Optical Communications

<u>Light wave Fundamentals</u>

Part3

Fiber Optic Communications

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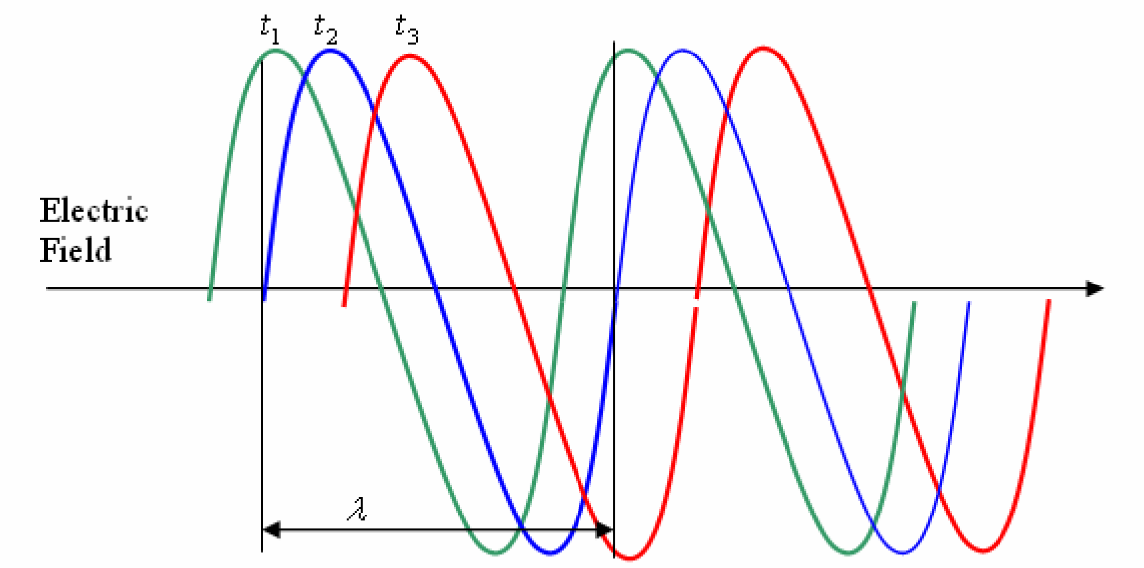
Light wave Fundamentals

Electromagnetic Waves

Light consists of an electric field and magnetic field that oscillate at very high rates (10^{14} Hz)



The wave repeats itself every λ (wavelength) and $1/\lambda$ is the wave number.

$$E = E_0 \sin(\omega t - kz)$$

Light wave Fundamentals

$\omega = 2\pi f$ (r/s) is the radian frequency. f is the frequency in Hz. k is the propogatin factor, where

$$k = \frac{\omega}{v}$$

$(\omega t - kz)$ is the phase of the wave

kz is the phase shift owing to travel over length z

v is the wave velocity of the wave and z is the length.

If $t = 0$ then $E = E_0 \sin(-kz) = -E_0 \sin(kz)$ (Sinusoidal spatial variation)

If $z = 0$ then $E = E_0 \sin(\omega t)$ (Fixed position)

We know that $v = \frac{c}{n}$, then $k = \frac{\omega n}{c}$ and in free space $(n = 1)$ $k_0 = \frac{\omega}{c}$ and $k = k_0 n$

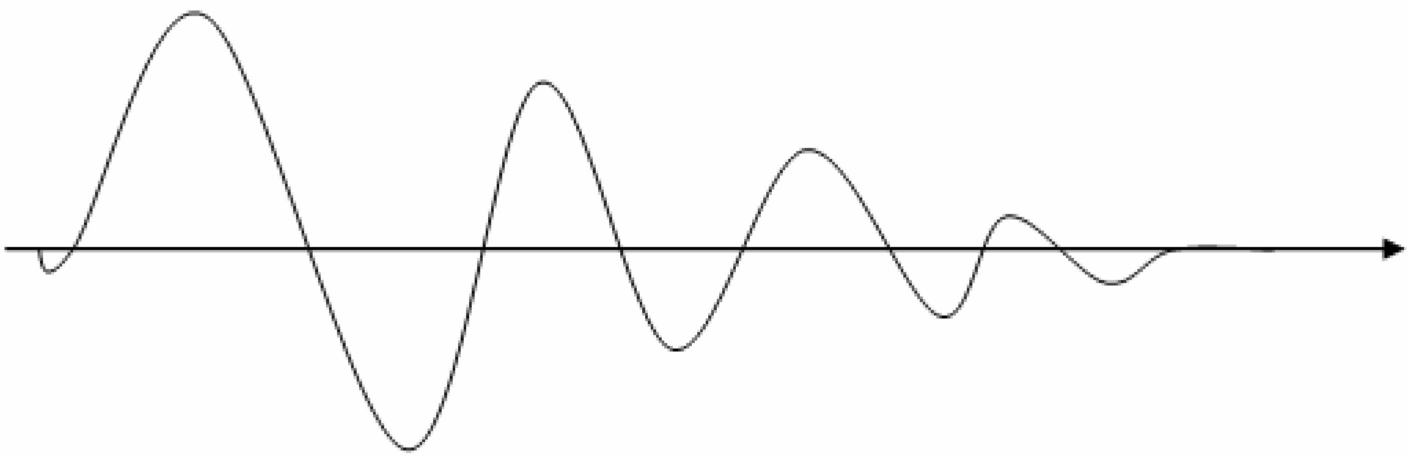
Or $\lambda = \frac{v}{f}$ and $k = \frac{2\pi}{\lambda}$ [this equation relates the propogation constatnt in a medium to the wavelength in that meduim.

