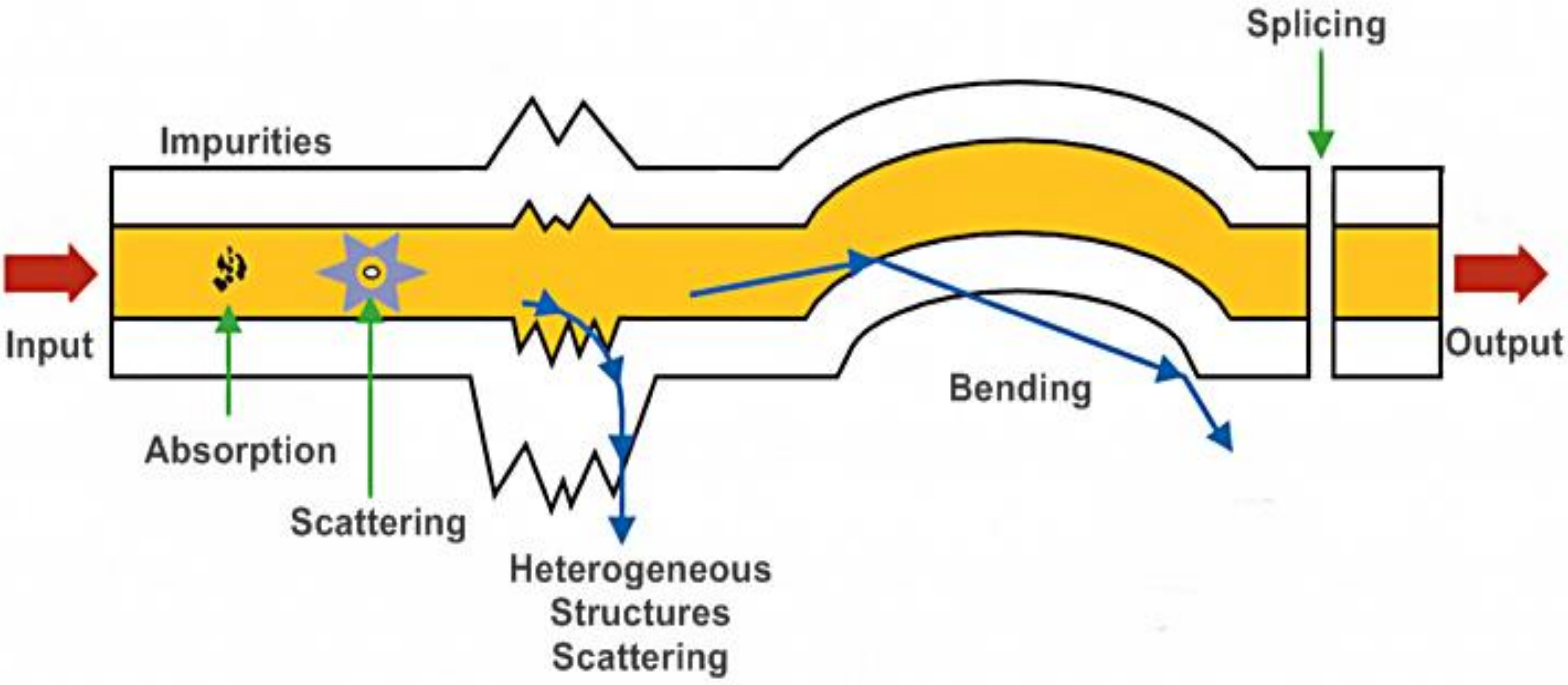
