Optical Communications

Modes in Optical Fibers

Part6

Fiber Optic Communications

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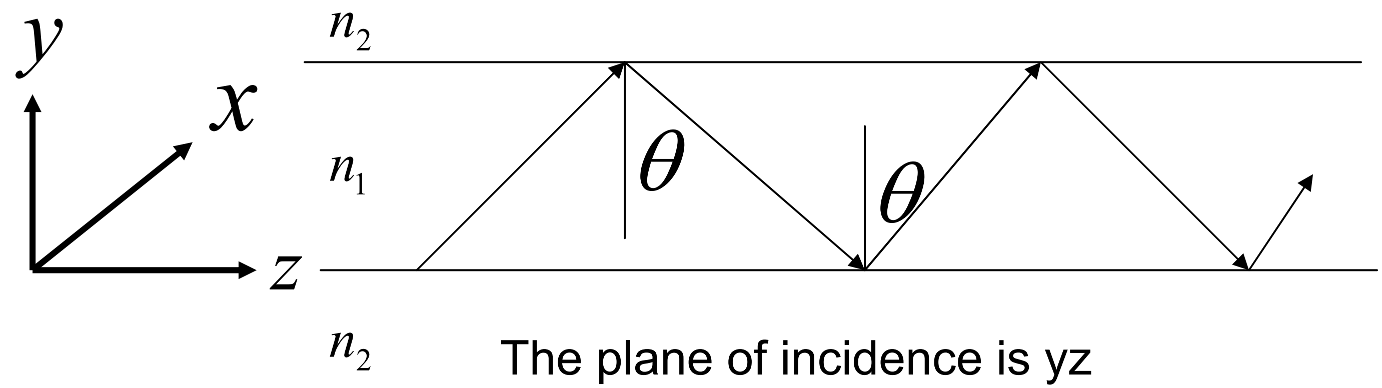
Fourth Edition PRENTICE HALL

Modes in Optical Fibers

TE and TM Polarization

There are two possible polarization, perpendicular and parallel to the plane of incidence, depending on the reflection from a plane boundary.



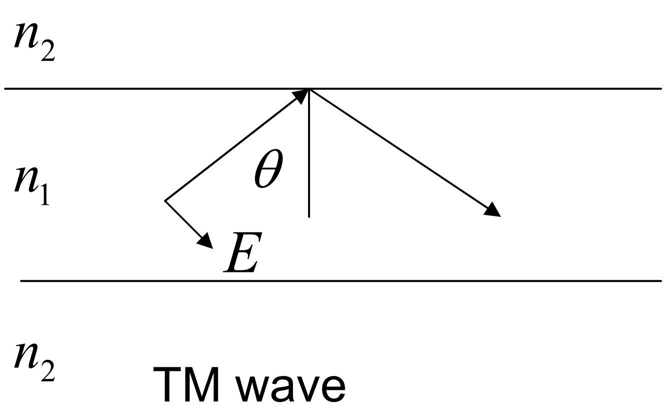
The plane of incidence is yz

An electric field pointing in the x direction corresponds to the perpendicular, or s , polarization. Waves with this polarization are labeled transverse electric (TE) fields because the electric field vector lies entirely in (xy plane) and transverse to direction of net travel (z direction).

In the case of parallel polarization, p polarization the electric field has a component along z direction. The magnetic field points in the x direction –transverse magnetic (TM).

Modes in Optical Fibers

TE and TM Polarization



Modes in step-index fibers:

The normalized frequency V

$$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2}$$

Core radius

Free space wavelength

Modes in Optical Fibers

Number of modes if v>10

$$N = \frac{V^2}{2}$$

Example:

Compute the number of modes for a fiber whose core diameter is 50 micrometers . Assume that n_1=1.48 and n_2=1.46 (all-glass fiber). Let $\lambda = 0.82\mu m$

Solution:

$$V = \frac{2\pi(25)}{0.82}\sqrt{1.48^2 - 1.46^2} = 46.45 > 10$$

$$N = \frac{V^2}{2} = 1078$$ modes

Modes in Optical Fibers

From example, even a moderately small fiber can support a large number of modes.

