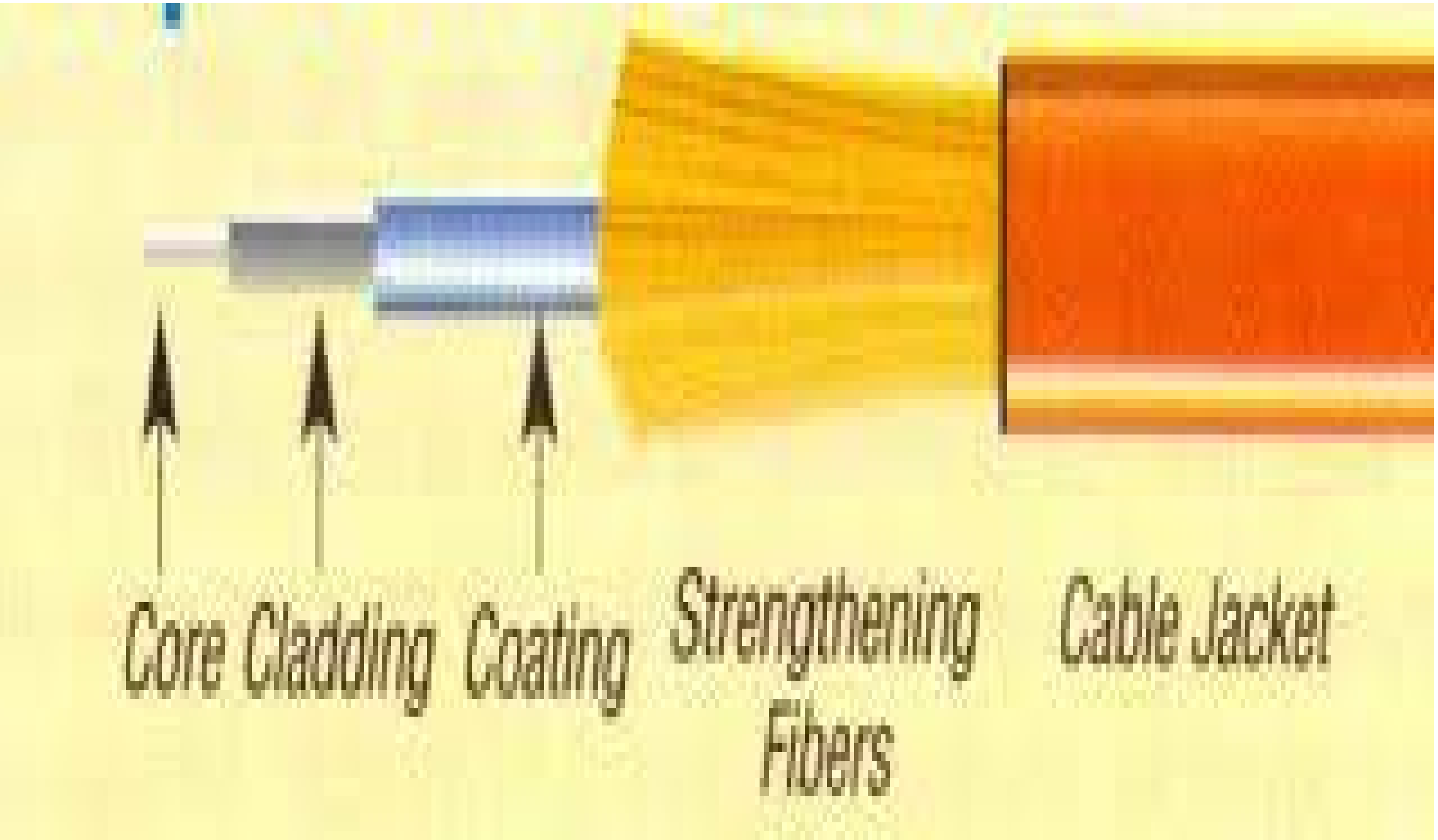
Fiber Optic Cables

Topics Covered:

- ✓ Introduction to Optical Fiber
- ✓ Classification of FOC based on modes:
  - ✓ Single Mode
  - ✓ Multi Mode
- ✓ Linearly Polarized Model