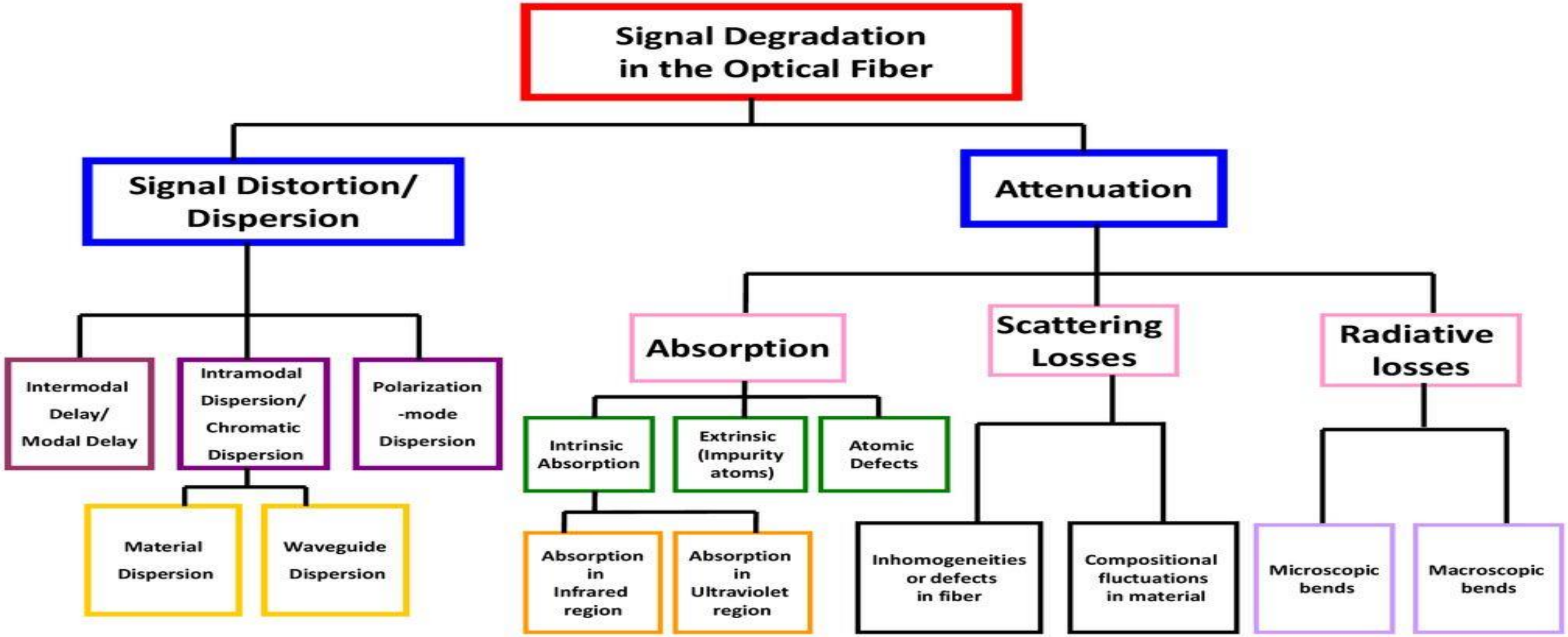


