Dispersion in Optical Fiber Communcation systems I

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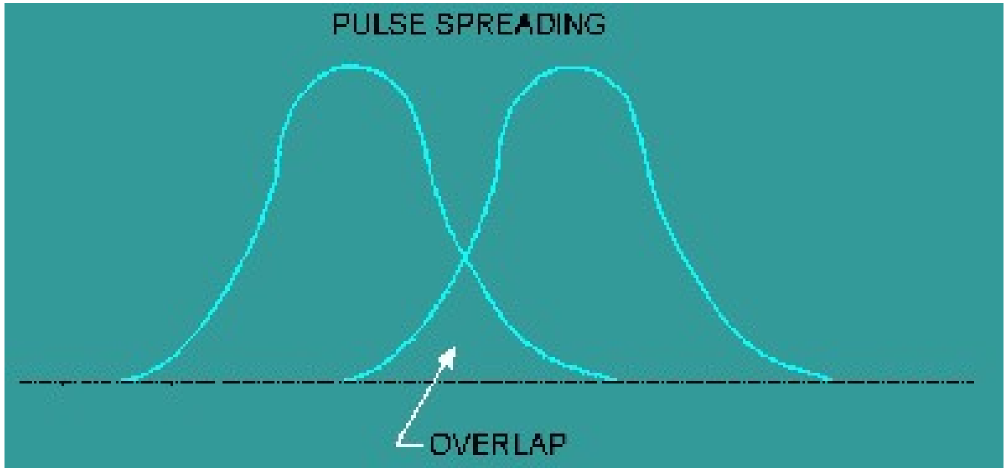
❑ DISPERSION

- Dispersion is the "spreading" of a light pulse as it travels down a fiber.

- The spreading of the optical pulse as it travels along the fiber limits the information capacity of the fiber.

Intersymbol interference



- For no overlapping of light pulses down on an optical fiber link, the digital bit rate B_T must be less than the reciprocal of the broadened (through dispersion) pulse duration (2τ) . Hence:

$$B_{\tau} \leq \frac{1}{2\tau}$$

$$B_{\tau\,(\max)} = \frac{1}{2\tau}$$

- This assumes that the pulse broadening due to dispersion on the channel is τ which dictates the input pulse duration is also τ.
- Another more accurate estimate of the maximum bit rate for an optical channel with dispersion may be obtained by considering the light pulses at the output to have a Gaussian shape with an RMS width of σ.

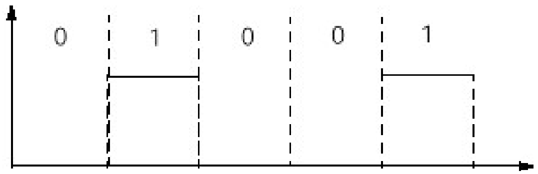
- The maximum bit rate is given approximately by

$$B_{\tau(\max)} \approx \frac{0.2}{\sigma} \qquad bit.s^{-1}$$

➢The conversion of bit rate to bandwidth in hertz depends on the digital coding format used.

