Lecture Three
Signal Degradation in Optical Fiber I

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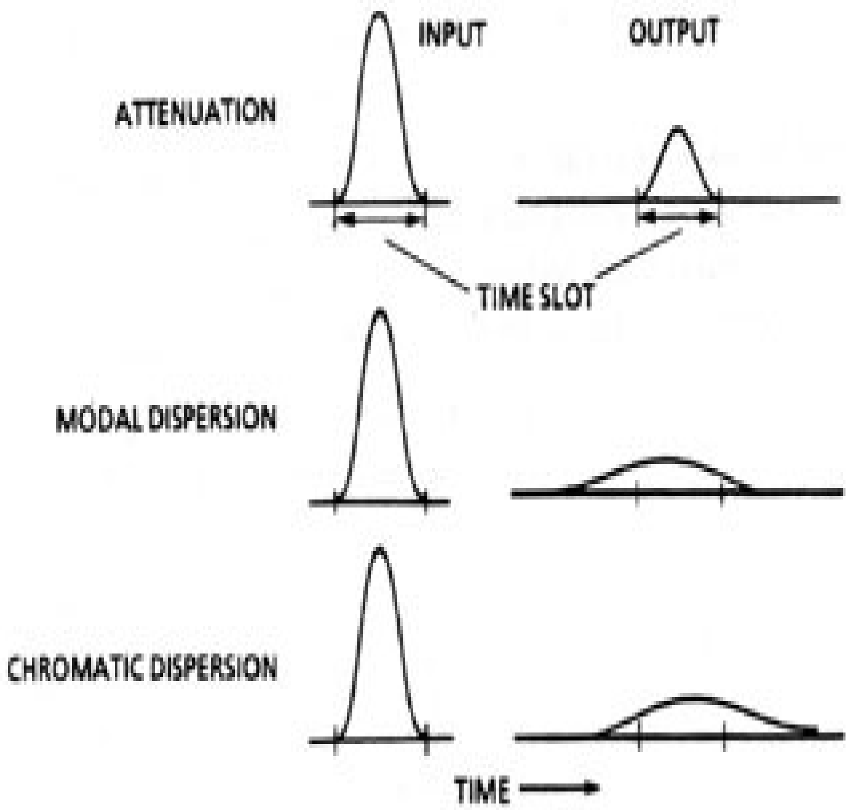
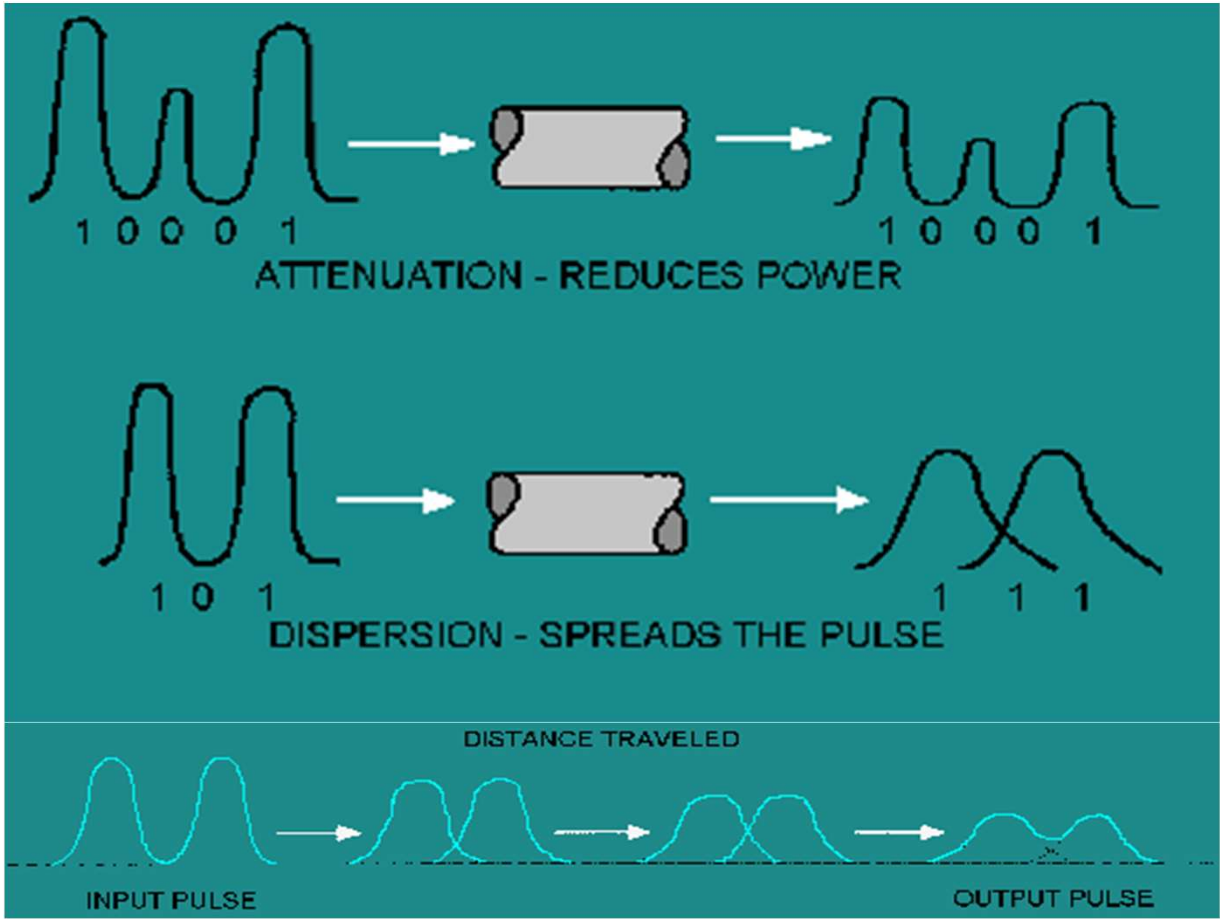
- Causes of signal degradation ***attenuation*** or fiber loss and ***dispersion***.
- Fiber loss will decrease the amount of light that is available for the receiver.
- Dispersion causes the signal to move out of its proper time interval.





