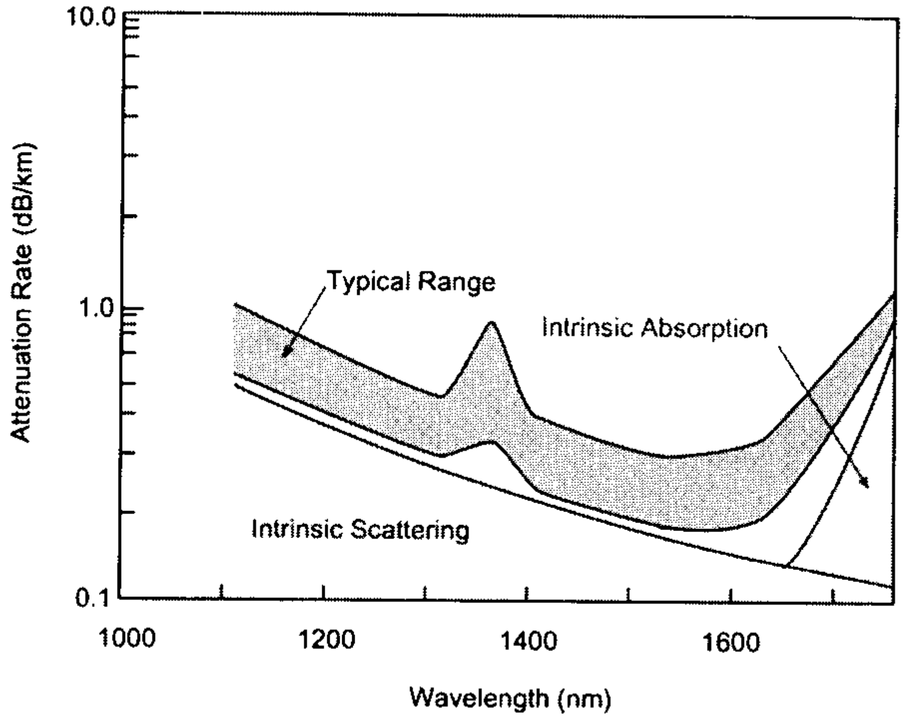
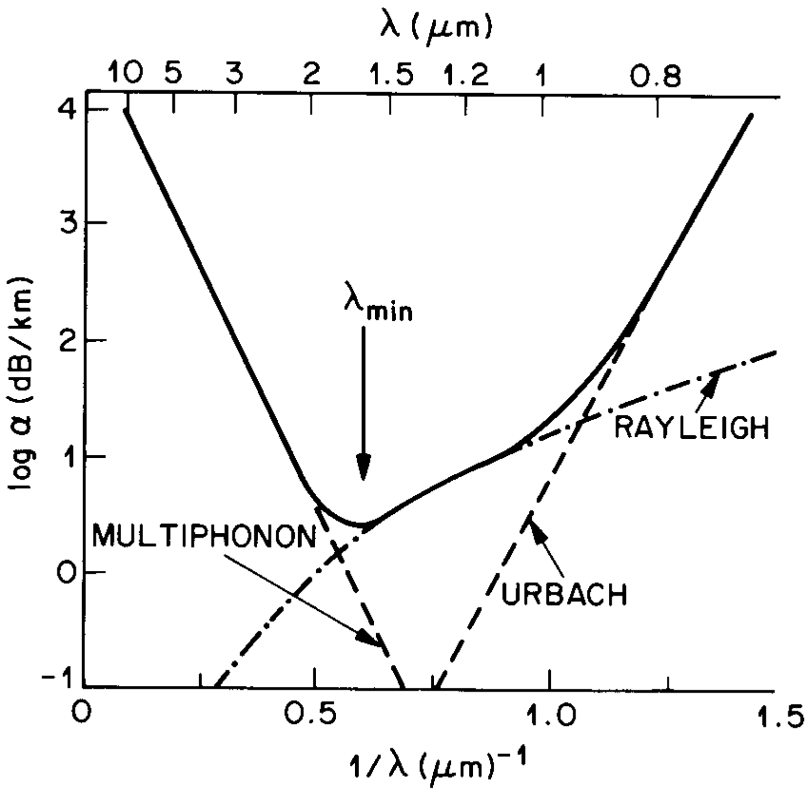
Optical Fiber Absorption





$$\Delta p(t) = \Delta\varepsilon E(t)$$

$$p = \Delta\varepsilon E_0$$

$$P_{rad} = \frac{\omega^4 p^2}{12\pi\varepsilon_0 c^3} = \frac{\omega^4 (\Delta\varepsilon)^2 E_0{}^2}{12\pi\varepsilon_0 c^3}$$ (power radiated by one scatterer)