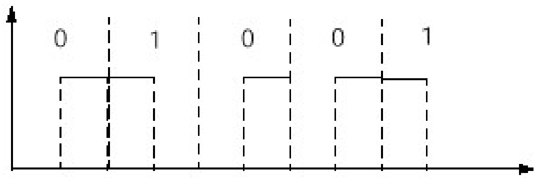
$$B_{\tau(max)} = 2B$$ NRZ

Nonreturn-to-zero code



$$B_{\tau(max)} = B$$ RZ

Return-to-zero (Manchester) code



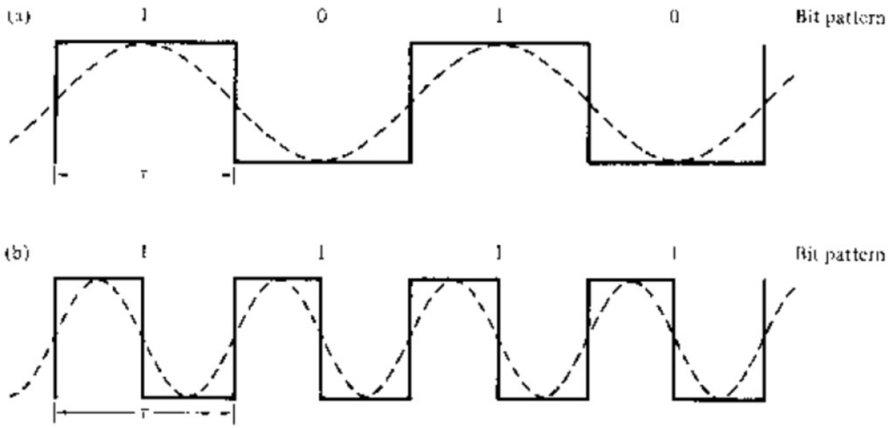


Fig. 3.6 Schematic illustration of the relationships of the bit rate to wavelength for digital codes: (a) non return to zero (NRZ); (b) return to zero (RZ).

- A measure of the information capacity of an optical waveguide is usually specified by **bandwidth-distance product** in MHz.km.

Fiber type	Bandwidth-distance product
Step index multimode	20 MHz.km
Graded index	20 GHz.km
Single mode	100 GHz.km

- In general, when a system's bandwidth is 200 MHz·km, it means that 200 million pulses of light per second will travel down 1 km (1000 meters) of fiber, and each pulse will be distinguishable by the receiver.

Example 3.5

A multimode graded index fiber exhibits total pulse broadening of 0.1 μs over a distance of 15 km. Estimate:

(a) the maximum possible bandwidth on the link assuming no intersymbol interference;
(b) the pulse dispersion per unit length;
(c) the bandwidth–length product for the fiber.

Solution: (a) The maximum possible optical bandwidth which is equivalent to the maximum possible bit rate (for return to zero pulses) assuming no ISI may be obtained from Eq. (3.9), where:

$$B_{opt} = B_T = \frac{1}{2\tau} = \frac{1}{0.2 \times 10^{-6}} = 5 \text{ MHz}$$

(b) The dispersion per unit length may be acquired simply by dividing the total dispersion by the total length of the fiber.

