Optical Wave Guides & Fiber Optics

- Optical wave guides are the basis of optical communications
- Wave guides consist of a high index inner core/layer n_1
- Surrounded by a lower index cladding n_2
- This creates the Total internal reflection possibility

Recall At a critical angle θ_c the beam is refracted 90^o

$$\frac{sin(\theta_c)}{sin(90^o)} = \frac{n'}{n}$$

$$sin(\theta_c) = \frac{n'}{n}$$

- All larger angles (shallower to surface) reflected

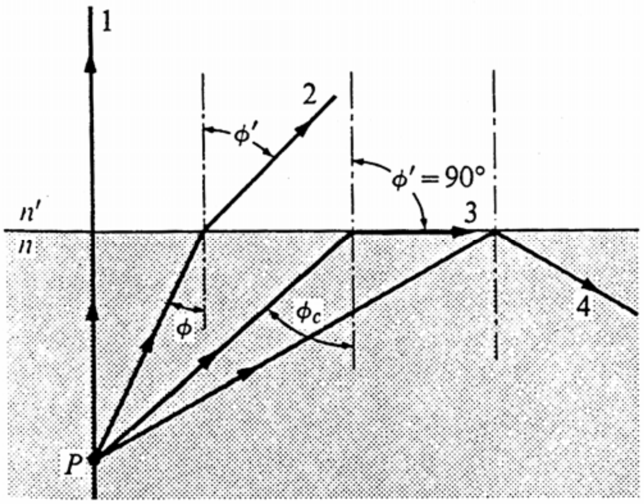
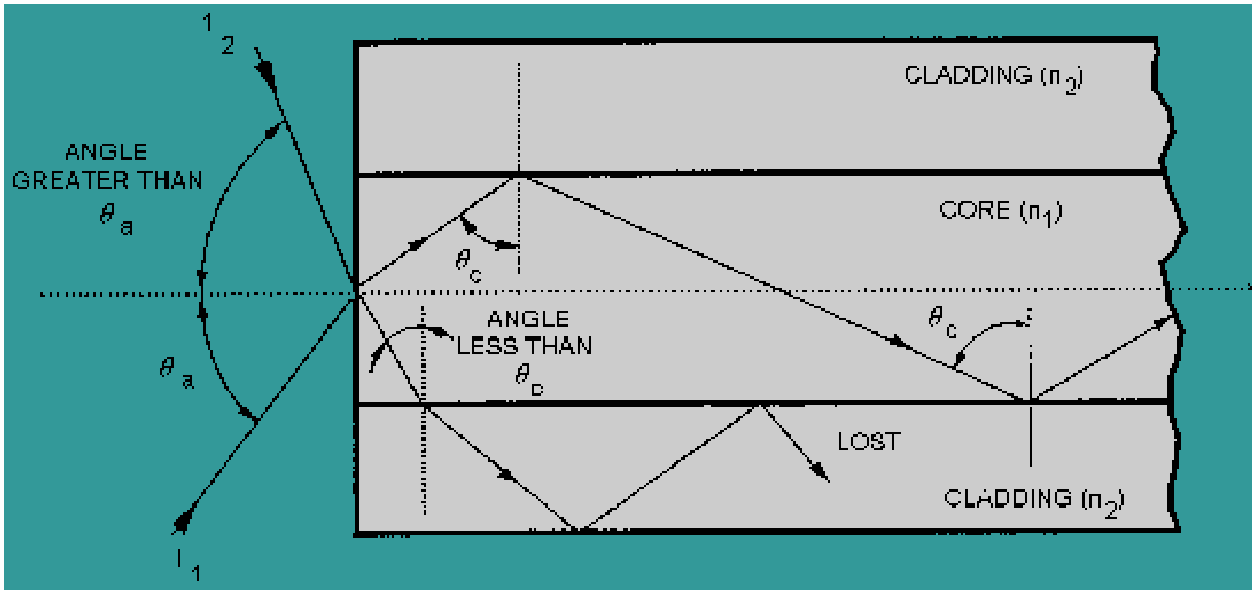
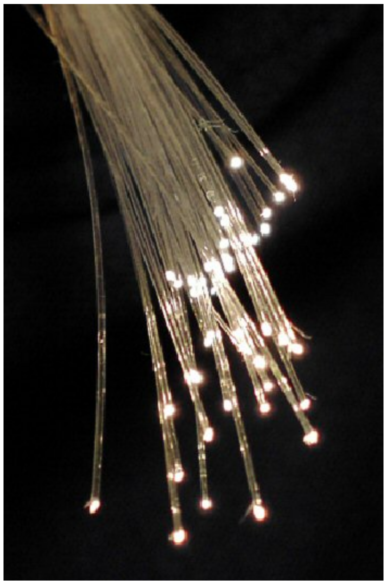


