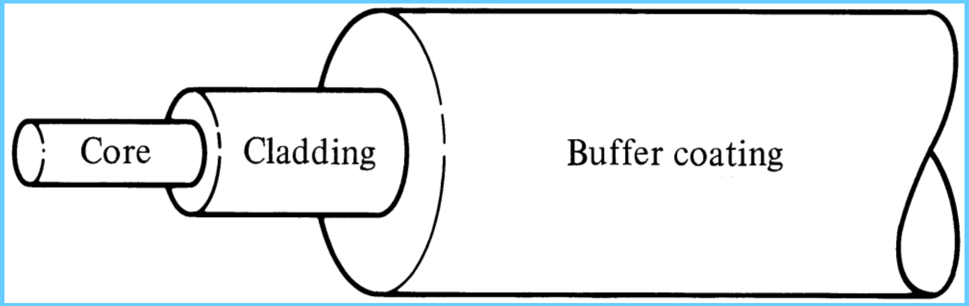
OPTICAL FIBER

- **<u>Optical Fiber</u> : *A long cylindrical dielectric waveguide, usually of circular cross-section, transparent to light over the operating wavelength.***

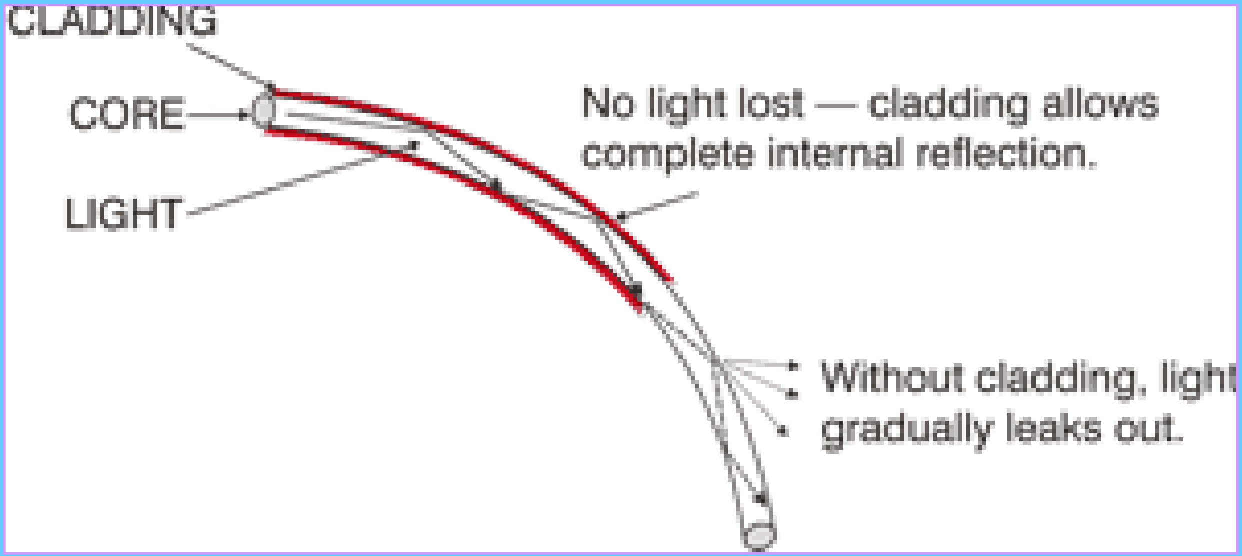
Fiber Structure



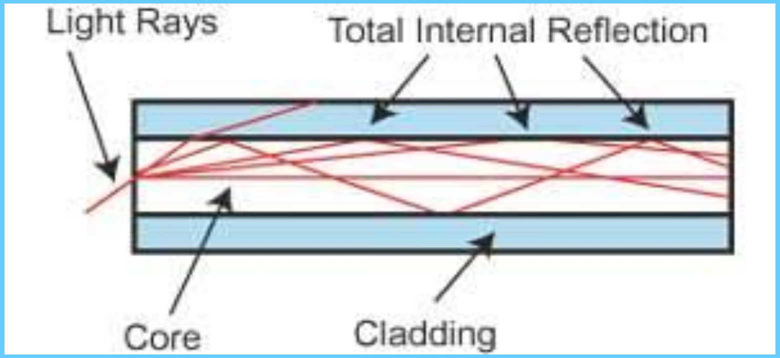
- **A solid dielectric of two concentric layers.**
  - Inner layer - **Core** of radius **'a'** and refractive index 'n_1'
  - Outer layer - **Cladding** has refractive index 'n_2'.

$n_2 < n_1$ $\rightarrow$ **Condition necessary for TIR**

Light Propagation through Optical Fiber



☞ **For light propagation through the fiber, the conditions for total internal reflection (TIR) should be met at the core-cladding interface.**



Optical Fiber Waveguiding

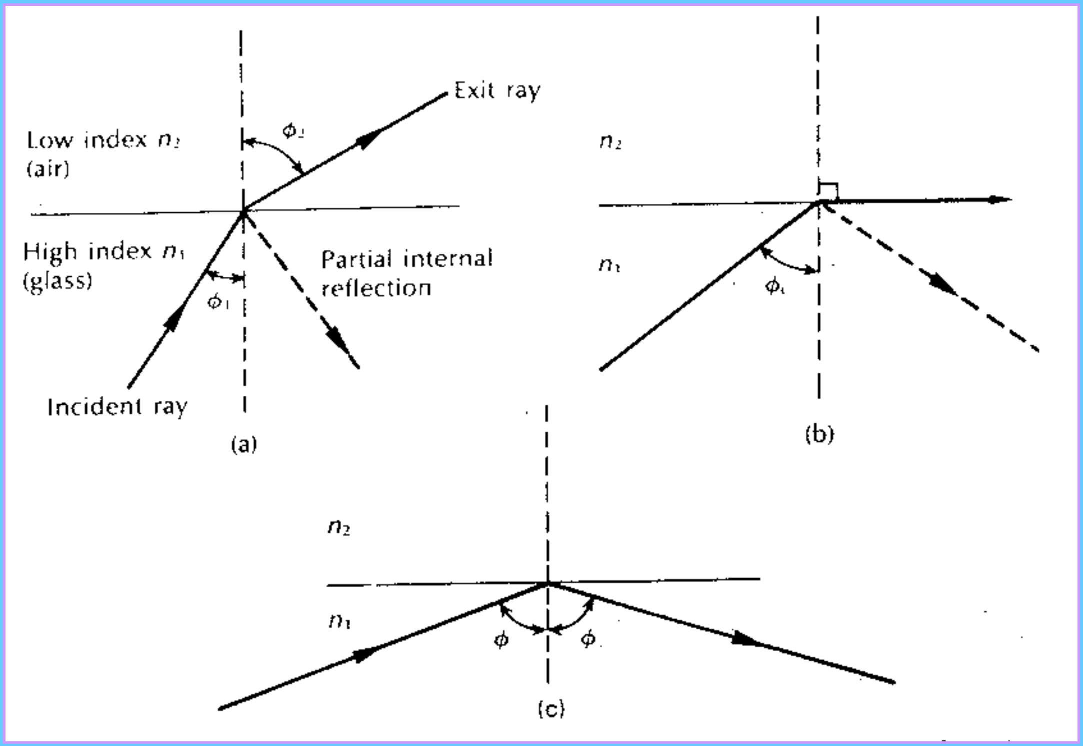
- To understand transmission mechanism in optical fibers with dimensions approximating to a human hair;
  - Necessary to consider the optical waveguiding of a cylindrical glass fiber.

- Fiber acts as an open optical waveguide – may be analyzed using simple ray theory – **Geometric Optics**
  - Not sufficient when considering all types of optical fibers (a/λ large $\Rightarrow$ Small wavelength limit)

- **Electromagnetic Mode Theory** for Complete Picture

Total Internal Reflection

- Light entering from glass-air interface ($n_1 > n_2$) - **Refraction**



Snell's Law:

$$n_1 \sin \phi_1 = n_2 \sin \phi_2$$

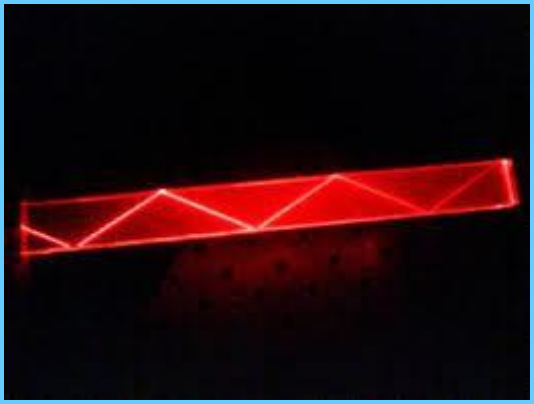
or $$\frac{\sin \phi_1}{\sin \phi_2} = \frac{n_2}{n_1}$$

$$\Rightarrow \phi_2 > \phi_1$$

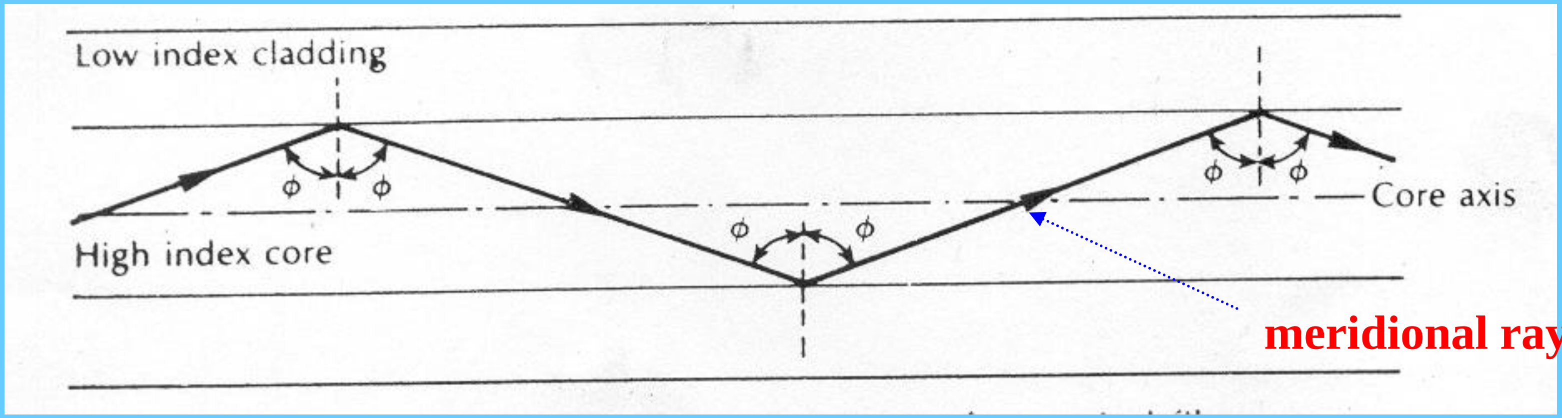
<u>Limiting Case</u> : At $\phi_2 = 90^o$, refracted ray moves parallel to interface between dielectrics and $\phi_1 < 90^o$

