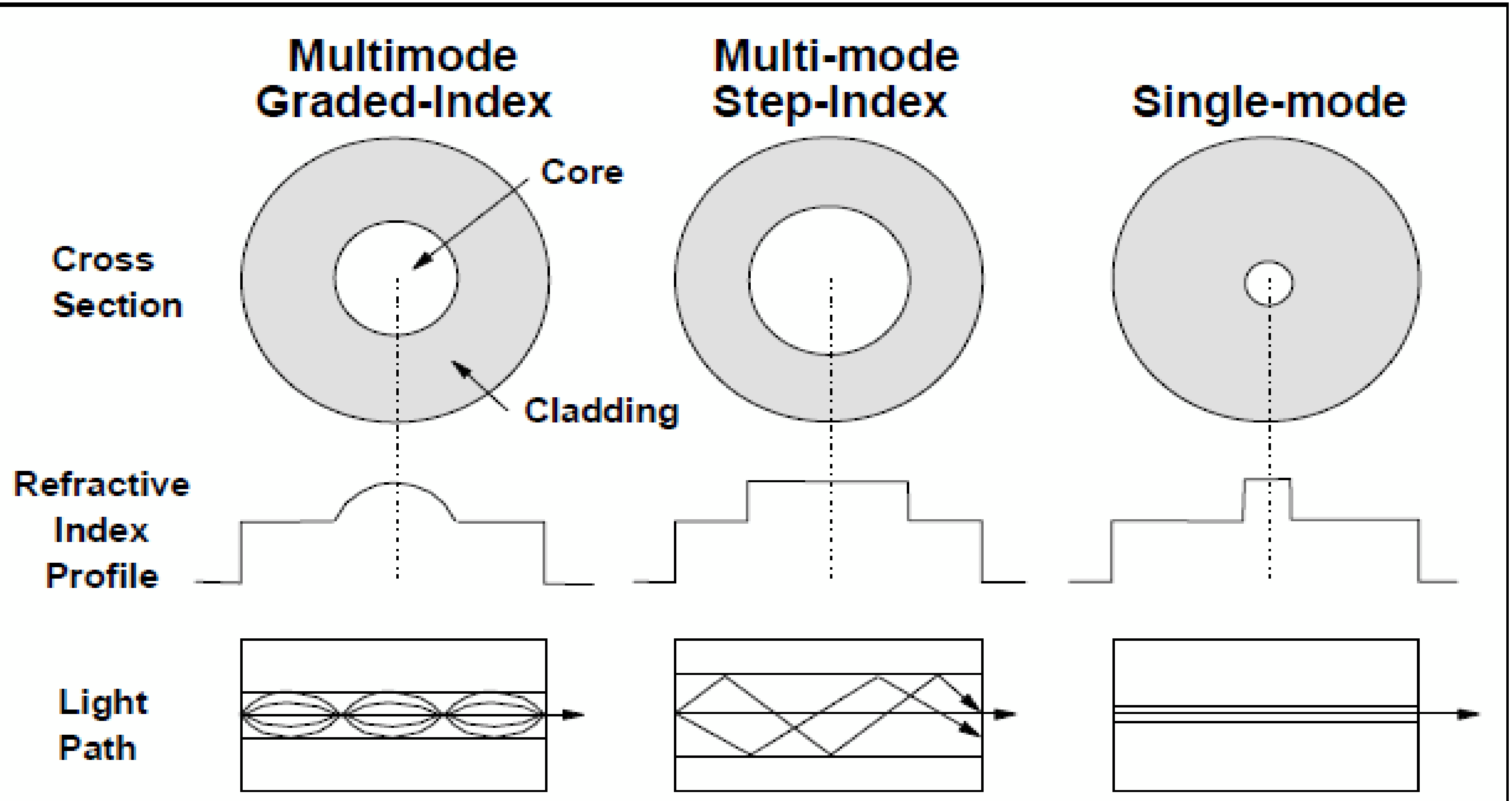


Fiber bend loss

- Optical fibers suffer radiation losses at bends or curves on their paths.
- This is due to the energy in the evanescent(বিলীয়মান) field at the bend exceeding the velocity of light in the cladding and hence the guidance mechanism is inhibited, which causes light energy to be radiated from the fiber.

