EE5706

Optical Communications

การสื่อสารทางแสง

01/06/2560

Signal Degradation in Optical Fibers

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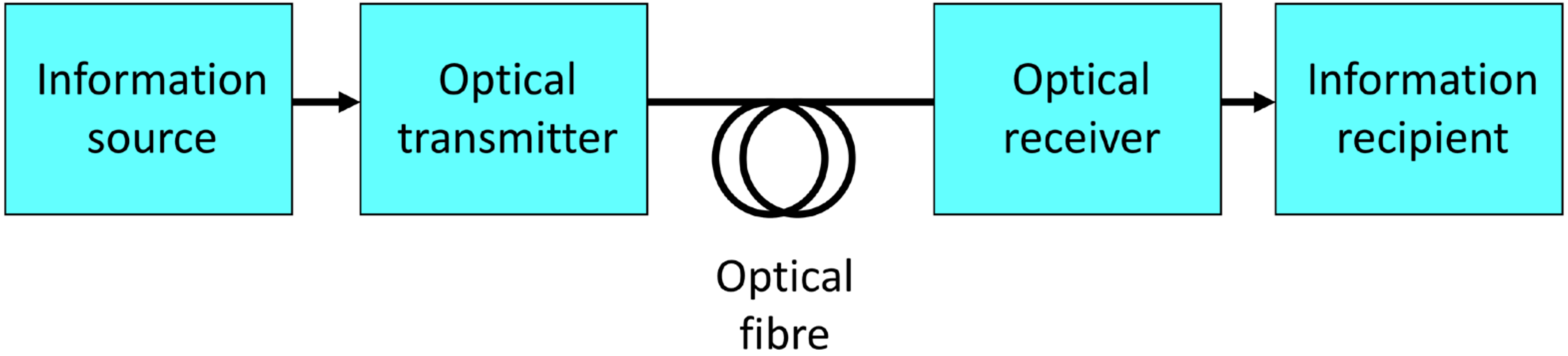
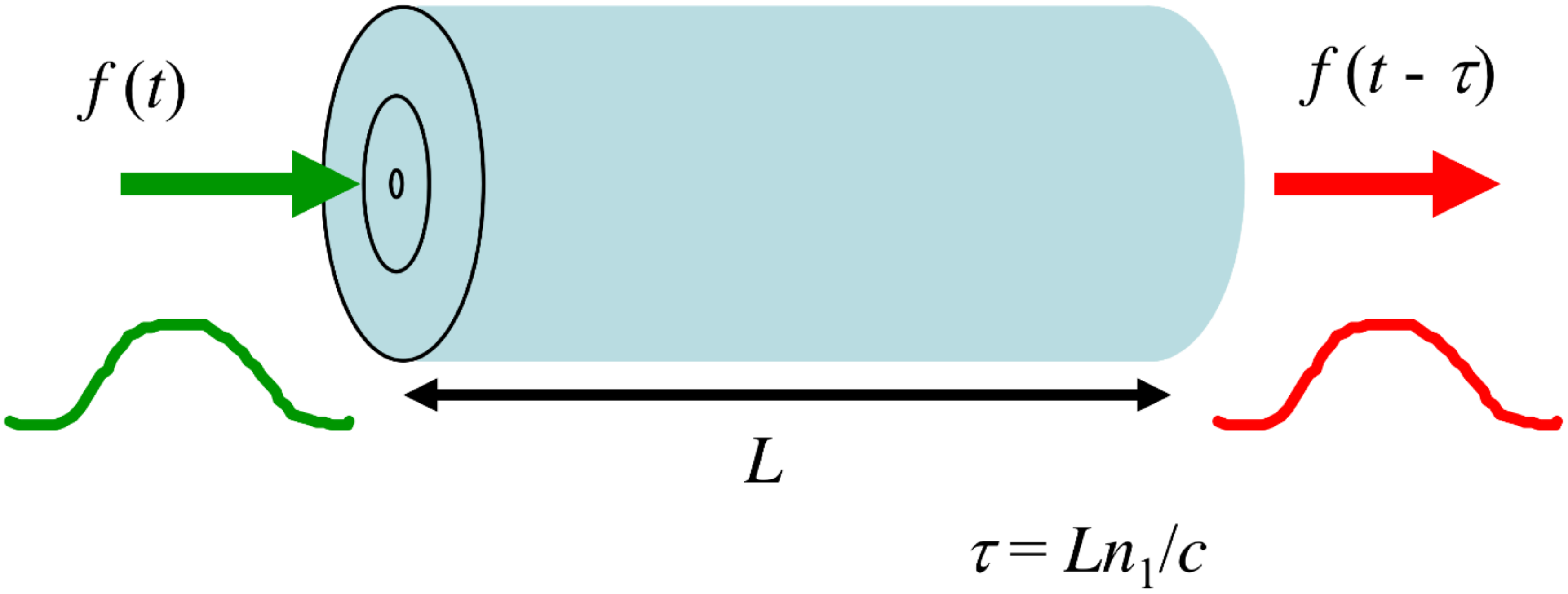
- The simplest optical fibre communications system is a point-to-point link in which an optical transmitter and receiver are connected to one another via an optical fiber. This simple architecture is typical of those used in trans-oceanic links.