Angle of incidence, $\phi_1 \to \phi_C$; **critical angle**

Total Internal Reflection



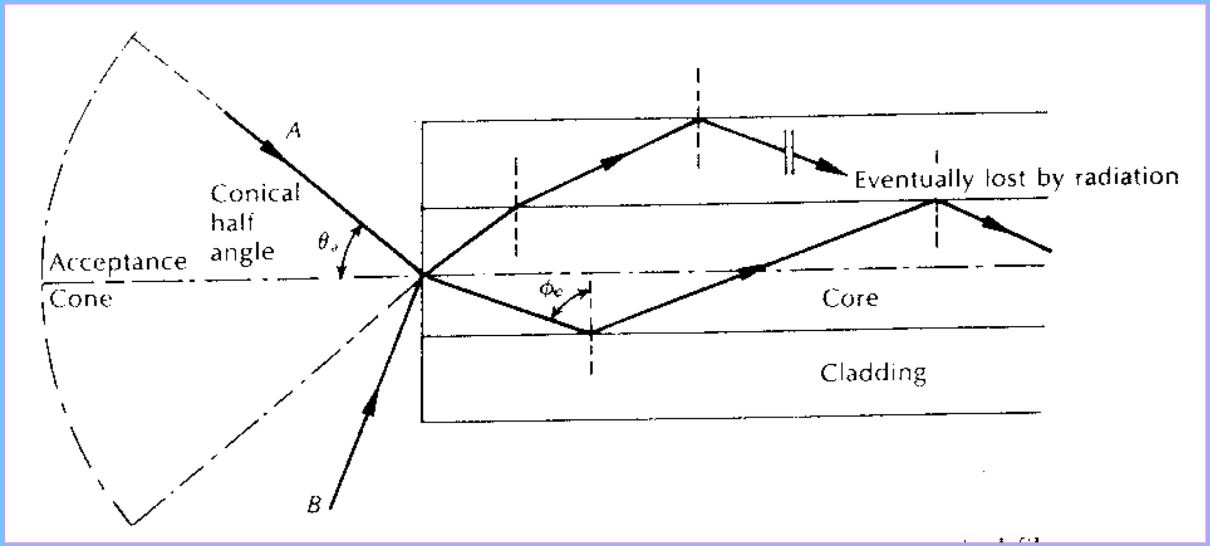
- Critical angle (ϕ_C); $\sin \phi_C = n_2/n_1$
- At angle of incidence greater than critical angle, the light is reflected back into the originating dielectric medium with high efficiency ($\approx$ 99.9%) $\Rightarrow$TIR



Transmission of light ray in a perfect optical fiber

Acceptance Angle

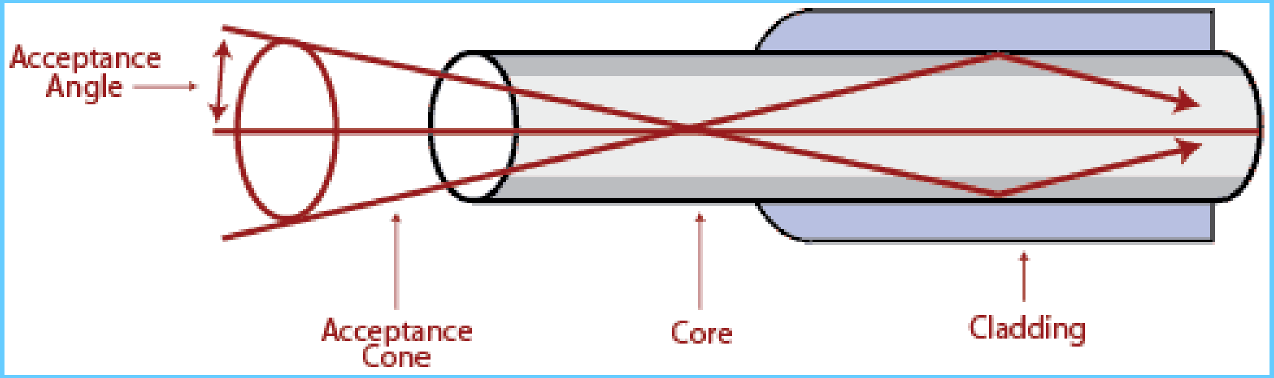
- Not all rays entering the fiber core will continue to be propagated down its length
  - Only rays with sufficiently shallow grazing angle (angle to the normal > ϕ_C) at the core-cladding interface are transmitted by TIR.



☞ Any ray incident into fiber core at angle $>\theta_a$ will be transmitted to core-cladding interface at an angle $<\phi_C$ and will not follow TIR $\Rightarrow$ Lost (case B)

Acceptance Cone

❖ For rays to be transmitted by TIR within the fiber core, they must be incident on the fiber core within an acceptance cone defined by the ***conical half angle*** "θ_a" .

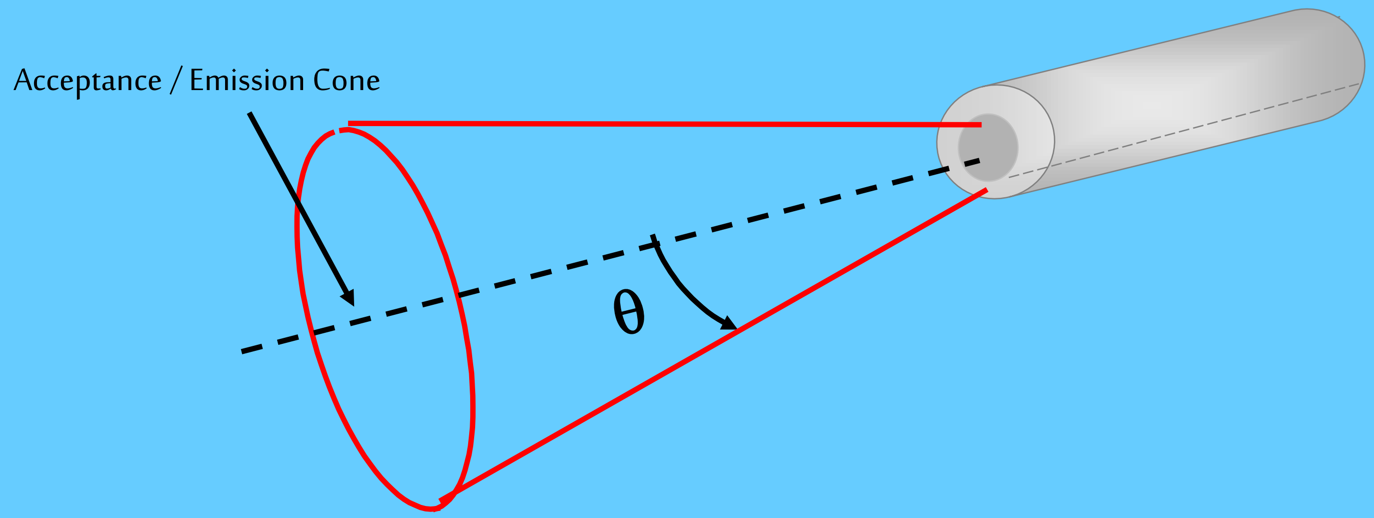


☞ **'θ_a' is the maximum angle to the axis** at which light may enter the fiber in order to be propagated by TIR

$\Rightarrow$ **Acceptance angle** for the fiber

Numerical Aperture (NA)

- **A Very useful parameter : *measure of light collecting ability of the fiber.***
  - Larger the magnitude of NA, greater the amount of light accepted by the fiber from the external source



$$NA = \sin\theta = \sqrt{n^2_{core} - n^2_{cladding}}$$

☛ **NA varies from: 0.12 - 0.20 for SMFs**
0.20 - 0.50 for MMFs

NA and Δ (Relative R.I Difference)

- In terms of relative R.I. difference 'Δ' between core and cladding,

$$\Delta = \frac{n_1^2 - n_2^2}{n_1^2 + n_2^2} \cong \frac{n_1{}^2 - n_2{}^2}{2n_1{}^2} \cong \frac{n_1 - n_2}{n_1} \quad (\text{for } \Delta << 1)$$

$$\text{NA} = n_1(2\,\Delta)^{1/2}$$

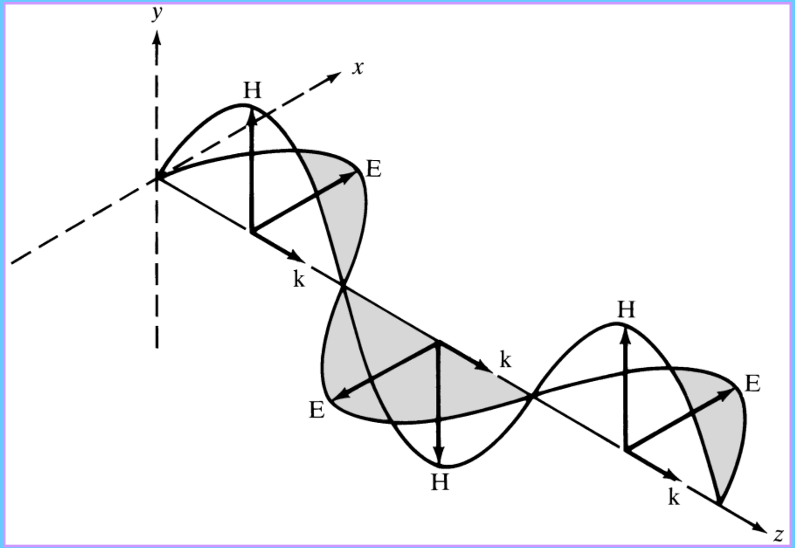
- NA ; independent of core and cladding diameters
- Holds for fiber diameters as small as 8 μm

Electromagnetic Theory

- To obtain detailed understanding of propagation of light in an optical fiber

Light as a variety of EM vibrations:

E and **H** fields at right angle to each other and perpendicular to direction of propagation.



- **Necessary to solve Maxwell's Equations**
  - Very complex analyses - ***Qualitative aspects only***

Maxwell's Equations

- Assuming a linear isotropic dielectric material having no currents and free charges

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t}$$

$$\nabla \cdot \mathbf{D} = 0$$

$$\nabla \cdot \mathbf{B} = 0$$

where $\mathbf{D} = \epsilon \mathbf{E}$ and $\mathbf{B} = \mu \mathbf{H}$.

Maxwell Equations

Substituting for **D** and **B** and taking curl of first equation

$$\nabla \times (\nabla \times \mathbf{E}) = -\mu \frac{\partial}{\partial t}(\nabla \times \mathbf{H}) = -\epsilon\mu \frac{\partial^2 \mathbf{E}}{\partial t^2}$$

Using vector identity

$$\nabla \times (\nabla \times \mathbf{E}) = \nabla(\nabla \cdot \mathbf{E}) - \nabla^2 \mathbf{E}$$

We get

$$\nabla^2 \mathbf{E} = \epsilon\mu \frac{\partial^2 \mathbf{E}}{\partial t^2}$$

Similarly

$$\nabla^2 \mathbf{H} = \epsilon\mu \frac{\partial^2 \mathbf{H}}{\partial t^2}$$

- Wave equations for each component of the field vectors **E** & **H**.