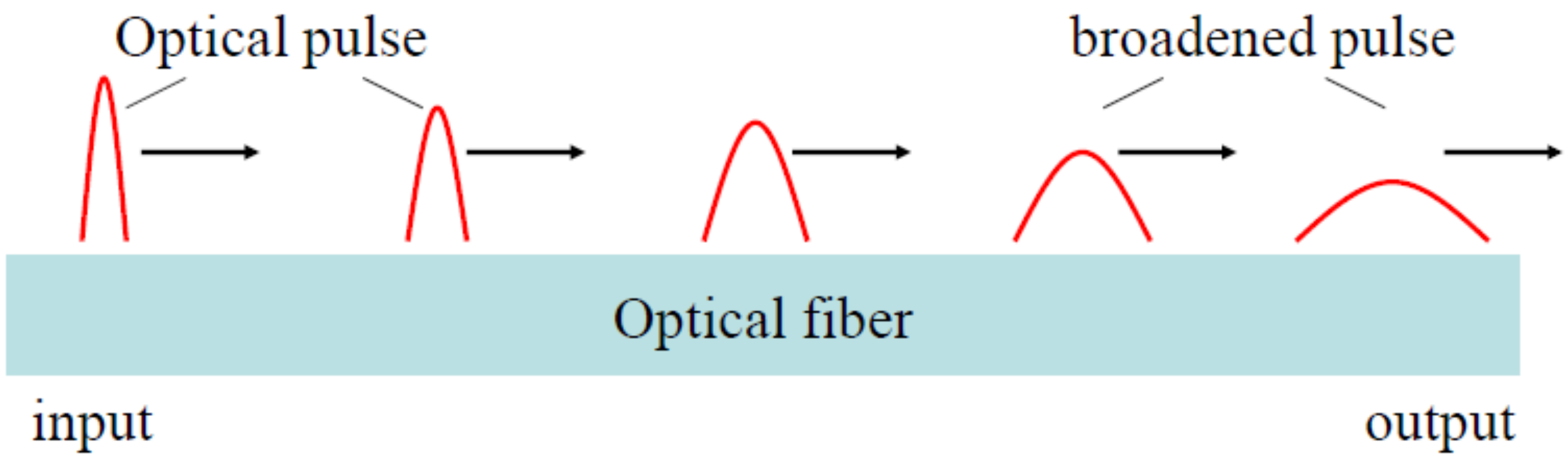
Module – 2
Signal Degradation

Signal degradation in fiber cable



Fiber Dispersion

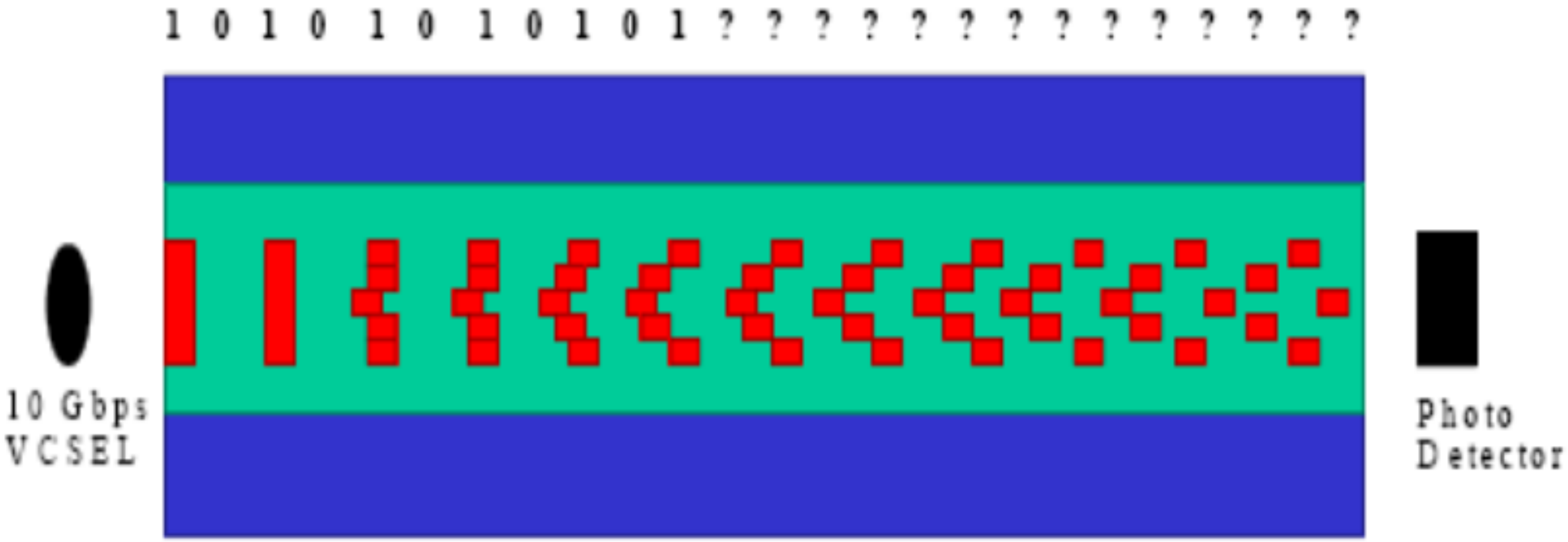
- Fiber dispersion results in optical pulse broadening and hence digital signal degradation.



