UNIT - II

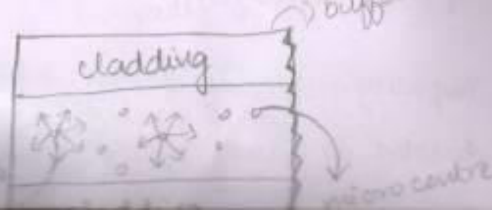
Distortion in optical fibers

- Dispersion (pulse broadening)
  - Material dispersion
  - Intermodal dispersion (modal delay) (only in multi-mode fibre)
  - Intramodal dispersion (single mode fibre)
- Attenuation (depends on material)
  - Material Attenuation
    - Absorption in material
    - Scattering (λ^{-4}) depends on wavelength
  - Micro bending (bending loss)
  - Macro bending → Attenuation due to radius

Rayleigh Scattering: depends on manufacturing (micro centre (defects), diff in Ref index) dimension & wave length (double the wavelength → reduce)

Rayleigh scattering is the strong function of wavelength as it varies inversely to λ^{-4}

If we double the wavelength, loss can be reduced



P(0) → Initial power

P(z) - distance

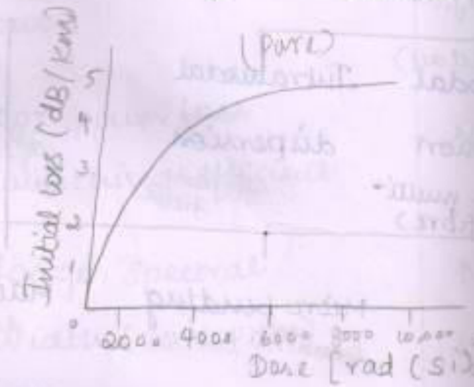
Attenuation → dB/Km ↓ power reduc

initial → signal high

distance ↑se → many loss introduce (Scattering, absorption) Impure → pure

Absorption → atomic defect, material

$$\alpha \, (dB/Km) = \frac{10}{z} \log \left[\frac{P(0)}{P(z)} \right]$$



1) Atomic defects: missing of O_2 ion

missing of molecules / ...

main reason Ionisation radiation: (UV rays

In space Ionisation rad → high

Applns

medical appln, x-rays

Indust appln, nuclear reactions

Reduce Atomic defects

fiber → pure silicon → radiation high

2) Impurity → cleaning process → water

dissolve in fibre

Pure Silica

3) particular wavelength → act as a bad conductivity → absorb

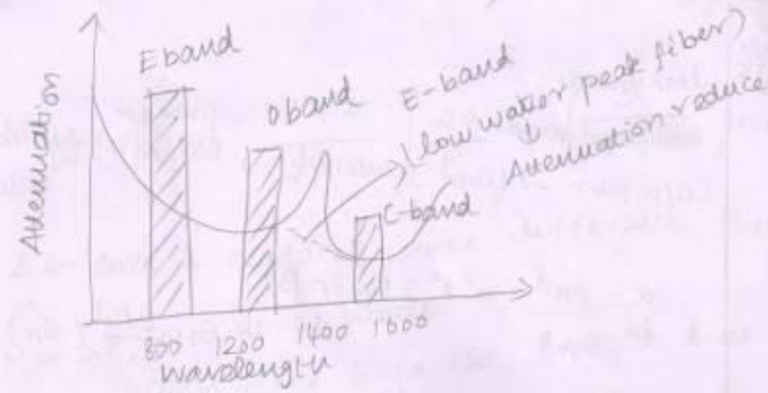
(near UV, IR wavelength) ↓ others waves propagate

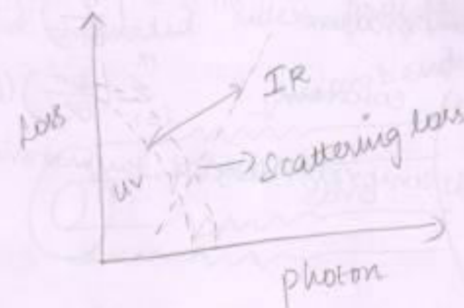
↓

$\alpha_{uv} = C e^{E/E_0}$

wavelength is important for attenuation

IR: $\alpha_{IR} = 7.81 \times 10^{11} \exp\left(\frac{-48.40}{T}\right)$





o.p fiber is inserted into cable → misalignment → loss due to micro bending

Radiation loss → cable bend↑ → radius↓ → o/p ↓ → macrobending (due to fibre loss)

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Scattering loss:

due to
- Microscopic variation in the material density
- Compositional fluctuations

glass small

Structural inhomogeneous

Structural Defects occuring during fabric

Types:

