Section - B

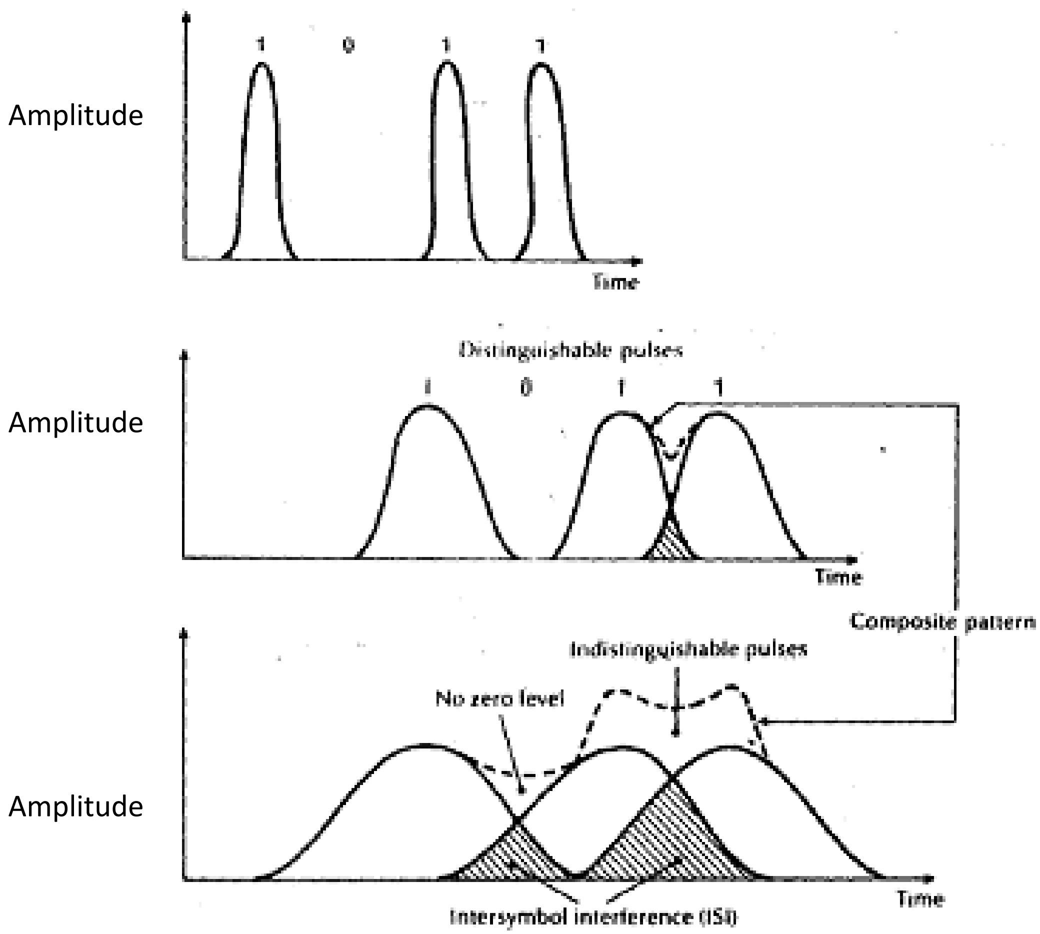
Lecture 6

ISI, Dispersion, Fiber bend Losses

ISI

- ISI RESULTS IN AN ERROR RATE WHICH IS A FUNCTION OF SIGNAL ATTENUATION AND SNR AT THE RECEIVER.
- SIGNAL DISPERSION LIMITS THE MAX. BANDWIDTH ATTAINABLE (TO THE POINT WHERE INDIVIDUAL SYMBOLS CAN NO LONGER BE DISTINGUISHED

- INTERSYMBOL INTERREFRENCE (ISI)



An illustration using the digital bit pattern 1011 of the broadening of light pulses as they are transmitted along a fiber: (a) fiber input; (b) fiber output at a distance L1;(c) fiber output at a distance L2> L1.