$$\frac{\lambda_0}{\lambda} = \frac{c}{v} = n > 1$$

Light wave Fundamentals

The intensity (power) of light beam is propotional to the square of its electric field.

For a path L, the ratio of the output power to the input power in dB=$10\log_{10} e^{-2\alpha L}$



α is the attenuation coefficient (losses in fiber) and $dB/km = -8.685\alpha$ (How?)

Beers's Law

$$\frac{P_{out}}{P_{in}} = 10^{\gamma L/10}$$

γ is the power change in dB/km

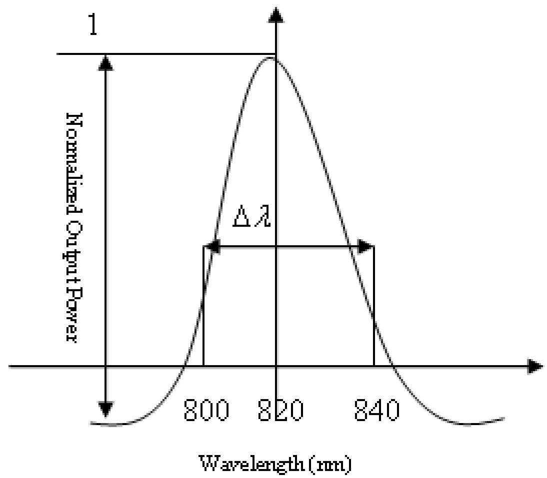
Light wave Fundamentals

Dispersion, pulse distortion and information rate

Real sources produce radiation over a range of wavelength (Spectral width or line-width). If line-width =0 then we have a monochromatic source.

Source	Line-width ($\Delta\lambda$)(nm)
LED	20-100
LD	1-50
Nd:YAG laser	0-1
HeNe laser	0.002

$$\frac{\Delta f}{f} = \frac{\Delta\lambda}{\lambda}$$



Example: for $\Delta\lambda = 30nm$ and spectral width (805-835) nm then the fractional bandwidth is

$$\frac{\Delta\lambda}{\lambda} = \frac{30}{820} = 3.7\%$$

Light wave Fundamentals

Material Dispersion and Pulse distortion:

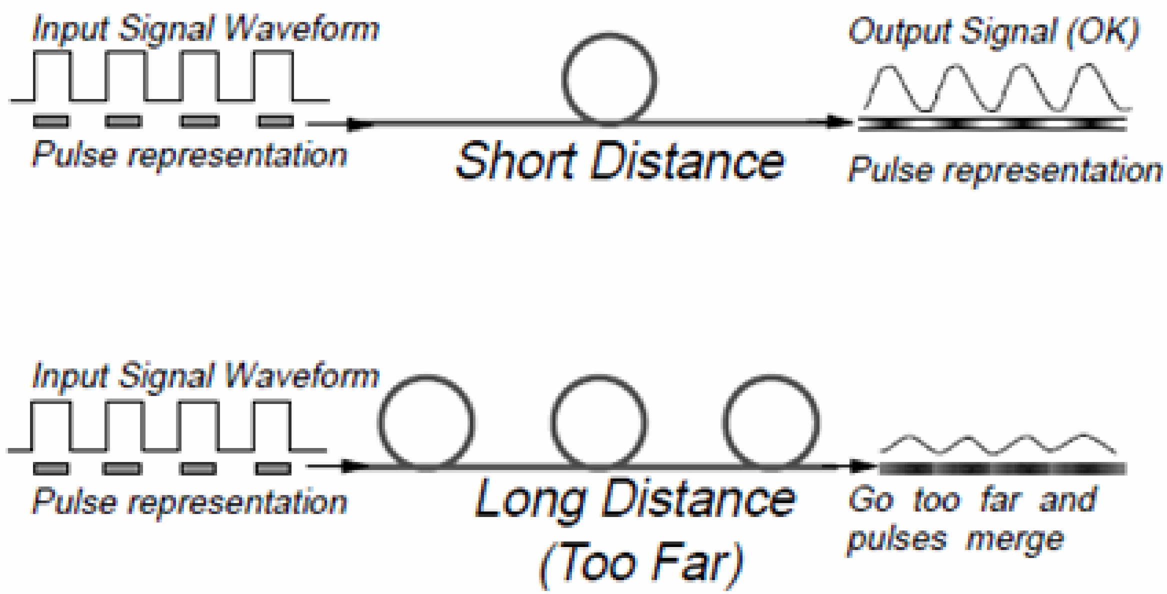


Figure 12. Effect of Dispersion. The circles in the figure represent fibre loops. This is the conventional way to indicate distance in system diagrams.

Light wave Fundamentals

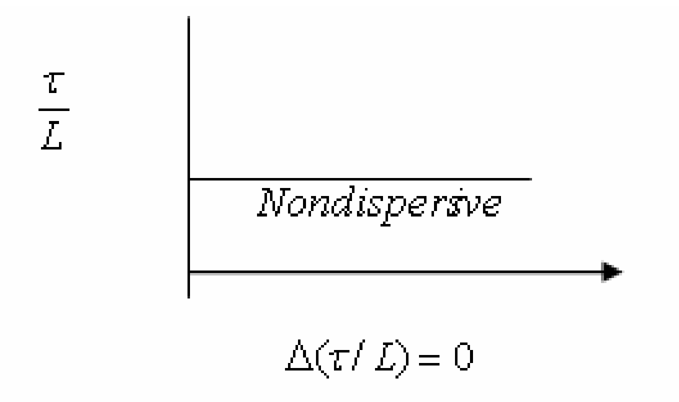
Dispersion occurs when a pulse of light is spread out during transmission on the fibre. A short pulse becomes longer and ultimately joins with the pulse behind, making recovery of a reliable bit stream impossible. (In most communications systems bits of information are sent as pulses of light. 1 = light, 0 = dark. But even in analogue transmission systems where information is sent as a continuous series of changes in the signal,dispersion causes distortion.)

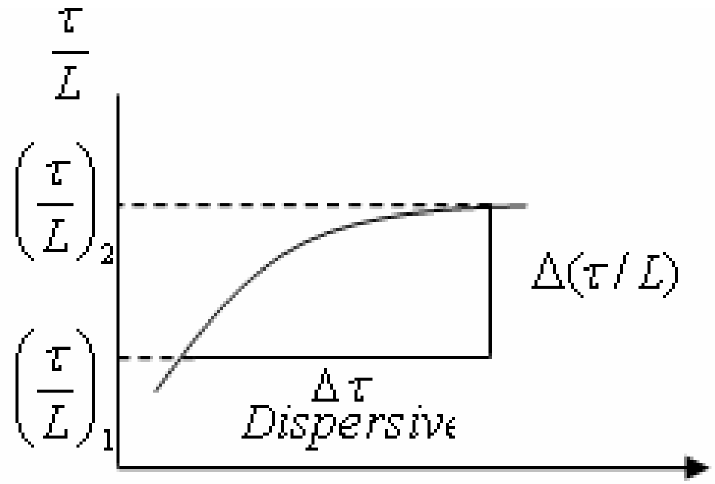
Material dispersion (chromatic dispersion) Both lasers and LEDs produce a range of optical wavelengths (a band of light) rather than a single narrow wavelength. The fibre has different refractive index characteristics at different wavelengths and therefore each wavelength will travel at a different speed in the fibre. Thus, some wavelengths arrive before others and a signal pulse disperses (or smears out).