- Wave equations hold for each component of the field vector (E or H), every component satisfying the scalar wave equation:

$$\nabla^2\psi = \frac{1}{v_p^2}\frac{\partial^2\psi}{\partial t^2}$$

v_p - phase velocity in the dielectric medium, given by

$$v_p = \frac{1}{(\mu\varepsilon)^{\frac{1}{2}}} = \frac{1}{(\mu_r\mu_0\varepsilon_r\varepsilon_0)^{\frac{1}{2}}}$$

μ_r and ε_r are relative permeability and permittivity for the dielectric medium.

- For planar wave guides described by Cartesian coordinates (x,y,z)

$$\nabla^2\psi = \frac{\partial^2\psi}{\partial x^2} + \frac{\partial^2\psi}{\partial y^2} + \frac{\partial^2\psi}{\partial z^2}$$

- For circular fibers described by Cylindrical coordinates (r,θ,ϕ)

$$\nabla^2\psi = \frac{\partial^2\psi}{\partial r^2} + \frac{1}{r}\frac{\partial^2\psi}{\partial r} + \frac{1}{r^2}\frac{\partial^2\psi}{\partial \phi^2} + \frac{\partial^2\psi}{\partial z^2}$$

☞ **Necessary to consider both the forms for a complete treatment of optical propagation in the fiber.**

- Basic solution of wave equation is **a sinusoidal wave**, and most important form is a uniform plane or linearly polarized wave given by

$$\psi = \psi_0 \exp j(\omega t - \mathbf{k}.r)$$

ω - angular frequency of the field, t - time, k - propagation vector $\Rightarrow$ gives direction of propagation and rate of change of phase with distance and r -coordinate point where field is observed.

- In most general form

$$A(x,t) = e_i A_o \exp\{j(\omega t - \mathbf{k}.\mathbf{x})\}$$

where

- $\mathbf{x} = xe_x + xe_y + xe_z$ (general position vector)
- $\mathbf{k} = k_x e_x + k_y e_y + k_z e_z$ (wave propagation vector); magnitude of wave vector k is $k = 2\pi/\lambda$, where λ is wavelength of light.
- A_o is the maximum amplitude of the wave
- ω is angular frequency ($\omega = 2\pi\nu$; ν is the frequency of light)
- e_i is unit vector lying parallel to axis designated by i

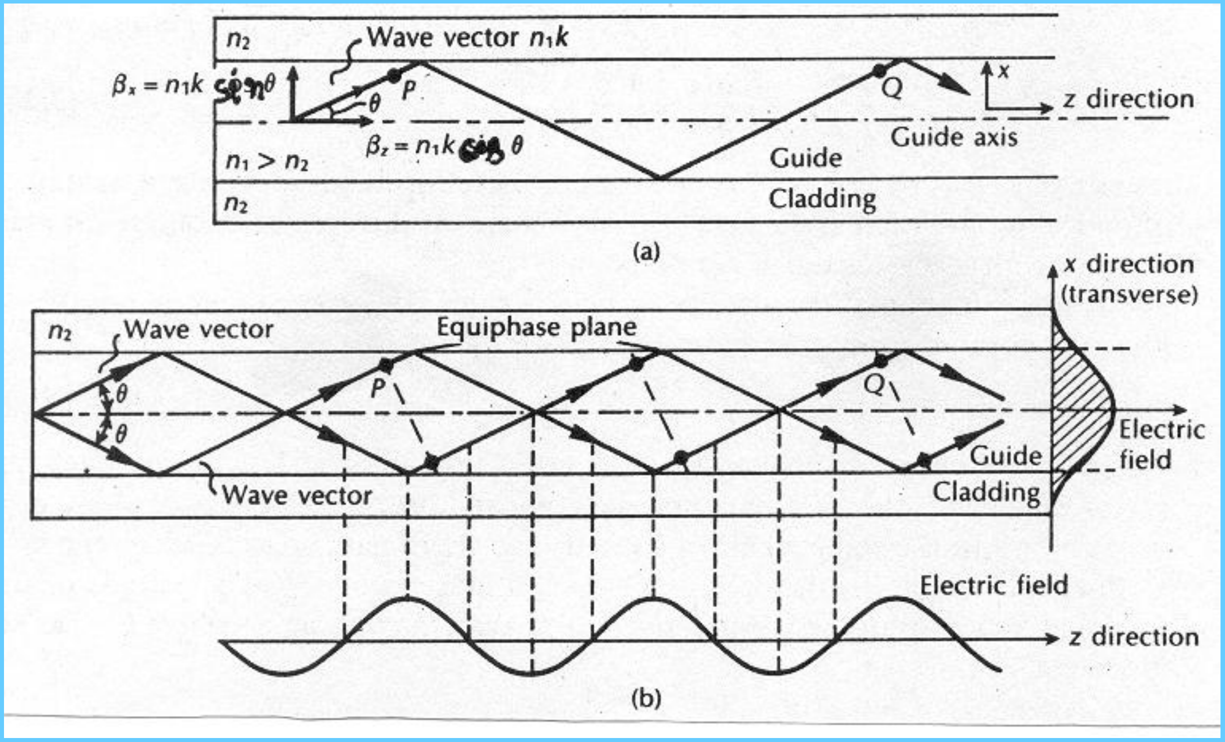
Concept of Modes

❖ A plane monochromatic wave propagating in direction of ray path within the guide of refractive index n_1 sandwiched between two regions of lower refractive index n_2

- Wavelength $= \lambda/n_1$
- Propagation constant
  $\beta = n_1 k$
- Components of β in z- and x- directions

  $\beta_z = n_1 k \cos\theta$

  $\beta_x = n_1 k \sin\theta$
- Constructive interference occurs and standing wave obtained in x-direction



(a) A plane wave propagating in the guide (b) Interference of plane wave in the guide (forming lowest order mode m=0)

- Components of plane wave in x-direction reflected at core-cladding interface and interefere
  - **Consructive**: when ***total phase change*** after two reflection is equal to $2m\pi$ radians; m an integer - **Standing wave in x-direction**
  - The optical wave is confined within the guide and the electric field distribution in the x-direction does not change as the wave propagate in the z-direction – **Sinusoidally varying in z-direction**

The stable field distribution in the x-direction with only a periodic z-dependence is known as a MODE.

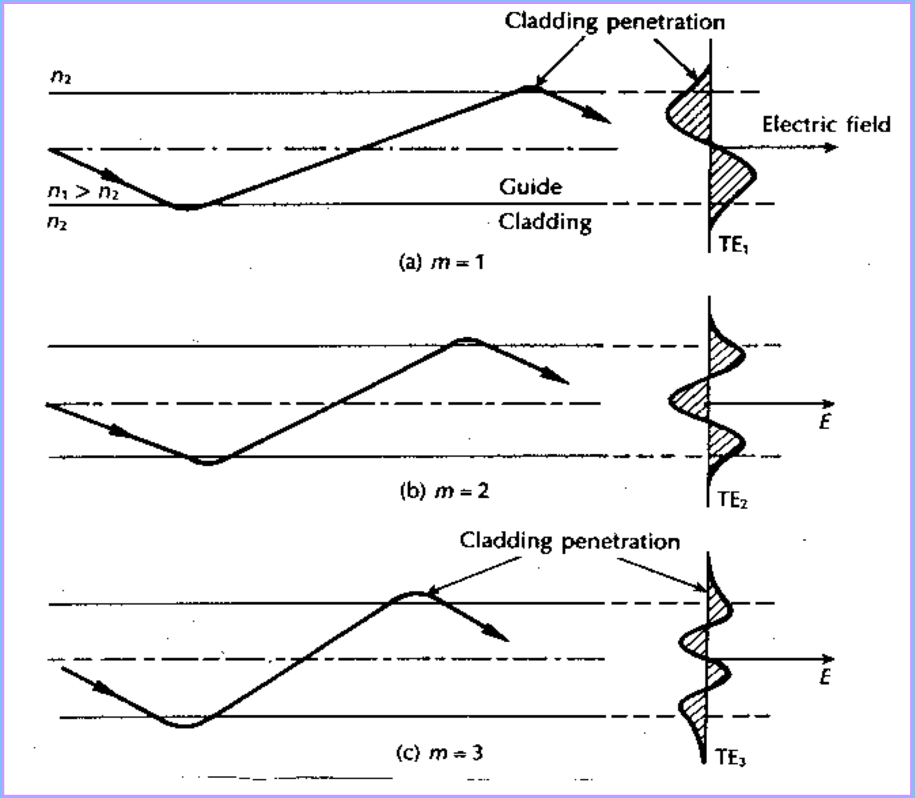
- Specific mode is obtained only when the angle between the propagation vectors and interface have a particular value – **Discrete modes** typified by a distinct value of θ
- Have periodic z-dependence of $\exp(-j\beta_z z)$ or commonly $\exp(-j\beta z)$
- Have time dependence with angular frequency ω, i.e. $\exp(j\omega t)$

Modes in Planar Waveguides

❖ For monochromatic light field of angular frequency ω, a mode traveling in positive z-direction has time and z-dependence given by

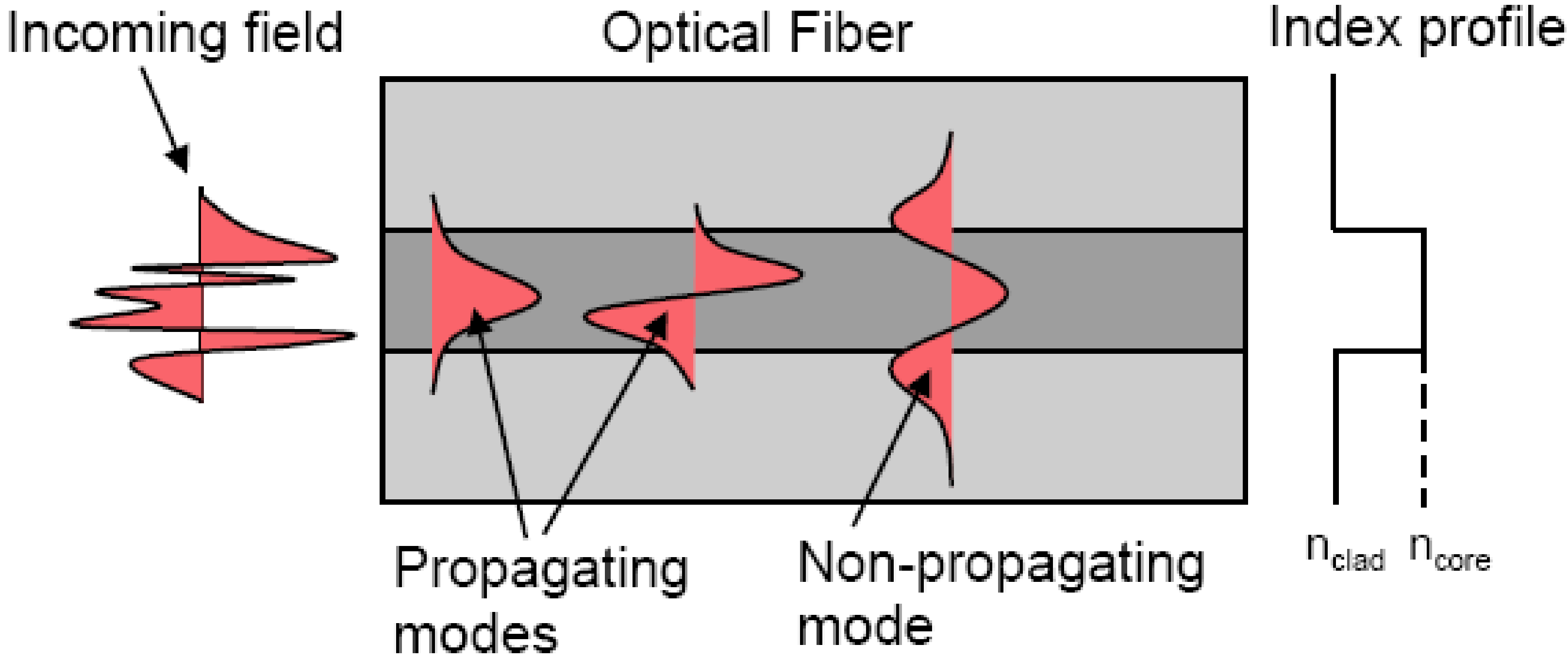
$$\Rightarrow \exp j(\omega t - \beta z)$$