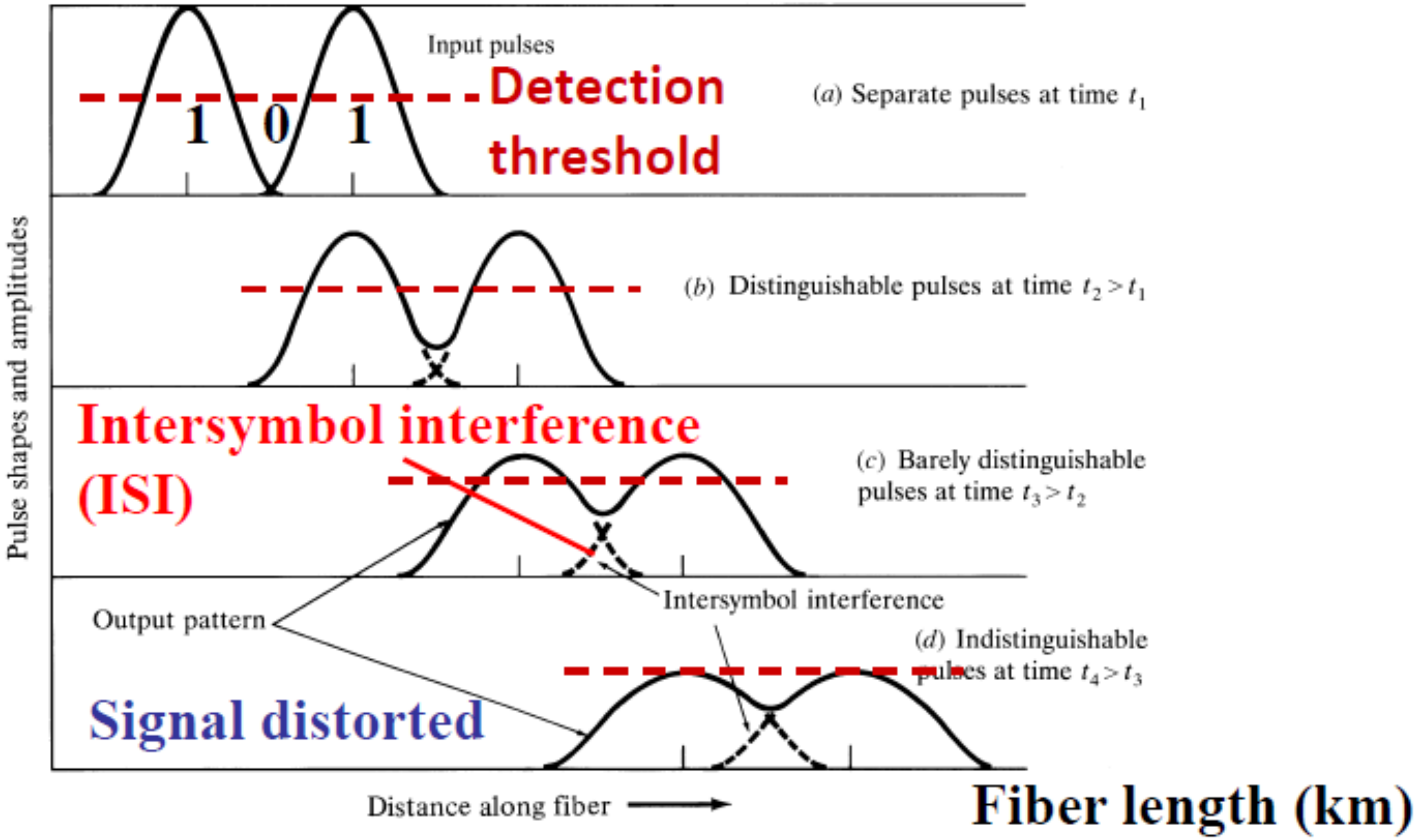
Dispersion mechanisms:

- Modal (or intermodal) dispersion
- Chromatic dispersion (CD)
- Polarization mode dispersion (PMD)

Dispersion in digital systems



Pulse broadening limits fiber bandwidth (data rate)



Dispersion types

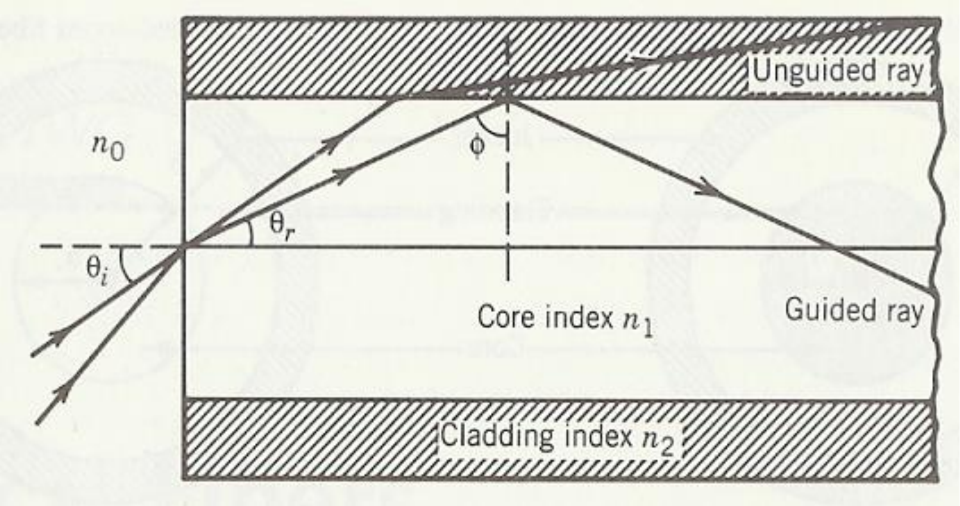
- Intermodal (modal) Dispersion
- Intramodal Dispersion
- Chromatic Dispersion
  - Material Dispersion
  - Waveguide Dispersion
- Polarization Mode Dispersion

Modal dispersion

- When numerous waveguide modes are propagating, they all travel with different net velocities with respect to the waveguide axis.
- An input waveform distorts during propagation because its energy is distributed among several modes, each traveling at a different speed.
- Parts of the wave arrive at the output before other parts, spreading out the waveform. This is thus known as multimode (modal) dispersion.
- Multimode dispersion does not depend on the source linewidth (even a single wavelength can be simultaneously carried by multiple modes in a waveguide).
- Multimode dispersion would not occur if the waveguide allows only one mode to propagate - the advantage of single-mode waveguides!

Dr. T.Ilavarasan, Associate Professor,SENSE, VIT

Inter modal dispersion (meridional rays)



Inter modal dispersion (meridional rays)