FOR NO OVERLAPPING OF LIGHT PULSES

DIGITAL BIT RATE, $B_T \leq 1/2\tau$

WHERE τ = INPUT PULSE DURATION

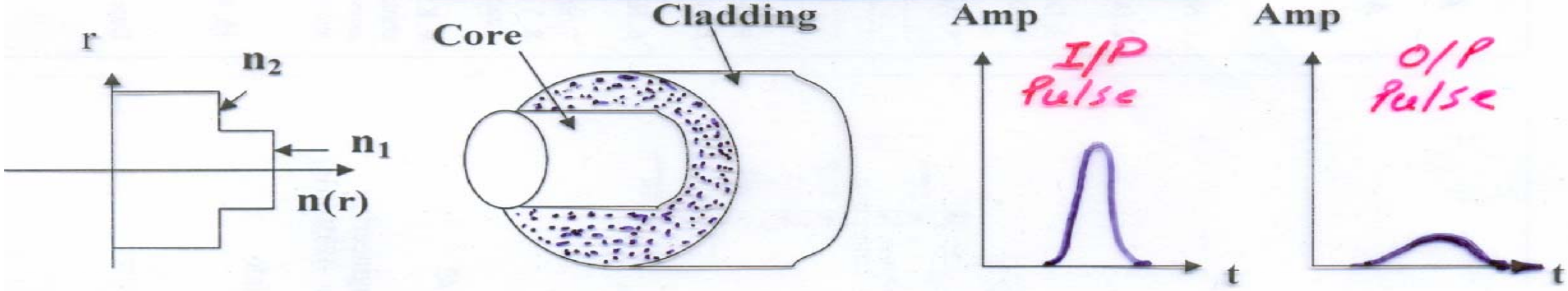
= PULSE BROADENING DUE TO DISPERSION

ALTERNATIVELY

$B_T = (1/4\sigma)/(1/\ 5\sigma)$

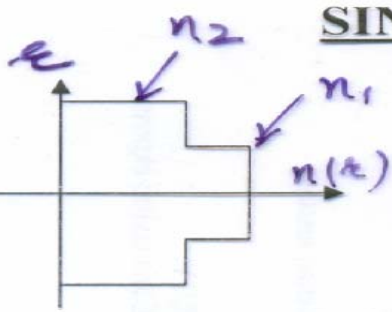
WHERE σ = RMS WIDTH OF GAUSSIAN SHAPE AT THE OUTPUT.

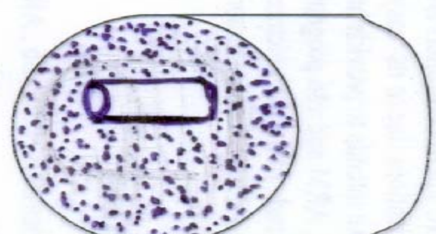
MULTIMODE STEP INDEX FIBER

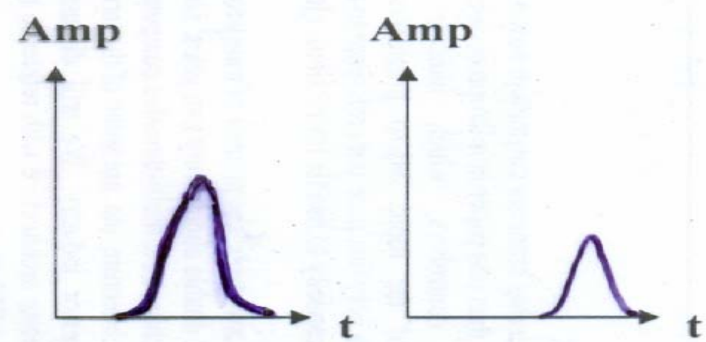


MULTIMODE GRADED INDEX FIBER

SINGLE MODE STEP INDEX FIBER







SINGLE MODE FIBER GIVES MIN PULSE BROADENING & THUS YIELDS MAX TRANSMISSION BW

INTRAMODAL DISPERSION

OPTICAL SOURCES DO NOT EMIT JUST A SINGLE FREQ, BUT A BAND OF FREQUENCIES.

THIS RESULTS IN PROPAGATIQNAL DELAY DIFFERENCES BETWEEN THE DIFFERENT SPECTRAL COMPONENTS OF THE Tx SIGNAL.

