Lecture Four

Signal Degradation in Optical Fibeir II

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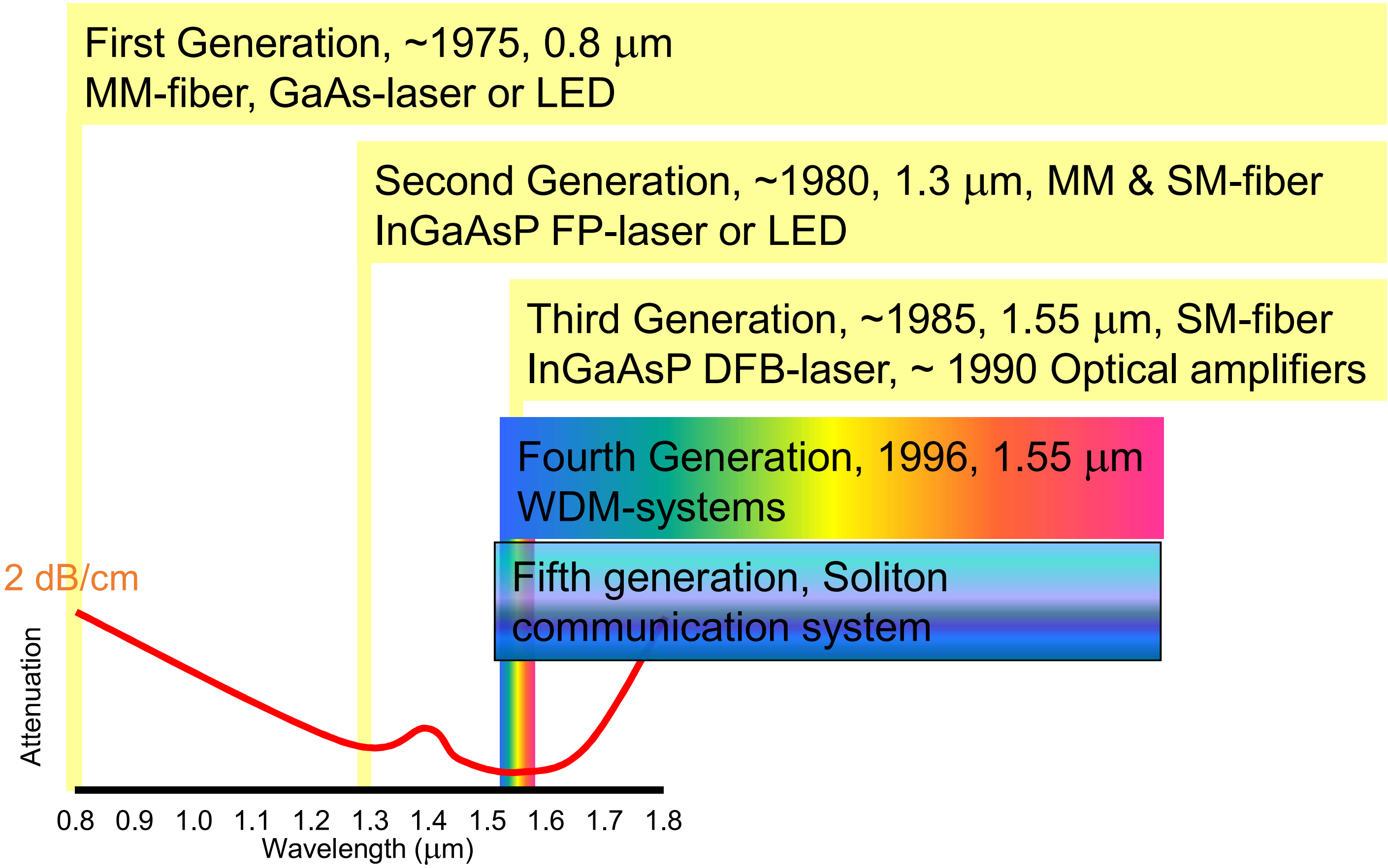
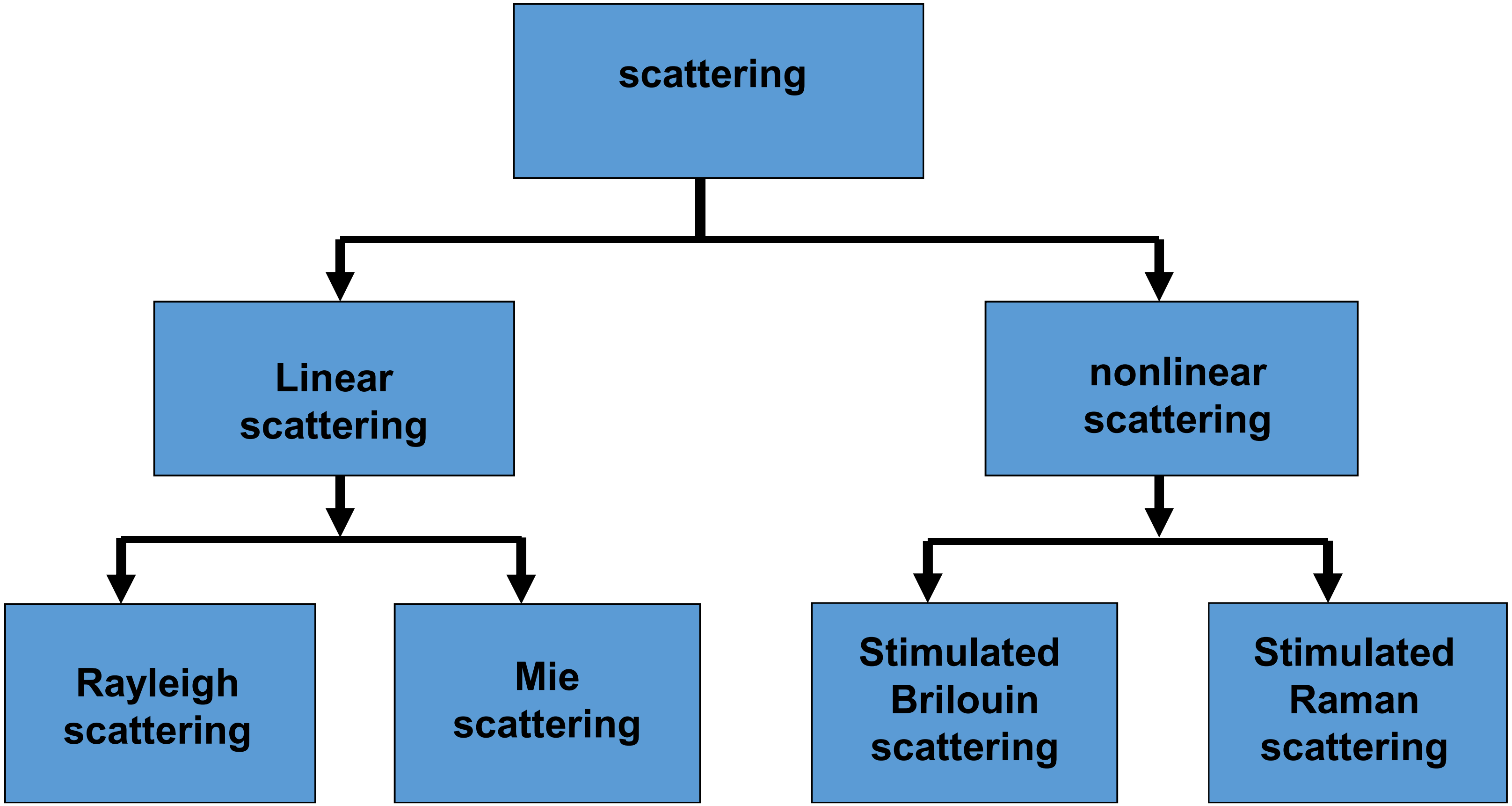
Optical communication windows