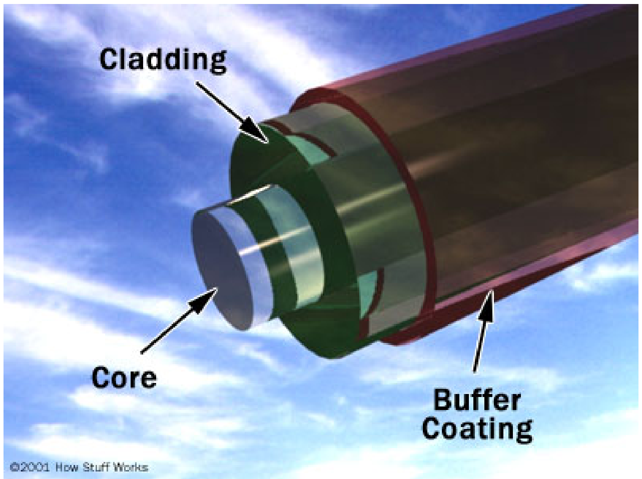
Fig. 38–7. Total internal reflection. The angle of incidence ϕ_c, for which the angle of refraction is 90°, is called the critical angle.

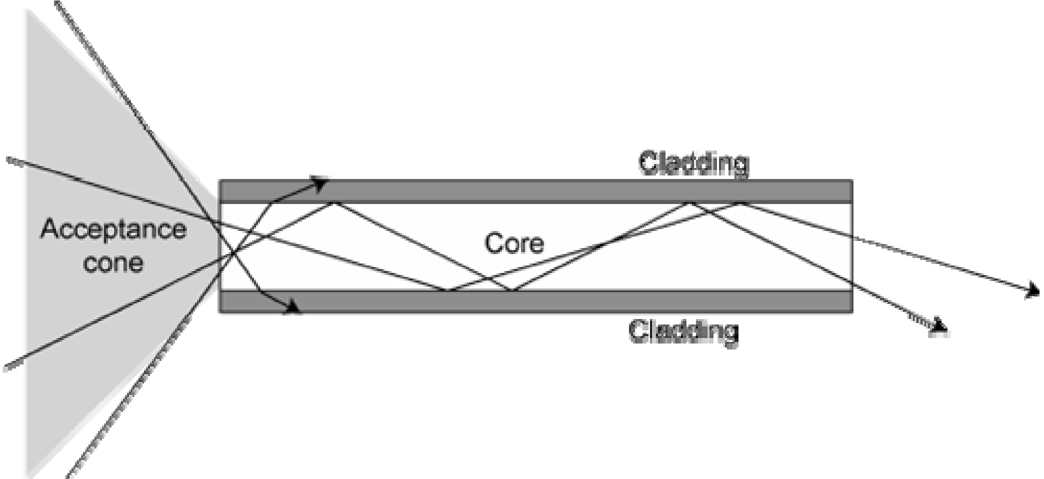


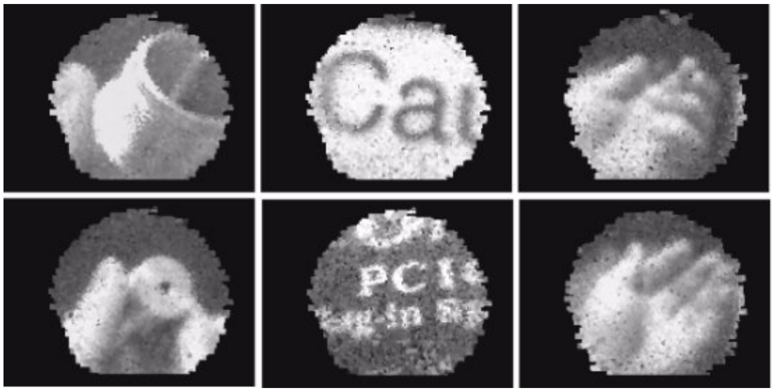
Confining Light to Wave Guide

- Concept of TIR by Jean-Daniel Colladon in1841
- Optical fibers started 1956
- Surrounding glass core with cladding keeps index change constant
- Thus light bounces through the fiber
- Initial application: if have bundle of fibers can transmit image
- Flexable line for image transmission