1 0 0 0 1
1 0 0 0 1
ATTENUATION - REDUCES POWER
1 0 1
1 1 1
DISPERSION - SPREADS THE PULSE
DISTANCE TRAVELED
INPUT PULSE
OUTPUT PULSE

Fiber Loss (attenuation)

- Signal attenuation is defined as the ratio of optical input power (P_i) to the optical output power (P_o).
- Optical input power is the power injected into the fiber of length **z** in km from an optical source.
- Optical output power is the power received at the fiber end or optical detector.
- The following equation defines signal attenuation as a unit of length:

$$\alpha z = 10 \log \frac{p_i}{P_o} \qquad in\ dB$$

- Where α is the attenuation coefficient of the fiber in dB/km.

- Each mechanism of loss is influenced by fiber-material properties and fiber structure.
- Fiber loss depends on the wavelength of the transmitted light.

0.2 dB/km at 1.55 μm at 1979

0.5 dB/km at 1.3 μm.

0.15 dB/km at 1.3 μm for silica fiber.

A note on dB and dBm

- dB

  optical signals: $$10\log\left(\frac{P_1}{P_2}\right)$$

  electrical signals: $$20\log\left(\frac{V_1}{V_2}\right) = 20\log\left(\frac{I_1}{I_2}\right) = 10\log\left(\frac{V_1 I_1}{V_2 I_2}\right)$$

  $$P_{opt} \propto I_{el} \propto \sqrt{P_{el}}$$

- Therefore: $dB_{opt} \neq dB_{el}$ → electrical dB = 2 x optical dB
- (3 dB optical power difference ⟷ 6 dB electrical power difference)
- dBm $$10\log\left(\frac{P}{1mW}\right)$$
  - absolute power value (with 1 mW as reference)

Optical Loss in dB (decibels)