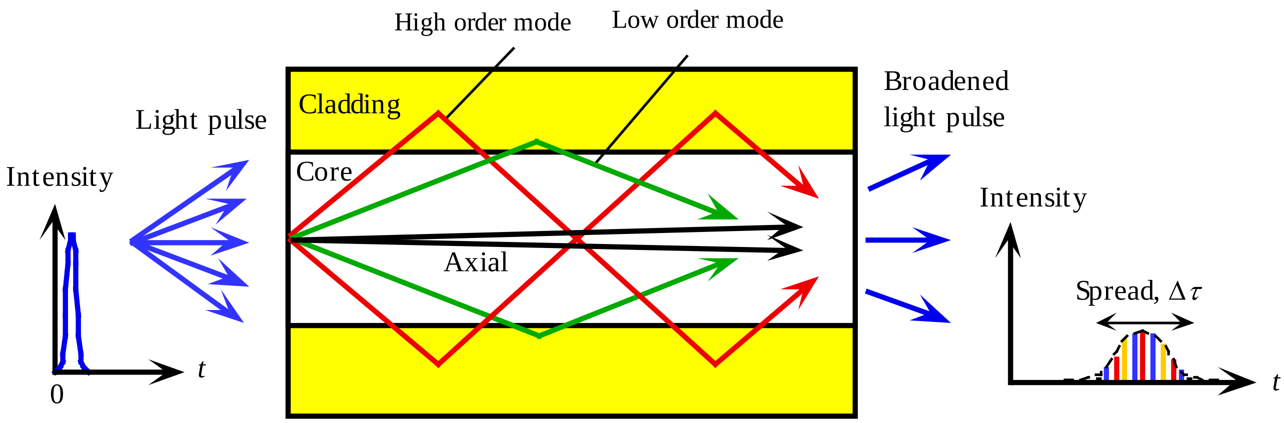
$$\bar{P}_{rad} = \frac{\omega^4 (\Delta\varepsilon)^2 E_0{}^2}{12\pi\varepsilon_0 c^3} N$$ (power radiated per unit volume)

This gives a wavelength dependent loss

$$Loss \sim \frac{1}{\lambda_0{}^4}$$

Best values: ~ 0.2 dB/km @ 1550 nm

Modal Dispersion



Schematic illustration of light propagation in a slab dielectric waveguide. Light pulse entering the waveguide breaks up into various modes which then propagate at different group velocities down the guide. At the end of the guide, the modes combine to constitute the output light pulse which is broader than the input light pulse.

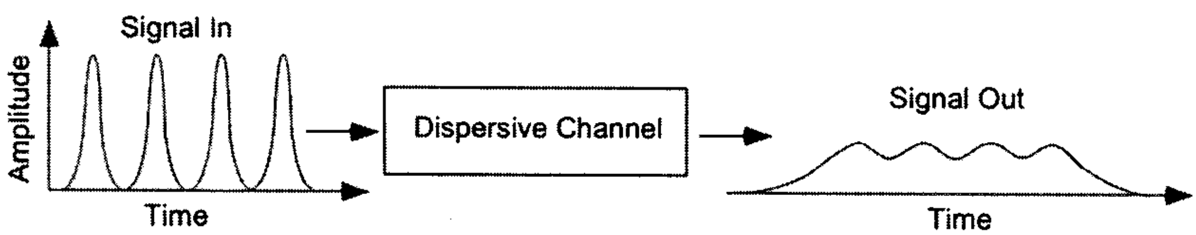


Figure 6.1. Short temporal pulses experience pulse spreading in a dispersive media. If they are not separated by enough time they will begin to overlap.