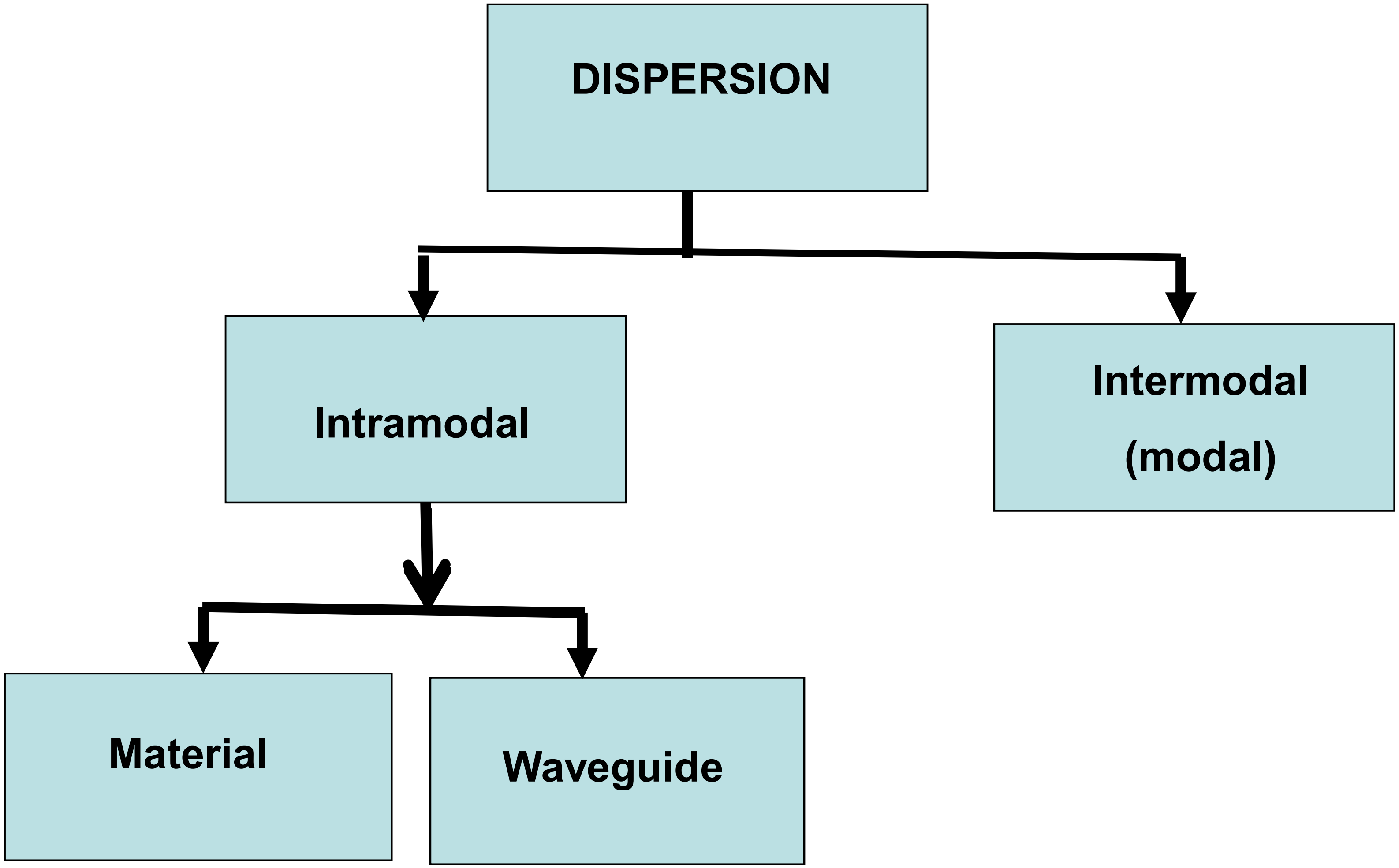
$$\text{dispersion} = \frac{0.1 \times 10^{-6}}{15} = 6.67 \text{ ns km}^{-1}$$

(c) The bandwidth–length product may be obtained in two ways. Firstly by simply multiplying the maximum bandwidth for the fiber link by its length. Hence:

$$B_{opt}L = 5 \text{ MHz} \times 15 \text{ km} = 75 \text{ MHz km}$$

Alternatively it may be obtained from the dispersion per unit length using Eq. (3.9) where:

$$B_{opt}L = \frac{1}{2 \times 6.67 \times 10^{-9}} = 75 \text{ MHz km}$$



- Intramodal, or chromatic, dispersion occurs in all types of fibers. Intermodal, or modal, dispersion occurs only in multimode fibers.

Intramodal (Chromatic) dispersion

- There are two types of intramodal dispersion.

1. material dispersion.

2. waveguide dispersion.