Optical Fiber Construction

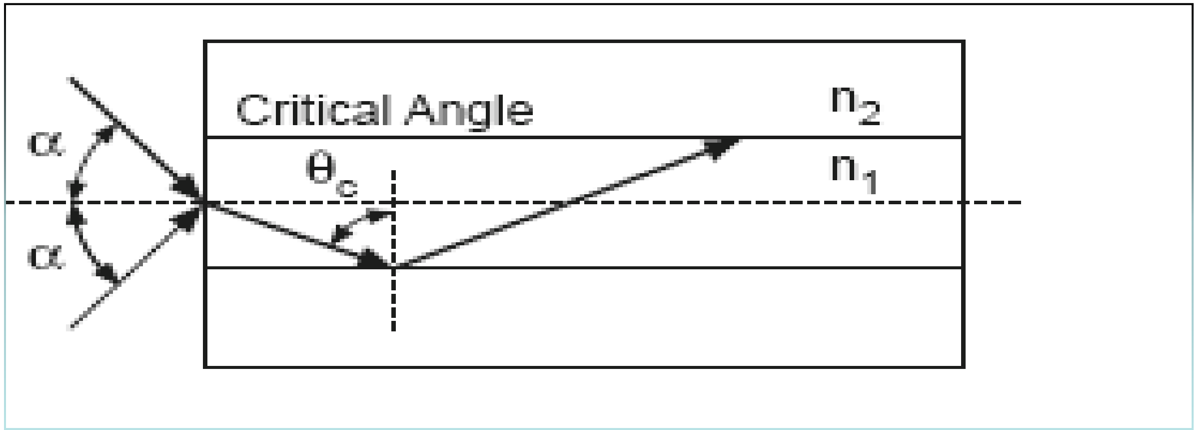


Optical Fiber Construction

- **Core**: It is the highly refractive central region of an optical fiber through which light is transmitted. Diameter of core in use with SMF is 8 to10 µm and with MMF is between 50 to 62.5 µm
- **Cladding**: The diameter of the cladding surrounding core is125 µm
- **Coating**: It is outer protective section. It does not have any optically properties. Standard size is 250µm-900µm

Total Internal Reflection

- Refractive index of core(n1) is higher than the cladding(n2) **n1>n2**
- When a ray of light strikes the boundary at an angle greater than critical angle it gets reflected and no light passes through