Signal Degradation in Optical Fibers

- Without looking into the detail of the optical fiber itself, today we will look at how two important parameters – attenuation and dispersion – can affect the above system.
- In an ideal fiber, "what goes in, is what comes out". In reality, the signal going through the fiber is degraded.



Signal Degradation in Optical Fibers

- The signal traveling through an optical fibre can be degraded due to:
  - Dispersion – leads to pulse spreading. Pulses become wider as they cover more distance in the fiber.
  - Attenuation (leads to loss of power)

Attenuation in Optical Fibers

- What are the loss or signal attenuation mechanism in a fiber?
- Signal attenuation (fiber loss) largely determines the maximum repeaterless separation between optical transmitter & receiver.

How far?

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Attenuation in Optical Fibers

Fiber Attenuation Coefficient

$$\alpha = \frac{P(0)\mathrm{dB} - P(z)\mathrm{dB}}{z} \ \mathrm{dB/km}$$

$$P(0)[\mathrm{dBm}]$$

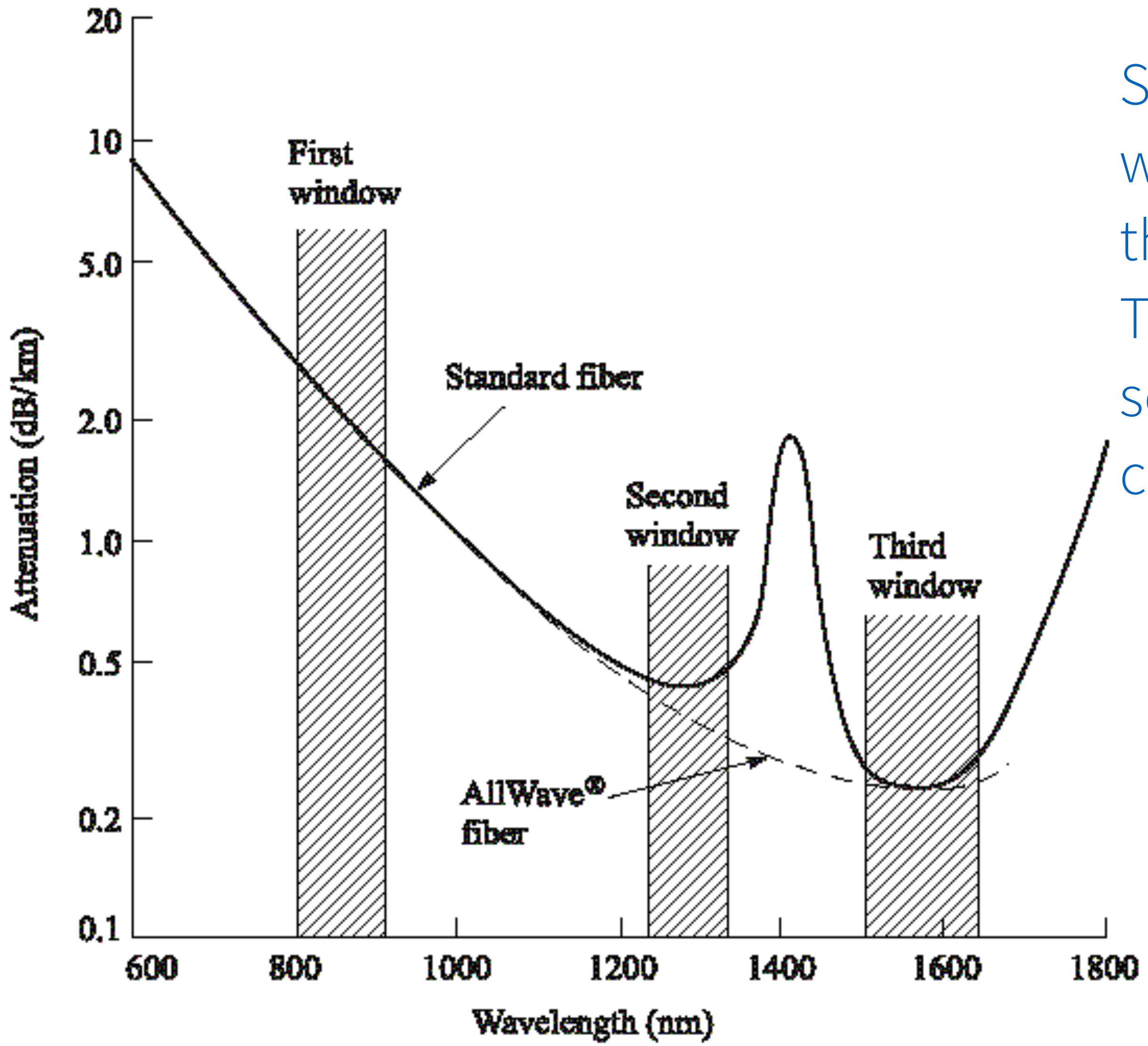
$$P(z) = P(0)e^{-\alpha_p z}$$

Attenuation in Optical Fibers

Fiber Attenuation Coefficient

$$\alpha[\mathrm{dB/km}] = \frac{10}{l}\log\left[\frac{P(0)}{P(l)}\right]$$

Optical fiber attenuation vs. wavelength



Silica optical fibre attenuation varies with wavelength, and over time it has been reduced through improved manufacturing methods. This has influenced the evolution of the first, second and third generations of optical fibre communications.