The condition of single-mode propagation is

$$\frac{a}{\lambda} = \frac{2.405}{2\pi\sqrt{n_1^2 - n_2^2}} = \frac{2.405}{2\pi.(NA)}$$

Example:

What is the maximum core radius allowed for a glass fiber having n1=1.465 and n2=1.46 if the wavelength is to support only one mode at wavelength of 1250nm

$$a = \frac{\lambda.2.405}{2\pi\sqrt{n_1^2 - n_2^2}} = 3.96\mu m$$

And diameter=7.9 μm

Modes in GRIN fibers:

The condition of single-mode GRIN is

$$\frac{a}{\lambda} < \frac{1.4}{\pi\sqrt{n_1(n_1 - n_2)}}$$

Example:

Consider a GRIN fiber having n_1=1.47 and n_2=1.46. compute the fractional refractive index change and the largest core size for single-mode propagation. Calculate the value of n_{eff} for the propagating mode by using the core size just found. The wavelength is 1300 nm.

solution $n_2 = n_1(1-\Delta)$, $\Delta = 1 - \frac{n_2}{n_1} = 1 - \frac{1.46}{1.47} = 0.0068$

$$\frac{a}{1.3\mu m} < \frac{1.4}{\pi\sqrt{1.47(1.47-1.46)}}$$

$$a = 4.8\mu m$$

$$n_{eff} = n_1 - \frac{\sqrt{2\Delta}}{k_o a} = 1.465 \qquad k_o = \frac{2\pi}{\lambda}$$

Pulse distortion and information rate in optic fibers

Distortion in SI fibers

$$\Delta(\tau / L) = \frac{n_1}{c}\Delta = \frac{NA^2}{2cn_1}$$

Compute the pulse spread for all-glass fiber.

The pulse spread owing to multimode pulse spread and dispersive spread

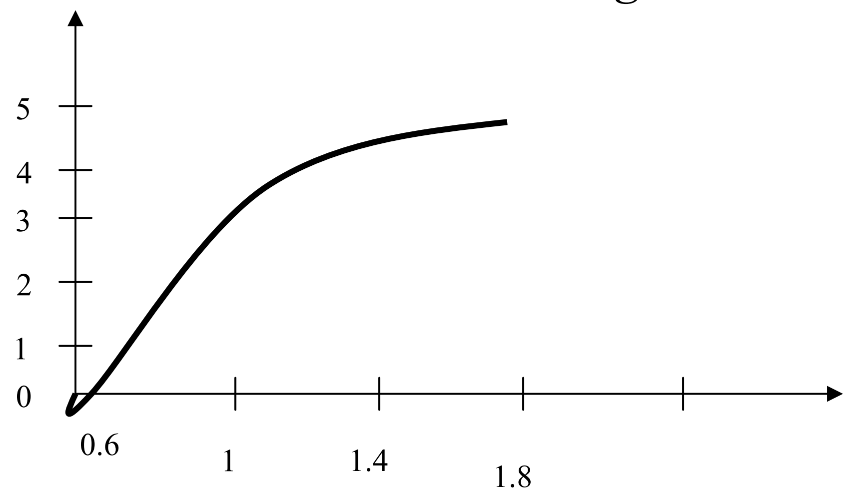
$$(\Delta\tau)^2 = (\Delta\tau)^2{}_{\text{mod}} + (\Delta\tau)^2{}_{dis}$$

Compute the multimode pulse spread for SI fiber made from pure silica if we used LED that operating at 820 nm and having a 20 nm spectral width.

Pulse distortion and information rate in optic fibers

The waveguide dispersion is

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



The total dispersive spread

$$\Delta(\tau / L)_{dis} = -(M + M_g)\Delta\lambda$$

Pulse distortion and information rate in optic fibers

Example: the material dispersion is 110 ps/(nmXkm) at 0.82 micrometers, but the waveguide dispersion is 2 ps/(nmXkm) which can be neglected except for systems operating in the region 1200-1600 nm.