If the data link is perfect, and loses no power

- The loss is 0 dB

If the data link loses 50% of the power

The loss is 3 dB, or a change of – 3 dB

If the data link loses 90% of the power

The loss is 10 dB, or a change of – 10 dB

If the data link loses 99% of the power

The loss is 20 dB, or a change of – 20 dB

Absolute Power in dBm

- The power of a light is measured in milliwatts
- For convenience, we use the dBm units, where

-20 dBm	= 0.01 milliwatt
-10 dBm	= 0.1 milliwatt
0 dBm	= 1 milliwatt
10 dBm	= 10 milliwatts
20 dBm	= 100 milliwatts

Fiber loss in dB/km

$P(0)[\text{dBm}]$ $\qquad$ $P(l) = P(0)e^{-\alpha_p l}$

$$P(l)[\text{dBm}] = P(0)[\text{dBm}] - \alpha[\text{dB/km}] \times l[\text{km}]$$

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EX

When the mean optical power launched into an 8km 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 and splices;

b the signal attenuation per kilometerse for the fiber;

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

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

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Determine:

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

Sol.:

a the overall signal attenuation in decibels through the fiber is:

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

$$= 16.0\,dB$$

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EX when the mean optical power launched into an 8km 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 and splices;

b the signal attenuation per kilometerse for the fiber;

b

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

hence;

$$\alpha_{dB} = \frac{16.0}{8} = 2.0 \text{ dB km}^{-1}.$$

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

Determine:

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

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

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

~~Hen~~ However, the link also has nine splices (at 1km intervals) e As $\alpha_{dB} = 2\,dB.km^{-1}$, the loss incurred along 10km of the fiber is given by

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

~~Hen~~ However, the link also has nine splices (at 1km intervals)

each with an attenuation of 1dB. Therefore, the loss due to the splices is 9 dB.

Hence, the overall signal attenuation for the link is:

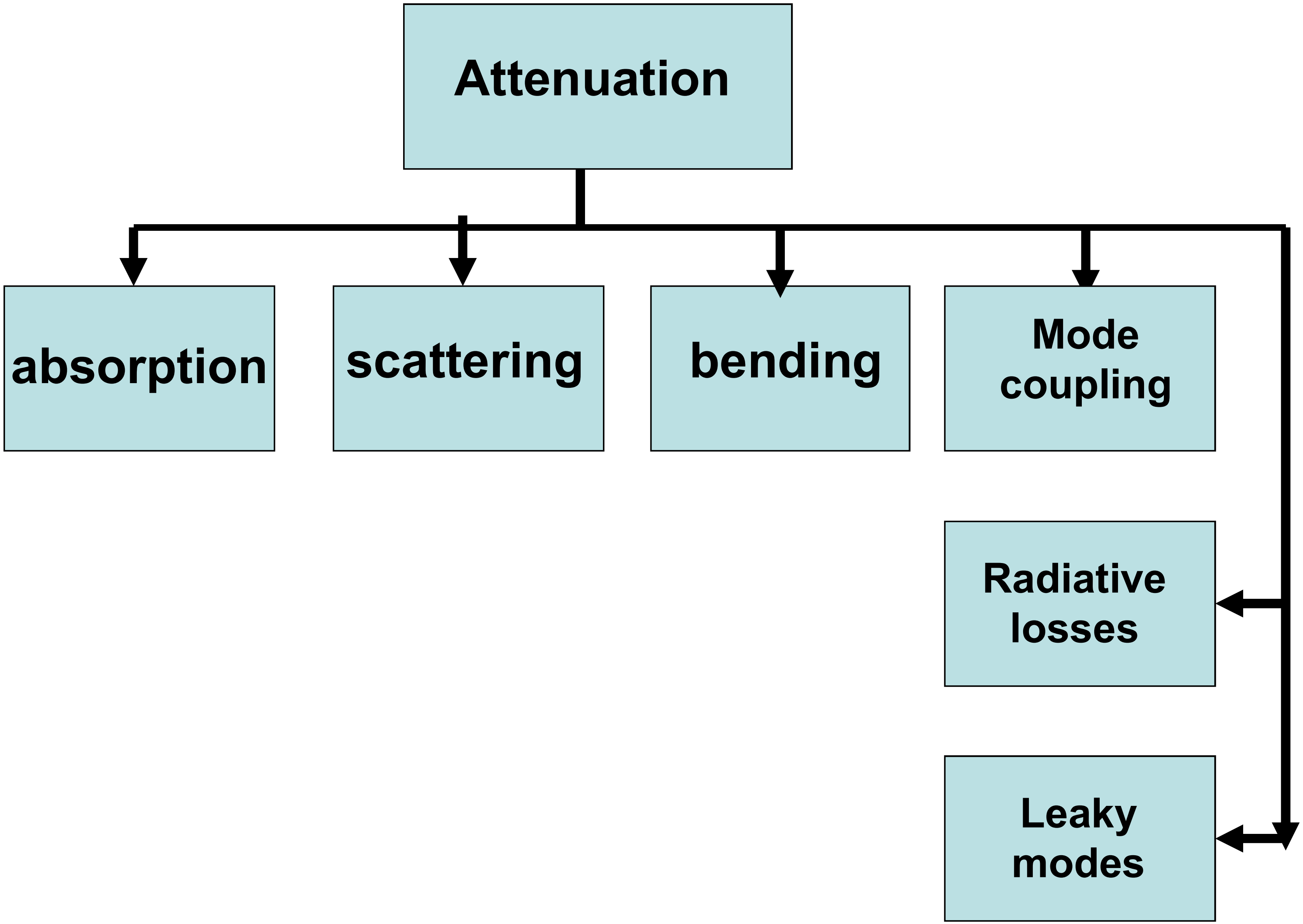
$$\text{Signal attenuation} = 20 + 9$$
$$= 29\,dB$$

