Unit-2

Lecture -4

Core and Cladding Losses, Information capacity, Group Delay, Dispersion and their types

Core and Cladding Losses

Core and cladding of any optical fiber have different refractive indices and the composition.

So they have different attenuation coefficients αcore & αclad.

If the mode coupling is ignored, the loss for a mode of order (v, m) for a step-index fiber is given by:

The total loss of the waveguide can be evaluated by summing loss for all modes.

$$\alpha_{vm} = \alpha_{core}\frac{P_{core}}{P} + \alpha_{clad}\frac{P_{clad}}{P} = \alpha_{core} + (\alpha_{clad} - \alpha_{core})\frac{P_{clad}}{P}$$

Dispersion in Optical Fibers

In digital communication systems, information to be sent is first coded in the form of pulses.

These pulses of light are then transmitted from the transmitter to the receiver.

At receiver the information is decoded.

The larger the number of pulses that can be sent per unit time at the receiver end, the larger will be the transmission capacity of the system.

A pulse of light sent into a fiber broadens in time as it propagates through the fiber.

This phenomenon is known as pulse dispersion.

Dispersion:
Any phenomenon in which the velocity of propagation of any electromagnetic wave is wavelength dependent.

In communication, dispersion is used to describe any process by which any electromagnetic signal propagating in a physical medium is degraded because the various wave characteristics (i.e., frequencies) of the signal have different propagation velocities within the physical medium.

Basically 2 kind of dispersions.

I. Intramodal Dispersion

a. Material Dispersion

b. Waveguide Dispersion

II. Intermodal Dispersion

If the pulse dispersion occurs in single mode fiber, it is said to be

***intramodal dispersion*.**

It takes place when group velocity becomes a function of wavelength.

The ***group velocity*** **is the speed at which the energy of the particular mode travels along the fiber.**

Since the spectral width is the band of wavelength over which the source emits light.

So the intramodal dispersion increases with increase in spectral width.

Dispersion in Optical Fibers

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- There are 3 dispersion types in the optical fibers, in general:

1. **Material Dispersion**
2. **Waveguide Dispersion**
3. **Polarization-Mode Dispersion**

Material & waveguide dispersions are main causes of Intramodal Dispersion.

Group Velocity

- Wave Velocities:
- 1- **Plane wave velocity**: For a plane wave propagating along *z*-axis in an unbounded homogeneous region of refractive index n_1 , which is represented by $\exp(j\omega t - jk_1 z)$, the velocity of constant phase plane is:

$$v = \frac{\omega}{k_1} = \frac{c}{n_1} \qquad [3\text{-}4]$$

- 2- **Modal wave phase velocity**: For a modal wave propagating along *z*-axis represented by $\exp(j\omega t - j\beta z)$, the velocity of constant phase plane is:

$$v_p = \frac{\omega}{\beta} \qquad [3\text{-}5]$$

3- For transmission system operation the most important & useful type of velocity is the **group velocity,** V_g **.** This is the actual velocity which the signal information & energy is traveling down the fiber. It is always less than the speed of light in the medium. The observable delay experiences by the optical signal waveform & energy, when traveling a length of *l* along the fiber is commonly referred to as **group delay.**

Group Velocity & Group Delay

- The group velocity is given by:

$$V_g = \frac{d\omega}{d\beta} \qquad [3\text{-}6]$$

- The group delay is given by:

$$\tau_g = \frac{l}{V_g} = l\frac{d\beta}{d\omega} \qquad [3\text{-}7]$$

- It is important to note that all above quantities depend both on **frequency** & the **propagation mode**. In order to see the effect of these parameters on group velocity and delay, the following analysis would be helpful.

Input/Output signals in Fiber Transmission System

- The optical signal (complex) waveform at the input of fiber of length l is $f(t)$. The propagation constant of a particular modal wave carrying the signal is $\beta(\omega)$. Let us find the output signal waveform $g(t)$.

$\Delta\omega$ is the optical signal bandwidth.

$$f(t) = \int_{\omega_c - \Delta\omega}^{\omega_c + \Delta\omega} \tilde{f}(\omega) e^{j\omega t} d\omega \qquad [3\text{-}8]$$

$$g(t) = \int_{\omega_c - \Delta\omega}^{\omega_c + \Delta\omega} \tilde{f}(\omega) e^{j\omega t - j\beta(\omega) l} d\omega \qquad [3\text{-}9]$$

If $\Delta\omega << \omega_c$

$$\beta(\omega) = \beta(\omega_c) + \left.\frac{d\beta}{d\omega}\right|_{\omega=\omega_c} (\omega - \omega_c) + \frac{1}{2}\left.\frac{d^2\beta}{d\omega^2}\right|_{\omega=\omega_c} (\omega - \omega_c)^2 + \ldots \qquad [3\text{-}10]$$

$$g(t) = \int_{\omega_c-\Delta\omega/2}^{\omega_c+\Delta\omega/2} f(\omega) e^{j\omega t - j\beta(\omega) l} d\omega \approx \int_{\omega_c-\Delta\omega/2}^{\omega_c+\Delta\omega/2} f(\omega) e^{j\omega t - j\left[\beta(\omega_c) + \left.\frac{d\beta}{d\omega}\right|_{\omega=\omega_c} (\omega-\omega_c)\right] l} d\omega$$

$$\approx e^{-j\beta(\omega_c) l} \int_{\omega_c-\Delta\omega/2}^{\omega_c+\Delta\omega/2} f(\omega) e^{j\omega\left(t - l\left.\frac{d\beta}{d\omega}\right|_{\omega=\omega_c}\right)} d\omega$$

$$= e^{-j\beta(\omega_c) l} f\left(t - l\left.\frac{d\beta}{d\omega}\right|_{\omega=\omega_c}\right) = e^{-j\beta(\omega_c) l} f(t - \tau_g) \qquad [3\text{-}11]$$

$$\tau_g = l\left.\frac{d\beta}{d\omega}\right|_{\omega=\omega_c} = \frac{l}{V_g} \qquad [3\text{-}14]$$