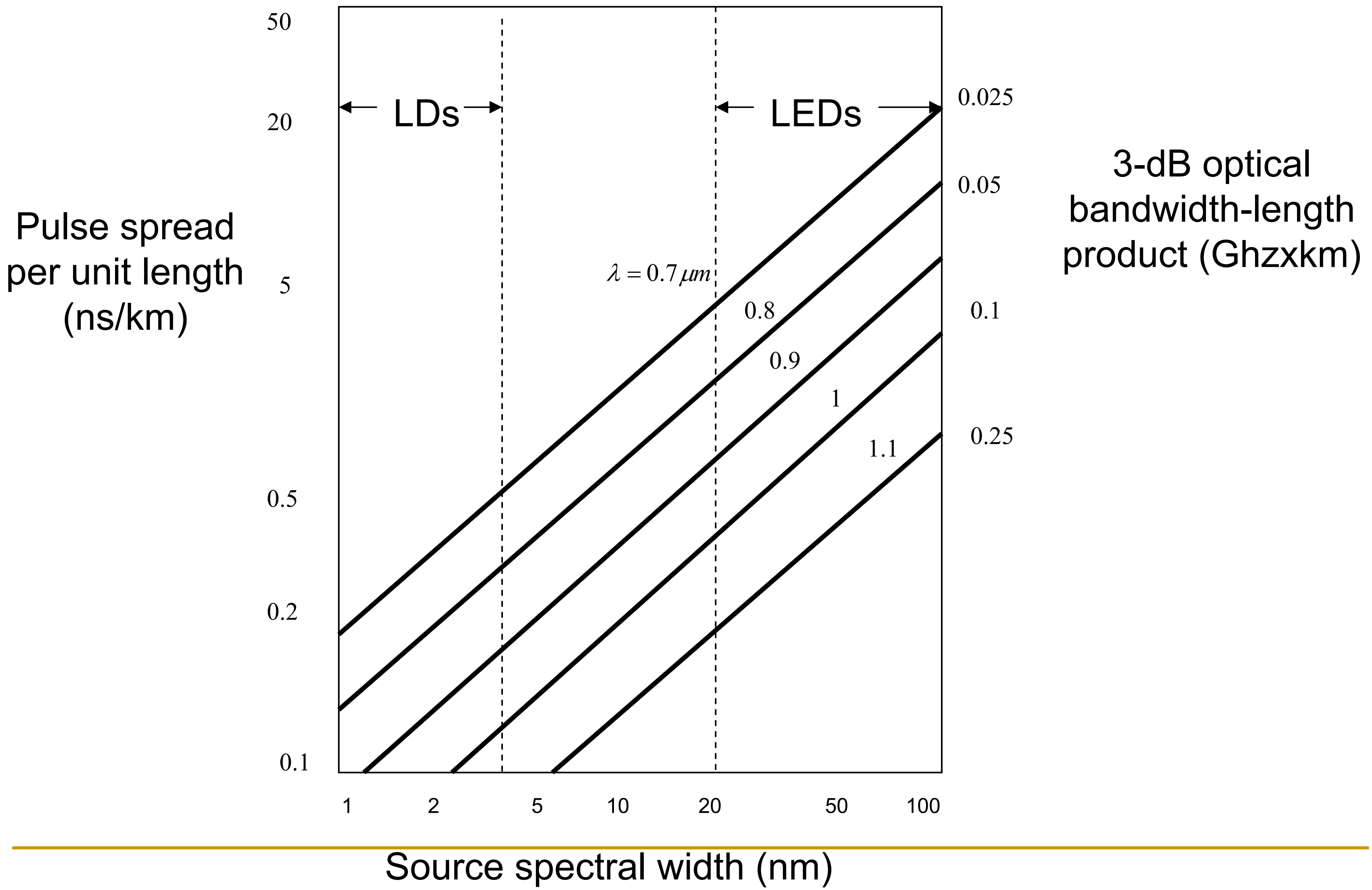
Distortion in single-mode fibers

The major pulse spreading is material dispersion and its true in the range 0.8-0.9 micrometers.

The pulse spread becomes smaller for longer wavelengths (see figure in the next slide).

When the operating wavelength is near 1300 nm, waveguide dispersion should be considered.

Pulse distortion and information rate in optic fibers



Pulse distortion and information rate in optic fibers

Distortion in GRIN fibers

$$\Delta(\tau / L) = \frac{n_1 \Delta^2}{2c}$$

For all glass fiber having n_1=1.48 and n_2=1.46

$$\Delta(\tau / L) = 0.45 ns / km$$

The total pulse spread

$$(\Delta \tau)^2 = (\Delta \tau)^2{}_{\text{mod}} + (\Delta \tau)^2{}_{dis}$$

Characteristics of commercial fibers

Description	Core Diameter	NA	Loss	$\Delta(\tau / L)$	$f_{3\text{-dB}}XL$	Source	Wavelength
	Micrometers		dB/km	ns/km	MHzXkm		nm
Multimode							
SI	50	0.24	5	15	33	LED	850
GRIN	50	0.24	5	1	500	LD	850
GRIN	50	0.20	1	0.5	1000	LED,LD	1300
PCS							
SI	200	0.41	8	50	10	LED	800
Plastic							
SI	1000	0.48	200	---	---	LED	850
Single-Mode							
Glass	5	0.10	4	<0.5	>1000	LD	850
Glass	10	0.10	0.5	0.006	83000	LD	1300
Glass	10	0.10	0.2	0.006	83000	LD	1550