- Dominant modes propagating in z-direction with electric field distribution in x-direction formed by rays with m=1,2,3
- m denotes number of zeros in this transverse pattern.
- Also signifies the order of the mode and is known as **mode number**.



Ray propagation and TE field patterns of three lower order modes in planar waveguide

Wave picture of waveguides



- The step-index profile provide focusing just like lenses and GRIN materials
- The guides modes of the fiber are those that propagate without changing their profile
- The guided modes are those intensity profiles, for which the focusing, due to the index profile, exactly matches the diffraction
- In the core is small, only one such mode exists (single mode fiber)

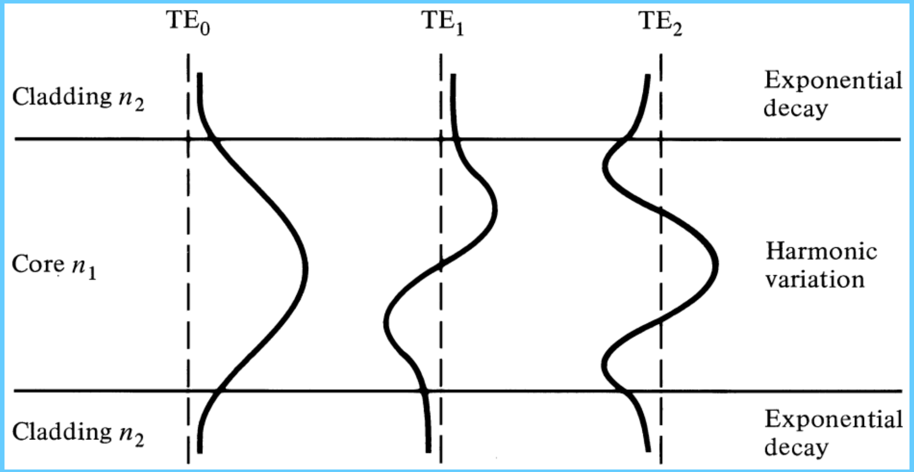
TE and TM modes

- **Transverse Electric mode (TE)**: Electric field is perpendicular to the direction of propagation, (E_z=0), but a corresponding component of the magnetic field **H** in the direction of propagation.

- **Transverse Magnetic (TM) mode**: A component of **E** field is in the direction of propagation, but H_z=0.

  - Modes with mode numbers;

    TE_m and TM_m



- **Transverse ElectroMagnetic (TEM)** : Total field lies in the transverse plane

  $\Rightarrow$ both E_z and H_z are zero.

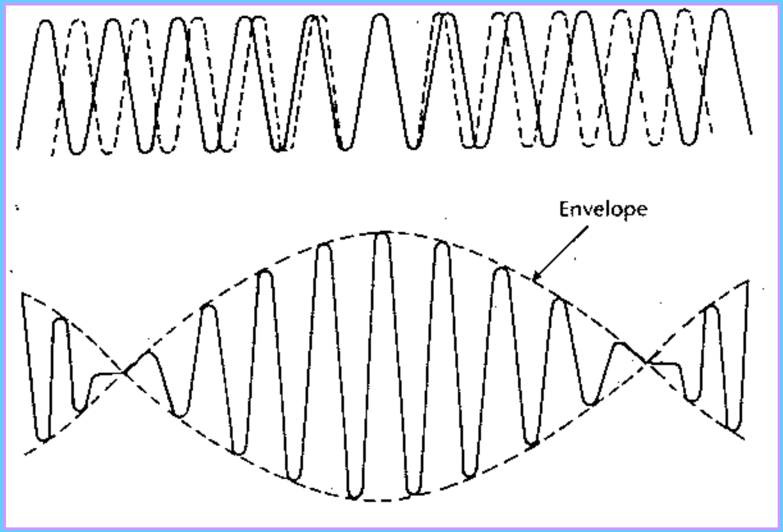
Phase and Group Velocity

- **Phase Velocity**: For a plane wave, there are points of constant phase, these constant phase points forms a surface, referred to as a **wavefront**.
  - As light wave propagate along a waveguide in the z-direction, wavefront travel at a phase velocity ; $\mathbf{v_p = \omega / \beta}$

☞Non-monochromaticity leads to group of waves with closely similar frequencies – **Wave Packet**

- **Wave packet** observed to move at a group velocity, $\mathbf{v_g = \delta\omega / \delta\beta}$

☞**$\mathbf{V_g}$ is of great importance in study of TCs of optical fibers ⇒ relates to propagation characteristics of observable wave groups**



Formation of wave packet from combination of two waves of nearly equal frequencies

Group Velocity & Group Index

- Propagation parameters for a group in an infinite medium of refractive index n_1

Propagation constant, $$\beta = n_1 k = n_1 \frac{2\pi}{\lambda} = n_1 \frac{\omega}{c}$$

Phase velocity, $$v_p = \frac{c}{n_1}$$

Group velocity, $$v_g = \frac{c}{\left(n_1 - \lambda \frac{dn_1}{d\lambda}\right)} = \frac{c}{N_g}$$

- Parameter N_g is known as the ***group index*** of the guide

Evanescent Field

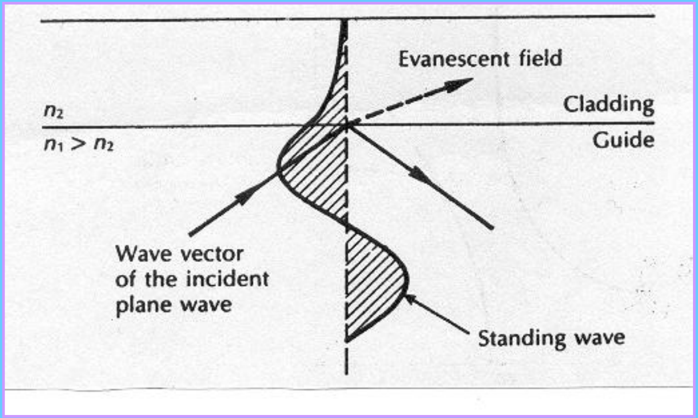
- Another phenomenon of interest under conditions of TIR is the form of the electric field in the cladding of the guide.

The transmitted wave field in the cladding is of the form

$$B = B_0 \exp(-\xi_2 x).\exp j(\omega t - \beta z)$$

- Amplitude of the field in cladding decay exponentially in the x-direction

  ⇒ ***Evanescent Field***



Exponentially decaying evanescent field in the cladding

- ***Field of this type stores energy and transports it in the direction of propagation(z), but does not transport energy in the transverse direction (x).***
- ***Indicates that a part of optical energy is transmitted into the cladding***

  ⇒ ***Accounts for loss of energy***

Cladding Material

- **The evanescent field gives rise to the following requirements for the choice of cladding material**
  - Should be transparent to light at the wavelengths over which the guide is to operate.
  - Should consist of a solid material to avoid both damage to the guide and the accumulation of foreign matter on the guide walls.
  - Cladding thickness (≈125μm) must be sufficient to allow the evanescent field to decay to a low value or losses from the penetrating energy may be encountered.

☞ Most widely used optical fibers consist of a core and cladding, both made of glass. Although, it give a lower NA for fiber, but provides a far more practical solution.

Cylindrical Fiber

- Exact solution of Maxwell's Eqns. for a cylindrical dielectric waveguide- ***very complicated & complex*** results

- In common with planar waveguide, TE and TM modes are obtained within dielectric cylinder.
  - A cylindrical waveguide is bounded in two dimensions, therefore, two integers, l and m to specify the modes.

    $\mathbf{TE}_{lm}$ and $\mathbf{TM}_{lm}$ modes

    - *These modes result from meridional rays propagation within guide*

- Hybrid modes where both $\mathbf{E}_z$ and $\mathbf{H}_z$ are nonzero – *results from skew ray propagation within the fiber.* Designated as

  $\mathbf{HE}_{lm}$ and $\mathbf{EH}_{lm}$ depending upon whether the components of H or E make the larger contribution to transverse field

Modes in Cylindrical Fibers

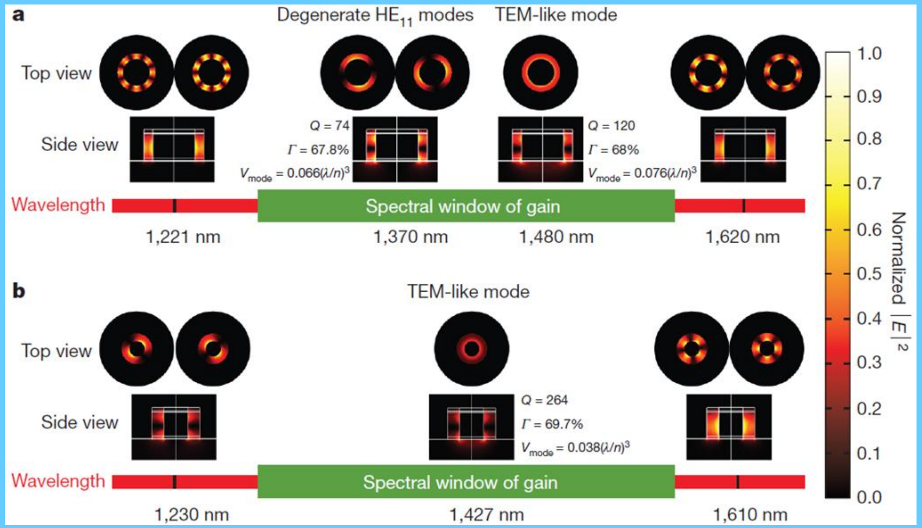
- ❑ Analysis simplified by considering fibers for communication purposes.
  - **Satisfy, weakly guided approximation, Δ<<1, small grazing angles θ**

- ❖ Approximate solutions for full set of HE, EH, TE and TM modes may be given by two linearly polarized (LP) components
  - Not exact modes of fiber except for fundamental mode, however, as Δ is very small, HE-EH modes pairs occur with almost identical propagation constants $\Rightarrow$ **Degenerate modes**
  - The superposition of these degenerating modes characterized by a common propagation constant corresponds to particular LP modes regardless of their HE, EH, TE or TM configurations.