Group Velocity Dispersion

Plane Waves in Dispersive Media

$$\text{Phase Velocity} \equiv \frac{\omega}{k} = \frac{c}{n}$$

$$\text{Group Velocity: } v_g \equiv \frac{d\omega}{dk} = \frac{c}{n_g}$$

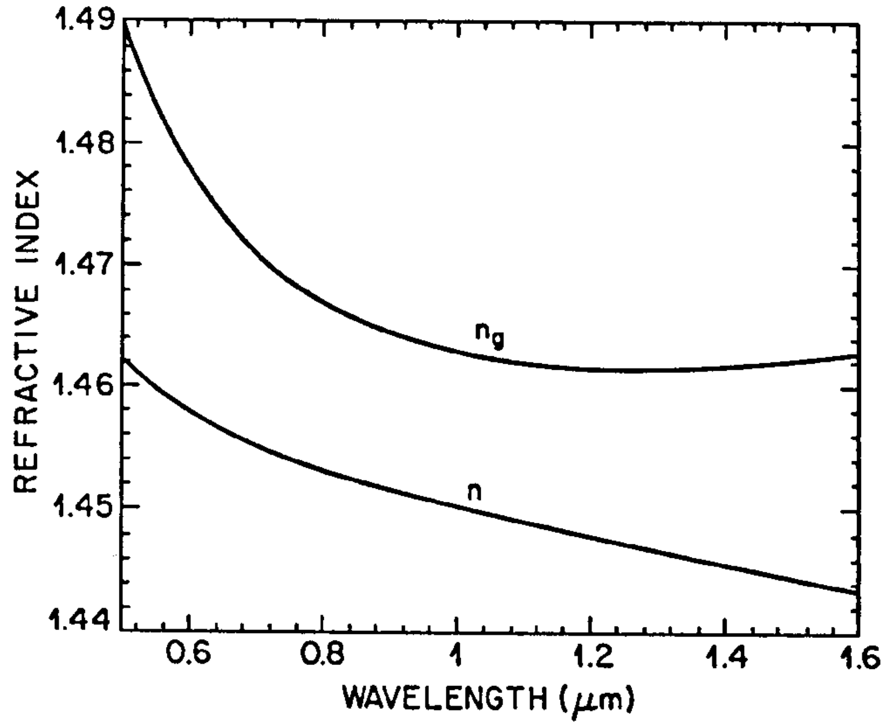
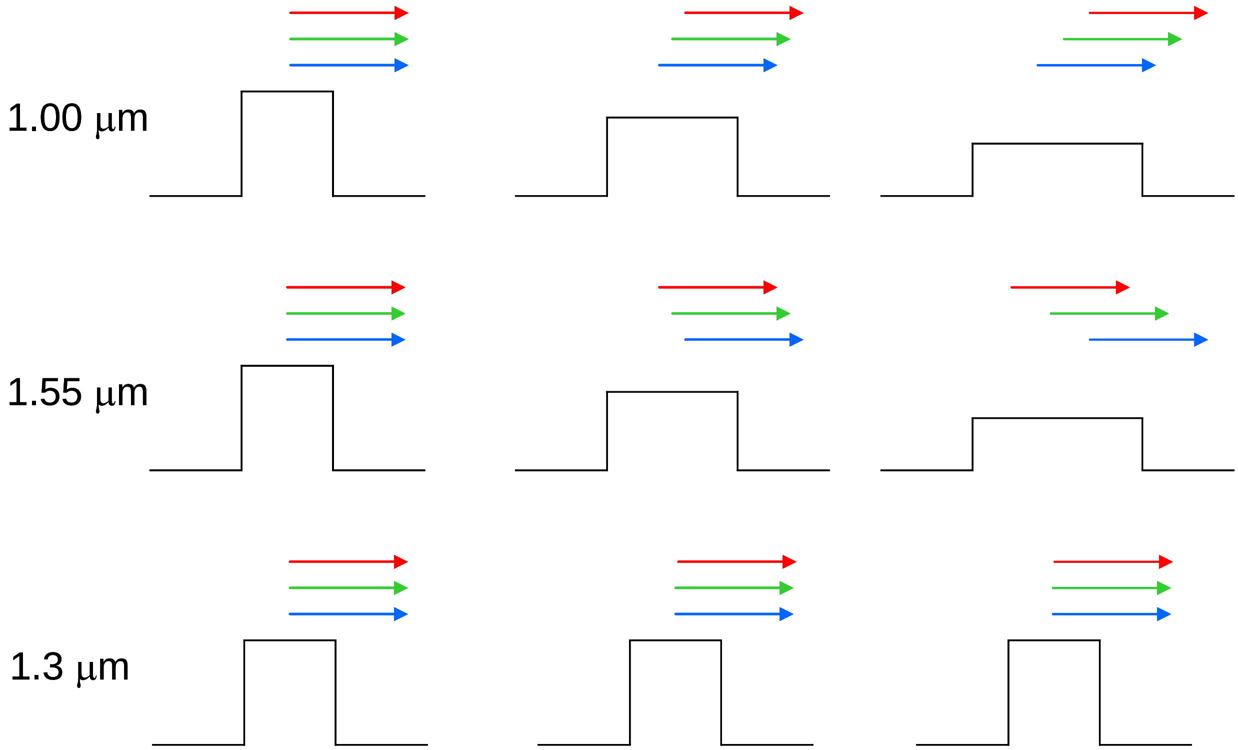