THIS CAUSES **BROADENING OF EACH TRANSMITTED MODE (INTRAMODAL DISPERSION).**

THE INTRAMODAL DISPERSION MAY BE CAUSED BY **MATERIAL DISPERSION** AND **WAVE GUIDE DISPERSION.**

MATERIAL DISPERSION

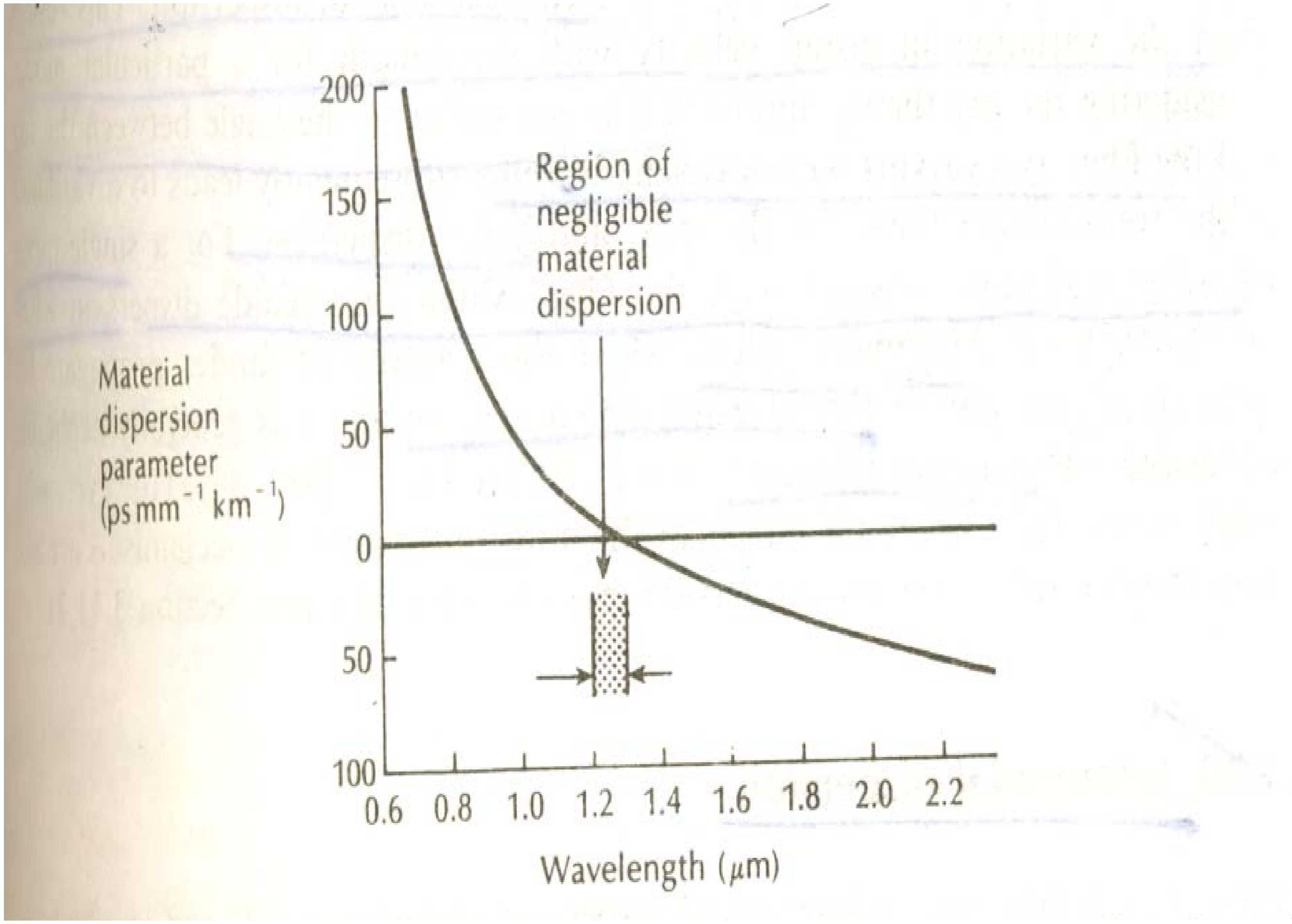
PULSE BROADENING RESULTS FROM DIFF.GROUP VELOCITIES OF VARIOUS SPECTRAL COMPONENTS LAUNCHED INTO OPTICAL FIBRE SOURCE.

PHASE VELOCITY OF WAVE VARIES NON-LINEARLY WITH WAVELENGTH.

A MATERIAL IS SAID TO EXHIBIT MATERIAL DISPERSION WHEN

$d^2n/ d\lambda^2 \neq 0$

- **0.1-0.2 ns / km in multimode fibers**



The material dispersion parameter for silica as a function of wavelength .

WAVE GUIDE DISPERSION

THIS RESULTS FROM VARIATION IN GROUP VELOCITY WITH WAVELENGTH FOR A PARTICULAR MODE.

IT IS EQUIVALENT TO VARIATION OF ANGLE BETWEEN RAY AND FIBER AXIS WITH WAVELENGTH, RESULTING IN VARIATION IN TRANSMISSION TIMES FOR THE RAYS, AND HENCE DISPERSION.

SINGLE MODE FIBER EXHIBITS WAVEGUIDE DISPERSION WHEN $d^2\beta/d\lambda 2 \neq 0$

MULTIMODE FIBERS ARE NORMALLY FREE OF WAVEGUIDE DISPERSION.