☞ This linear combination of degenerate modes produces a useful simplification in the analysis of weakly guiding fibers.

Correspondence between the lower order in linearly polarized modes and the traditional exact modes from which they are formed.

Linearly polarized	Exact
LP_{01}	HE_{11}
LP_{11}	HE_{21}, TE_{01}, TM_{01}
LP_{21}	HE_{31}, EH_{11}
LP_{02}	HE_{12}
LP_{31}	HE_{41}, EH_{21}
LP_{12}	HE_{22}, TE_{02}, TM_{02}
LP_{lm}	HE_{2m}, TE_{0m}, TM_{0m}

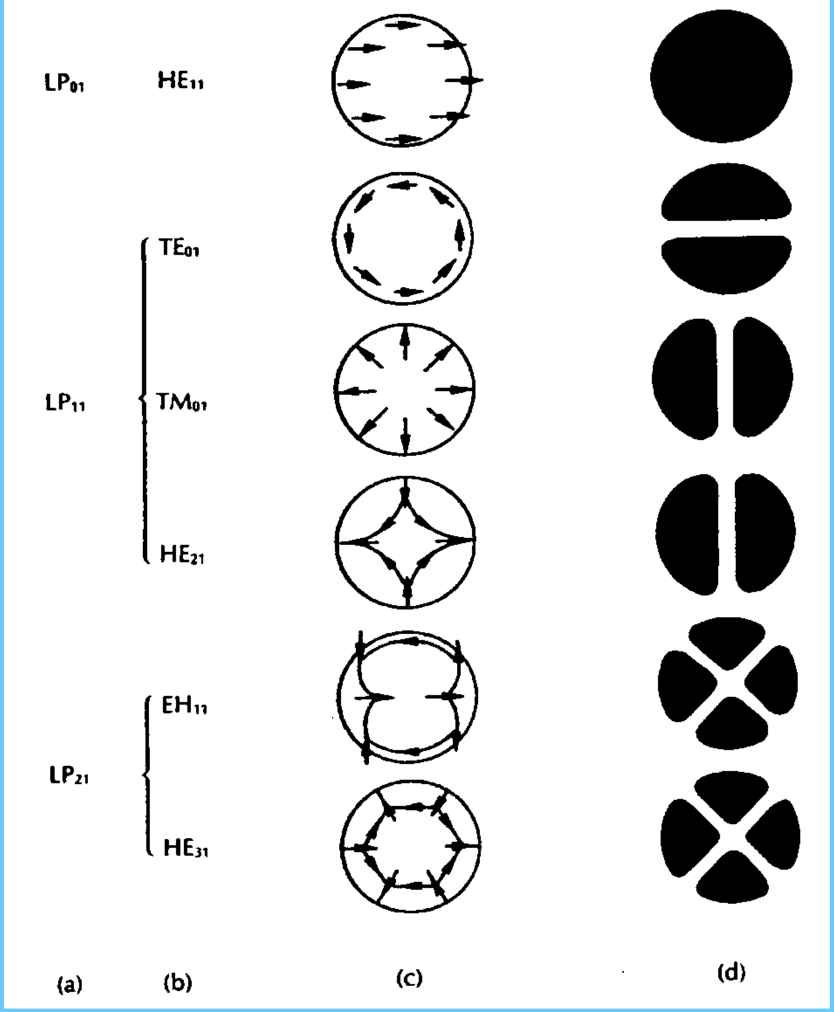


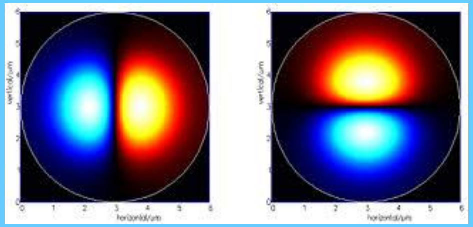
Intensity Profiles

- **Electric field configuration for the three lowest LP modes in terms of their constituent exact modes:**

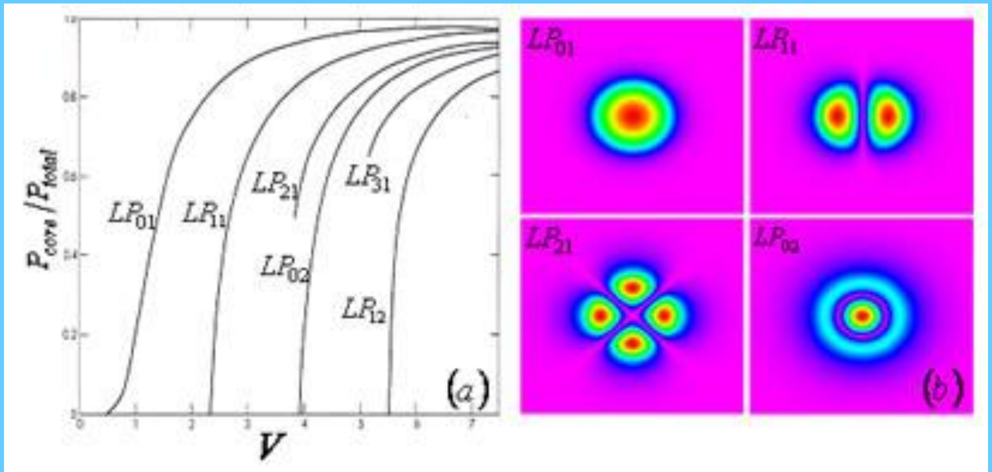
    (a) LP mode designations;
    (b) Exact mode designations;
    (c) Electric field distribution of the exact modes;
    (d) Intensity distribution of E_x for exact modes indicating the electric field intensity profile for the corresponding LP modes.

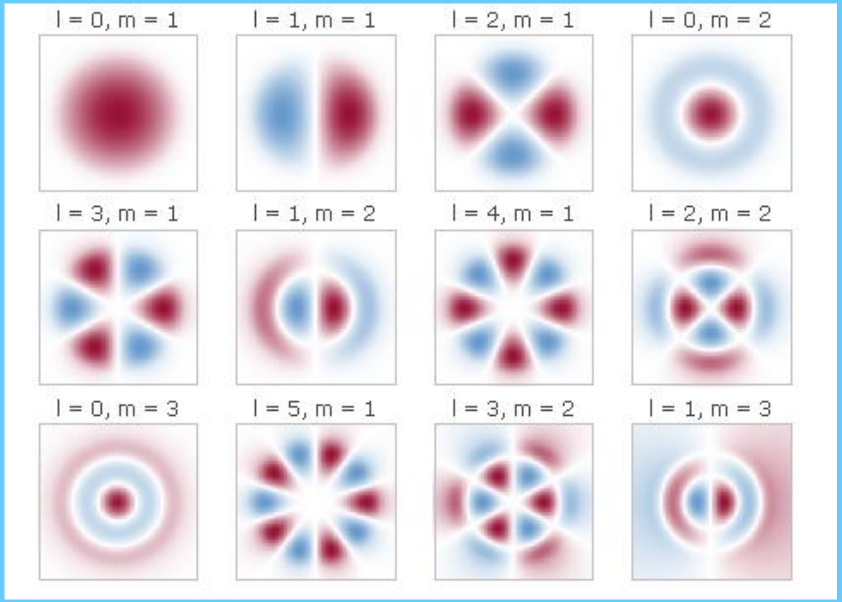
- **Field strength in the transverse direction is identical for the modes which belong to the same LP mode.**

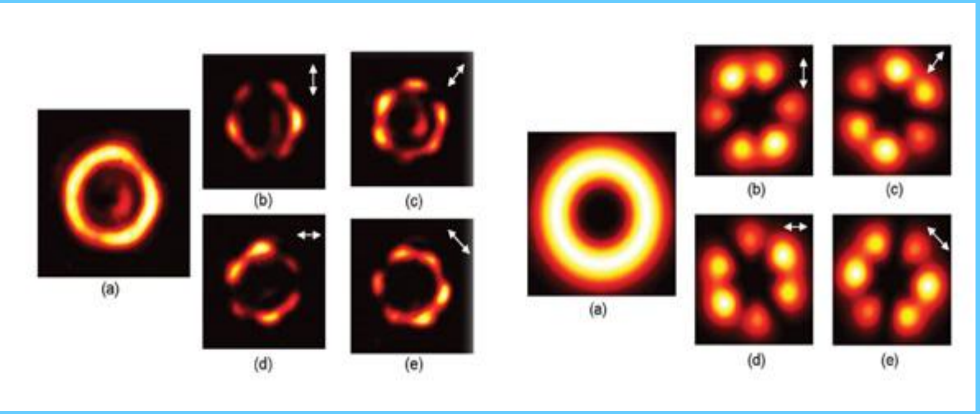




Modes in Optical Fiber







V-Number

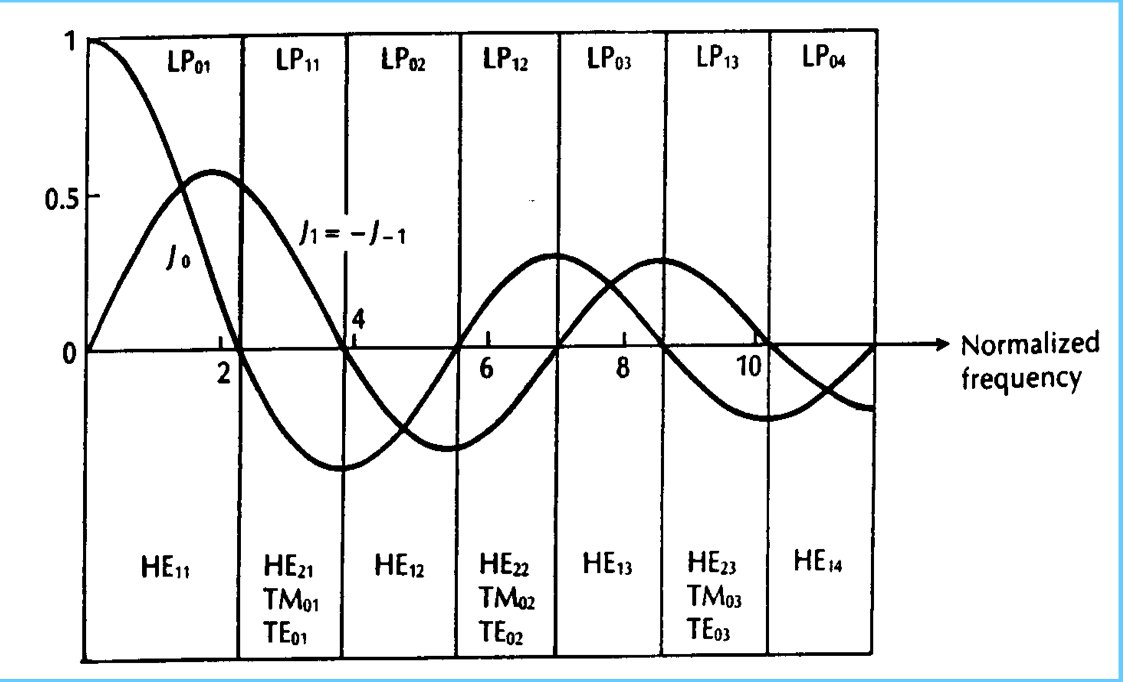
❖ Normalized frequency 'V' is expressed in terms of NA and Δ

$$V = \frac{2\pi}{\lambda} a(NA) = \frac{2\pi}{\lambda} a\, n_1 (2\Delta)^{\frac{1}{2}}$$

- Normalized frequency is a dimensionless parameter and simply called ***V-number*** or ***value of the fiber***.
- It combines in a very useful manner the information about three fiber parameters, **a**, **Δ** and **λ**.
- Accounts for number of modes in a fiber.

