Attenuation

Fiber loss or attenuation is a limiting factor in transmission distance

Attenuation can be described by the general relationship

$$\frac{dP}{dz} = -\alpha P$$

solving this differential equation gives

$$P_{out} = P_{in}\, e^{-\alpha L}$$

The power budget is the difference between the transmission power and the minimum detectable power

Power bugdet is $\quad PB = \dfrac{P_{tx}}{P_{min}}$

Example : $P_{tx} = 10mw$
$P_{min} = 1\mu w$

$$10^{-6} = 10^{-2}\, e^{-\alpha L}$$

$$\ln(10^{-8}) = -\alpha L$$

$$L = \frac{\ln(10^{-8})}{-\alpha}$$

Rather than work with ln and dividing it is faster to work with dB

$$PB(dB) = 10\log_{10}\left(\frac{P_{tx}}{P_{min}}\right)$$

For our example $\quad PB = 10\log_{10}\left(\frac{10^{-6}}{10^{-2}}\right) = 80dB$

We need (1) Power in dB
(2) Attenuation in dB

(1) dB is a relative unit
To get power in dB we calculate it relative to 1mw and call it dBm

$$P_{dBm} = 10\log_{10}\left(\frac{P}{1mw}\right)$$

$$10mw = 10\log_{10}(10) = 10\,dBm$$

(2) To get attenuation in dB

$$P_{out} = P_{in}\, e^{-\alpha L}$$

$$10 \log_{10} (P_{out}) = 10 \log_{10} (P_{in}\, e^{-\alpha L})$$

$$= 10 \log_{10} (P_{in}) + 10 \log_{10} e^{-\alpha L}$$

$$= 10 \log_{10} (P_{in}) + (10)(-\alpha L) \log_{10} e$$

$$= 10 \log_{10} (P_{in}) - \underbrace{(10 \alpha \log_{10} e)}_{\alpha_{dB}} L$$

$$\alpha_{dB} = 4.34\, \alpha$$

Examples

BYU liquid core ARROWs $\alpha = 0.3\ cm^{-1}$

metal coated micro-fluidic waveguides $0.5\ \mu m^{-1}$

Example : Minimum detectable power

$$P_{min} = 0.1\ \mu W$$

Laser power

$$P_{laser} = 10\, mW$$

Coupling loss at transmitter and receiver

$$\alpha_{coupling} = 1\ dB \text{ each}$$

Splice required every 10 Km

$$\alpha_{splice} = 0.3\ dB \text{ each}$$

What is the maximum transmission length at $\lambda = 1550\ nm$?

look up transmission loss in spec.

$$\alpha = 0.19\ dB/Km$$

$$P_{min}(dBm) = 10 \log_{10}\left(\frac{0.1 \times 10^{-6}}{1 \times 10^{-3}}\right) = 40 dB_m$$

$$P_{laser}(dBm) = 10 \log_{10}\left(\frac{10}{1}\right) = 10\, dB_m$$

$$\text{Power Budget} = 10 - (-40) = 50\ dB$$

$$= P_{coupling} + P_{splice} + \alpha L$$

$$50 = (2)(1) + (0.3)(N) + 0.19\, L$$

First assume $N=0$

$$50 = 2 + 0.19L$$

$$L = 48/.19 = 252.6 \text{ Km}$$

$$\frac{L}{10} = 25.3 \text{ segments}$$

$$N = 26-1 = 25$$

$$50 = 2(1) + (25)(.3) + 0.19L$$

$$L = \frac{50 - 2 - (25)(.3)}{.19} = 213.2$$

$$\frac{L}{10} = 21.3$$

now $N = 22-1$

$$L = \frac{50 - 2 - (21)(.3)}{.19} = 219.5$$

$\frac{L}{10} = 21.9$ N is still 21

so $L = 219.5$ Km

What about at other wavelength?