Several pulses travel at different velocities $v = \frac{c}{n}$ reaching the end of the fiber at different times. They summed and produce lengthening or spread. The pulse spread per unit length is

$$\Delta\left(\frac{\tau}{L}\right) = \left(\frac{\tau}{L}\right)_2 + \left(\frac{\tau}{L}\right)_1$$

Light wave Fundamentals





The pulse spread per unit length can be written

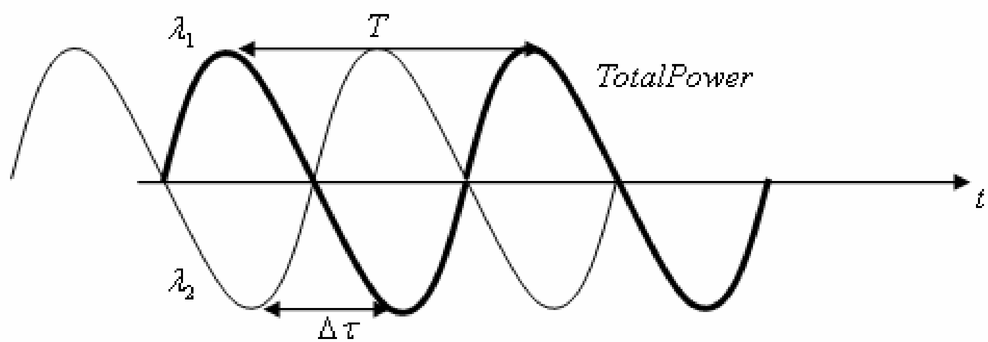
$$\Delta(\tau / L) = -M \Delta \lambda$$

Where M is the material dispersion and can be found from figure (3-8)(textbook) and its unit is picosecond of pulse spreading pernanometer of source spectral width and per kilpmeter of path length.

Light wave Fundamentals

Information rate

Pulse spreading limits the information capacity of any transmission system. Dispersion broadens a pulse by an amount unrelated to the length of the pulse. Dispersion becomes a problem for a receiver when it exceeds about 20% of the pulse length. Thus, if a pulse at 200 Mbps is dispersed on a given link by 15% then the system will probably work. If the data rate is doubled to 400 Mbps the dispersion will be 30% and the system will probably not work. Hence the higher the data rate, the more important the control of dispersion becomes.



$$\Delta\tau = \frac{T}{2}$$

With this amount of delay, the modulation cancels out completely when the two waves are added.

Light wave Fundamentals

$$f = \frac{1}{T} \le \frac{1}{2\Delta\tau}$$

Where f is the modulation frequency

$$f_{3-dB} = \frac{1}{2\Delta\tau}$$

and

$$f_{3-dB} \times L = \frac{1}{2\Delta(\tau / L)}$$

The modulation-frequency dependent loss (owing pulse spread)

$$L_f = -10\log\left\{\exp\left[-0.693\left(\frac{f}{f_{3-dB}}\right)^2\right]\right\}$$

Light wave Fundamentals

The loss is 1.5 dB at frequency

$$f_{1.5-dB} = 0.71 f_{3-dB}$$

It is important because it correspond to the electrical power in the reciever diminshes bu half. The optic 1.5-dB bandwidth equals the electrical 3-dB bandwidth

$$f_{1.5-dB}(optic) = f_{3-dB}(electrical) = 0.71 f_{3-dB}(optic)$$

Light wave Fundamentals

Since $f_{3-dB}(optic) = \frac{1}{2\Delta\tau}$, we can write that

$$f_{3-dB}(electrical) \times L = \frac{0.35}{\Delta(\tau / L)}$$

If we consider a return-to-zero digital signal then

$$R_{RZ} \times L = \frac{1}{T} = f_{3-dB}(electrical) \times L = \frac{0.35}{\Delta(\tau / L)}$$

For Nonreturn-to-zero

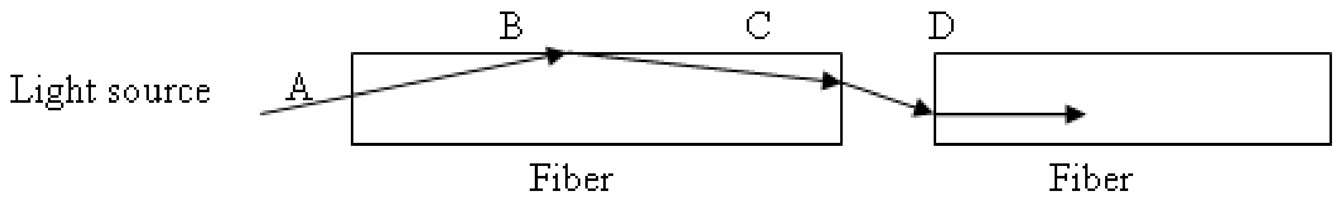
$$R_{NRZ} \times L = 2 f_{3-dB}(electrical) \times L = \frac{0.7}{\Delta(\tau / L)}$$

Example 3-6 (table 3-2) textbook

Light wave Fundamentals

Reflection at plane boundary

Problems concerning the amount of light reflected at boundary between two dielectrics are an important part of the study and practice of optics.