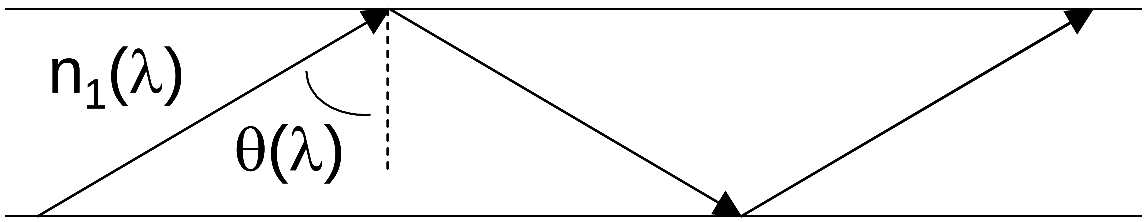
Figure 2.8 Variation of refractive index n and group index n_g with wavelength for fused silica.

From Fiber-Optic Communication Systems, 2nd Ed., Agrawal

The curve for n_g shows that longer wavelengths travel faster near 1.0 micron, slower near 1.55 micron, and about the same as shorter wavelengths near 1.3 micron. This causes pulse spreading for pulses with wavelength centered near 1.0 micron and 1.55 micron, but not for optical pulses with center wavelengths near 1.3 micron.


1.00 μm
1.55 μm
1.3 μm

Group Velocity Dispersion in Optical Waveguides



Different wavelengths travel at different group velocities because of:

1. changing optical path length due to a changing refractive index n_1

2. changing optical path length due to a changing θ (required in order to maintain constructive interference between the bouncing waves)

Definitions for Guided Waves

Phase Velocity $\equiv \dfrac{\omega}{\beta} = \dfrac{c}{n_{eff}}$

Group Velocity: $v_g \equiv \dfrac{d\omega}{d\beta} = \dfrac{c}{n_g}$

Group Delay: $\tau \equiv \dfrac{1}{v_g} = \dfrac{d\beta}{d\omega} = \dfrac{1}{c}\dfrac{d\beta}{dk_0}$