Attenuation in Optical Fibers

- Silica has lowest attenuation at 1550 nm.
- Once light is coupled into a standard optical fibre, the attenuation is mainly caused by absorption and scattering.
- Attenuation happens because:
  - Absorption (extrinsic and intrinsic)
  - Scattering losses (Rayleigh, Mie)
  - Bending losses (macro and micro bending)

Absorption losses

- Absorption is caused by three different mechanisms:

  1- Extrinsic absorption (Impurities in fiber material): from transition metal ions (must be in order of ppb) & particularly from OH ions with absorption peaks at wavelengths 2700 nm, 400 nm, 950 nm & 725nm.

  2- Intrinsic absorption (fundamental lower limit): electronic absorption band (UV region) & atomic bond vibration band (IR region) in basic SiO_2.

  3- Absorption by atomic defects in glass

Absorption losses: extrinsic

- Extrinsic absorption is caused by metal (iron, cobalt, copper and chromium) and hydroxyl (OH) ions. In the early years, fibers had a high water impurity content, and hence high overtones of the water absorption peak.
- In high purity modern fibers (low OH), loss due to extrinsic absorption has been significantly reduced. (This is achieved by drying the glass in chlorine gas to leach out the water vapor).
- For both OH and metal ions, ion concentrations of one part per billion or less are needed to minimize losses to acceptable levels.