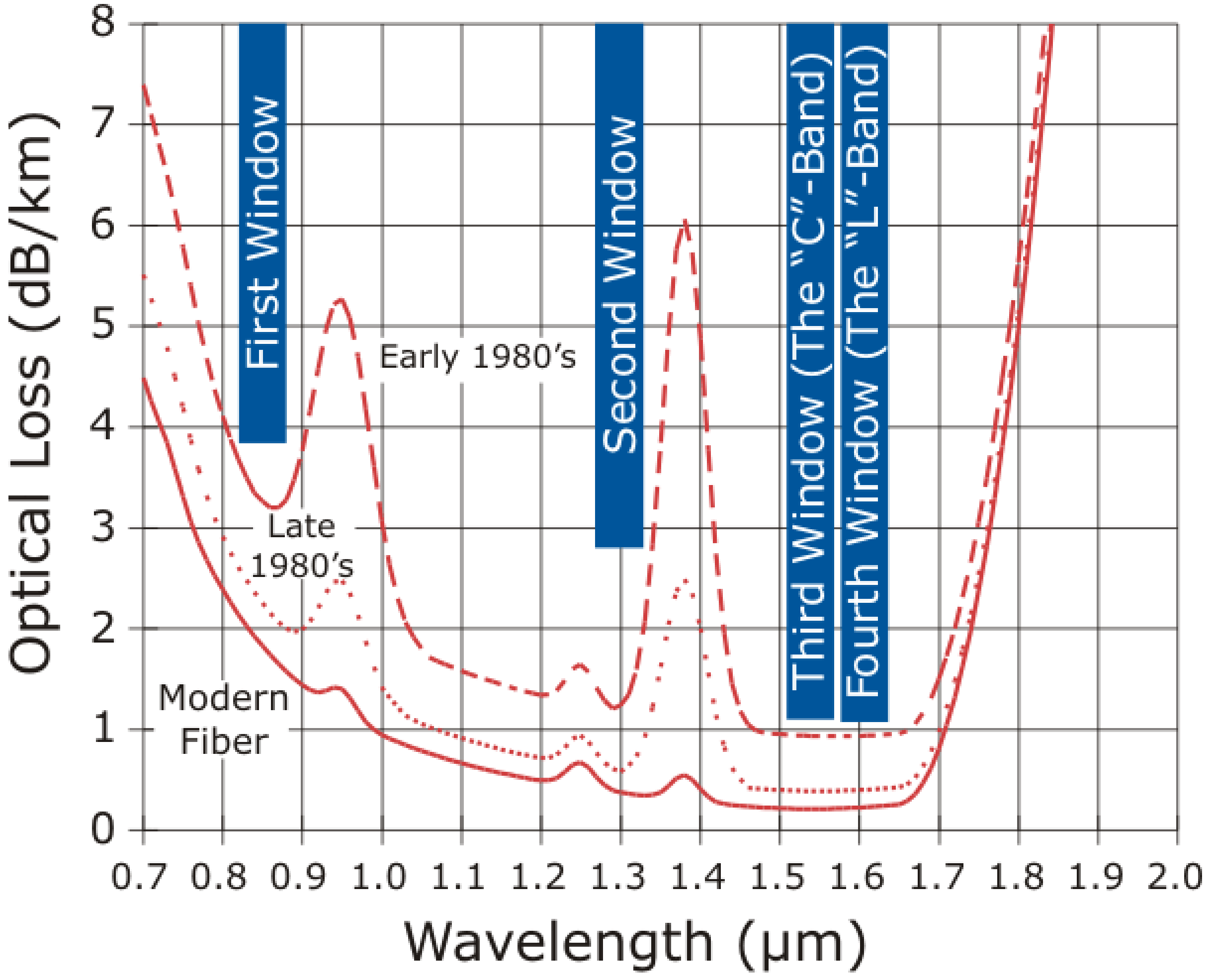






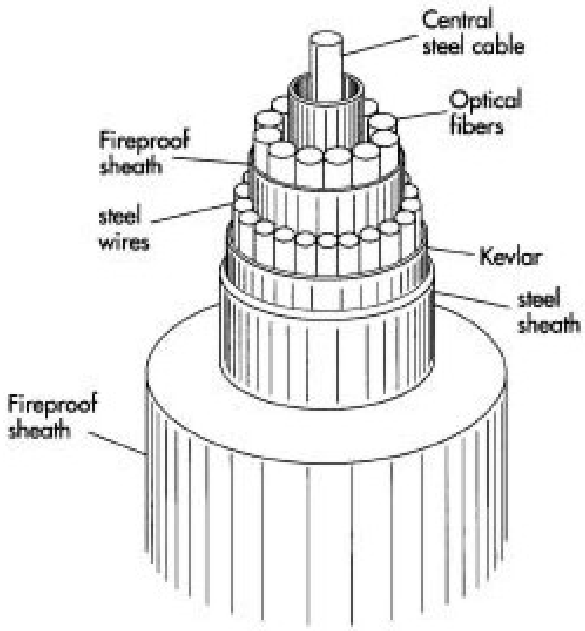
Optical Fiber Communications

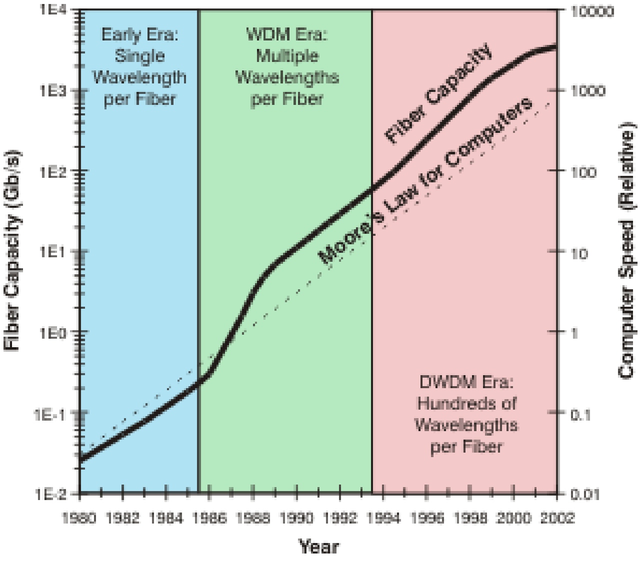
- Optical Fiber communications: Charles Kao & Charles Hockham
- Standard Telecommunication Laboratory in England in 1966
- At that time fiber had a lose of 1000 db/Km
- Stated if could get fiber to 20 db/Km would equal coaxial cable
- Need amplifier for 100 db loss – which was 5 km on coaxial
- Realized problem was impurity in glass
- 1970 Maurer, Keck, & Schultz of Corning Glass: 17 db/Km
- First fibers used GaAs lasers at ~850 nm, 3-4 db/Km
- New lasers targeted 1310 nm min absorption band 0.5 db/Km
- 1977 Nippon Telephone & Telegraph went to 1550 nm 0.2 db/Km
- Modern fibers <<1 db/km