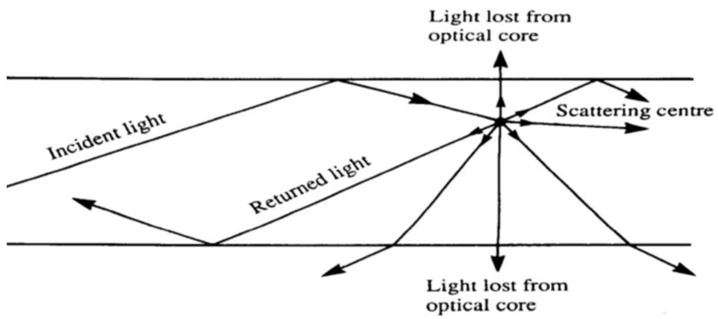
Scattering

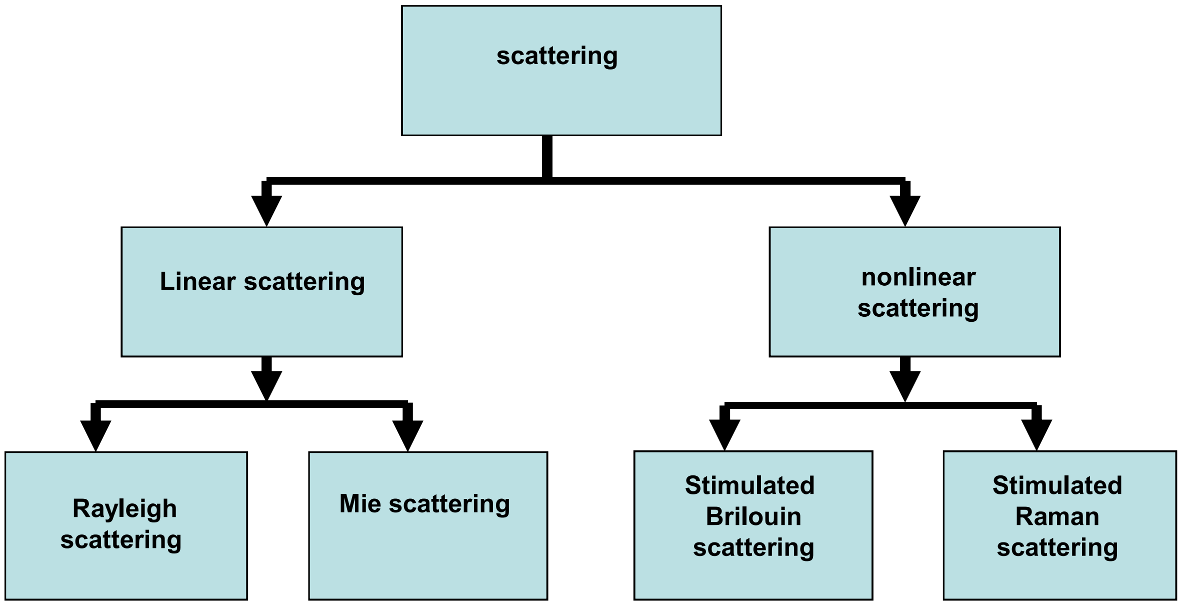


scattering
Linear scattering
nonlinear scattering
Rayleigh scattering
Mie scattering
Stimulated Brilouin scattering
Stimulated Raman scattering

Linear Scaterring:

Basically, scattering losses are caused by the interaction of light with density fluctuations within a fiber. Density changes are produced when optical fibers are manufactured.





- The **Rayleigh scattering coefficient** α_R at a wavelength λ resulting from density fluctuations can be approximated by:

$$\alpha_R = \frac{A_r}{\lambda^4} (dB.km^{-1})$$

- Where C is a constant in the range 0.7-0.9 (dB/km).μm^4, depending on the constituents of the fiber core.
- These values defines the values of α_R between 0.12 – 0.16 dB/km at wavelength 1.55μm. So Rayleigh scattering is dominate at this wavelength.

the Rayleigh scattering coefficient is related to the transmission loss factor (transmissivity) of the fiber τ of length of **L** as

$$\tau = \exp(-\alpha_R L)$$

- The Rayleigh scattering coefficient A_r depends:
  - -The fiber refractive index profile
  - -The doping used to achieve a given core refractive index

- For a step index germanium doped fiber A_r is given by:

  $A_r = 0.63 + 2.06.NA$ dB/km

- For a graded index near-parabolic profile fiber A_r is given by:

  $A_r = 0.63 + 1.75.NA$ dB/km

- The rayleigh scattering is strongly reduced by operating at longer wavelength.
- Rayleigh scattering is the main loss mechanism between the ultraviolet and infrared regions.
- **Rayleigh scattering** occurs when the size of the density fluctuation (fiber defect) is less than **one-tenth** of the operating wavelength of light.

Mie scattering: occurs when the size of the defect is greater than one-tenth of the wavelength of light.

- Mie scattering, caused by these large defects in the fiber core, scatters light out of the fiber core.

- However, in commercial fibers, the effects of Mie scattering are insignificant. Optical fibers are manufactured with very few large defects.

❑ Nonlinear Scattering

➢ it is related to the channel (optical fiber)nonlinearity.

➢ The nonlinear scattering causes a partial power of propagation mode to be transferred to a mode of different frequency.

❑ **Nonlinear scattering**

1. **Stimulated Brillouin scattering**
2. **Stimulated Raman scattering**

➢ Nonlinear scattering depends upon the optical power density within the fiber and hence becomes significant above threshold power levels. The levels are 100mW for Brillouin scattering and 1W for Raman scattering.

