UNIT - 2

TRANSMISSION CHARACTERISTICS OF OPTICAL FIBERS

Introduction, Attenuation, absorption, scattering losses, bending loss, dispersion, Intra modal dispersion, Inter modal dispersion.

RECOMMENDED READINGS:

TEXT BOOKS:


REFERENCE BOOK:

LECTURE-1

Introduction

- One of the important properties of optical fiber is signal attenuation. It is also known as fiber loss or signal loss. The signal attenuation of fiber determines the maximum distance between transmitter and receiver. The attenuation also determines the number of repeaters required, maintaining repeater is a costly affair.

- Another important property of optical fiber is distortion mechanism. As the signal pulse travels along the fiber length it becomes broader. After sufficient length the broad pulses start overlapping with adjacent pulses. This creates error in the receiver. Hence the distortion limits the information carrying capacity of fiber.

2.1 Attenuation

- Attenuation is a measure of decay of signal strength or loss of light power that occurs as light pulses propagate through the length of the fiber.

- In optical fibers the attenuation is mainly caused by two physical factors absorption and scattering losses. Absorption is because of fiber material and scattering due to structural imperfection within the fiber. Nearly 90% of total attenuation is caused by Rayleigh scattering only. Micro bending of optical fiber also contributes to the attenuation of signal.

- The rate at which light is absorbed is dependent on the wavelength of the light and the characteristics of particular glass. Glass is a silicon compound, by adding different additional chemicals to the basic silicon dioxide the optical properties of the glass can be changed.

- The Rayleigh scattering is wavelength dependent and reduces rapidly as the wavelength of the incident radiation increases.

- The attenuation of fiber is governed by the materials from which it is fabricated, the manufacturing process and the refractive index profile chosen. Attenuation loss is measured in dB/km.

Attenuation Units

- As attenuation leads to a loss of power along the fiber, the output power is significantly less than the couples power. Let the couples optical power is \( P(0) \) i.e. at origin \( z = 0 \).

Then the power at distance \( z \) is given by,

\[
P(z) = P(0)e^{-\alpha_p z} \quad \text{... (2.1.1)}
\]

where, \( \alpha_p \) is fiber attenuation constant (per km).
This parameter is known as fiber loss or fiber attenuation.

- Attenuation is also a function of wavelength. Optical fiber wavelength as a function of wavelength is shown in Fig. 2.1.1.

**Example 2.1.1:** A low loss fiber has average loss of 3 dB/km at 900 nm. Compute the length over which –

a) Power decreases by 50 %

b) Power decreases by 75 %.

Solution: \( \alpha = 3 \text{ dB/km} \)

a) Power decreases by 50 %.

\[ \Rightarrow \frac{p(0)}{p(z)} = 50\% = 0.5 \]

\( \alpha \) is given by,
\[ z = 1 \text{ km} \quad \ldots \text{ Ans.} \]

\[ 3 = 10 \times \frac{1}{z} \log [0.25] \]

\[ z = 2 \text{ km} \quad \ldots \text{ Ans.} \]

**Example 2.1.2:** For a 30 km long fiber attenuation 0.8 dB/km at 1300nm. If a 200 µWatt power is launched into the fiber, find the output power.

**Solution:**

\[ z = 30 \text{ km} \]

\[ \alpha = 0.8 \text{ dB/km} \]

\[ P(0) = 200 \mu\text{W} \]

Attenuation in optical fiber is given by,

\[ \alpha = 10 \times \frac{1}{z} \log \left[ \frac{P(0)}{P(z)} \right] \]

\[ 0.8 = 10 \times \frac{1}{30} \log \left[ \frac{200 \mu\text{W}}{P(z)} \right] \]

\[ 2.4 = 10 \times \log \left[ \frac{200 \mu\text{W}}{P(z)} \right] \]

\[ \left[ \frac{200 \mu\text{W}}{P(z)} \right] = 10^{2.4} \]
Example 2.1.3: When mean optical power launched into an 8 km length of fiber is 12 µW, the mean optical power at the fiber output is 3 µW.

Determine –

1) Overall signal attenuation in dB.

2) The overall signal attenuation for a 10 km optical link using the same fiber with splices at 1 km intervals, each giving an attenuation of 1 dB.

Solution: Given: \( z = 8 \text{ km} \)

\[
P(0) = 120 \mu W
\]

\[
P(z) = 3 \mu W
\]

1) Overall attenuation is given by,

\[
\alpha = 10 \log \left( \frac{P(0)}{P(z)} \right)
\]

\[
\alpha = 10 \log \left( \frac{120}{3} \right)
\]

\[
\alpha = 16.02 \text{ dB}
\]

2) Overall attenuation for 10 km,

Attenuation per km \( \alpha_{dB} \) = \( \frac{16.02}{8} \) = 2.00 dB/km

Attenuation in 10 km link = 2.00 x 10 = 20 dB

In 10 km link there will be 9 splices at 1 km interval. Each splice introducing attenuation of 1 dB.