Allowed LP modes

- **Lower order modes obtained in a cylindrical homogeneous core waveguide**



The allowed regions for the LP modes of order l = 0,1 against normalized frequency (V) for a circular optical waveguide with a constant refractive index core (step index fiber).

- Value of V, where J_0 and J_1 cross the zero gives the cutoff point for various modes.

$$\mathbf{V = V_c}$$

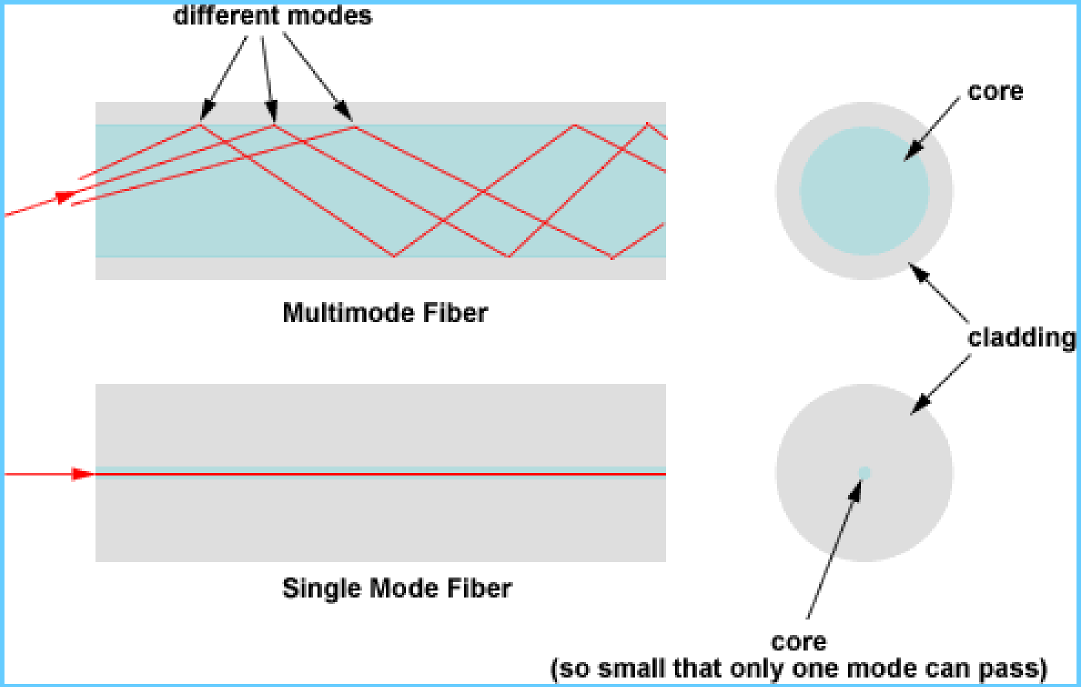
- V_c is different for different modes

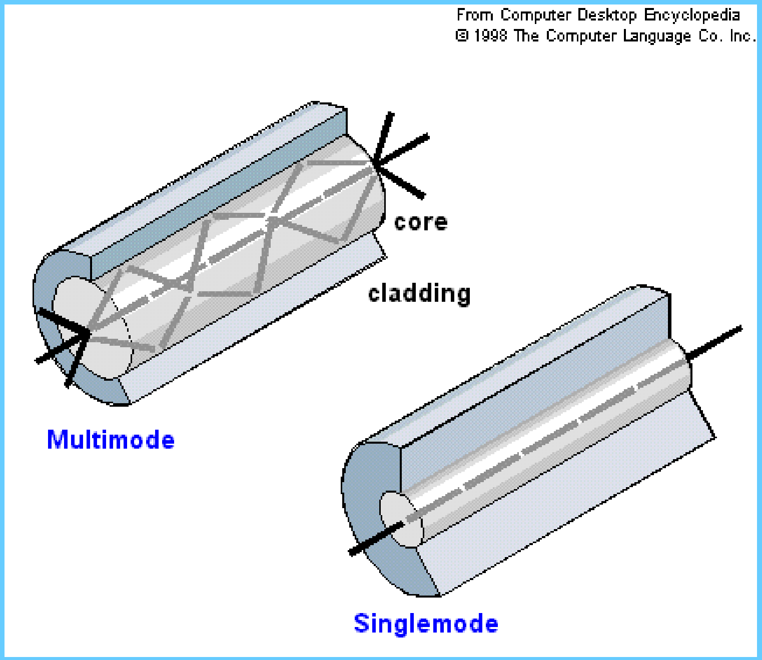
= 0 for LP_{01} mode

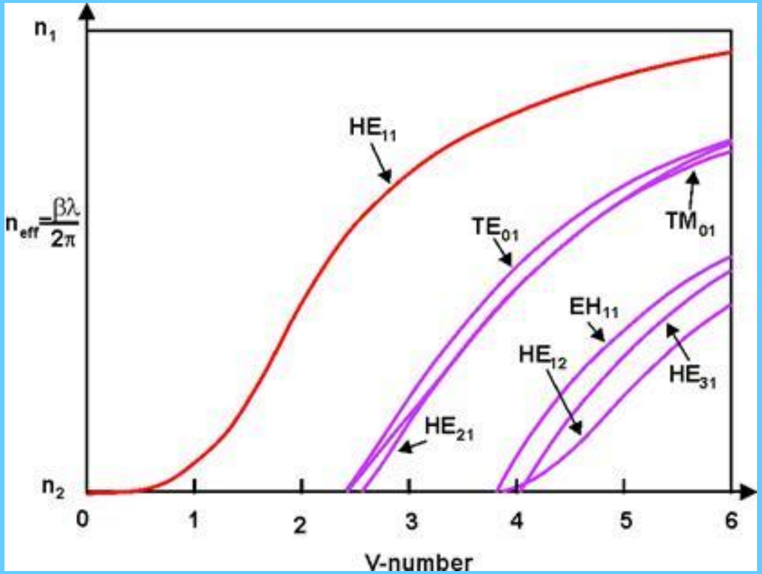
= 2.405 for LP_{11}

= 3.83 for LP_{02}

Single/Multimode fibers







V-Number

- **Single mode Propagation: V≤2.405**
- **Multimode Propagation: V>10**

Leaky & Guided Modes

Limit of mode propagation i.e. $n_2k < \beta < n_1k$

- **Cut OFF**: When, $\beta = n_2k$; the mode phase velocity is equal to the velocity of light in the cladding and mode is no longer properly guided.
  - ***Mode is said to be cut off*** and eigenvalue W=0

- ***Unguided (Radiation, Leaky) modes: Frequencies below cutoff***, $\beta < n_2k$ and hence W is imaginary. Nevertheless, wave propagation does not cease abruptly below cutoff. Modes exist near the core-cladding interface.
  - Solns of wave equation giving these states are called ***leaky modes***, and often behaves as very lousy guided modes rather than radiation modes.

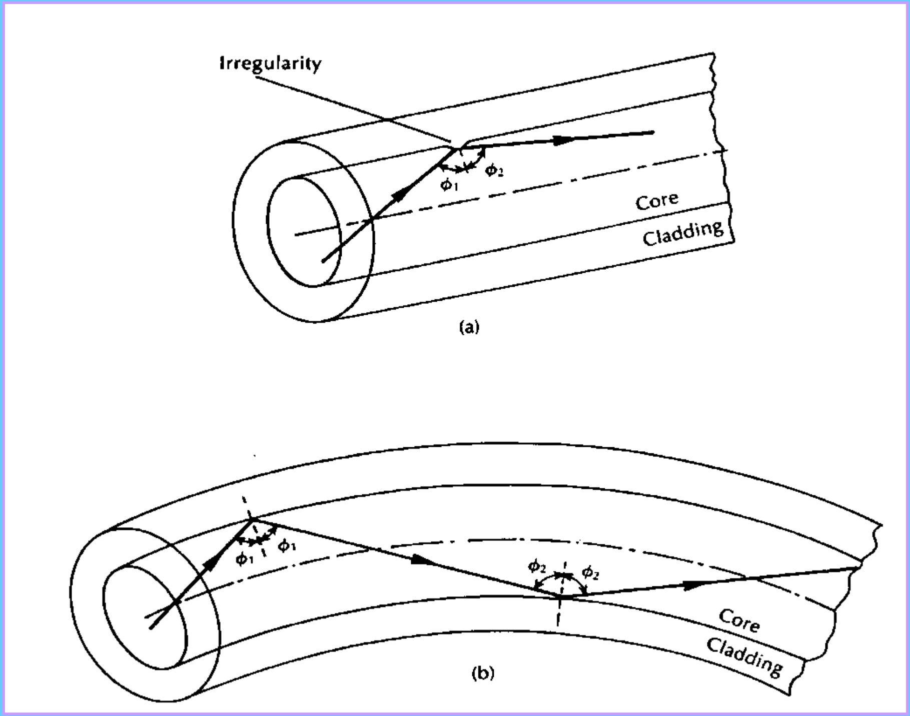
- **Guided Modes**: For $\beta > n_2k$, less power is propagated in the cladding until at $\beta = n_1k$ - all the power is confined to the fiber core.
  - This range of values for β signifies guided modes of the fiber.