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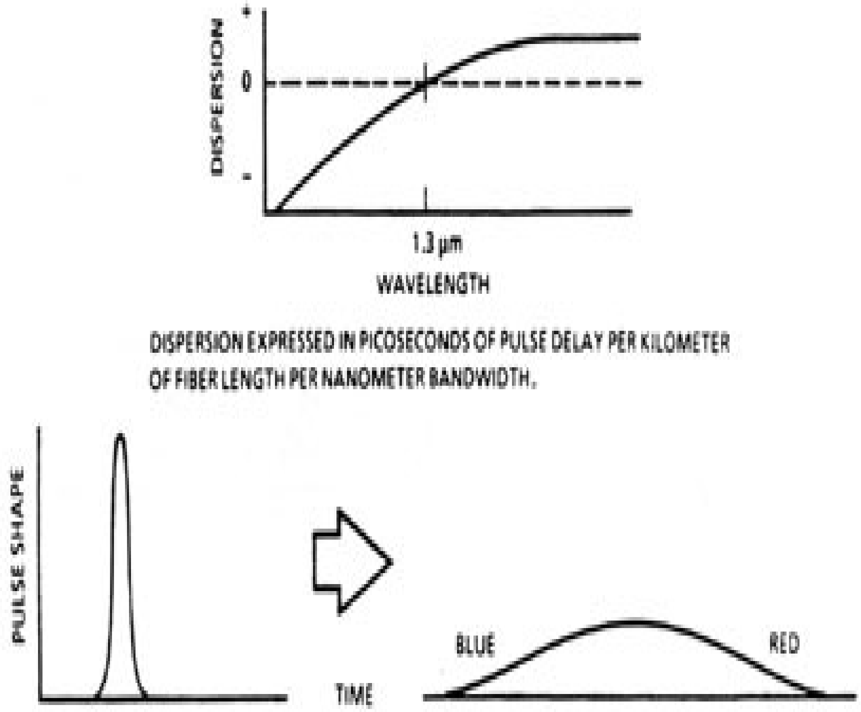


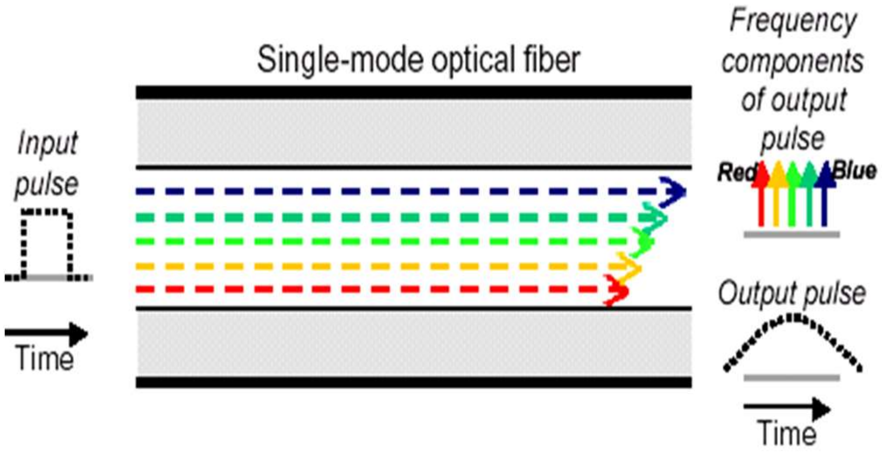
- This is of most importance in single-mode applications.

➢Material dispersion

➢ Material dispersion is a function of the source spectral width.

➢Material dispersion is less at longer wavelengths.

It is said to to have material dispersion when the second derivative of refractive index with respect to wavelength is not zero $[d^2n/ d\lambda^2 \neq 0]$.



CD causes the shorter λ to travel faster than the longer λ.

The group delay is given by:

$$\tau_g = d\beta / d\omega = (1/c)(n_1 - \lambda\, dn_1 / d\lambda) \quad 1$$

The pulse delay τm due to material dispersion in a fiber of length L is therefore:

$$\tau_m = L/C\, (n_1 - \lambda\, dn_1 / d\lambda)$$

For a source with RMS spectral width σ_λ and a mean wavelength, the RMS pulse broadening due to material dispersion

- Hence the pulse broadening may be evaluated by considering the dependence of τ_m on λ where from eq (2):

$$\frac{d\tau_m}{d\lambda} = \frac{-L\lambda}{c}\frac{d^2 n_1}{d\lambda^2} \qquad (2)$$

Substituting eq (4) in eq (3)

$$\sigma_m \cong \frac{\sigma_\lambda L}{c}\left|\lambda \frac{d^2 n_1}{d\lambda^2}\right| = \sigma_\lambda M L \qquad (3)$$