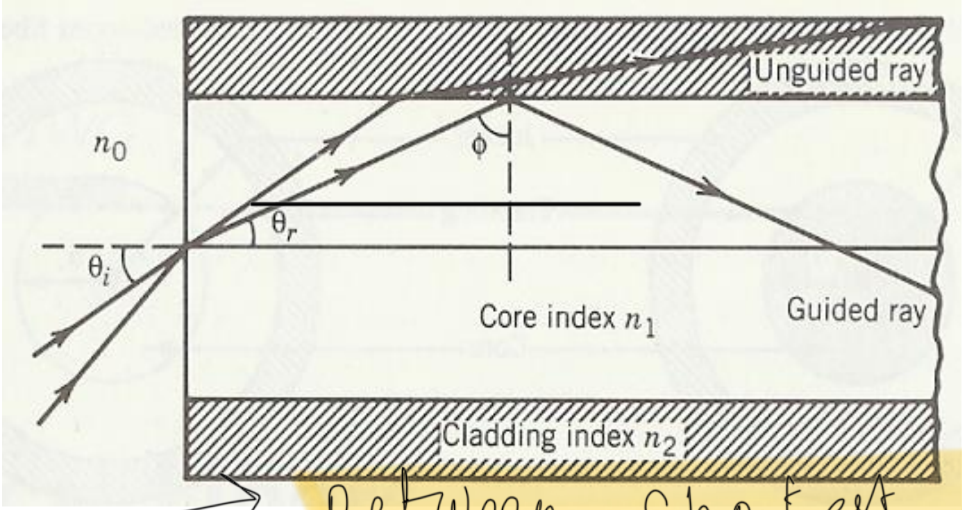
Shortest path ➔ $\theta_i = 0$

path length = L

Longest path ➔ $\phi = \phi_c$

path length = L / Sin ϕ_c

Velocity V ➔ c / n_1



Between shortest and longest

Time delay ΔT_{mod} = Path length difference / Velocity

$$= [\, (L / \sin\phi_c) - L \,] \;/\; [c / n_1]$$

$\boxed{\sin\phi_c = n_2 / n_1}$ ➔ $\Delta T_{mod} = (L / c)\,(n_1^2 / n_2)\,\Delta = L n_1 \Delta / c$

$\boxed{\dfrac{L}{\sin\phi_c} - L}$

$$\Delta T_{mod} = \frac{\text{Path length difference}}{\text{velocity}}$$

$$= \frac{\frac{L}{\sin \phi_c} - L}{c/n_1}$$

$$= \frac{L}{c}\left[\frac{n_1^2}{n_2}\right]$$

$$\frac{L}{c}\Delta n_1$$

RMS pulse broadening

RMS pulse width $\sigma = \tau / (2\sqrt{3})$

$$\sigma = \frac{\tau}{2\sqrt{3}}$$

RMS pulse spread for a MMSIF:

$$\sigma_s = \Delta T_{mod} / (2\sqrt{3}) = L n_1 \Delta / (c\, 2\sqrt{3})$$

RMS pulse spread for a MMSIF considering mode coupling:

$$\sigma_{sc} = \Delta T_{sc} / (2\sqrt{3}) = (L L_c)^{1/2} n_1 \Delta / (c\, 2\sqrt{3})$$

$L_c \rightarrow$ characteristic length of fiber

RMS pulse spread for a MMGIF:

$\Delta T_{gi} = L n_1 \Delta^2 / 2c$ [using ray theory approach]

$= L n_1 \Delta^2 / 8c$ [using mode theory approach]

$= L n_1 \Delta^2 / Dc$ [where D varies from 2 to 10]

$\sigma_{gi} = \Delta T_{gi} / (2\sqrt{3})$

$= L n_1 \Delta^2 / (20\, c\sqrt{3}) = \sigma_s (\Delta / 10)$

Attenuation units – Numerical problem

Compare the rms pulse broadening per kilometer for the following three fibers:
(i). a multimode step index fiber with core index $n_1 = 1.49$ and $\Delta = 1.0$ %,
(ii). a graded index fiber having an optimum parabolic index profile and the same n_1 and Δ as in (i),
(iii). the same type of graded index fiber as in (ii) but with $\Delta = 0.5$ %.

Attenuation units – Numerical problem

Compare the rms pulse broadening per kilometer for the following three fibers:
(i). a multimode step index fiber with core index $n_1 = 1.49$ and $\Delta = 1.0\ \%$,
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(iii). the same type of graded index fiber as in (ii) but with $\Delta = 0.5\ \%$.