- Signal travels 500-800 km without amps.
- 1990 Bells labs achieved 7500 km at 2.5 Gb/s without amps

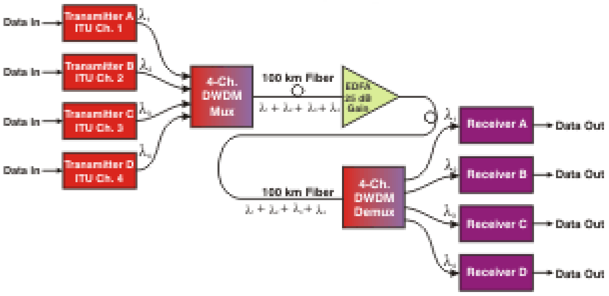


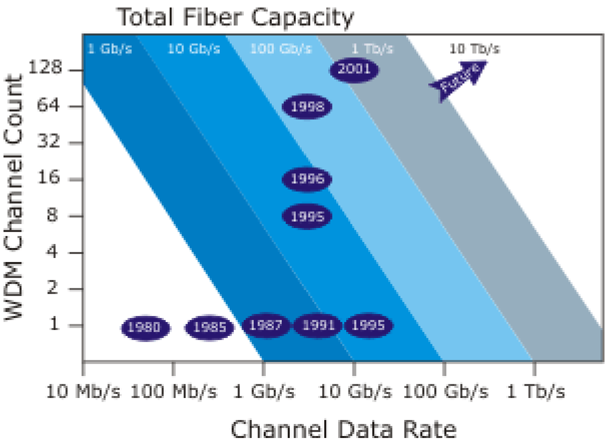
Fiber Communications

- After fiber next limits was getting lasers and detectors
- Needed long life (50,000 hrs) & speed at desired wavelength
- In 1980's fiber cable: single coaxial size but many fibers
- Vast increase in bit rate to GigaBits/s
- Initial increase was single wavelength fibers
- Next change was Wavelength-Division Multiplexing (WDM)
- Different wavelengths do not interfere
- Thus can keep cable the same and add several signals
- Replace with multiple laser diodes/detectors
- Currently Dense WDM (DWDM) 128 λ in single cable