Optical Fiber Components

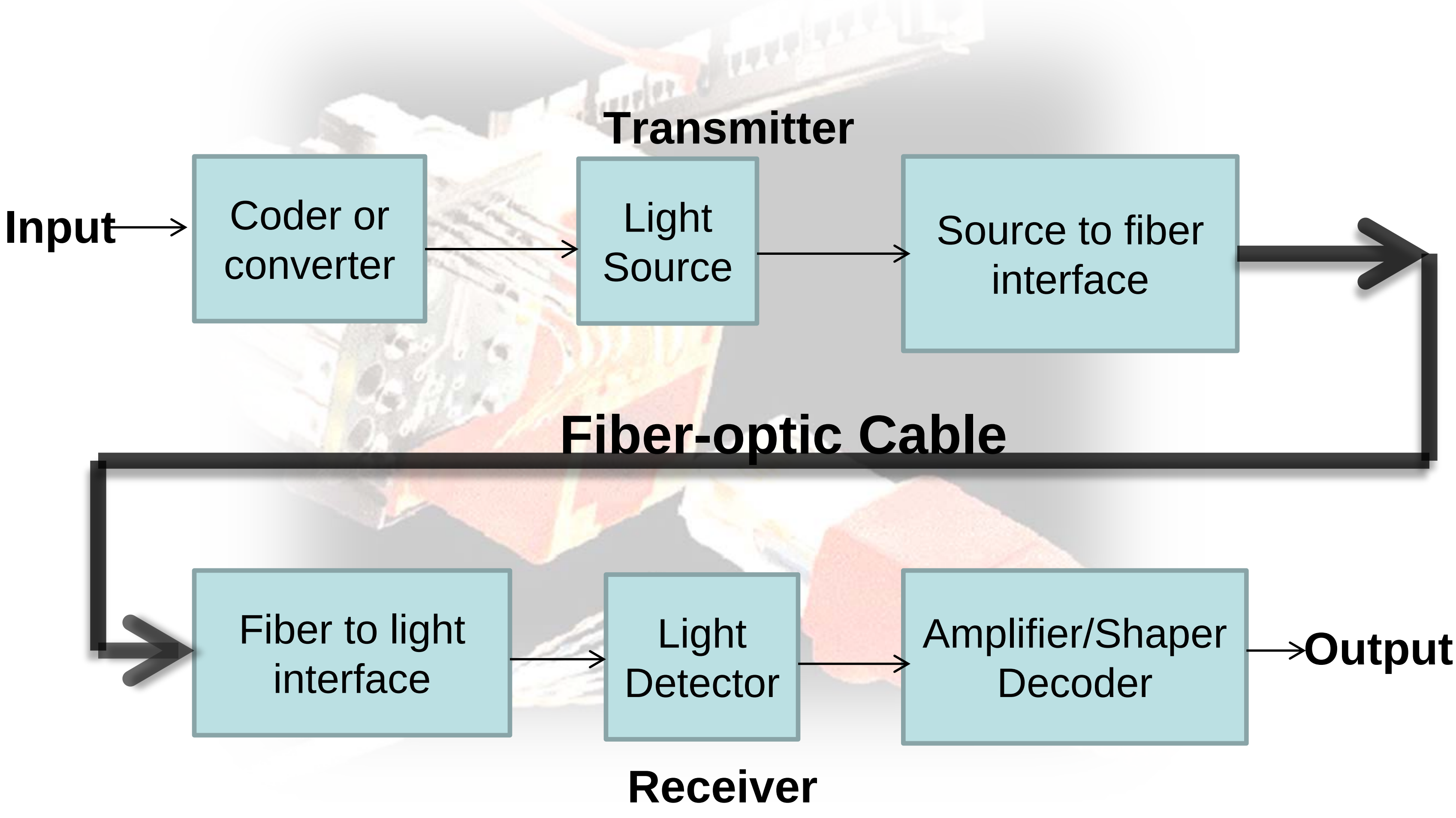
- **Fiber Connector:** an optical fiber connector terminates the end of an optical fiber, and enables quicker connection and disconnection
- **Broadband light source (BBS):**a light source that emit lights over a large wavelength range

  Example: ASE source, EELED,SLED
- **Fiber coupler:** an optical device that combines or splits power from optical fibers
- **Circulator:** a passive three-port device that couple light from Port 1 to 2 and Port 2 to 3 and have high isolation in other directions

Optical Fiber Components Cont..

- ✓ **Mode scrambler:** an optical device that mixes optical power in fiber to achieve equal power distribution in all modes
- ✓ **Index matching fluid:** A liquid with refractive index similar to glass that is used to match the materials at the ends of two fibers to reduce loss and back reflection
- ✓ **Wavelength division multiplexer:** a device that combines and split lights with different wavelengths