Linear, Non-linear → o/p pwr → diff freq → f/w & b/w direc

Rayleigh → UV region → in all direction (λ^{-4})

leaky mode,

radiated mode

(o/p pwr → fiber transmit → linear → one mode transfer differ mode

$$\alpha_{sc} = \frac{8\pi^3}{3\lambda^4}(n^2-1^2) K_B T_F \beta_T \qquad \alpha = \frac{8\pi^3}{3\lambda^4}(\delta n^2)\delta$$

n → Refractive index

T_F → fictive Temperature $\quad (\delta n^2)^2 = \left(\frac{\partial n}{\partial P}\right)^2 (\delta P)^2$

K_B → Bolztmann's constant $\quad \sum_{i=1}^{m} \left(\frac{\partial n^2}{\partial C_i}\right)(\delta C_i)$

β_T → Isothermal compressibility of the material

Bending loss:

occur due to manufacture of fibre

Bending the radius of curvature → occur loss

large radius loss or simply bending loss

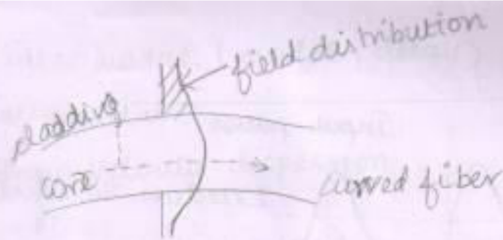
1. Macro Bending (radius of curva > fibre diameter
2. Micro Bending (radius of curvature ↓, loss

mode coupling loss

Reduce macrobending (cable → misalignment bend) Micro bending

fibre axis → Small fluctuation

rf index diff large



field distribution same → bend ↓ field distribution distorts → Higher modes loss ↓ information > speed of the light

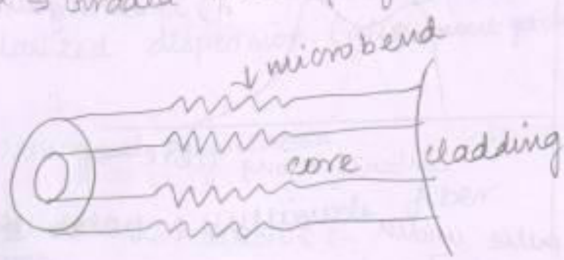
normal transfer ⇐ mode propagation.

$$M_{eff} = M_\infty \left\{ 1 - \frac{\alpha + 2}{2\alpha\Delta}\left[\frac{2a}{R} + \left(\frac{3}{2 n_2 k R}\right)^{2/3}\right]\right\}$$

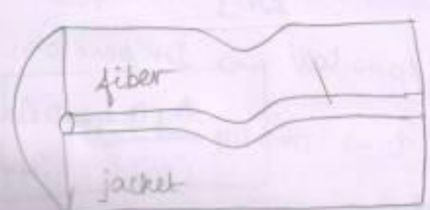
Δ ← core & cladding index difference

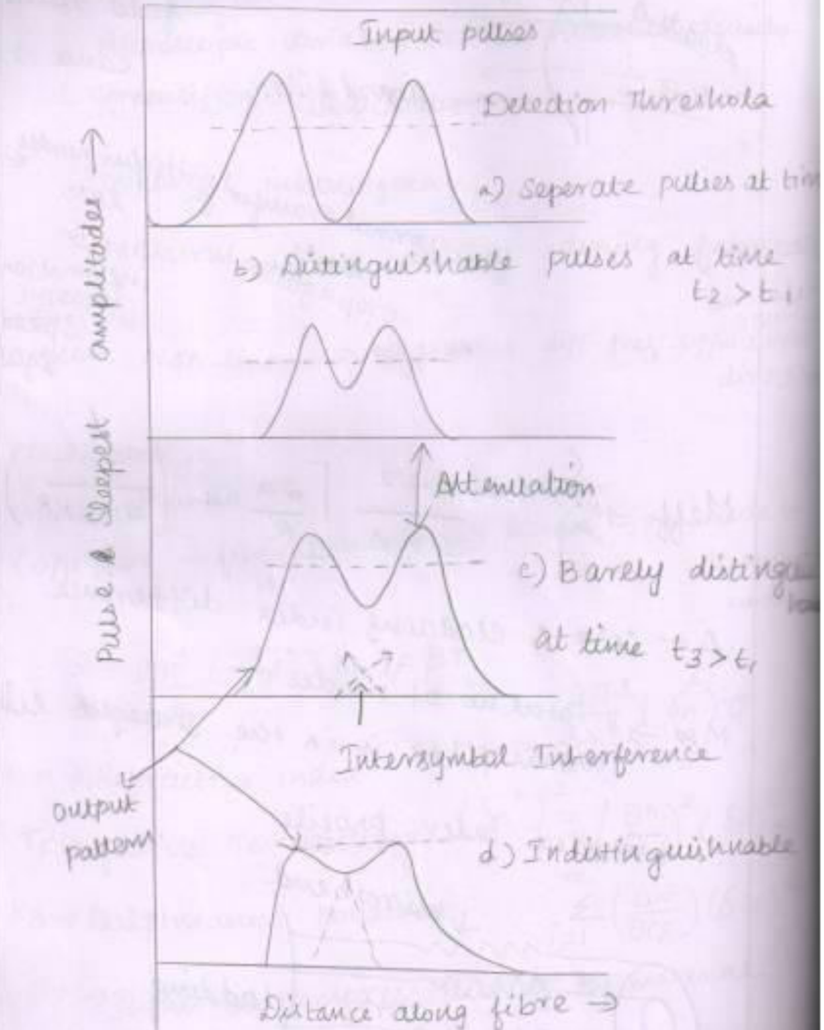
M_∞ → Total no. of modes. when fibre is in the straight line