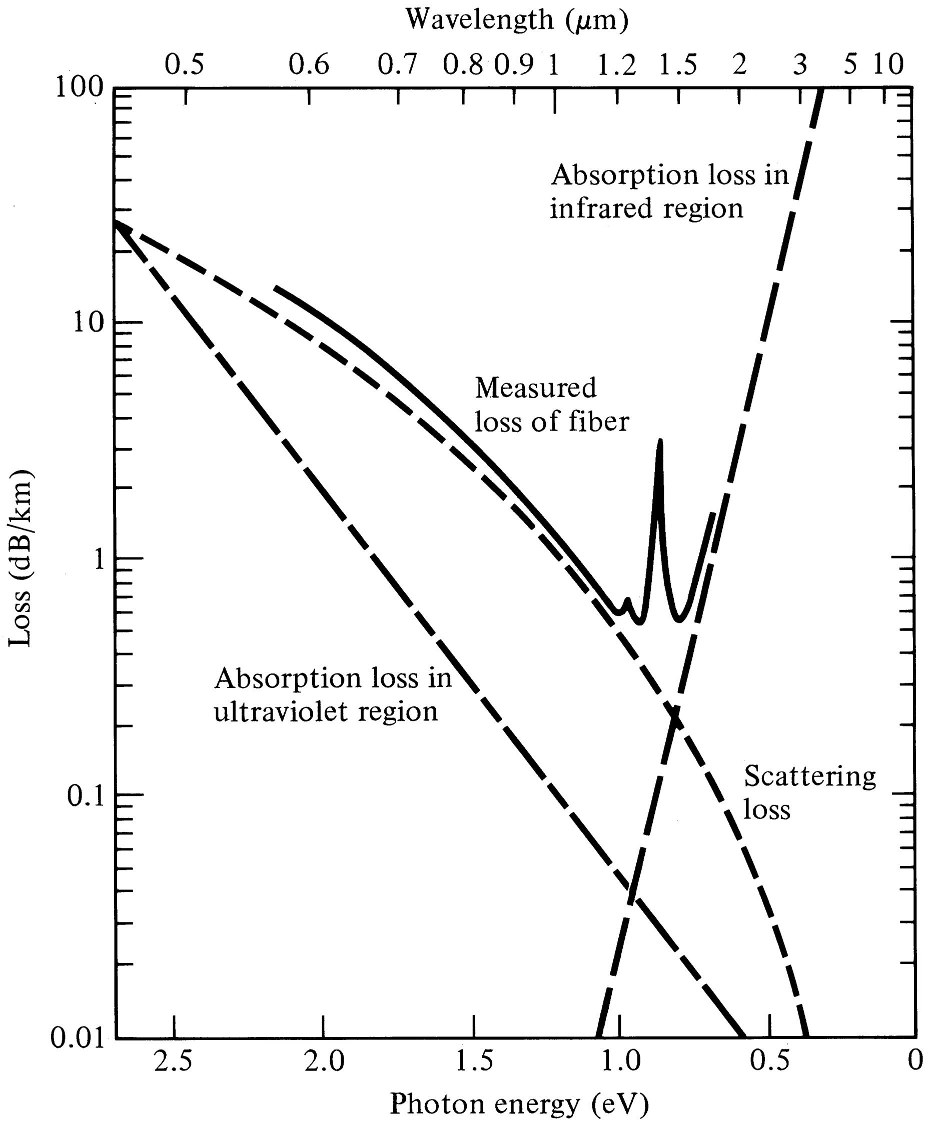
Absorption losses: intrinsic

- Intrinsic absorption results from electronic absorption bands in the UV region and atomic vibration bands in the near infrared region. It is the loss associated with the pure fibre material, and therefore sets the lower limit on absorption.
  - In other words, loss due to absorption cannot be reduced below this limit.
- Attenuation caused by intrinsic absorption in the UV and IR regions is wavelength dependent.