Light Transmission in Fiber Cables

- Light traveling down the fiber has Emag wave distribution
- Consider a fiber with a core of radius a and core index n_1
- Solution of wave equations allows only certain angles θ_m
- Called the waveguide conditions

$$m\pi = \left(\frac{2\pi n_1 (2a)}{\lambda}\right) cos(\theta_m) - \phi_m$$

Where m is an integer: the mode number

ϕ = phase change for given mode

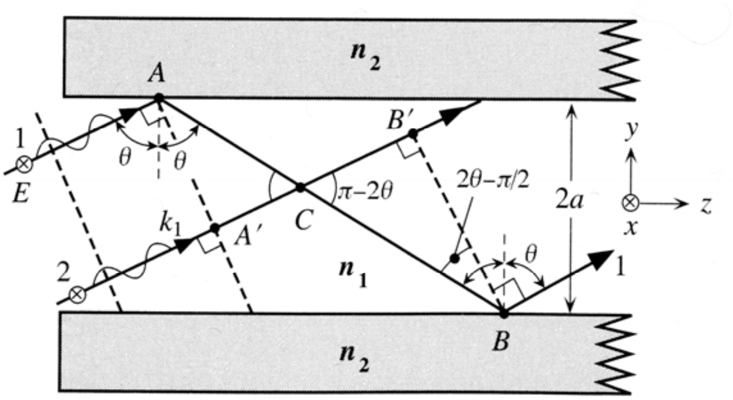
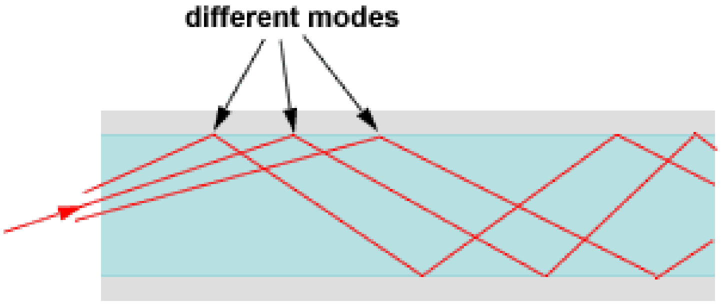


FIGURE 2.3 Two arbitrary waves 1 and 2 that are initially in phase must remain in phase after reflections. Otherwise the two will interfere destructively and cancel each other.



Step-Index Multimode Fiber

Light Transmission in Fiber Cables

- Light traveling down the fiber has Emag wave distribution
- But wave is dependent on the angle of the reflections
- Diferrent angles give different modes
- The propagation constant for each possible mode angle is

$$\beta_m = \left(\frac{2\pi n_1}{\lambda}\right) sin(\theta_m)$$

- Emag wave in the fiber becomes

$$E(y,z,t) = 2E_m(y)\, cos(\omega t - \beta_m z)$$

Where y is axial radius, z length, t time

- Different modes different wave distribution

FIGURE 2.3 Two arbitrary waves 1 and 2 that are initially in phase must remain in phase after reflections. Otherwise the two will interfere destructively and cancel each other.

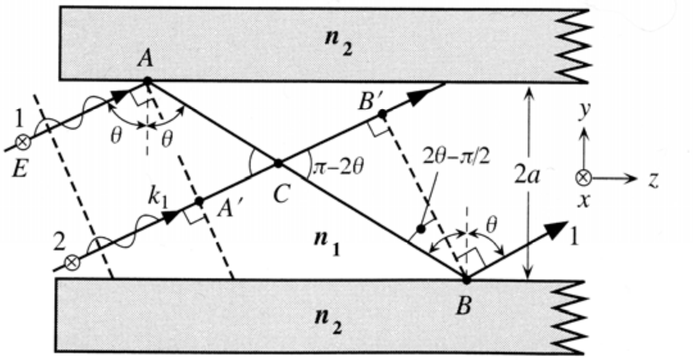


FIGURE 2.5 The electric field pattern of the lowest mode traveling wave along the guide. This mode has $m = 0$ and the lowest θ. It is often referred to as the glazing incidence ray. It has the highest phase velocity along the guide.