❑ Stimulated Brillouin Scattering (SBS)

➢ Assuming that the polarization state of the transmitted light is not maintained the threshold power P_B is given by :

$$P_B = 4.4 \times 10^{-3} d^2 \lambda^2 \alpha_{dB} \nu \qquad \text{(watts)} \quad (x)$$

➢ where d is the fiber core diameter in mm

λ is the operating wavelength in mm

α_{dB} is the attenuation in decibels per kilometer

υ is the source bandwidth (i.e. injection loser) GHZ

❑ Stimulated Raman Scattering (SRS)

- The nonlinear Raman scattering effect has been used for optical amplification.
- The threshold optical power for SRS **P_R** in a long single mode fiber is given by:

$$P_R = 5.9 * 10^{-2} d^2 \lambda \alpha_{dB} \qquad (y)(Watts)$$

- In general, nonlinear scattering may be avoided by use of a suitable optical signal level (i.e. working below threshold optical powers).

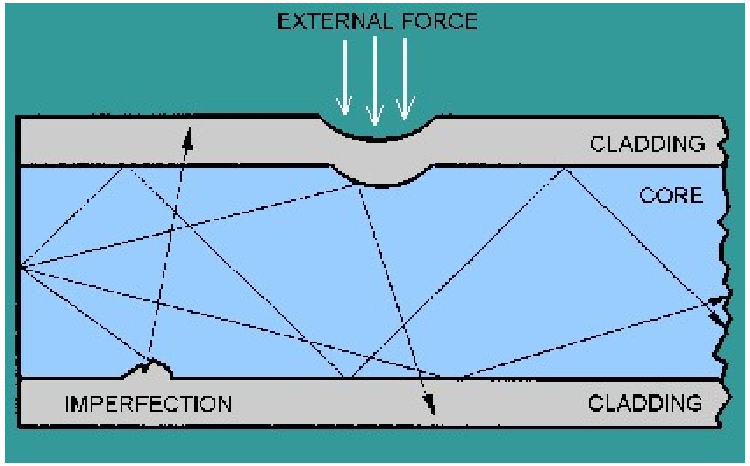
- The threshold optical powers for SBS & SRS mechanisms may be increased by suitable adjustment of the other parameters in equations x &y . For example, operation at the longest possible wavelength is advantageous although this may be offset by the reduced fiber attenuation (from Rayleigh and material absorption) normally obtained.

- **<u>BENDING LOSS.</u> -** Bending the fiber also causes attenuation. Bending loss is classified according to the bend radius of curvature: microbend loss or macrobend loss.

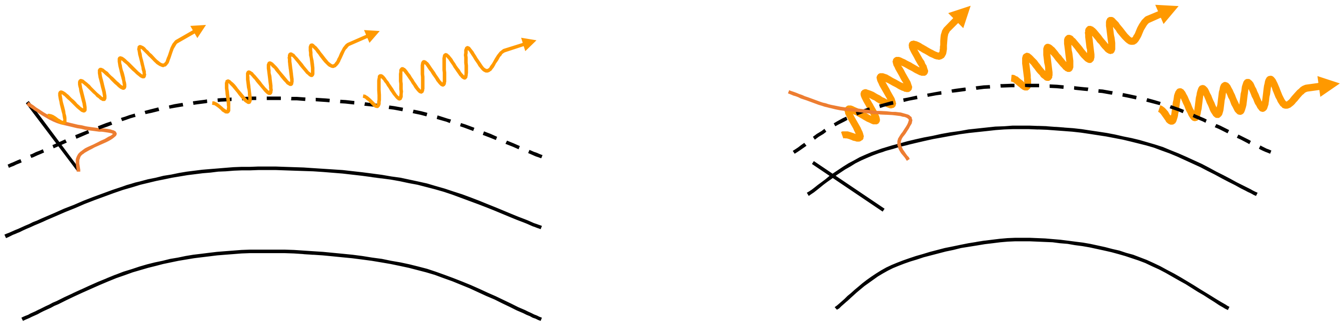
- **Microbends** are small microscopic bends of the fiber axis that occur mainly when a fiber is cabled.

- Microbend and macrobend losses are very important loss mechanisms.
- Fiber loss caused by microbending can still occur even if the fiber is cabled correctly. During installation, if fibers are bent too sharply, macrobend losses will occur.
- External forces are also a source of microbends. An external force deforms the cabled jacket surrounding the fiber but causes only a small bend in the fiber.
- Microbends change the path that propagating modes take, as shown in the figure. Microbend loss increases attenuation because low-order modes become coupled with high-order modes that are naturally lossy.