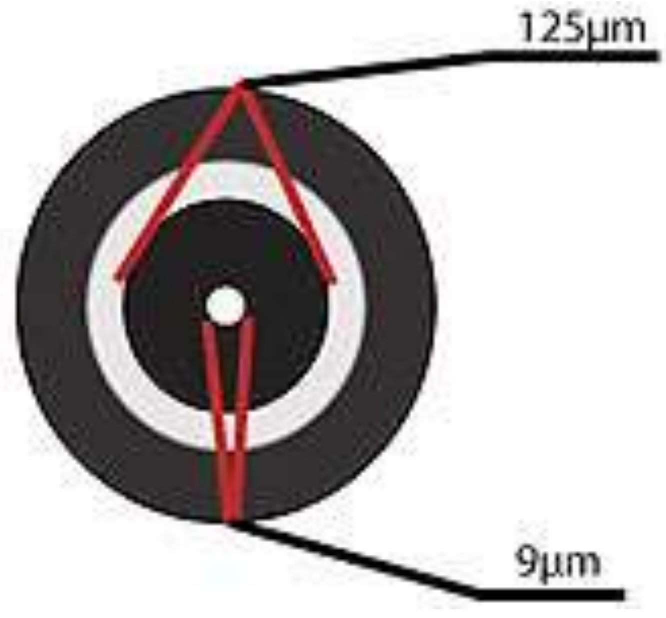


Different mode fiber



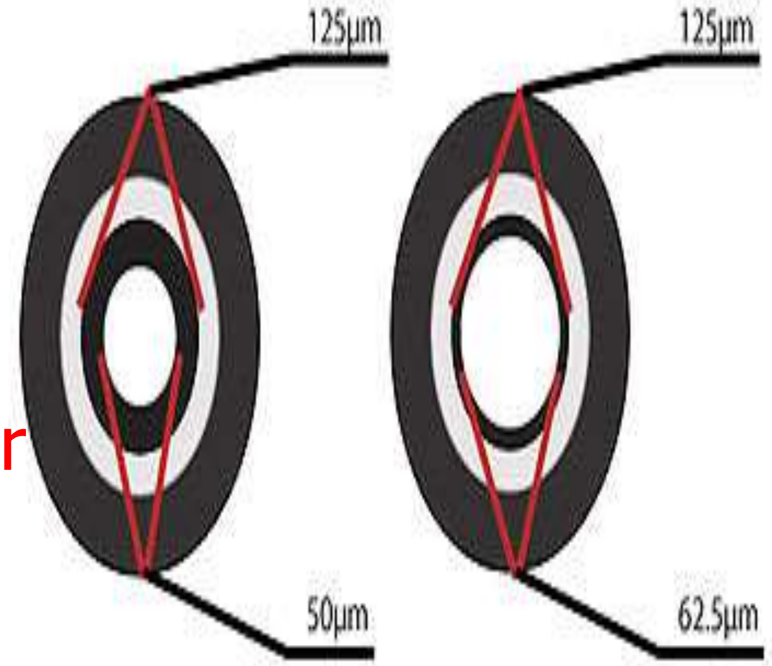
Single Mode Fiber Optic Cable

- Single Mode fiber optic cable has a small diametral core that allows only one mode of light to propagate.
- This application is typically used in long distance
- *Left: Single Mode fiber is usually 9/125 in construction. This means that the core to cladding diameter ratio is 9 microns to 125 microns.*



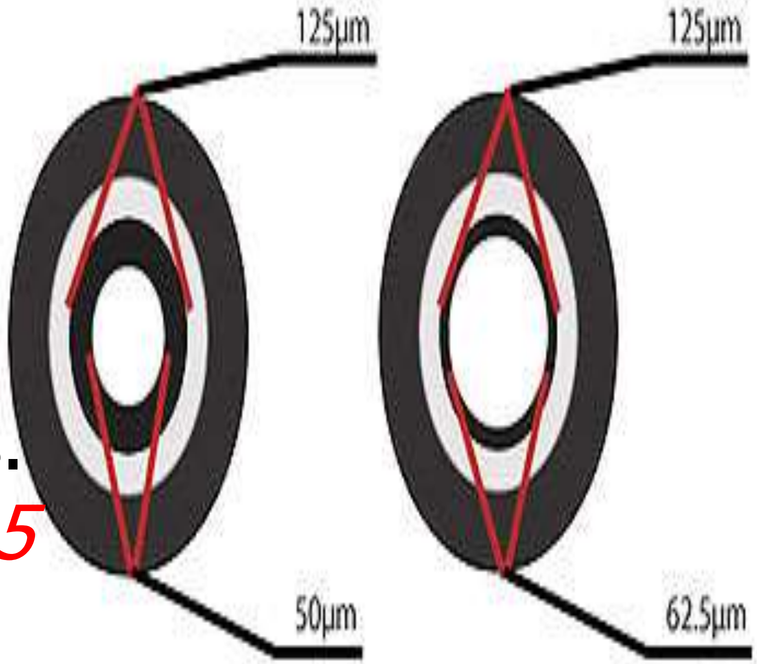
Multimode Fiber Optic Cable

- Multimode fiber optic cable has a large diametral core that allows multiple modes of light to propagate.
- Because of this, the number of light reflections created as the light passes through the core increases, creating the ability for more data to pass through at a given time.



Multimode Fiber Optic Cable

- Because of the high dispersion and attenuation rate with this type of fiber, the quality of the signal is reduced over long distances.
- This application is typically used for short distance, data and audio/video applications in LANs.
- *Multimode fiber is usually 50/125 and 62.5/125 in construction.*
- *This means that the core to cladding diameter ratio is 50 microns to 125 microns and 62.5 microns to 125 microns.*



Dispersion

- Dispersion of the transmitted optical signal causes distortion for both digital and analog transmission along optical fibers.
- Dispersion mechanisms within the fiber cause broadening of the transmitted light pulses as they travel along the channel.
- The phenomenon is illustrated in Figure 3.7, where it may be observed that each pulse broadens and overlaps with its neighbors, eventually becoming indistinguishable at the receiver input.

An illustration using digital bit pattern 1011: broadening of light pulses as they are transmitted along a fiber

- :
- (a) fiber input;
- (b) fiber output at a distance *L1;*
- *(c) fiber output at a distance L2 L1*