INTERM0DAL / MODAL/ MODE DISPERSION

PULSE BROADENING RESULTS FROM THE PROPAGATION DELAY DIFFERENCES BETWEEN MODES WITHIN A MULTIMODE FIBER

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DIFFERENT MODES IN A MULTIMODE FIBER
TRAVEL ALONG THE CHANNEL AT DIFFERENT
GROUP VELOCITIES.

<u>INTERM0DAL / MODAL/ MODE DISPERSION</u>

MULTIMODE STEP INDEX FIBERS EXHIBIT MAX INTERMODAL DISPERSION.

GRADED INDEX FIBERS EXHIBIT FAR LESS PULSE BROADENING THAN THE ABOVE CASE (TYPICALLY BY A FACTOR OF 100). **SO HIGHER BW IS AVAILABLE**.

SINGLE MODE STEP INDEX FIBERS EXHIBIT LEAST PULSE BROADENING AND HENCE THE GREATEST POSSIBLE BW.

REDUCING INTERMODAL DISPERSION

- BY ADOPTION OF AN OPTIMUM REF. INDEX PROFILE

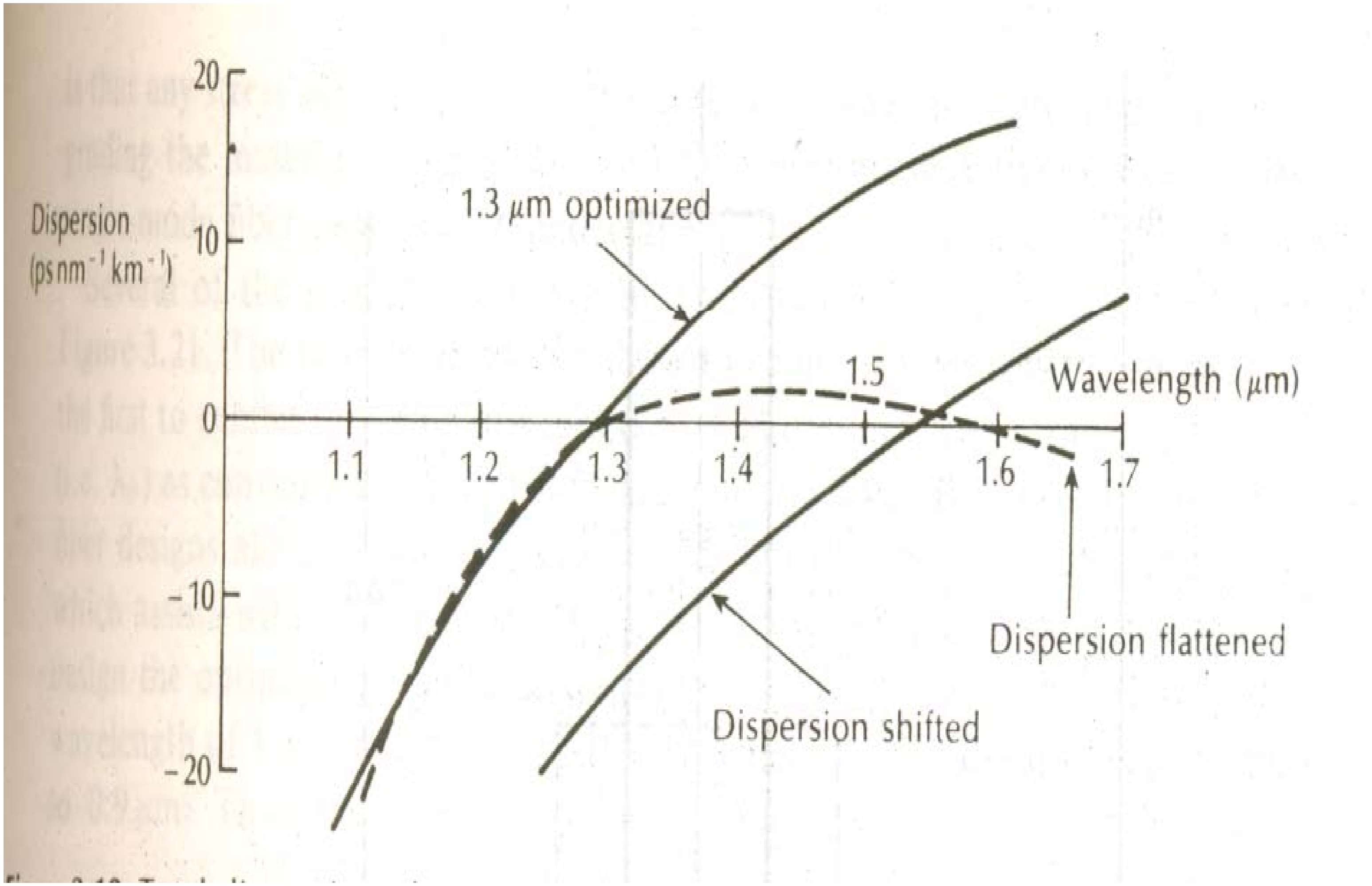
GRADING THE CORE REFRACTIVE INDEX TO FOLLOW A NEAR PARABOLIC PROFILE.