And

$$M = \frac{1}{L}\cdot\frac{d\tau m}{d\lambda} = \frac{\lambda}{c}\left|\frac{d^2 n_1}{d\lambda^2}\right| \qquad (4)$$

- Where M is the material dispersion parameter and is often expressed in units of

(ps.nm^{-1}.km^{-1})

- it may be observed that the material dispersion tends to zero in the longer wavelength region around 1,3 Mm (for pure silica)

- it can be reduced either by choosing sources with narrower spectral output width (reducing $\boldsymbol{\sigma}_\lambda$) like using injection laser diode or operating at longer wavelength

- it is of particular importance for single–mode waveguides and LED system (since an LED has broader output spectrum than a laser diode)

P.109
Ex 2

Estimate the rms pulse broadening per Kilometere for the fiber in the previous example when the optical source used is an injection laser with a relative spectral width σ_λ/λ of 0.0012 at a wavelength of 0.85 μm.

Sol.

The rms spectral width may be obtained from the relative spectral width by:

$$\sigma_\lambda = 0.0012\,\lambda = 0.0012 \times 0.85 \times 10^{-6}$$
$$= 1.02\ \text{nm}.$$

The rms pulse broadening is

$$\sigma_m \simeq \sigma_\lambda L M$$

P.109
Ex 2

Estimate the rms pulse broadening per Kilometere for the fiber in the previous example when the optical Source used is an injection laser with a relative spectral width σ_λ / λ of 0.0012 at a wavelength of 0.85 μm.

Therefore, the rms pulse broadening per kilometere due to material dispersion is:

$$\sigma_m \simeq 1.02 \times 1 \times 98.1 \times 10^{-12}$$

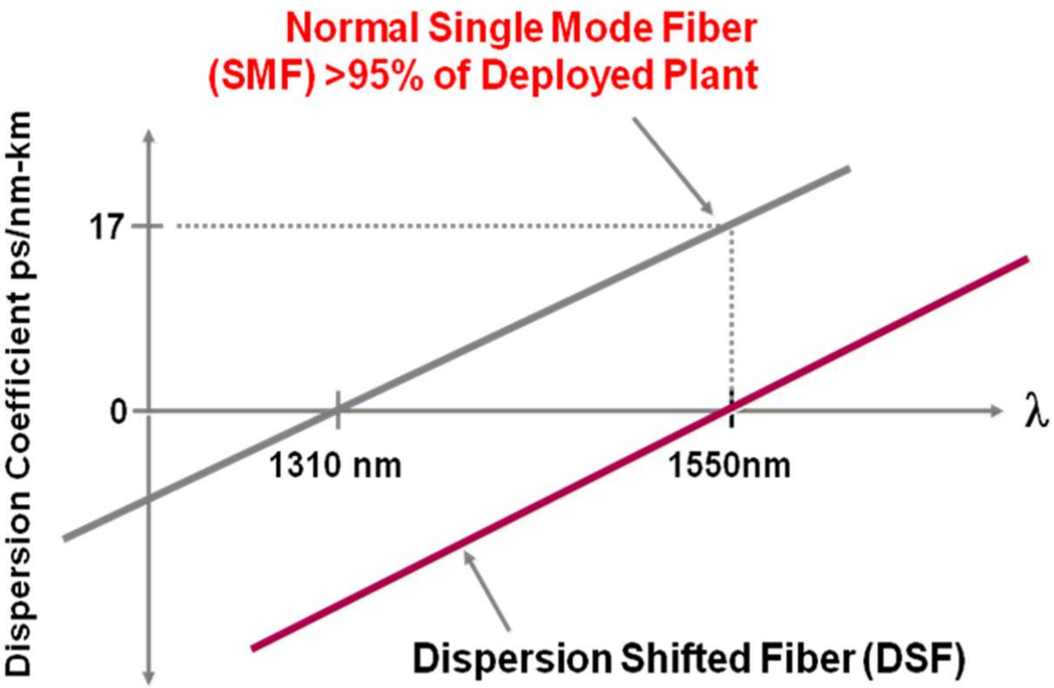
$$= 0.1 \text{ ns.km}^{-1}$$

- **Waveguide dispersion** occurs because the mode propagation constant (β) is a function of the size of the fiber's core relative to the wavelength of operation. Waveguide dispersion also occurs because light propagates differently in the core than in the cladding.