Mode Coupling

- **Waveguide perturbations**;
  - Deviations of fiber axis from straightness
  - Variations in core diameter,
  - Irregularities at core-cladding interface
  - RI variations

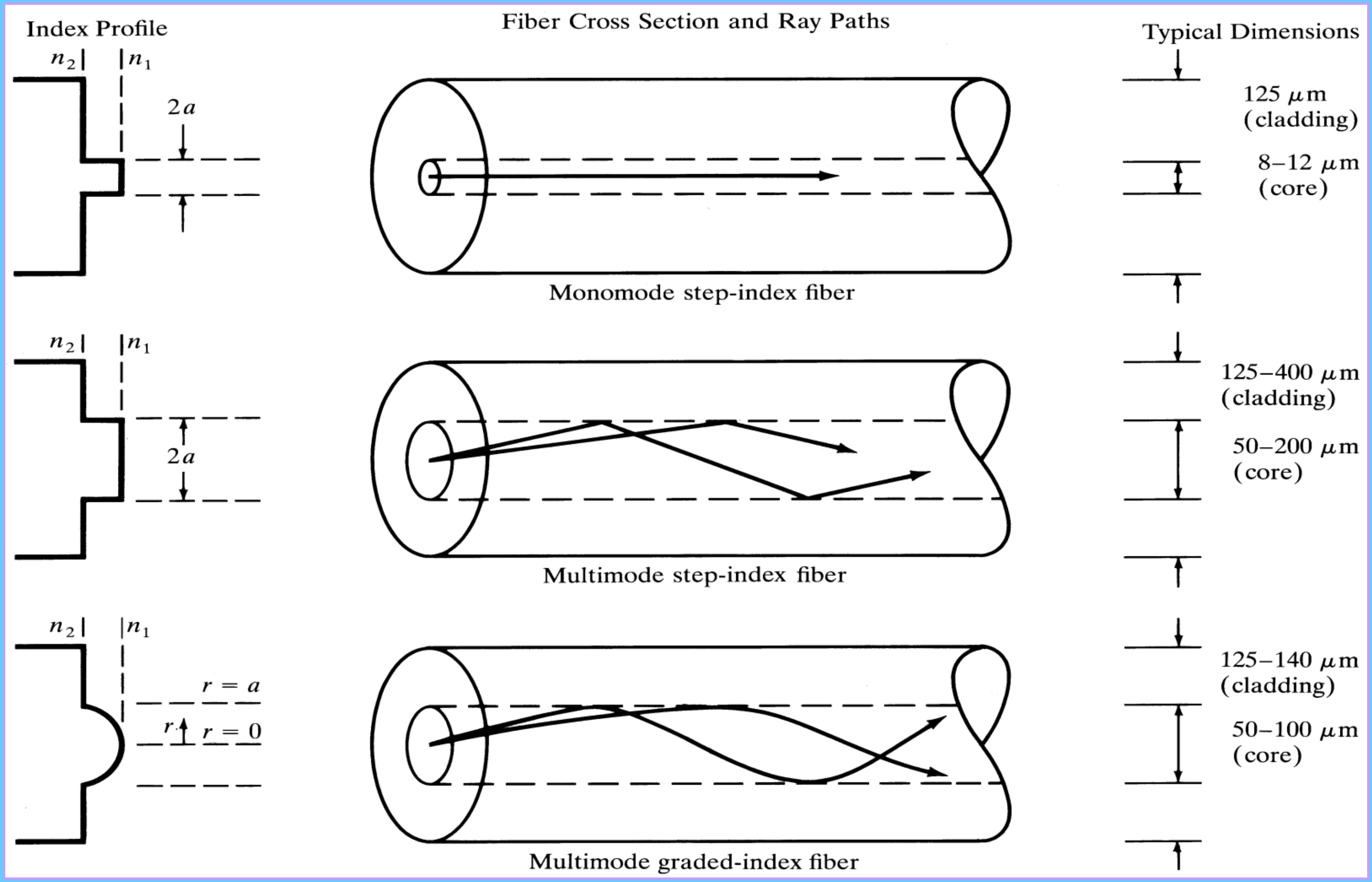
  changes the propagation characteristics of fiber

- Have the effect of coupling energy travelling in one mode to another- ***mode coupling*** or ***mixing***
- Affects the fiber performance



Ray theory illustrations showing two of the possible fiber perturbations, which give mode coupling: (a) irregularity at the core-cladding interface; (b) fiber bend.

Step Index / Graded Index



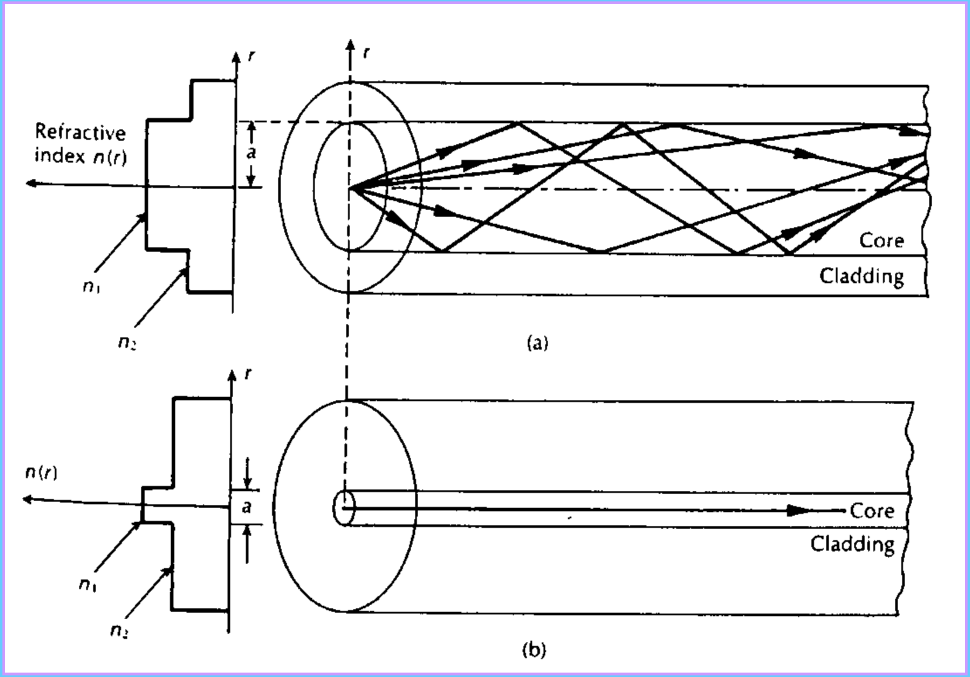
Step Index Fibers

- Fiber with a core of constant refractive index n_1 and a cladding of slightly lower refractive index n_2 .
  - Refractive index profile makes a step change at the core-cladding interface

Refractive index profile

$$n(r) = \begin{cases} n_1 & ; \quad r<a \quad \text{(core)} \\ n_2 & ; \quad r \geq a \quad \text{(cladding)} \end{cases}$$

- Multimode Step Index
- Single mode Step Index



The refractive index profile and ray transmission in step index fibers: (a) multimode step index fiber. (b) single-mode step index fiber.

Modes in SI Fibers

- **MM SI fibers allow the propagation of a finite number of guided modes along the channel.**
  - Number of guided modes is dependent upon the physical parameters ; a, Δ of fibers and wavelength of the transmitted light – included in **V-number**

- Total number of guided modes or mode volume M_s for SI fiber is related to V-number for the fiber by approximate expression

$$M_s \approx V^2/2$$

  - Allows an estimate of number of guided modes propagating in a particular MM SI fiber.

- **Example**: A MM SI fiber of core diameter 80μm, core refractive index 1.48, relative index difference of 1.5% and operating at 850nm
  - Supports 2873 guided modes.

Power Flow in Step-Index Fibers

- Far from the cutoff the average power in the cladding has been derived for the fibers in which many modes can propagate.
  - Because of the large number of modes, those few modes that are appreciably close to cutoff can be ignored to a reasonable approximation.

The total average cladding power is thus approximated by

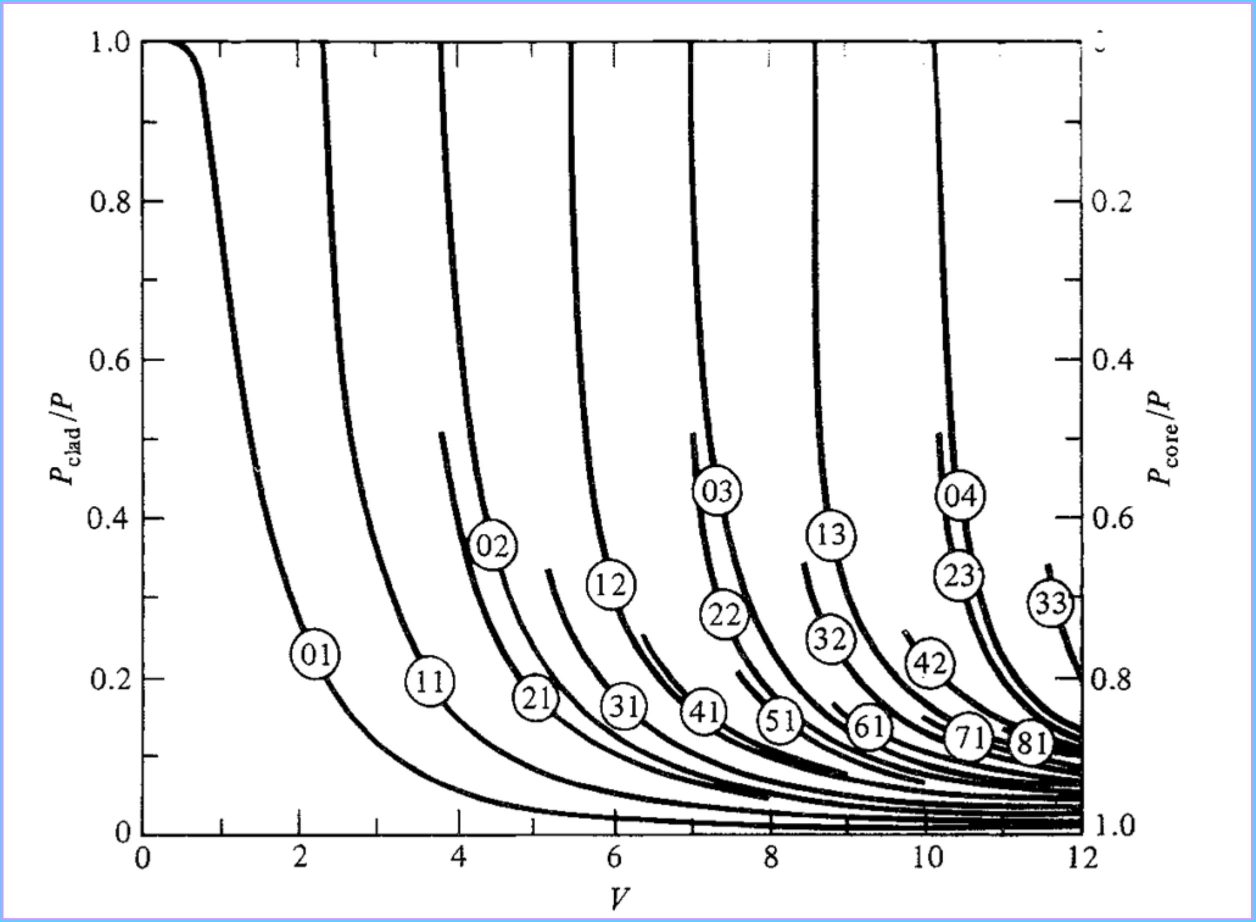
$$\left(\frac{P_{clad}}{P}\right)_{total} = \frac{4}{3} M^{-\frac{1}{2}}$$

Here M is the total number of modes entering the fiber

☞ Since M is proportional to V^2, the power flow in the cladding decreases as V increases.