α ⇒ Graded index profile



Reduce: By placing compressible Jacket it (20-500 GPa) can reduced.





i) Finite pulse width → Distance ↑, pulse width ↑, amp ↓ →

ii) Sample & hold ckt → pulses → error rate ↓

Correct error receiver

Irregular o/p → loss → Dispersion (ISI)

Pulse width ↑ → overlap → 2 pulse cant diff → ISI (cant seperate)

1. Inter modal (modal delay) → multimode fibre → pulse broadening → ∝ wavelength (sgl propagate w.r.t modes) → Group Velocity → Velocity equal → (Vg) vary → pulse broadening

2. Intra modal

(Group Velocity dispersion or chromatic dispersion)

↓

Single mode fibre.

(due to narrow spectral width)

↓

Band of frequency

(Range of wavelength)

Pulse broadening vary.

Types:

* Material dispersion
* Waveguide dispersion

Graded index reduce — Axis of fiber → Fundamental modes (short time period); Higher order mode (long time period)

3. polarized dispersion (alignment get disturb)

↓

orthogonal polarization

Modal delay: Multimode fiber

$$\Delta T = T_{max} - T_{min} = \frac{n_1}{c}\left[\frac{L}{\sin\phi_c} - L\right]$$

$$= \frac{Ln_1^2}{cn_2}\Delta$$

$$\boxed{\Delta T = \frac{Ln_1\Delta}{c}}$$

T_{min} ← Time taken by fundamental mode

T_{max} ← Time taken by higher order mode

15/8 Polarization

Electrical orientation of signal arrangement

(Signal propagate from one mode to another)

orthogonal modes:

→ Horizontal (nx)

→ vertical (ny)

Birefringence:

(disalignment) → group velocity differ → pulse broadening → width ↑, amp ↓ (infm loss)

difference in modes

Reason for disalignment:

Attenuation (Atomic defect, Scattering, bending loss)

Ideal condition

Waveguide:

directly ppt coupling efficiency → Total power confined into core

I/p source → signal reach → per rate → core, n_1

remaining → cladding → index = n_2

Sgl

diff in phase velocity → p. broadening → dispersion.

Group delay:

→ Each mode contain all the spectral

Components in the wavelength

→ All these spectral components is

→ As signal propagates along the fibe[r] each will travel independently and und[ergo] time delay (or) group delay per unit leng[th] $\left(\frac{\tau_g}{L}\right)$

$$\frac{\tau_g}{L} = \frac{1}{v_g} = \frac{1}{c}\frac{d\beta}{dk} = \frac{-\lambda^2}{2\pi c}\cdot\frac{d\beta}{dk}$$

$$V_g = c\left[\frac{d\beta}{dk}\right]^{-1} = \left[\frac{\partial\beta}{\partial\omega}\right]^{-1}$$

group delay depends on wavelength, Spectral component

Total delay difference δ_z, over a distan[ce] L is

$$\delta_z = \frac{d\tau_g}{d\lambda}\,\delta\lambda$$

$$= \frac{-L}{2\pi c}\left[2\lambda\frac{d\beta}{d\lambda} + \lambda^2\frac{d^2\beta}{d\lambda^2}\right]\delta\lambda$$

In terms of angular frequency ω,

$$\delta\tau = \frac{d\tau_g}{d\omega}\,\delta\omega$$

$$= \frac{d}{d\omega}\left[\frac{L}{V_g}\right]\delta\omega$$

$$= L\left[\frac{d^2\beta}{d\omega^2}\right]\delta\omega$$

The factor $\beta_2 = \frac{d^2\beta}{d\omega^2}$ => determine how much a light pulse broadens as it travel