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

d To obtain numerical value for the input / output power ratio,

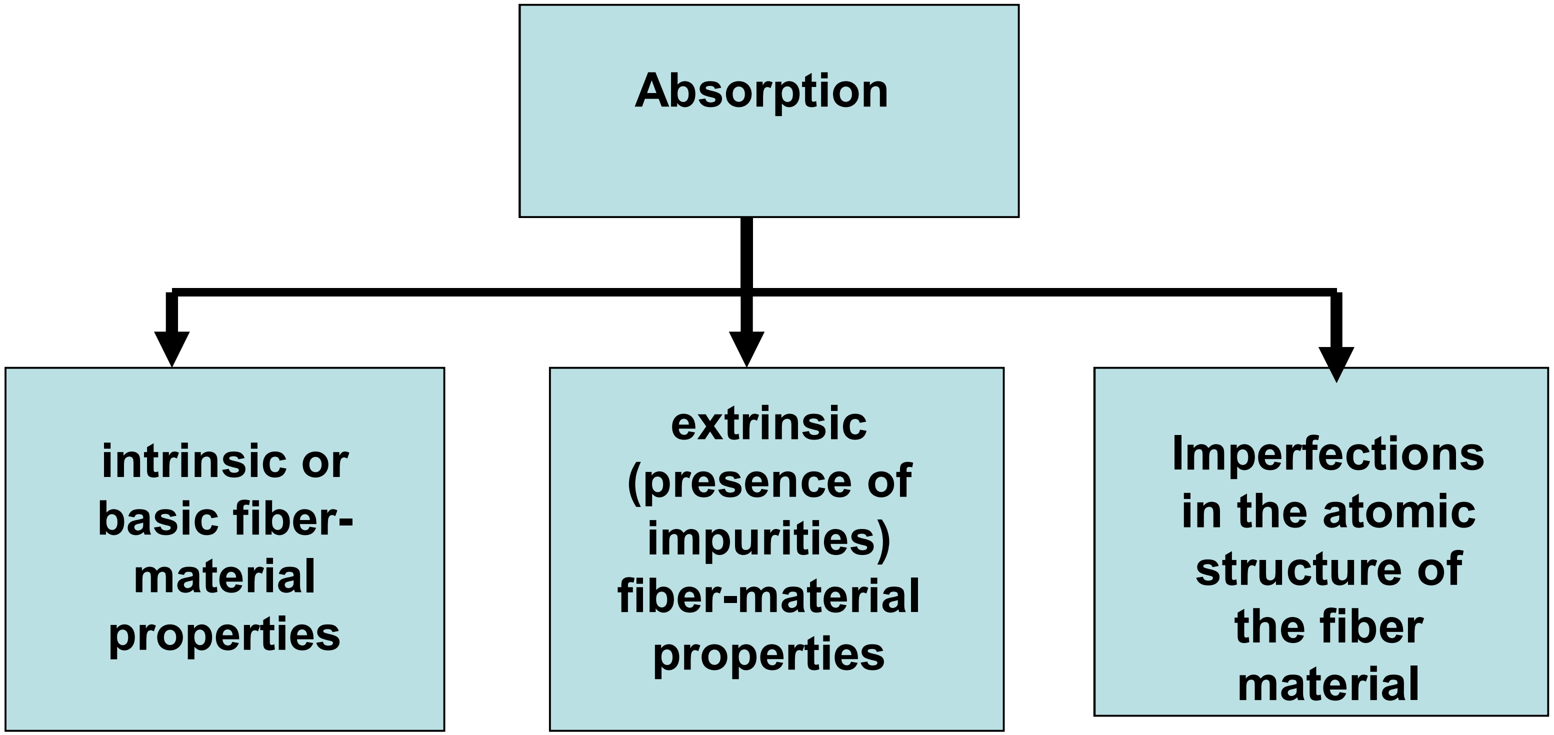
$$\frac{P_i}{P_o} = 10^{29/10} = 794.3$$