(i) $\sigma_{step} = 14.3$ ns / km
(ii) $\sigma_{gi} = 14.3$ ps / km
(iii) $\sigma_{gi} = 3.58$ ps / km

Dispersion Characteristics of optical fiber

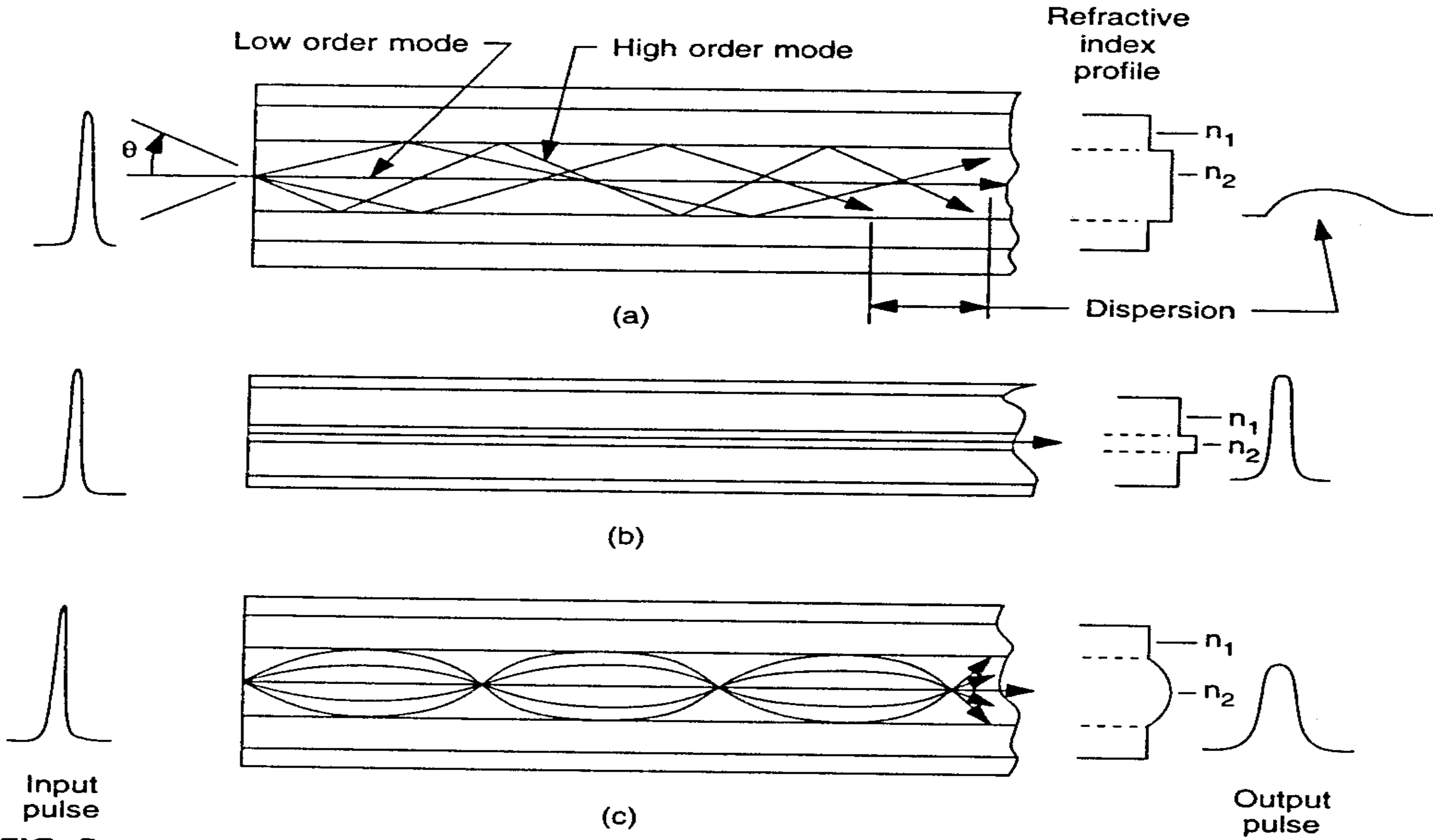


FIG. 2. Characteristics of common optical fibers—(a) multimode step index; (b) single-mode step index; (c) multimode graded index.

Bit-rate distance product

How much will a light pulse spread after traveling along 1 km of a step-index fiber whose NA = 0.275 and ncore = 1.487?