The rms pulse width,

$$\sigma_g = \left| \frac{d\tau_g}{d\lambda} \right| \sigma_\lambda$$

$$= \frac{L\sigma_\lambda}{2\pi c} \left| 2\lambda \frac{d\beta}{d\lambda} + \lambda^2 \frac{d^2\beta}{d\lambda^2} \right|$$

$$D = \frac{1}{L} \frac{d\tau_g}{d\lambda} = \frac{d}{d\lambda}\left[\frac{1}{v_g}\right] = -\frac{2\pi c}{\lambda^2}\beta_2$$

D ← Dispersion is measured in picosec per kilometer per nanometer [ps/(nm·km)]

Material Dispersion:

consider a plane wave propagation infinitely extended dielectric medium that has refractive index $n(\lambda)$

The propagation constant $\beta = \frac{2\pi n(\lambda)}{\lambda}$

Material dispersion given by,

$$\tau_{mat} = \frac{L}{c}\left(n - \lambda \frac{dn}{d\lambda}\right)$$

$$\sigma_{mat} = \left| \frac{d\tau_{mat}}{d\lambda} \right| \sigma_\lambda$$

$$= \sigma_\lambda L \, |D_{mat}(\lambda)|$$

$D_{mat}(\lambda) \rightarrow$ material dispersion

Waveguide dispersion :

Group delay interms of normalised Propagation constant b.

$$b = 1 - \left[\frac{ua}{V}\right]^2 = \frac{\beta^2/k^2 - n_2^2}{n_1^2 - n_2^2} = \frac{\beta/k - n_2}{n_1 - n_2}$$

$$\beta = n_2 k (b\Delta + 1)$$

$$\tau_{wg} = \frac{L}{c}\frac{d\beta}{dk} = \frac{L}{c}\left[n_2 + n_2\Delta \frac{d(kb)}{dk}\right]$$

$$V = k a n_1 \sqrt{2\Delta}$$

$$\tau_{wg} = \frac{L}{c}\left[n_2 + n_2\Delta \frac{d(Vb)}{dV}\right]$$

Cable → diameter → micrometer

Coupling efficiency ↑ → lensing scheme

Source, fibre starting point

↓

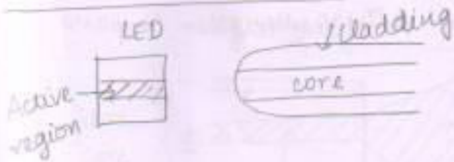
emitting area (active region) > fibre → Total optical pwr couple

< → cant couple

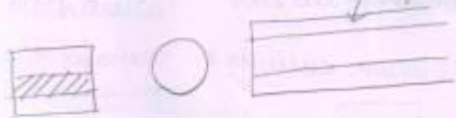
↳ Total optical pwr cant

LENS kept b/wn LED & fibre → Enlarge active region → Total optical pwr coupled to fibre
↑ coupling efficiency
(fibre small)

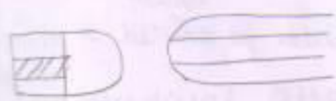
Rounded End Fiber



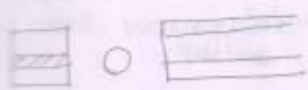
Imaging sphere :



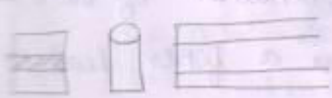
Spherical surfaced LED and Spherical Ended fiber :



Non-Imaging Microsphere :



Cylindrical lens



Taper Ended Fibre :

Source manufacture
Attached
1m - pit tail
cable (flylead)

Coupling efficiency :

$$\eta = \frac{P_F}{P_S}$$

8M. Connectors – temporary
Splicers – permanent — fusion
(Semi-permanent) — mechanical

8M Loss dependent factor: fiber to fiber coupling
→ Core radius
→ i/p Power distribution
→ mechanical misAlignment of two fiber
→ Numerical aperture
→ refractive index b/wn emitting & receiving fiber

i/p power distribution:

Consider emitting fiber only.