DISPERSION SHIFTED FIBERS

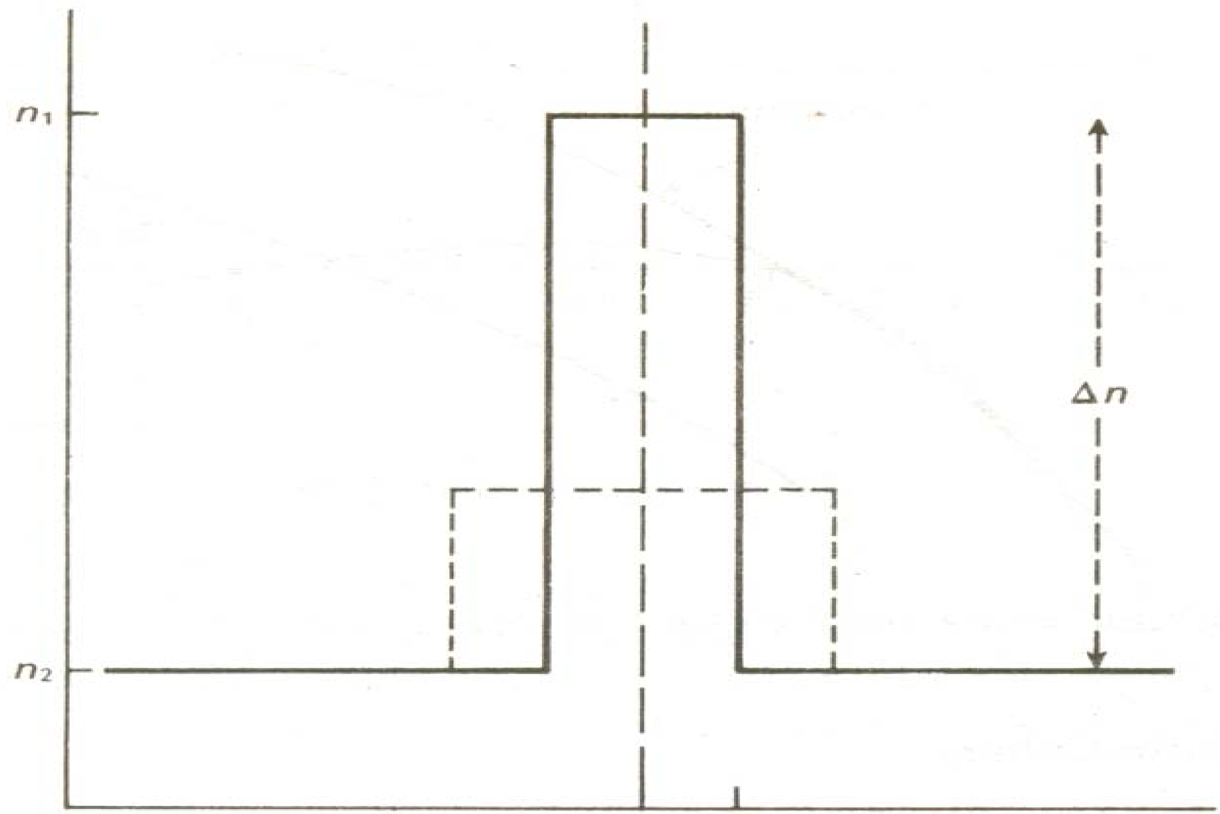
- Refractive Index profile can be modified in order to tune to zero dispersion wavelength point
- **Shift to a longer wavelength by reducing the core dia and increasing the fractional refractive index difference(fig)**
- **Higher concentration of the dopant causes a shift to longer wavelength**

DISPERSION SHIFTED FIBERS(contd)