Fiber Loss (attenuation)



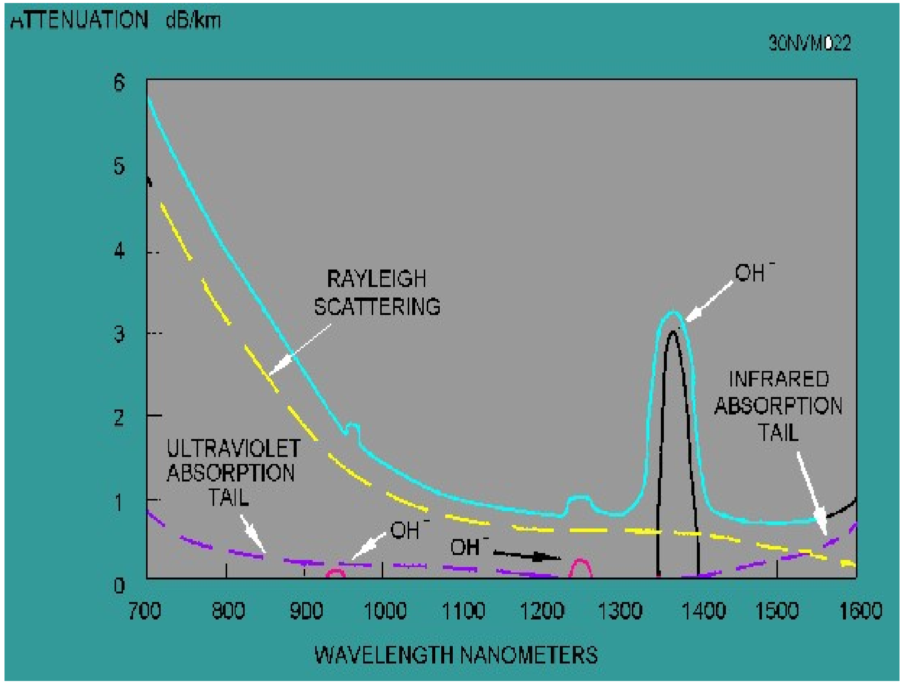
ABSORPTION

- **Absorption** is a major cause of signal loss in an optical fiber.
- **Absorption** is defined as the portion of attenuation resulting from the conversion of optical power into another energy form, such as heat. in