Scattering Loss

- Small (compared to wavelength) variation in material density, chemical composition, and structural inhomogeneity scatter light in other directions and absorb energy from guided optical wave.
- The essential mechanism is the Rayleigh scattering. Since the black body radiation classically is proportional to λ^{-4} (this is true for wavelength typically greater than 5 micrometer), the attenuation coefficient due to Rayleigh scattering is approximately proportional to λ^{-4}.

Absorption & scattering losses in fibers



1 Linear scattering:

- Here the amount of optical power transferred from a wave is proportional to the power in the wave. There is **no frequency change** in the scattered wave.
    - **Rayleigh scattering**
    - **Mie Scattering**

Rayleigh scattering:

- It results from the interaction of the light with the inhomogeneties in the medium that are one-tenth of the wavelength of the light. Rayleigh scattering in a fiber can be expressed as :

$$\boxed{\gamma_{RS} \propto \frac{1}{\lambda^4}}$$

- It means that a system operating at longer wavelengths have lower intrinsic loss.

Mie Scattering:

- If the defects in optical fibers are larger than $\lambda/10$ the scattering mechanism is known as 'Mie scattering'.
- These large defect sites are developed by the inhomogeneities in the fiber and are associated with in complete mixing of waveguide dopants or defects formed in the fabrication process.
- These defects physically scatter the light out of the fiber core.
- **Mie scattering is rarely seen in commercially available silica-based fibers due to the high level of manufacturing expertise.**

2

Non-linear scattering:

- High electric fields within the fiber leads to the non-linear scattering mechanism.
- It causes the scattering of significant power in the forward, backward or sideways depending upon the nature of the interaction.
- This scattering is accomplished by a **frequency shift** of the scattered light.

Raman scattering: (forward light scattering or SRS)

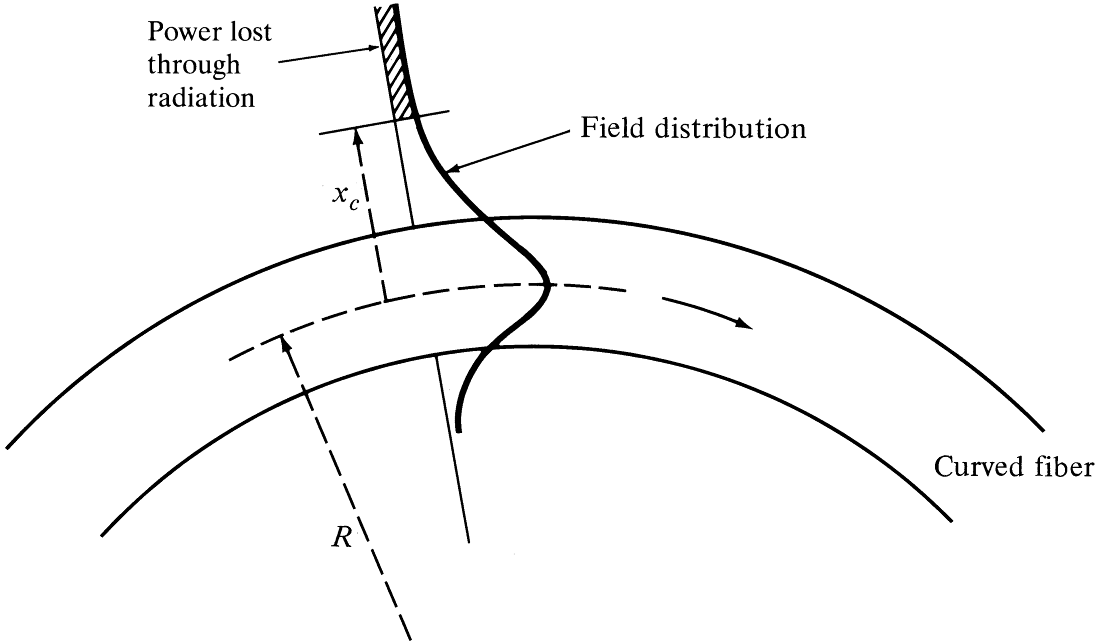
- It is caused by **molecular vibrations of phonons** in the glass matrix.
- This scattering is **dependent on the temperature of the material**.