λ (nm)	α (dB/Km)	L (Km)
850	1.8	26
1310	0.34	130
1383	0.50	90
1550	0.19	219

Environmental Specifications

Environmental Test Condition	Induced Attenuation 1310 nm/1550 nm (dB/km)
Temperature Dependence -60°C to +85°C*	≤0.05
Temperature-Humidity Cycling -10°C to +85°C*, up to 98% RH	≤0.05
Water Immersion, 23°± 2°C*	≤0.05
Heat Aging, 85° ± 2°C*	≤0.05

*Reference temperature = +23°C

Operating Temperature Range

-60°C to +85°C

Dimensional Specifications

Length (km/reel): fiber lengths available up to 50.4*

* Longer spliced lengths available at a premium.

Glass Geometry

Fiber Curl: ≥ 4.0 m radius of curvature
Cladding Diameter: 125.0 ± 0.7 µm
Core-Clad Concentricity: ≤ 0.5 µm
Cladding Non-Circularity: ≤ 1.0%

Defined as: $\left[1-\frac{\text{Min. Cladding Diameter}}{\text{Max. Cladding Diameter}}\right] \times 100$

Coating Geometry

Coating Diameter: 245 ± 5 µm
Coating-Cladding Concentricity: <12 µm

Mechanical Specifications

Proof Test

The entire fiber length is subjected to a tensile proof stress ≥ 100 kpsi (0.7 GN/m²)*.

* Higher proof test levels available at a premium.

Performance Characterizations

Characterized parameters are typical values.

Core Diameter: 8.2 µm

Numerical Aperture: 0.14

NA is measured at the one percent power level of a one-dimensional far-field scan at 1310 nm.

Zero Dispersion Wavelength **(λ_0):** 1313 nm

Zero Dispersion Slope **(S_0):** 0.086 ps /(nm²·km)

Refractive Index Difference: 0.36%

Effective Group Index of Refraction, **(N_{eff} @ nominal MFD):**

1.4677 at 1310 nm
1.4682 at 1550 nm

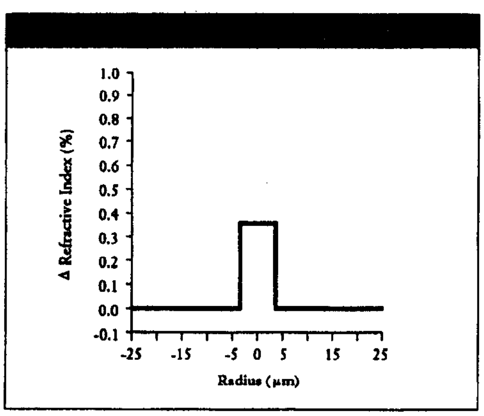
Fatigue Resistance Parameter **(n_d):** 20

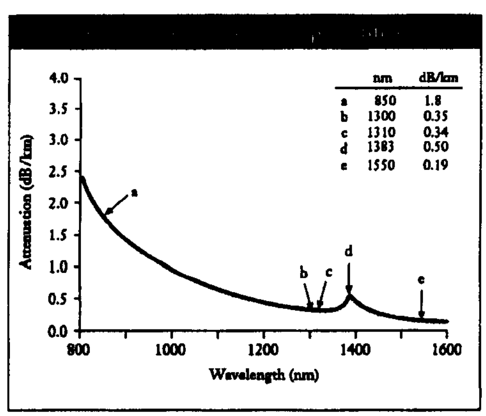
Coating Strip Force:

Dry: 0.6 lbs. (3N)
Wet, 14-day room temperature: 0.6 lbs. (3N)

Rayleigh Backscatter Coefficient **(for 1 ns pulse width):**

1310 nm: -77 dB
1550 nm: -82 dB





Material Absorption

- Material absorption
  - Intrinsic: caused by atomic resonance of the fiber material
    - Ultra-violet
    - Infra-red: primary intrinsic absorption for optical communications
  - Extrinsic: caused by atomic absorptions of external particles in the fiber
    - Primarily caused by the O-H bond in water that has absorption peaks at λ=2.8, 1.4, 0.93, 0.7 μm
    - Interaction between O-H bond and SiO_2 glass at λ=1.24 μm
    - The most important absorption peaks are at λ=1.4 μm and 1.24 μm