- Multimode waveguide dispersion is generally small compared to material dispersion. **Waveguide dispersion is usually neglected.**

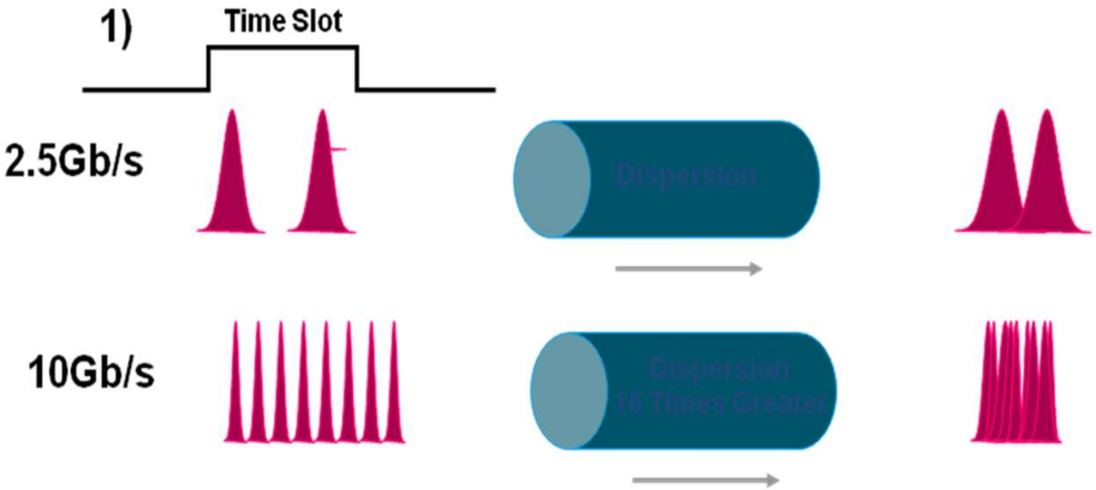
- However, in single mode fibers, material and waveguide dispersion are interrelated.

Dispersion Management: Problem Fiber Dispersion Characteristic



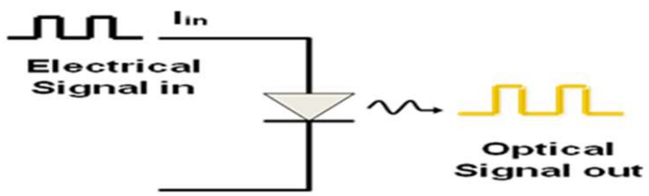
Dispersion Management: Problem Increasing the Bit Rate

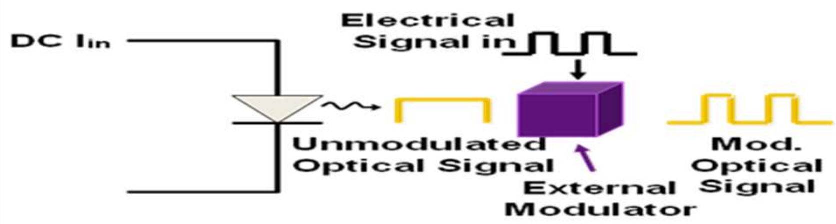
Higher Bit Rates experience higher signal degradation due to Chromatic Dispersion:



Dispersion Scales as (Bit Rate)^2

Dispersion Management: Solution Direct vs. External Modulation





Laser diode's bias current is • modulated with signal input to produce modulated optical output
•Approach is straightforward and low cost, but is susceptible to chirp (spectral broadening) thus exposing the signal to higher dispersion

The laser diode's bias current is • stable
•Approach yields low chirp and better dispersion performance, but it is a more expensive approach