Total attenuation = 20 dB + 9 dB = 29 dB
Example 2.1.4: A continuous 12 km long optical fiber link has a loss of 1.5 dB/km.

i) What is the minimum optical power level that must be launched into the fiber to maintain as optical power level of 0.3 µW at the receiving end?

ii) What is the required input power if the fiber has a loss of 2.5 dB/km?

[July/Aug.-2007, 6 Marks]

Solution: Given data: \(z = 12 \text{ km}\)

\[\alpha = 1.5 \text{ dB/km}\]

\[P(0) = 0.3 \mu \text{W}\]

i) Attenuation in optical fiber is given by,

\[\alpha = 10 \times \frac{1}{z} \log \left(\frac{P(0)}{P(z)}\right)\]

\[1.5 = 10 \times \frac{1}{12} \log \left(\frac{0.3 \mu \text{W}}{P(z)}\right)\]

\[\log \left(\frac{0.3 \mu \text{W}}{P(z)}\right) = \frac{1.5}{0.833}\]

\[= 1.80\]

\[\left(\frac{0.3 \mu \text{W}}{P(z)}\right) = 10^{1.8}\]

\[P(z) = \frac{0.3 \mu \text{W}}{10^{1.8}} = \frac{0.3}{63.0}\]

\[P(z) = 4.76 \times 10^{-9} \text{W}\]

Optical power output = \(4.76 \times 10^{-9} \text{W}\) … Ans.

ii) Input power =? \(P(0)\)

When \(\alpha = 2.5 \text{ dB/km}\)
Example 2.1.5: Optical power launched into fiber at transmitter end is 150 µW. The power at the end of 10 km length of the link working in first window is $-38.2$ dBm. Another system of same length working in second window is 47.5 µW. Same length system working in third window has 50% launched power. Calculate fiber attenuation for each case and mention wavelength of operation. [Jan./Feb.-2009, 4 Marks]

Solution: Given data:

\[
P(0) = 150 \, \mu W
\]

\[
z = 10 \, \text{km}
\]

\[
P(z) = -38.2 \, \text{dBm} \Rightarrow \begin{cases} 
-38.2 = 10 \log \left( \frac{P(z)}{1 \, \text{mW}} \right) \\
P(z) = 0.151 \, \mu W
\end{cases}
\]

\[
z = 10 \, \text{km}
\]

Attenuation in 1st window:

\[
\alpha_1 = 10 \times \frac{1}{z} \log \left( \frac{P(0)}{P(z)} \right)
\]

\[
\alpha_1 = 10 \times \frac{1}{10} \log \left[ \frac{150}{0.151} \right]
\]
\[ \alpha_1 = 2.99 \text{ dB/km} \] ...

Attenuation in 2\textsuperscript{nd} window:
\[ \alpha_2 = 10 \times \left( \frac{1}{10} \log \left( \frac{150}{47.5} \right) \right) \]
\[ \alpha_2 = 0.49 \text{ dB/km} \] ...

Attenuation in 3\textsuperscript{rd} window:
\[ \alpha_3 = 10 \times \left( \frac{1}{10} \log \left( \frac{150}{75} \right) \right) \]
\[ \alpha_3 = 0.30 \text{ dB/km} \] ...

Wavelength in 1\textsuperscript{st} window is 850 nm.
Wavelength in 2\textsuperscript{nd} window is 1300 nm.
Wavelength in 3\textsuperscript{rd} window is 1550 nm.

**Example 2.1.6:** The input power to an optical fiber is 2 mW while the power measured at the output end is 2 \( \mu \)W. If the fiber attenuation is 0.5 dB/km, calculate the length of the fiber.

[July/Aug.-2006, 6 Marks]

**Solution:**

Given:
\[ P(0) = 2 \text{ mWatt} = 2 \times 10^{-3} \text{ watt} \]
\[ P(z) = 2 \text{ \( \mu \)Watt} = 2 \times 10^{-6} \text{ watt} \]
\[ \alpha = 0.5 \text{ dB/km} \]

\[
\begin{align*}
0.5 &= 10 \times \frac{1}{z} \log \left( \frac{2 \times 10^{-3}}{2 \times 10^{-6}} \right) \\
0.5 &= \frac{1}{z} \\
z &= \frac{3}{0.05}
\end{align*}
\]
\[ z = 60 \text{ km} \]  

... Ans.