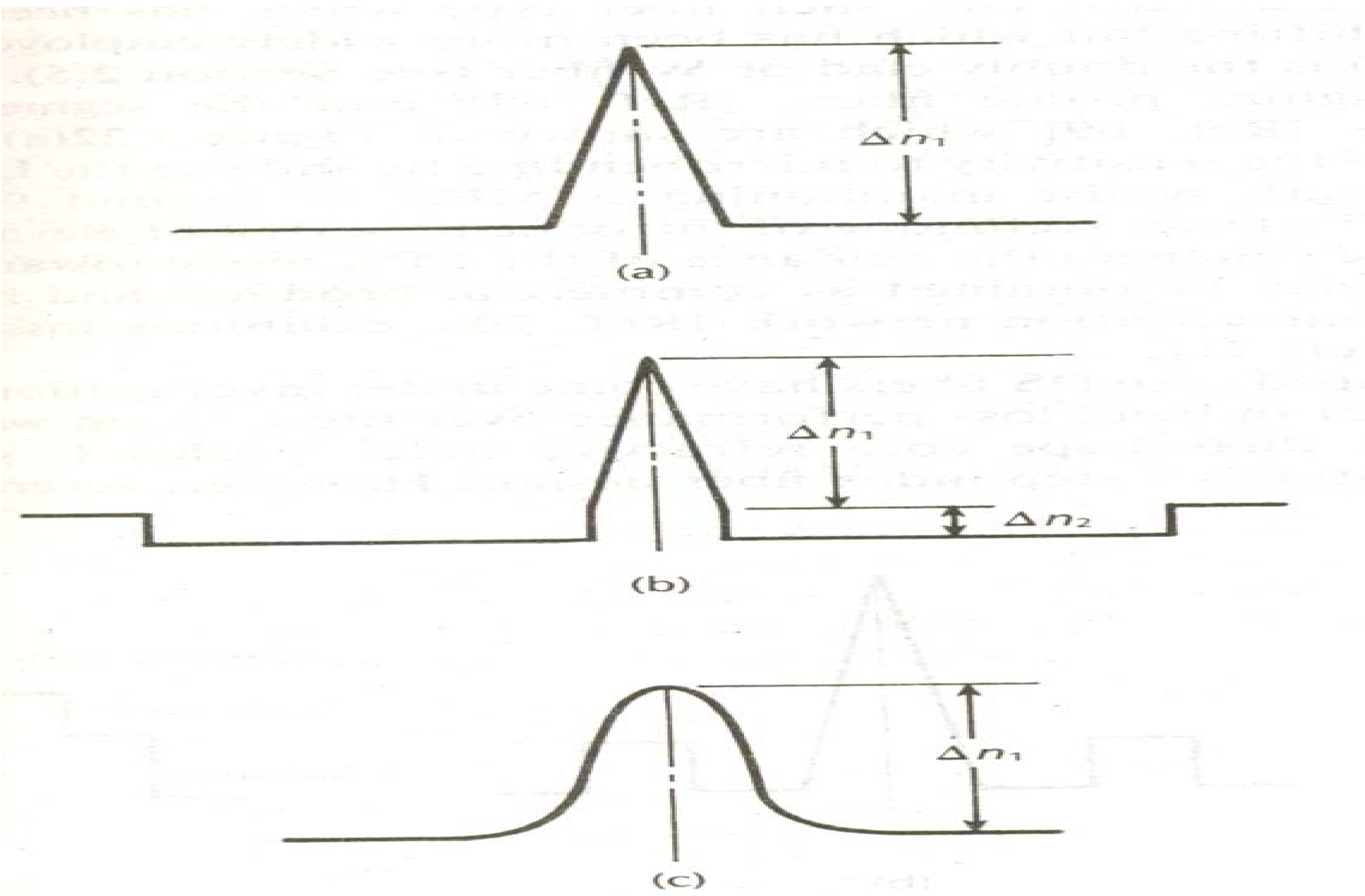
- **Increased dopant level however causes higher loss (2 dB / km).** This is overcome by using triangular profile. The loss is reduced to 0.24 dB / km at a wavelength of 1.56 μm (fig)
- The triangular profile is sensitive to bend induced losses. Remedy is to employ a triangular index profile combined with depressed cladding index or use a guassian refractive index profile. (fig)



Total dispersion characteristics for the various types of single – mode fiber .



Refractive index profile of a step index dispersion shifted fiber (solid) with a conventional nonshifted profile design (dashed)



Refractive index profiles for graded index dispersion shifted fibers:
a) triangular profile ;
b) depressed cladding triangular profile
c) Gaussian profile

Factors responsible for signal attenuation

- Material composition
- Preparation & purification technique
- Wave guide structure
- Curve& micro bending losses
- Mode coupling radiation losses.
- Losses due to leaky modes.
- Material scattering

  -linear scattering

  -non-linear scattering
- Connector losses
- Splice losses

NON-LINEAR SCATTERING LOSSES.

- Non linear scattering normally occurs at high power levels.
- Power is transfered either in the forward or backward direction to the same or other modes at a different frequency.