Brillouin scattering: (backward light scattering or SBS).

- It is induced by **acoustic waves as opposed to thermal phonons**.
- Brillouin scattering is a backscatter phenomenon.
- The importance of SRS and SBS is that they can be the limiting factor in high-power system designs.
- Raman scattering loss is unaffected by spectral source width but requires at least an order of magnitude more power for onset.
- Brillouin scattering loss can be decreased by using a light source with a broad spectral width. A broad spectral width reduces the light-material interaction.

Bending Losses

- Macrobending Loss: The curvature of the bend is much larger than fiber diameter. Lightwave suffers sever loss due to radiation of the evanescent field in the cladding region. As the radius of the curvature decreases, the loss increases exponentially until it reaches at a certain critical radius. For any radius a bit smaller than this point, the losses suddenly becomes extremely large. Higher order modes radiate away faster than lower order modes.

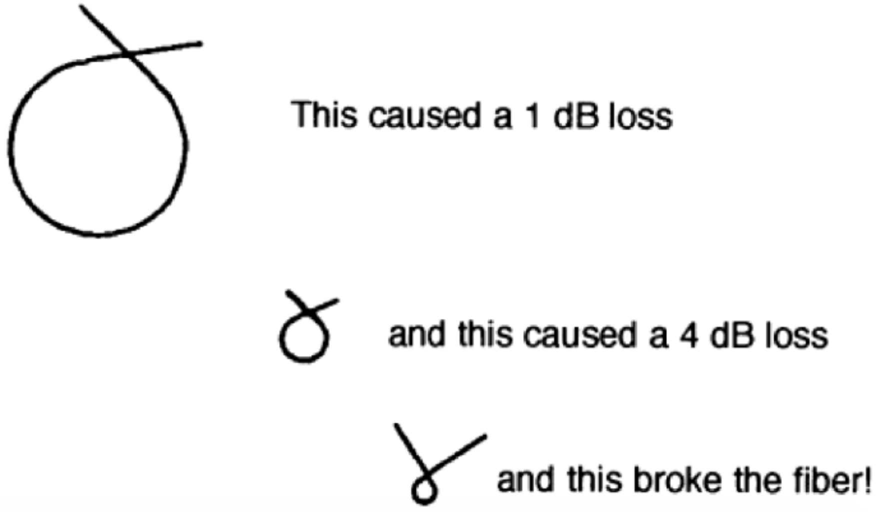


$$\boxed{R = \frac{3 n_2 \lambda}{4 \pi NA^3}}$$

- For slight bends, the excess loss is extremely small. As the radius of curvature decreases, the loss increases exponentially until a certain critical radius occurs. At this point the macro bend losses are significant.

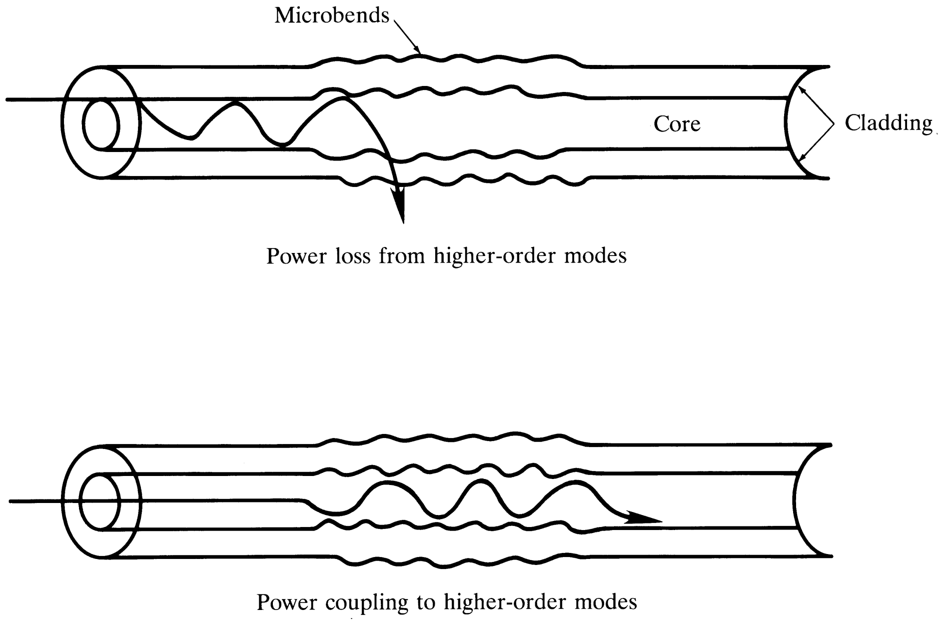
- These losses become extremely large when the bend crosses the critical/threshold point.