Bit-rate distance product

How does modal dispersion restricts fiber bit rate?

Suppose we transmit at a low bit rate of 10 Mb/s
→Pulse duration = 1 / 10^7 s = 100 ns

Using the above e.g., each pulse will spread up to approx. 100 ns (i.e. approx. pulse duration !) every km

→The broadened pulses overlap! (Intersymbol interference (ISI))

*Modal dispersion limits the bit rate of a fiber-optic link to ~ 10 Mb/s.
(a coaxial cable supports this bit rate easily!)

Bit-rate distance product

- We can relate the pulse broadening ΔT to the information-carrying capacity of the fiber measured through the bit rate B.
- Although a precise relation between B and ΔT depends on many details, such as the pulse shape, it is intuitively clear that ΔT should be less than the allocated bit time slot given by 1/B.
- An order-of-magnitude estimate of the supported bit rate is obtained from the condition $B\Delta T < 1$.
- Bit-rate distance product (limited by modal dispersion)

$$BL < \frac{c}{n_1 \Delta}$$

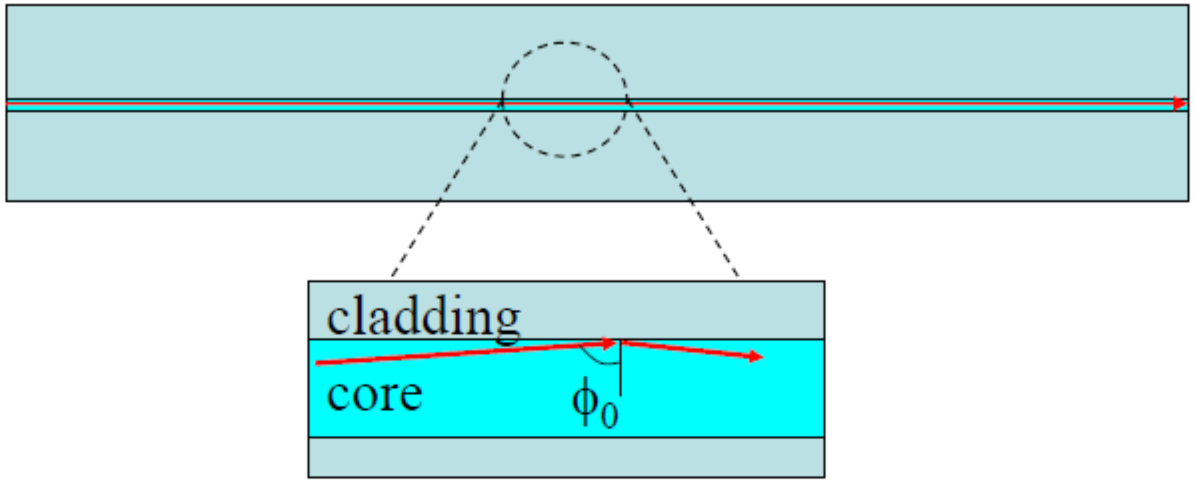
- This condition provides a rough estimate of a fundamental limitation of step-index multimode fibers.

(the smaller is the NA, the larger is the bit-rate distance product)

Bit-rate distance product

- The capacity of optical communications systems is frequently measured in terms of the bit rate-distance product.
- e.g. If a system is capable of transmitting 10 Mb/s over a distance of 1 km, it is said to have a bit rate-distance product of 10 (Mb/s)-km.
- This may be suitable for some local-area networks (LANs).
- Note that the same system can transmit 100 Mb/s along 100 m, or 1 Gb/s along 10 m, or 10 Gb/s along 1 m, or 100 Gb/s along 10 cm, 1 Tb/s along 1 cm

Single-mode fiber eliminates modal dispersion



- The main advantage of single-mode fibers is to propagate only one mode so that modal dispersion is absent.

- However, pulse broadening does not disappear altogether. The group velocity associated with the fundamental mode is frequency dependent within the pulse spectral linewidth because of chromatic dispersion.