Microbend loss.



- **Macrobend losses** are observed when a fiber bend's radius of curvature is large compared to the fiber diameter.
  - These bends become a great source of loss when the radius of curvature is less than several centimeters.
  - Light propagating at the inner side of the bend travels a shorter distance than that on the outer side. To maintain the phase of the light wave, the mode phase velocity must increase. When the fiber bend is less than some critical radius, the mode phase velocity must increase to a speed greater than the speed of light. However, it is impossible to exceed the speed of light.



- This condition causes some of the light within the fiber to be converted to modes. These high-order modes are then lost or radiated out of the fiber.

- Fiber sensitivity to bending losses can be reduced. If the refractive index of the core is increased, then fiber sensitivity decreases.

- Sensitivity also decreases as the diameter of the overall fiber increases. However, increases in the fiber core diameter increase fiber sensitivity. Fibers with larger core size propagate more modes. These additional modes tend to be more lossy.

- The loss can be generally represented by a radiation attenuation coefficient α_r which has the form

$$\alpha_r = c_1 \exp\left(-c_2 R\right)$$

Where **R** is the radius of curvature of the fiber bent and $\mathbf{c_1}$ **&** $\mathbf{c_2}$ are constant which are independent on R.

- The critical radius of curvature R_c for a multimode fiber can be estimated as:

$$R_c = \frac{3n^2\lambda}{4\pi(n_1^2 - n_2^2)^{1/2}} \qquad (1)$$

- From (1), that potential macrobending losses may be reduced by:

1. Designing fiber with large relative refractive index difference.
2. Operating at shorter wavelength.

- The critical radius of curvature for a single mode fiber R_{cs} can be estimated as :

$$R_{cs} = \frac{20\lambda}{(n_1 - n_2)^{1/2}}\left(2.748 - 0.996\frac{\lambda}{\lambda_c}\right)^{-3}$$

Where λ_c is the cutoff wavelength of the single mode fiber.

Ex. 98 Two step fiber exhibit the following parameters:

a Amultimode fiber wore a core refractive index of 1.5, a relative refractive index difference of 3% and an operating wavelength of 0.82 μm.

b An 8 μm core diameter single-mode fiber with core refractive index the same as in (a), a relative refractive index difference of 0.3% and an operating wavelength of 1.55 μm.

Sol Estimate the critical radius of curvature at which large bending losses occur in both cases.

1

Ex. 98 Two step fiber exhibit the following parameters:

a Amultimode fiber wore a core refractive index of 1.5, a relative refractive index difference of 3% and an operating wavelength of 0.82 μm.

SoL: a) The relative refractive index is given by:

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2}$$

hence

$$n_2^2 = n_1^2 - 2\Delta n_1^2 = 2.25 - 0.06 \times 2.25$$

$$= 2.115$$

The critical radius of curvature:

$$R_c \simeq \frac{3n_1^2 \lambda}{4\pi (n_1^2 - n_2^2)^{1/2}} = \frac{3 \times 2.25 \times 0.82 \times 10^{-6}}{4\pi (1.35)^{1/2}}$$

$$= 9 \mu m.$$

b An 8 μm core diameter single-mode fiber with core refractive index the same as in (a), a relative refractive index difference of 0.3% and an operating wavelength of 1.55 μm.

Sol: Estimate the critical radius of curvature at which large bending losses occur in both cases.

b Ajoin

$$n_2^2 = n_1^2 - 2\Delta n_1^2 = 2.237$$

$$\lambda_c = \frac{2\pi a n_1 (2\Delta)^{1/2}}{2.405}$$

$$= 1.214 \ \mu m$$

$$R_{cs} = \frac{20\lambda}{(n_1 - n_2)^{1/2}} (2.748 - 0.996 \frac{\lambda}{\lambda_c})^{-3}$$

$$R_{cs} = 34 \ mm$$

❑Mode Coupling

- In real system, pulse distortion will increase less rapidly after a certain initial length of fiber because of mode coupling and differential loss.

- Mode coupling is the coupling of energy from one mode to another because of structural imperfections, fiber diameter and refractive index variations and cabling induced microbends.

- Mode coupling tends to average out the propagation delays associated with the modes, therby reducing intermodal dispersion, and its effects can be significant for large fibers.