- For V = 1; ⇒ 70% of power flow in cladding
- For V = 2.405; ⇒ 20% of power flow in cladding.

Power Flow in Step-Index Fibers



Fractional power flow in the cladding of a SI fiber as a function of V.

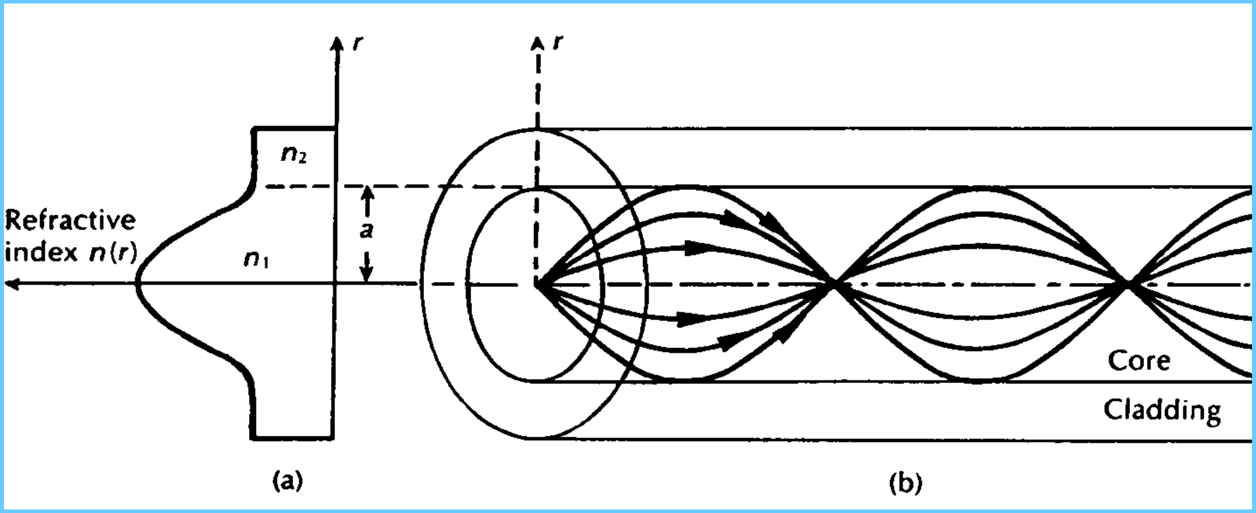
Graded Index Fiber Structure

- GI fibers do not have a constant refractive index in the core, but a ***decreasing core index n(r) with radial distance*** from a maximum value of n_1 at the axis to a constant value n_2 beyond the core radius 'a' in the cladding $\Rightarrow$ ***Inhomogeneous core fibers***

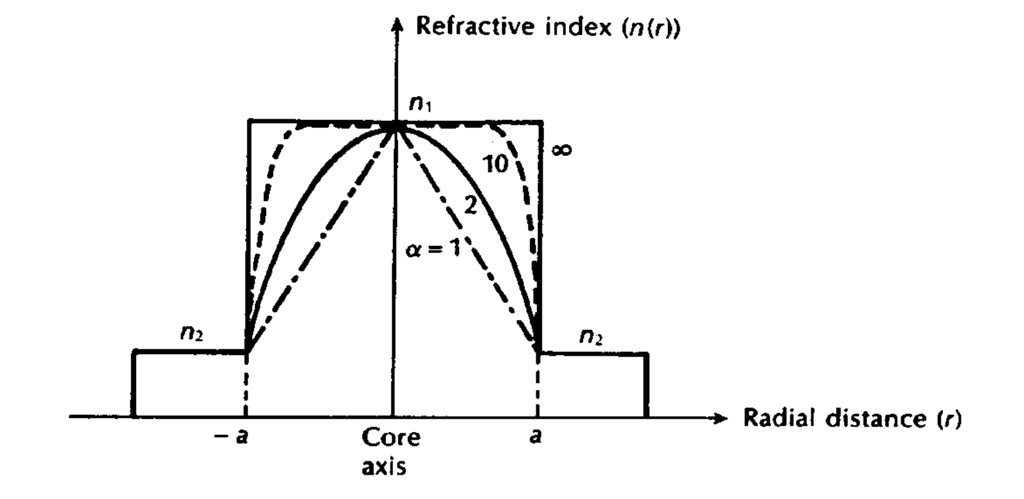
Index variation is represented as

$$n(r) = \begin{cases} n_1\left[1 - 2\Delta\left(\frac{r}{a}\right)^{\alpha}\right]^{1/2} & \text{for} \quad 0 \leq r \leq a \\ n_1(1-2\Delta)^{1/2} \simeq n_1(1-\Delta) = n_2 & \text{for} \quad r \geq a \end{cases}$$

where, Δ is relative refractive index difference and α is the profile parameter which gives the characteristic RI profile of the fiber core.



The refractive index profile and ray transmission in a multimode graded index fiber.



Possible fiber refractive index profiles for different values of α

$\alpha = \propto$; Step index profile

$\alpha = 2$; Parabolic profile

$\alpha = 1$ Triangular profile

Graded Index Fiber Parameters

- Parameters defined for SI fibers (NA, Δ, V) may be applied to GI fibers for comparison between two. However, in GI fibers situation is more complicated because of radial variation of RI of core from the axis, NA is also function of radial distance.

Local numerical aperture

$$\mathrm{NA}(r) = \begin{cases} [n^2(r) - n_2^2]^{1/2} \simeq \mathrm{NA}(0)\sqrt{1-(r/a)^\alpha} & \text{for} \quad r \le a \\ 0 & \text{for} \quad r > a \end{cases}$$

Axial numerical aperture

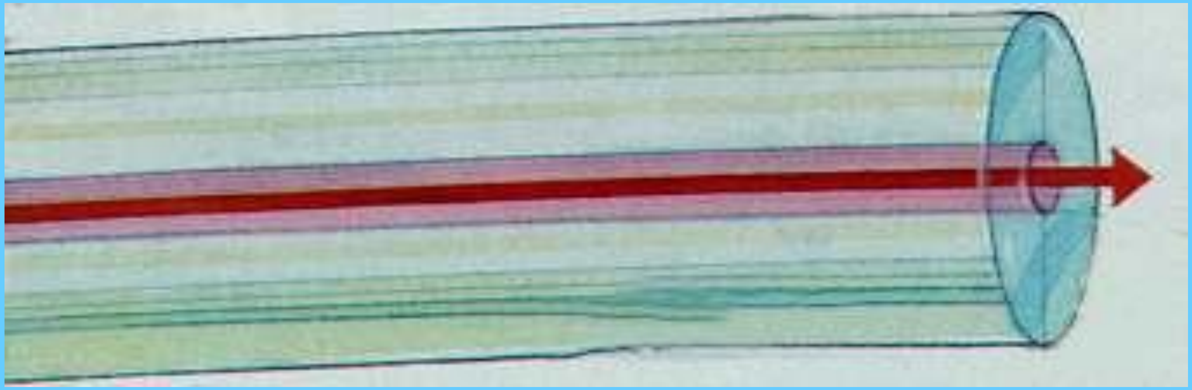
$$\mathrm{NA}(0) = [n^2(0) - n_2^2]^{1/2} = (n_1^2 - n_2^2)^{1/2} \simeq n_1\sqrt{2\Delta}$$

Number of bound modes in graded index fiber

$$M_g = \left(\frac{\alpha}{\alpha+2}\right)(n_1ka)^2\Delta \cong \left(\frac{\alpha}{\alpha+2}\right)\left(\frac{V^2}{2}\right)$$

- For parabolic profile core (α=2), $M_g=V^2/4$,
- Half the number supported by a SI fiber with same V value

Single mode (mono-mode) Fibers

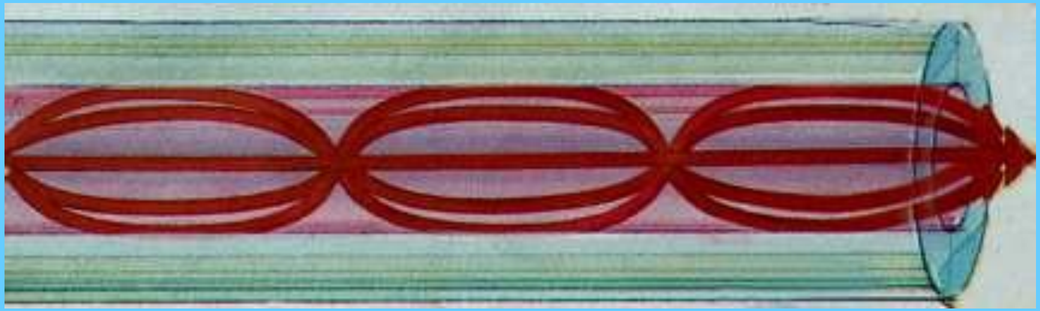


- SMFs: Most important for long-haul use (carrier and Internet core).
- Small core (8 to 10 microns) that forces the light to follow a linear single path down its length.
- Lasers are the usual light source.
- Most expensive and delicate to handle,
- Highest bandwidths (GHz) and distance ratings (more than 100 km).

Multimode Fibers

- Relatively large diameter core (50 to 100 microns)- easier to couple
- Step-index multimode cable has an abrupt change between core and cladding. Limited to data rates $\cong$ 50 Mbits/sec
- Graded-index multimode cables has a gradual change between core and cladding. Limited to data rates $\cong$1 Gbit/sec.

SI



GI

DESIGNER'S PARAMETERS

- **Numerical Aperture (NA)** :

  $NA = \sin\theta_a = [(n_1)^2 - (n_2)^2]^{1/2}$

  0.12-0.20 for SMF, 0.15-0.25 for MMF

- **Relative Refractive Index Difference (Δ):**

  $\Delta = (n_1 - n_2)/n$; n- the average refractive index

  <0.4% for SMF, >1% for MMF

- **Normalized Frequency** or **V-Number:**

  $V = [(2\pi a)/\lambda]\ NA$

  $V \leq 2.405$ for SMF; ≥ 10 for MMF

▪ Cutoff Wavelength

For, SM operation only above a theoretical cutoff wavelength, λ_c:

$$\lambda_c = \frac{2\pi a n_1}{V_c}(2\Delta)^{\frac{1}{2}}$$

λ_c is the wavelength above which a particular fiber become single mode

▪ Power distribution:

- At V=2.405: 80% of mode's power in core
- At V=1: only 30% power in core;
- Do not want V too small, design compromise: $2<V_{SM\ SI}<2.405$

Application Areas

- ❑ **<u>Single mode fibers</u>**: Mostly Step index type
  - ➢ Ideally suited for high bandwidth, very long-haul applications using single-mode ILD sources; **Telecommunication, MANs**

- ❑ **<u>Multimode fibers</u>** : Step index, Graded index
  - **Step Index Fibers**: Best suited for short-haul, limited bandwidth and relatively low cost applications.
  - **Graded Index Fibers**: Best suited for medium-haul, medium to high bandwidth applications using incoherent and coherent sources (LEDs and ILDs); LANs

THANK YOU