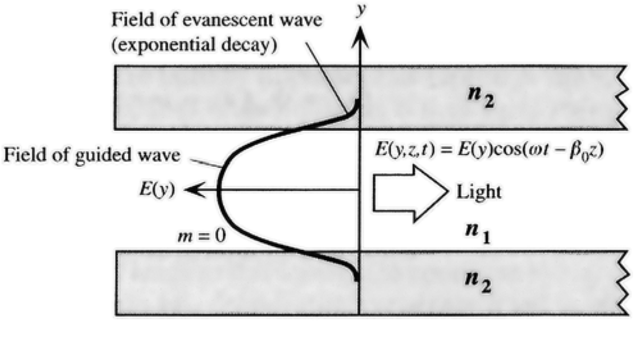
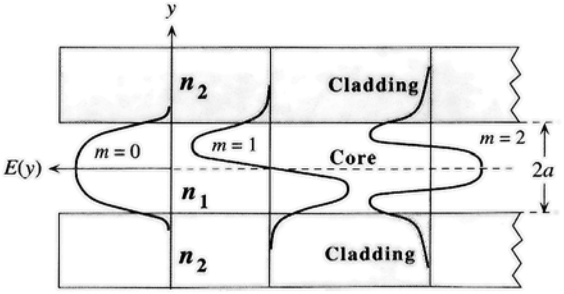
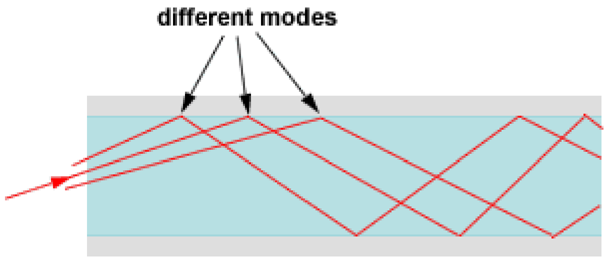


FIGURE 2.6 The electric field patterns of the first three modes ($m = 0, 1, 2$) traveling wave along the guide. Notice different extents of field penetration into the cladding.



Effect of Different Fiber Modes

- Modes of propagation have effect on the signal
- Different modes at different angles mean light path length changes
- Thus some modes arrive before others
- This creates a spreading of the light pulse



Step-Index Multimode Fiber

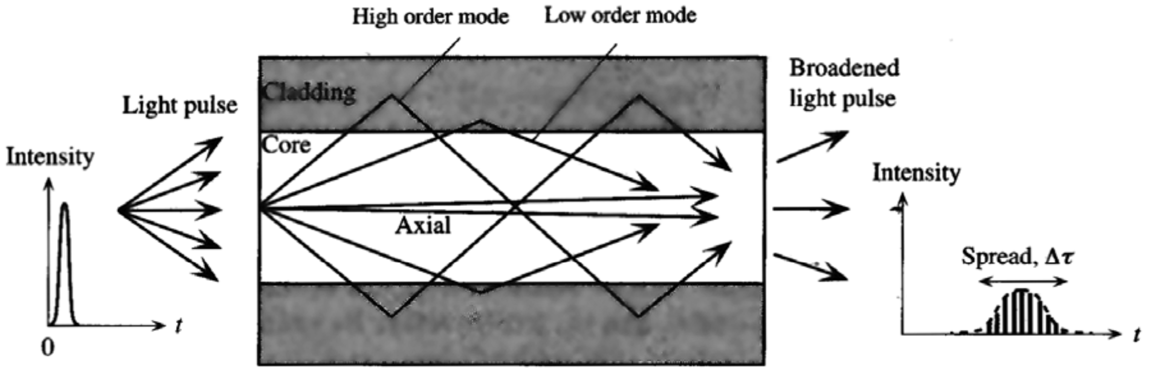


FIGURE 2.7 Schematic illustration of light propagation in a slab dielectric waveguide. Light pulse entering the waveguide breaks up into various modes that then propagate at different group velocities down the guide. At the end of the guide, the modes combine to constitute the output light pulse which is broader than the input light pulse.