Scattering Loss

- There are four primary kinds of scattering loss
  - Rayleigh scattering is the most important

$$\alpha_R = c_R \frac{1}{\lambda^4} \quad (dB/km)$$

  where c_R is the Rayleigh scattering coefficient and is the range from 0.8 to 1.0 $(\text{dB/km})\cdot(\mu\text{m})^4$

- Mie scattering is caused by inhomogeneity in the surface of the waveguide
  - Mie scattering is typically very small in optical fibers
- Brillouin and Raman scattering depend on the intensity of the power in the optical fiber
  - Insignificant unless the power is greater than 100mW

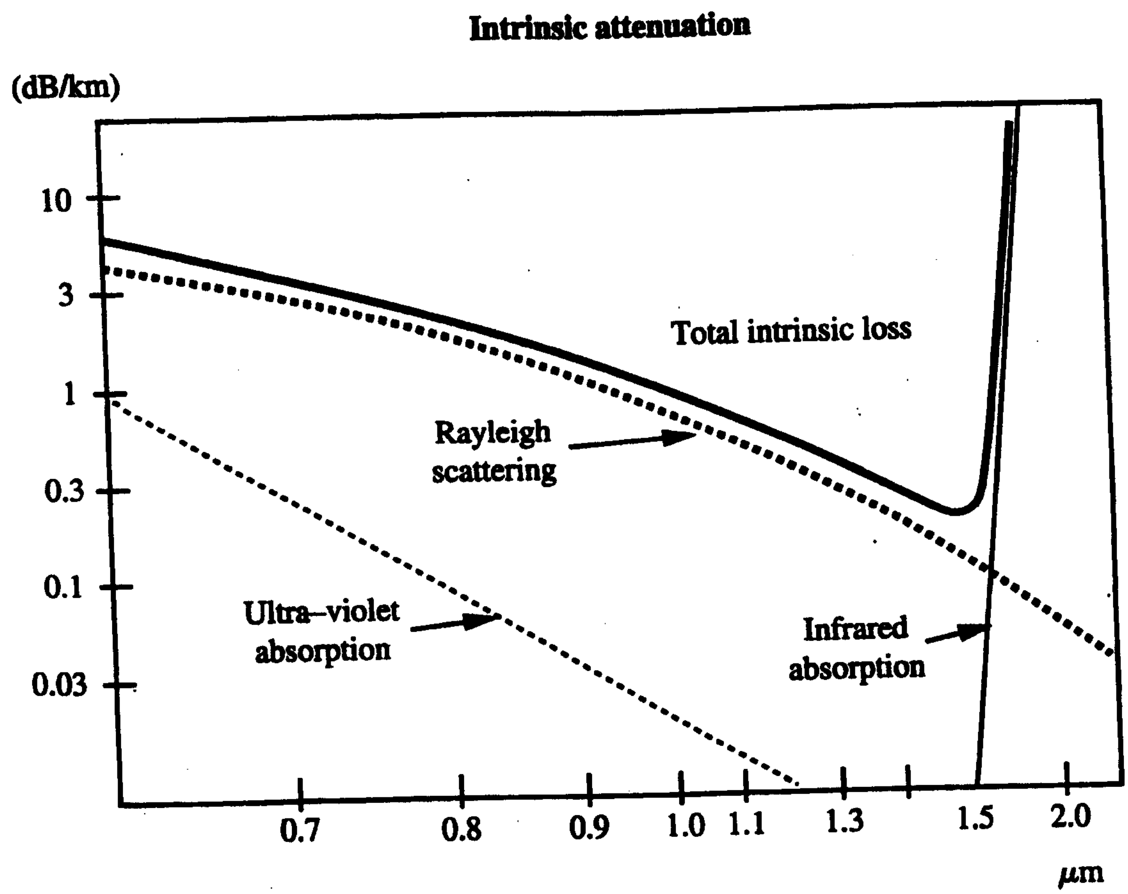
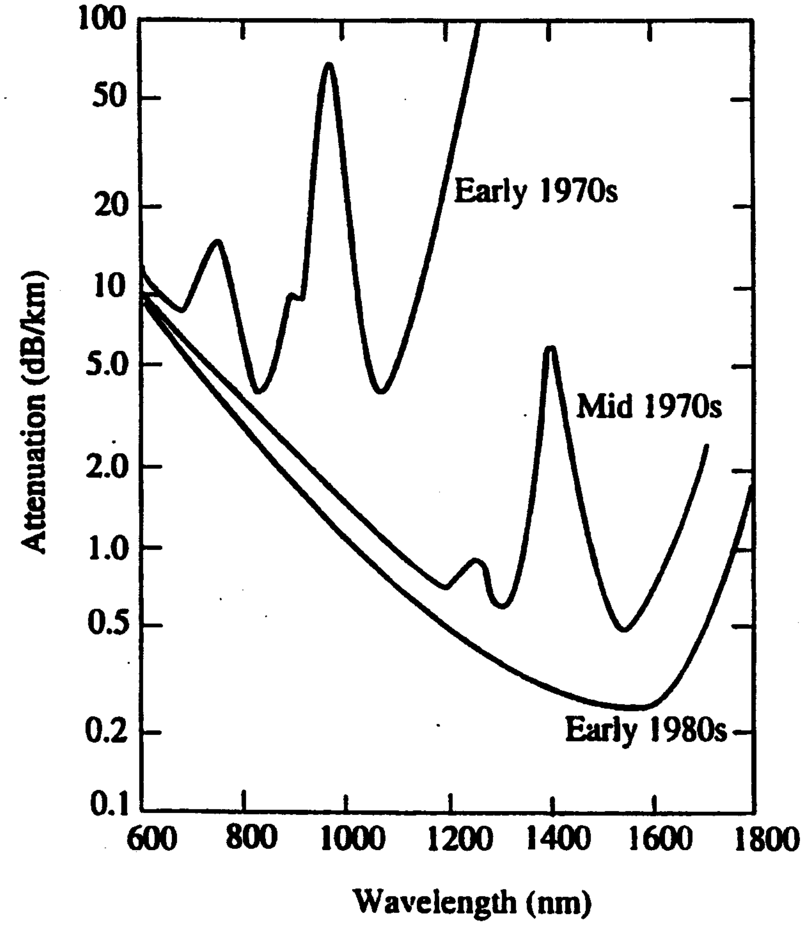