Optical Fiber Link



Optical Fiber

Advantages

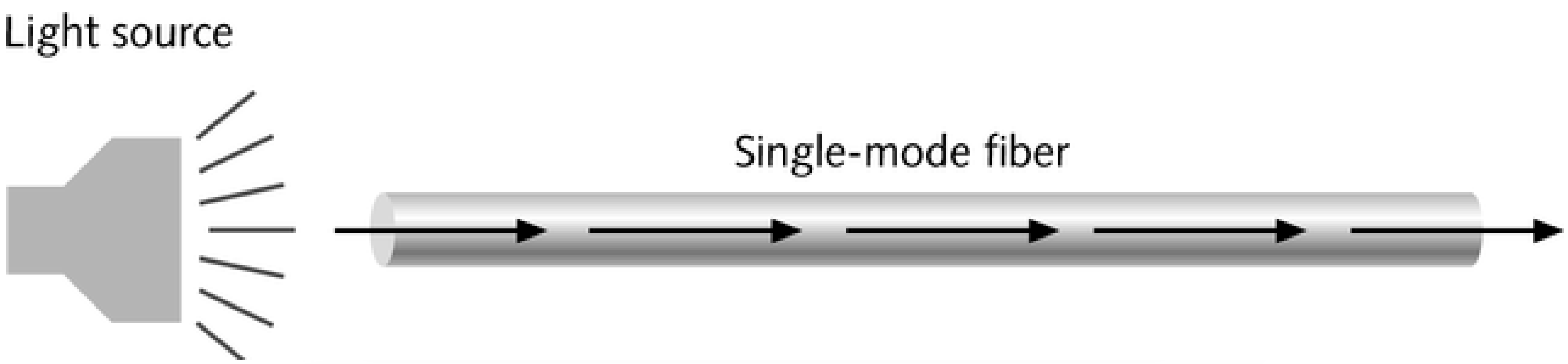
- ✓ Capacity: much wider bandwidth(10GHz)
- ✓ Crosstalk immunity
- ✓ Safety: fiber is nonmetallic
- ✓ Longer lasting
- ✓ Security: tapping is difficult
- ✓ Economics: fewer repeaters Fiber connector

Disadvantages

- ✓ Higher initial cost in installation
- ✓ Interfacing cost
- ✓ Strength: lower tensile strength
- ✓ More expensive to repair/maintain

Single Mode Fibers

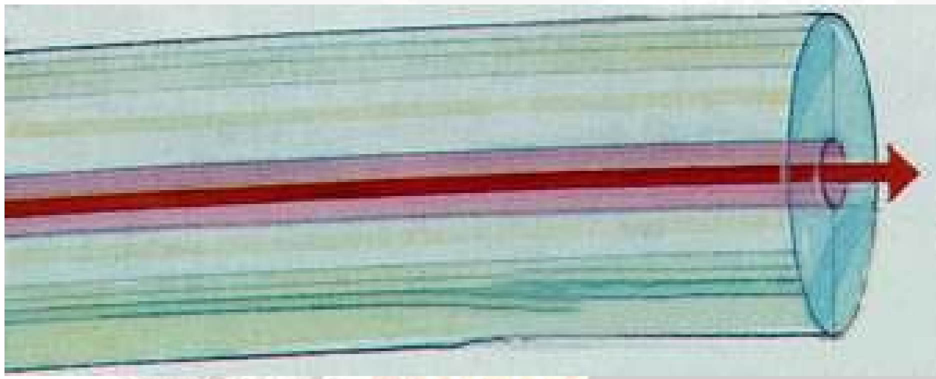
- Carries light pulses along **single path.** Only the lowest order mode (**fundamental mode**) can propagate in the fiber and all higher order modes are under cut-off condition (**non-propagating**)
- Uses **Laser Light** source



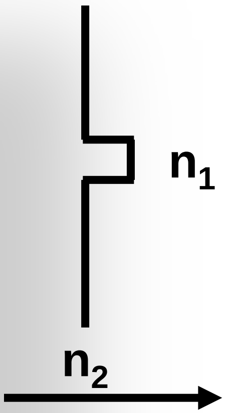
Single Mode Fibers

- **Advantages**
  - Less dispersion
  - Less degradation
  - Large information capacity
  - Core diameter is about 10 μm
  - Difference between the RI of core and cladding is small
- **Drawbacks**
  - Expensive to produce
  - Joining two fibers is difficult
  - Launching of light into single mode is difficult

Propagation Modes of Single Mode Step Index Fibers



Refractive Index Profile



Refractive Index

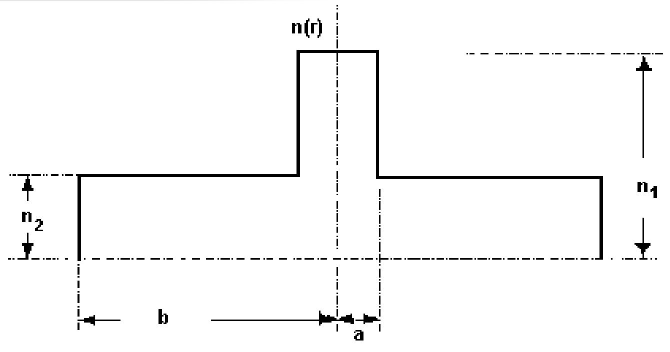
- **Core dimensions:** 8 to 12 µm (narrow as compared to cladding)
- Propagation through **single mode** due to the geometry of the core
- **Cut-off wavelength:** smallest operating wavelength
- **Advantages:** no energy loss, less attenuation, less dispersion, o/p pulse has same duration as i/p pulse, high BW (**> 400 MHz/km**)