- Types of non linear scattering
- -Stimulated Brillouin scattering (SBS)
- -Stimulated Raman scattering (SRS)
- SBS
- It can be regarded as modulation of light thr ‘ thermal molecular vibrations (within the fiber) – USB/LSB

<u>Brillouin scattering (SBS)-contd</u>

- The incident photon produces a phonon of acoustic freq. as well as a scattered photon.
- This produces **an optical freq. shift which is max. in the backward direction** and zero in the forward direction.
- Threshold power (watts)P_B=

$$\mathbf{4.4*10^{-3}d^2\lambda^2\alpha_{db}{}^{V}}$$

- α_{db} =fibre attenuation (db/km), v= source bandwidth (GHz)

Note: for single mode fiber ,$P_{B=10}$ mw, which is quite high value & can be avoided.

- **<u>STIMULATED RAMAN SCATTERING (SRS</u>)**
- Similar to SBS except that a high freq. optical phonon rather than an acoustic phonon is generated.
- It can occur both in the forward as well as backward direction.

THRESHOLD POWER, $P_R = 5.9\times10^{-2}\, d^2 \lambda\, \alpha\, dB$ Watts

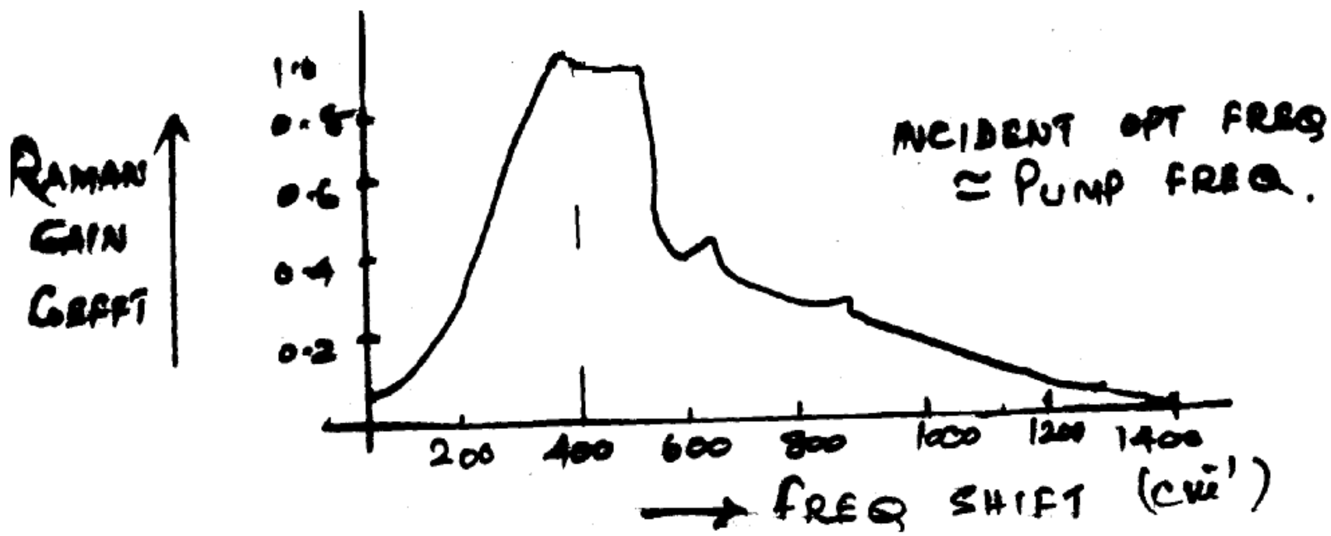
$$P_R > 3\, P_B$$

NOTE : SBS & SRS ARE NORMALLY NOT OBSERVED IN MULTIMODE FIBERS.

LINEAR SCATTERING PROCESS IS ELASTIC WHEREAS NON-LINEAR SCATTERING IS INELASTIC (FREQ. SHIFTS)

THE INELASTIC PROCESS RESULTS NOT ONLY IN SHIFT OF FREQ, BUT ALSO PROVIDES OPTICAL GAIN (AMPLICATION) AT THE SHIFTED FREQ.

RAMAN GAIN EXTENDS OVER A SUBSTANTIAL BAND WIDTH.