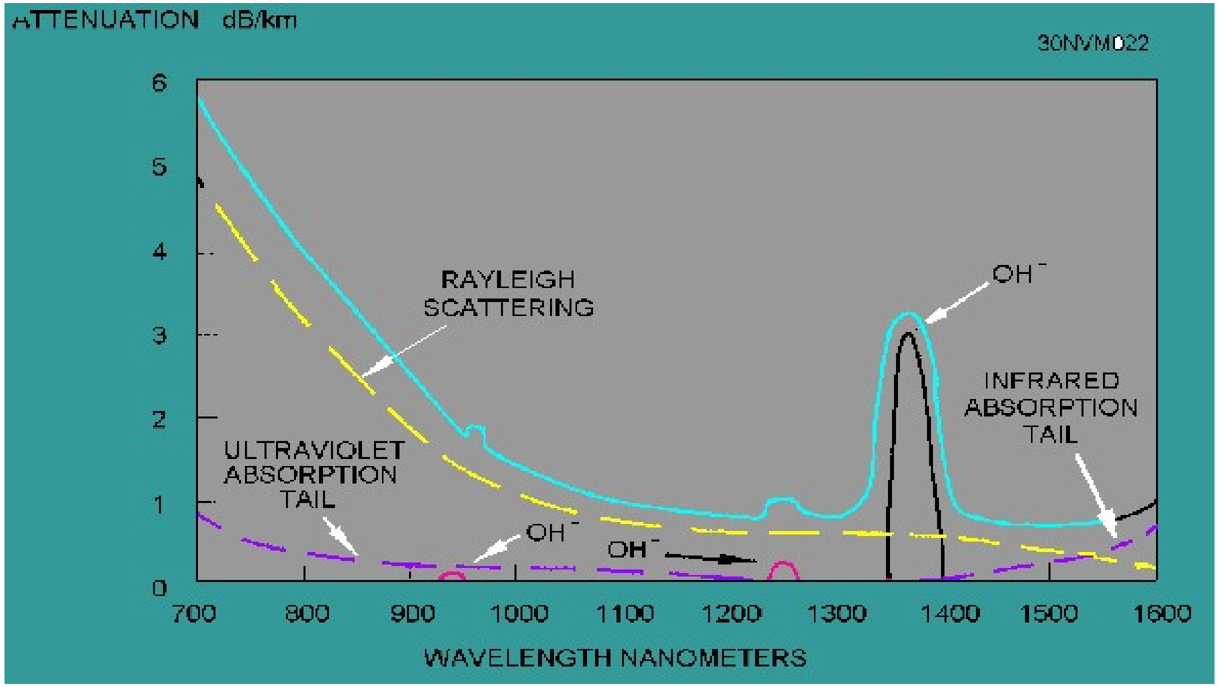
- ***Intrinsic Absorption***. - Intrinsic absorption is caused by basic fiber-material properties.