At A the reflection should be minimum and at B should be maximum. The reflection coefficient ρ is the ratio of the reflected electric field to the incidenet electric field.

$$\rho = \frac{n_1 - n_2}{n_1 + n_2}$$

n_1 is the refractive index in the incident region and n_2 is the refractive index in the transmitted region. If $n_2 > n_1$, then $\rho > 0$ which indicates a 180 phase shift between the incident and the reflected.

Light wave Fundamentals

And the reflectance is

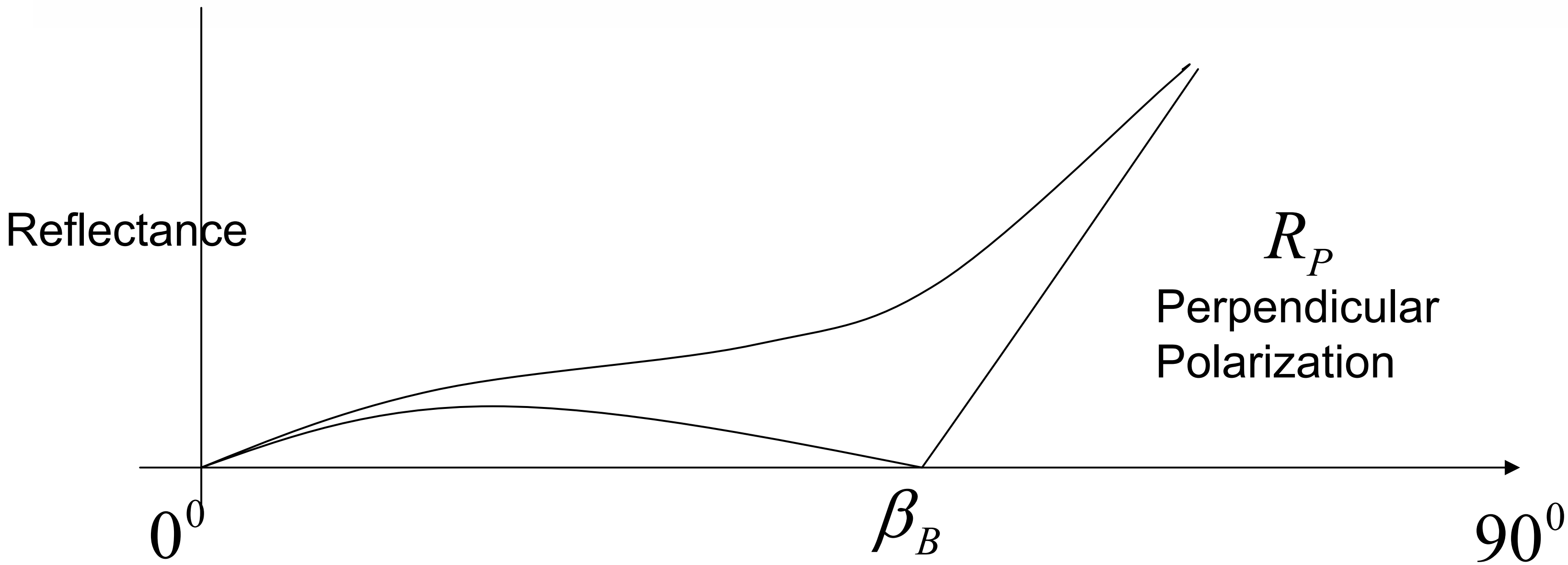
$$R = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2$$

Example (3-8)

The reflection will be zero if light incidents at angle called Brewster angle

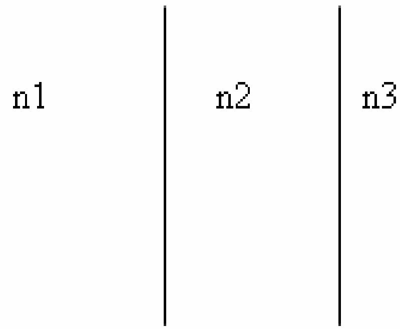
$$\tan\theta_B = \frac{n_2}{n_1}$$

Example (3-9)



The amount of light reflected when beam moves from one material to another can be reduced by placing a thin coating layer between them. The reflectance become:

$$R = \frac{[n_1 n_3 - n_2{}^2]^2}{[n_1 n_3 + n_2{}^2]^2}$$



The reflectance becomes zero if the index of the coating layer

$$n_2 = \sqrt{n_1 n_3}$$

Critical Angle

Total reflection for incident beat at critical angle

$$\sin \theta_c = \frac{n_2}{n_1} \qquad (n_1 > n_2)$$

table 3-3 textbook

Light wave Fundamentals