Pwr distribution → 1) all modes get equally excited → acceptance angle, Numerical aperture → couple to receiving end

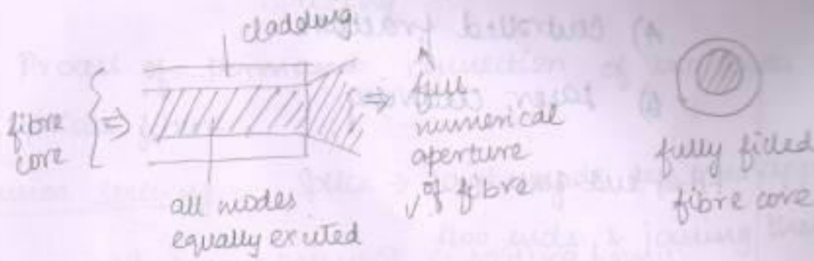
High order → Interface
2) Low order → axis (modes pwr excited) } Steady State modal distribution

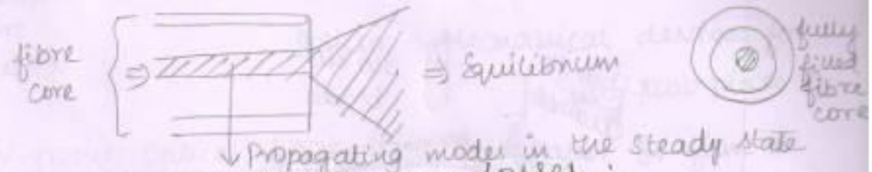
misalignment consider

3/89 Different modal distribution of the optical beam emerging from a fiber lead to different degrees of coupling loss

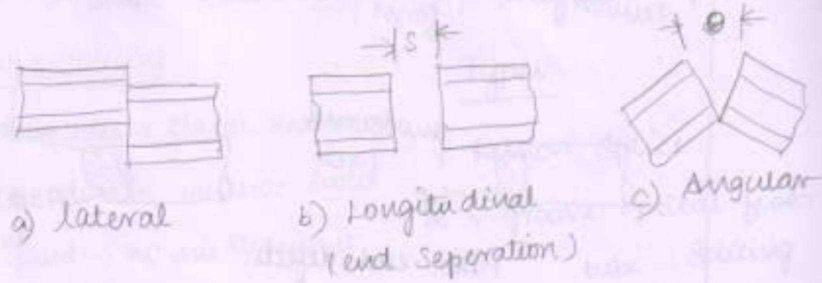
a) when all modes are equally excited, the output beam fills the entire output NA

b) for a steady state modal distribution, only the equilibrium NA is filled by the output





Mechanical misalignment losses :



Longitudinal offset effect

Losses due to differences in the geometry and waveguide characteristics of the fibers

$$L_F(a) = -10 \log \frac{(a_R)^2}{(a_E)^2} \quad \text{for } a_R \le a_E$$

$$L_F(a) = -10 \log \frac{(NA_R)^2}{(NA_E)^2} \quad \text{for } NA_R \le NA_E$$

E & R subscripts refer to emitting & receiving fibers

End preparation technique

1) Sawing

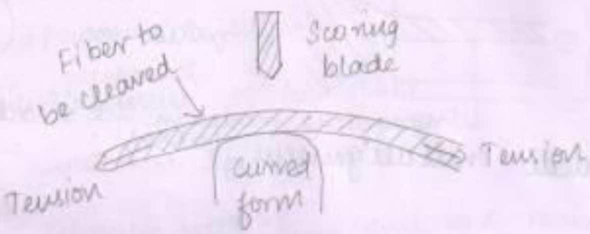
2) Grinding

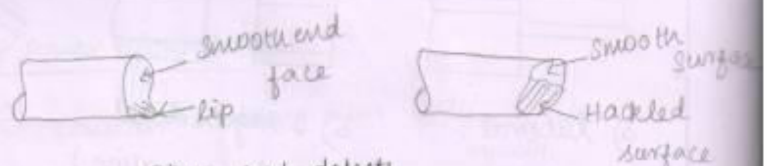
4) Controlled fracture

5) Laser cleaving

Fiber end face:

curved position → Pressure





Fiber end defects

Fiber to Fiber Joint

Fiber to Fiber coupling loss

$$L_F\,[dB] = -10 \log \eta_F$$

Low loss fiber – fiber joints are either:

1. splice (permanent bond)
2. connector (demountable connection)

Common end face defects:

- Lip
- Roll off
- Chip
- Hackle
- Mist
- Spiral or Step

Splicing

Process of permanent connection of two pieces of optical fibers.

Splice → joint made by overlapping two ends & joining them

Splicer → Mechanical device for joining two pieces of paper or film or magnetic tape

Types:

1. Fusion Splice
2. V-groove optical fiber tube splicing
3. Elastic tube splicing

Fusion Splicing

Electric arc (heat) → melt → mould

V-groove optical fiber splicing:

V-shape → adhesive gum

Elastic splicing:

Two sides → elastic material

core radius < insertion hole

expand → no misalignment