Figure 4.4 Intrinsic attenuation in optical fibers.

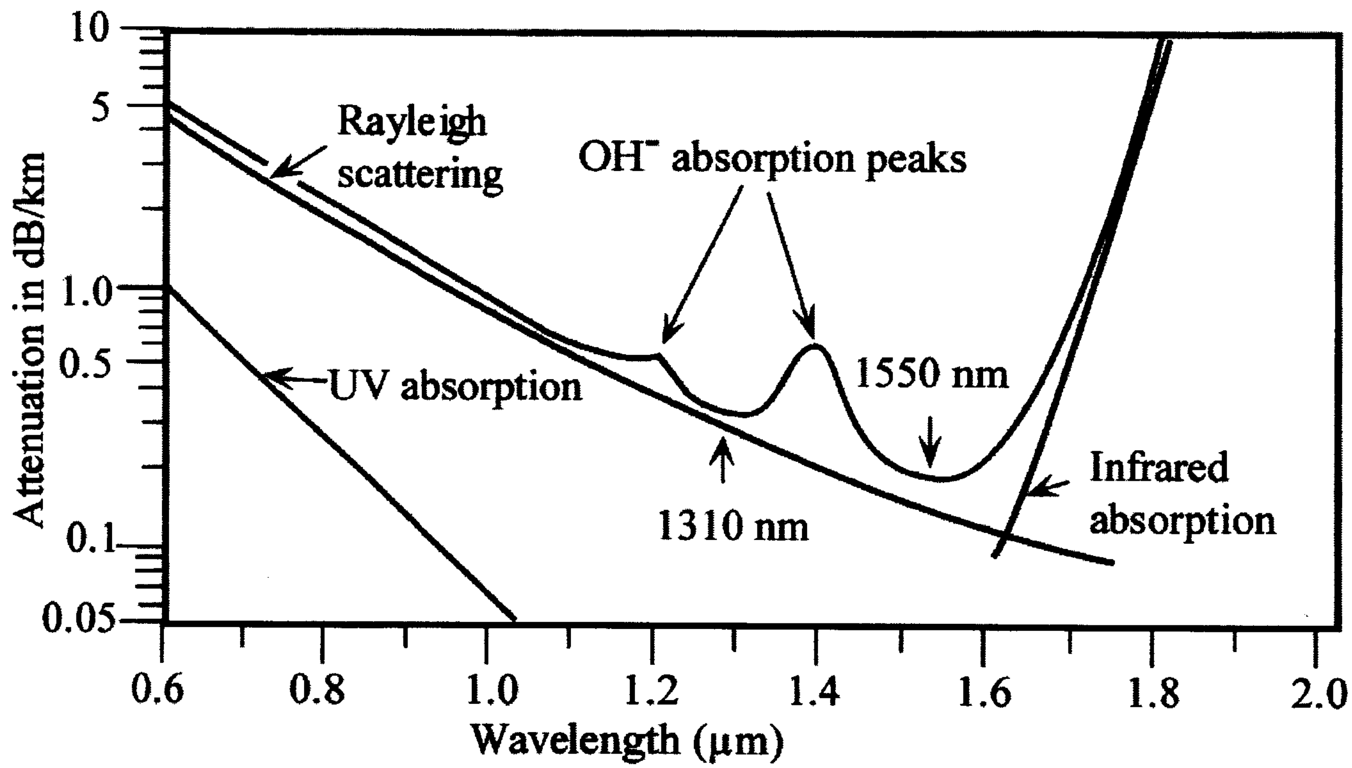
Historical Progression of Attenuation vs Wavelength

Bhattacharya, (after Keiser), Figure 1.19



Scientific Atlanta

Absorption and Scattering Loss



External Losses

- Bending loss
  - Radiation loss at bends in the optical fiber
  - Insignificant unless $R<1mm$
  - Smaller curvature become significant if there are accumulated bending losses over a long distance
- Coupling and splicing loss
  - Misalignment of core centers
  - Tilt
  - Air gaps
  - End face reflections
  - Mode mismatches

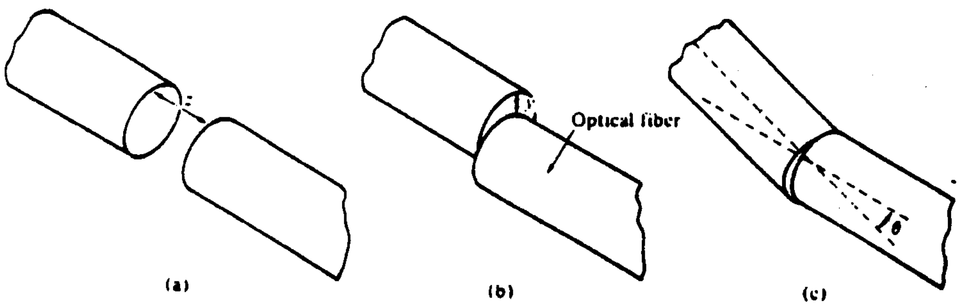


Fig. 4.26 The three possible types of misalignment which may occur when jointing compatible optical fibers [Ref. 58]: (a) longitudinal misalignment; (b) lateral misalignment; (c) angular misalignment.