FIBER BEND LOSS

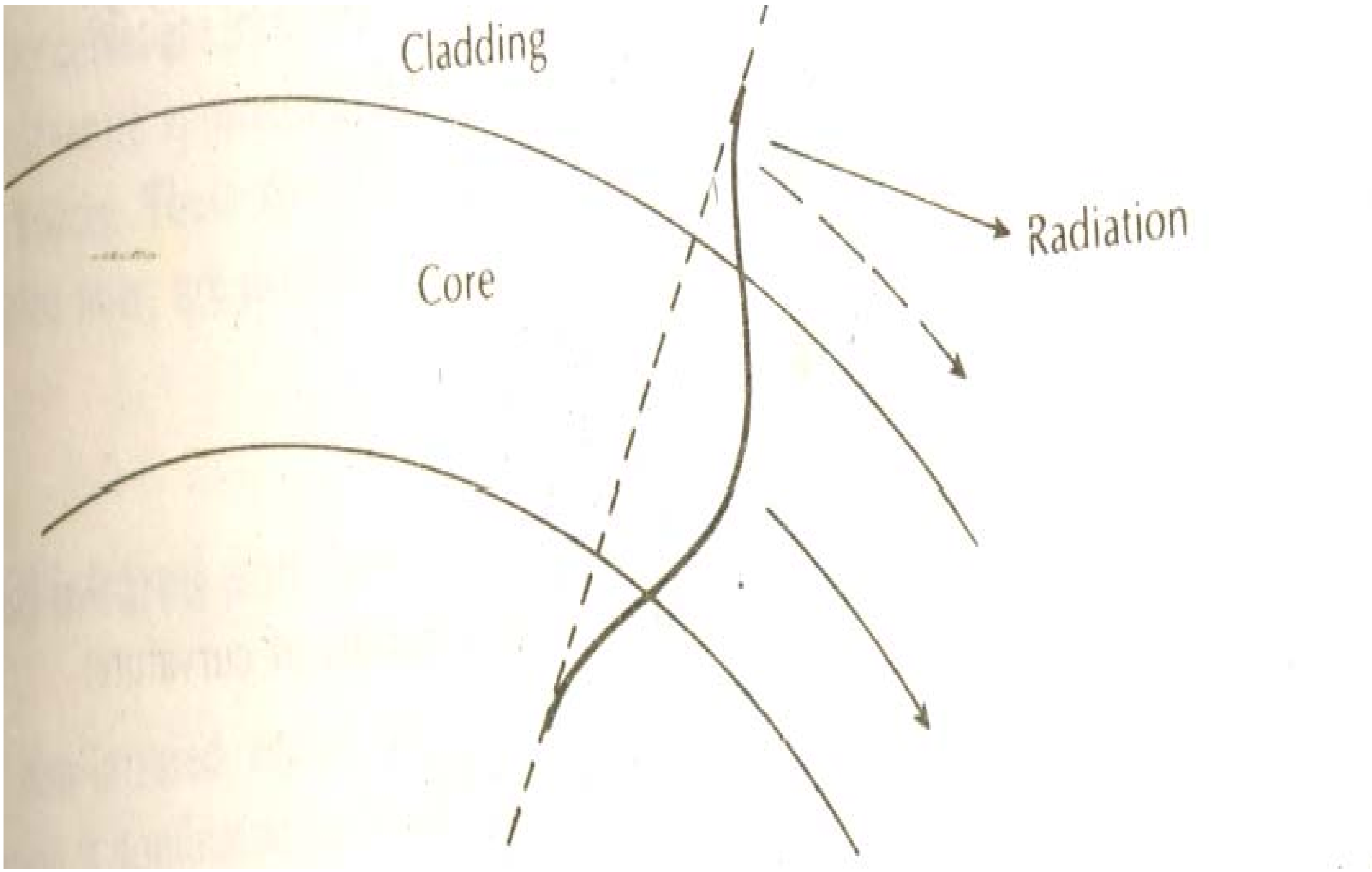
The losses at bends are due to the energy in the **short time field** ,at the bend exceeding the velocity of light in the cladding.

Guidance mechanism is slowed down.

This causes light energy to be radiated from the fiber.

Part of the mode in the cladding is required to travel faster than the velocity of light ,(in that medium)

FIBER BEND LOSS



FIBER BEND LOSS (Contd.)

Radiation .Attn. Coefficient. $\alpha_r = c_1 e - c_2 R$ where R is the Radius of curvature of bend

c_1, c_2 :constants.

Rc (critical rad. of curvature)$=3n_1^2 \lambda/4\pi (n_1^2-n_2^2)^{3/2}$

(for MM fiber)

Rc $= 20\lambda/(n_1-n_2)^{3/2} [2.748- 0.996 \lambda / \lambda c]^{-3}$,

where λc=cut-off wave length for single mode fiber.

Note: **Sharp bends with R=Rc must be avoided**

ASSIGNMENT NO 4

- A) Distinguish between Phase velocity and and Group velocity
- B) Explain ISI briefly