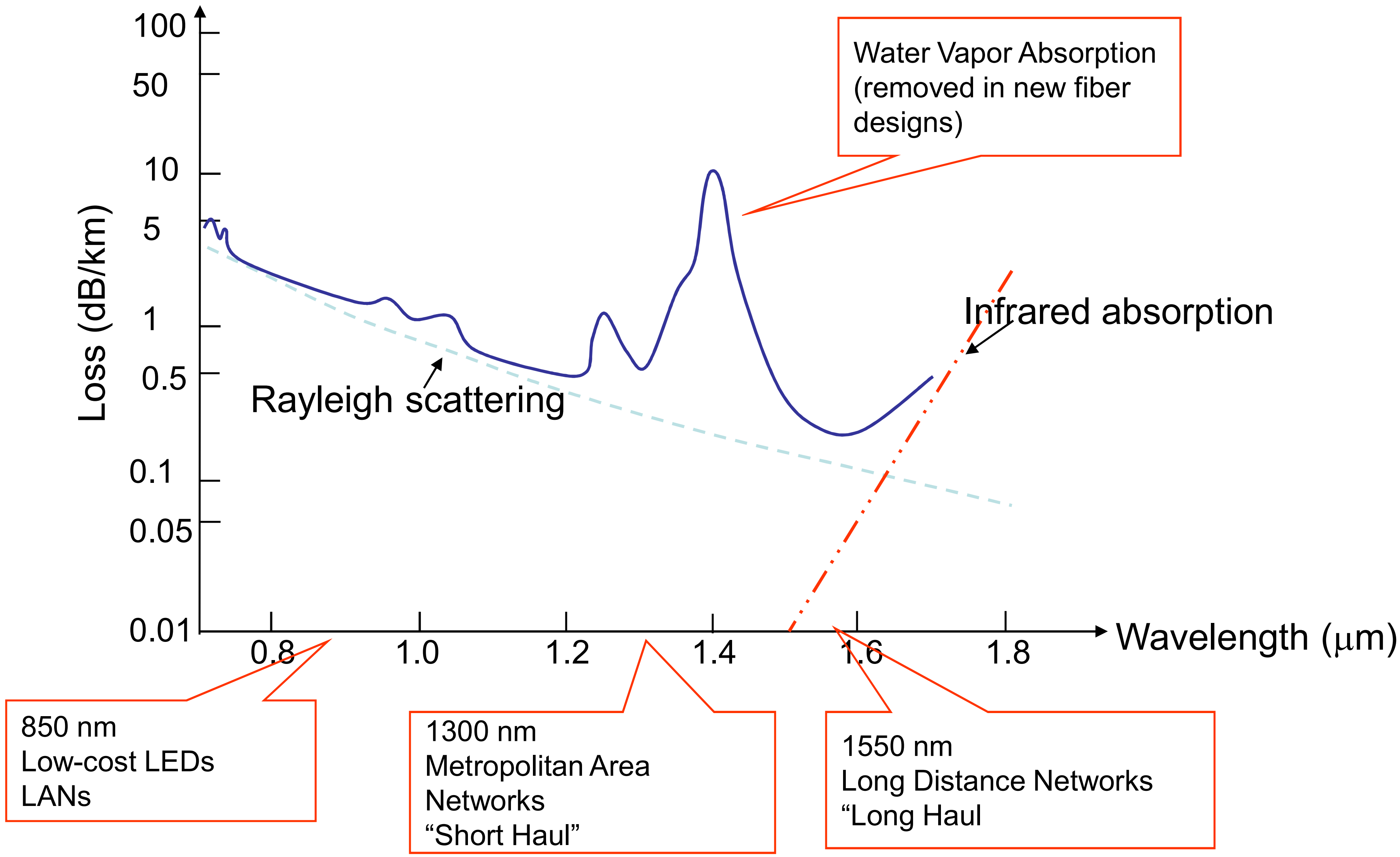
- In fiber optics, silica (pure glass) fibers are used predominately. Silica fibers are used because of their low intrinsic material absorption at the wavelengths of operation.



0.5 dB at 1300 nm

0.3 dB at 1500 nm for a single mode fiber


ATTENUATION dB/km
30NVM022
6
5
4
3
2
1
0
RAYLEIGH SCATTERING
OH⁻
INFRARED ABSORPTION TAIL
ULTRAVIOLET ABSORPTION TAIL
OH⁻
OH⁻
700
800
900
1000
1100
1200
1300
1400
1500
1600
WAVELENGTH NANOMETERS



- ***Fiber attenuation is ~0.2 dB/km at around 1550 nm***
- ***The bandwidth around low attenuation is 25 Tb/sec***

- **Extrinsic Absorption.** –

➢ Extrinsic absorption is caused by impurities introduced into the fiber material.

➢ **Extrinsic absorption** is caused by the electronic transition of these metal ions from one energy level to another.

➢ These losses are effective in the visible and infrared regions.

- **<u>Imperfections in the atomic structure</u>**

- In the near infrared region above 1200 nm, the optical waveguide loss is predominantly determined by the presence of OH ions and the inherent infrared absorption of the constituent material.

Fiber type	**Typical loss dB / km**
Plastic SI	100 – 500
Glass GRI	1 – 5
Glass SM	0.2 - 3