Dispersion Parameter: $D \equiv \dfrac{d\tau}{d\lambda_0}$

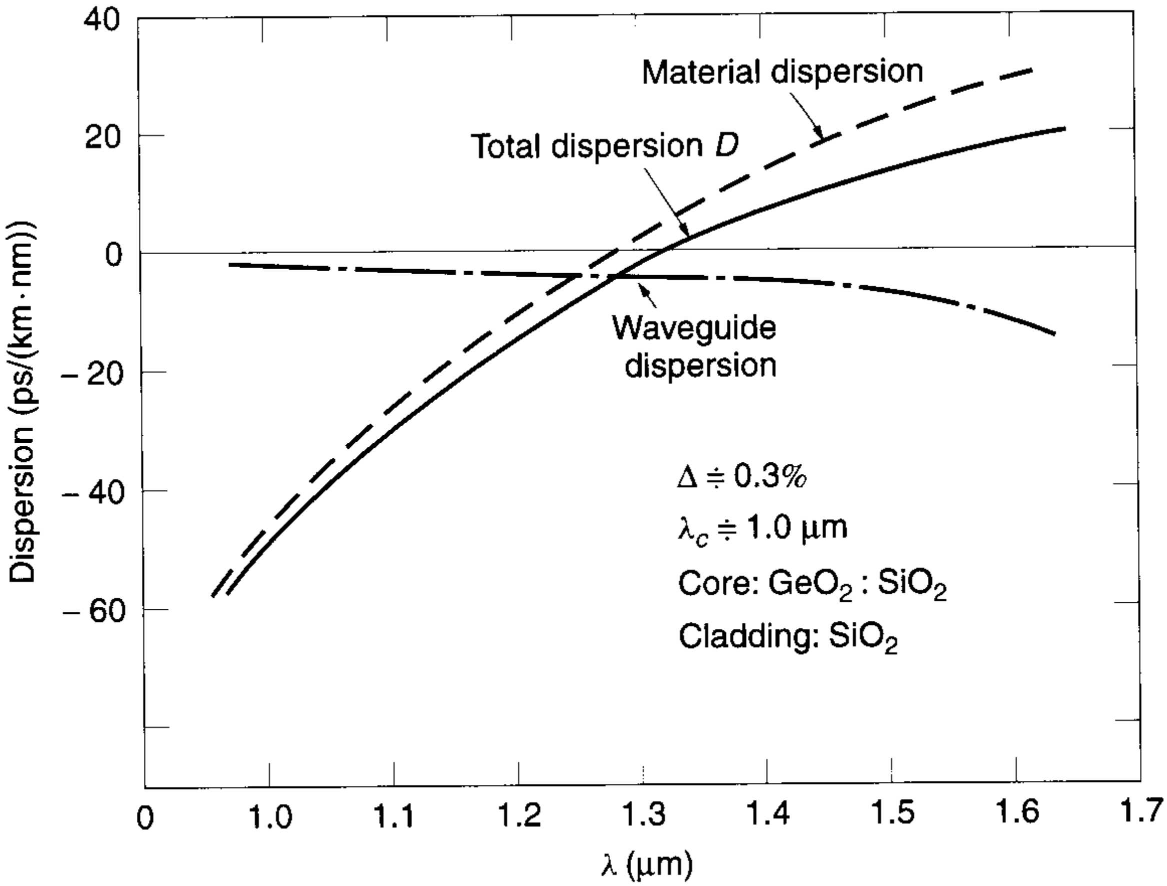


Figure 11.9 Dispersion of a single mode fiber. (After D. B. Keck [12].)

From Elements of Photonics, Volume II, Iizuka

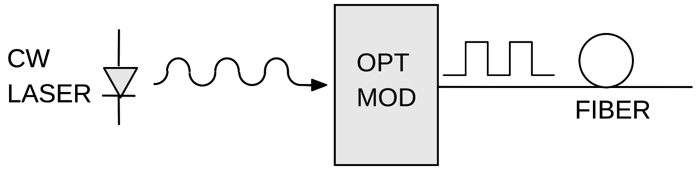
$$D_{total} = D_{mat} + D_{wg}$$

Pulse Spreading

$$\Delta\tau_{total} = \sqrt{\left(\Delta\tau_{mat} + \Delta\tau_{wg}\right)^2 + \left(\Delta\tau_{modal}\right)^2}$$

$$\Delta\tau_p^f = \sqrt{\left(\Delta\tau_p^i\right)^2 + \left(\Delta\tau_{tot}\right)^2}$$

Example:



A binary optical signal with on-off keying, non-return-zero-format, and a data rate of 100 gigabits per second (10 psec per bit), a wavelength of 1.0 μm is transmitted in a standard, single mode optical fiber. The frequency spread for an optical pulse can be taken to be the transform limit (i.e. ≈ one over the pulse width). Estimate the distance the optical signal can travel in the fiber before pulse spreading due to group velocity dispersion becomes a problem (i.e. pulses double in width).

$$\Delta\tau_{tot} = D_{total} \times L \times \Delta\lambda$$

$$\Rightarrow L = \frac{\Delta\tau_{tot}}{D_{total} \cdot \Delta\lambda}$$

Pulse spreading is a problem when $\Delta\tau_p^f = 2\Delta\tau_p^i = 20ps$.

Since $\Delta\tau_p^f = \sqrt{\left(\Delta\tau_p^i\right)^2 + \left(\Delta\tau_{tot}\right)^2}$,

pulse spreading becomes a problem when

$$\Delta\tau_{tot} = \sqrt{\left(\Delta\tau_p^f\right)^2 - \left(\Delta\tau_p^i\right)^2} = 17.32ps.$$

$$D_{total} = -50 \frac{ps}{km \cdot nm}$$ (from the dispersion graph)

$$\Delta\nu = \frac{1}{\Delta\tau_p^i} = \frac{1}{10ps} = 100GHz$$

$$\Rightarrow \Delta\lambda = \lambda \frac{\Delta\nu}{\nu} = \lambda^2 \frac{\Delta\nu}{c} = \left(1\times10^{-6} m\right)^2 \frac{100\times10^9 s^{-1}}{3\times10^8 \frac{m}{s}} = 0.33nm$$

This means $L = \frac{17.23}{50 \cdot 0.33} = 1.044\,km$