- The macro bend losses occur when optical fibers are packed for transportation to the field of installation during installation process.



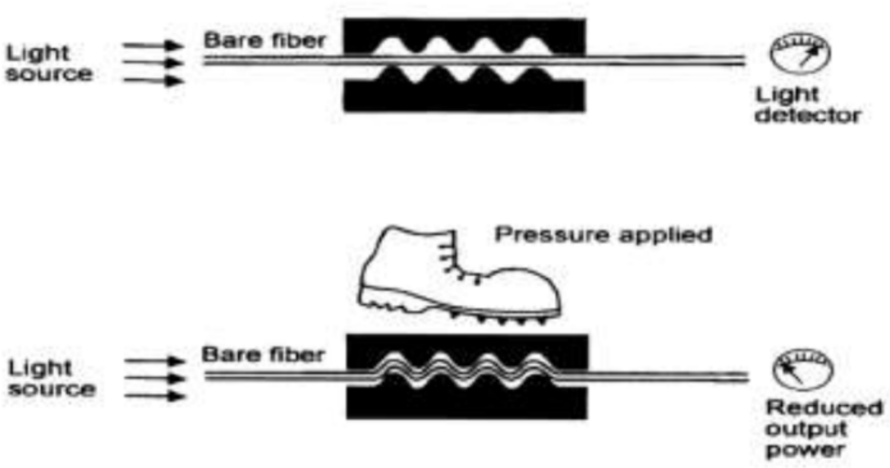
Microbending Loss

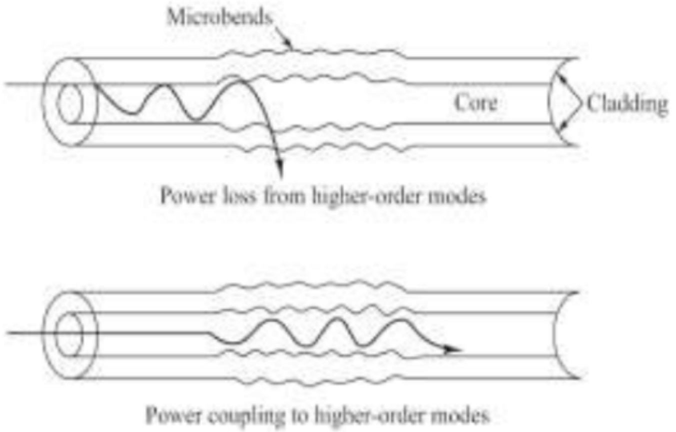
- Microbending Loss: microscopic bends of the fiber axis that can arise when the fibers are incorporated into cables. The power is dissipated through the microbended fiber, because of the repetitive coupling of energy between guided modes & the leaky or radiation modes in the fiber.



Micro bend losses:

- These losses are associated with **small perturbations of the fiber**, induced by the factors like **uneven coating application or cabling induced stresses.**
- The results of the perturbations is to **cause the coupling of propagating modes in the fiber by changing the optical path length**. This de stabilisation of the modal distribution **causes the lower-order modes to couple to the higher-order modes** which are lossy in nature.





3.8 *Small-scale fluctuations in the radius of curvature of the fiber axis lead to microbending losses. Microbends can shed higher-order modes and can cause power from low-order modes to couple to higher-order modes*

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