Dispersion Modified Single Mode Fibers

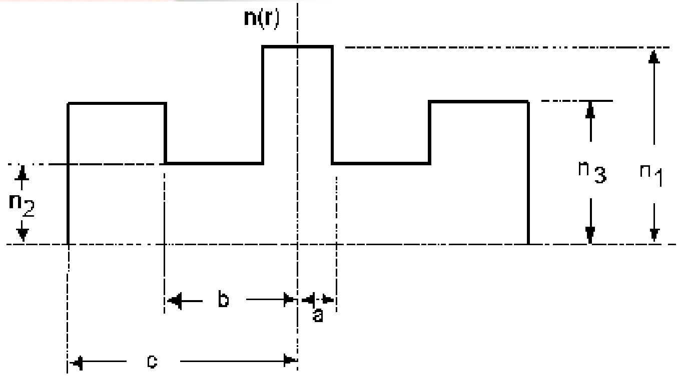
- During propagation, light ray is subjected to many **losses** due to:
  - splicing
  - micro-bending
  - losses in connectors
  - losses due to fiber misalignment
  - losses due to NA mismatch
- Dispersion during propagation causes broadening leading to **Inter Symbol Interference** that limits Information Carrying Capacity
- In single mode fibers, intramodal dispersion occurs, caused by **material** and **waveguide** dispersion
- Thus, special **Dispersion Modified Single Mode Fibers** are used as waveguide dispersion depends upon FOC design

Matched Clad & Depressed Clad

- There are two basic types of single mode step-index fibers:
  - **Matched Clad**
  - **Depressed Clad**
- **Matched cladding** means that the fiber cladding consists of a single homogeneous layer of dielectric material.
  - **Core of radius a and RI n_1**
  - **Cladding of RI n_2 where $n_1 > n_2$**



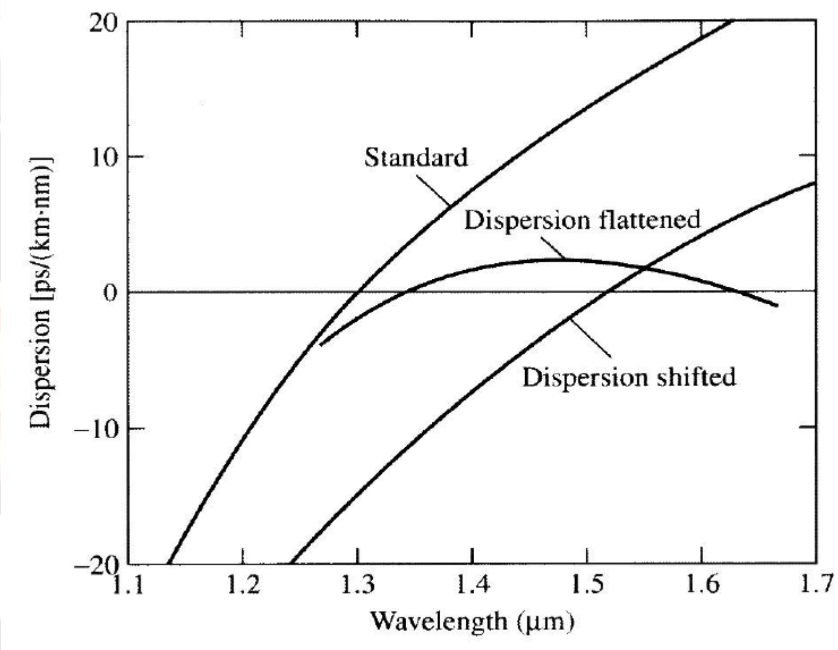
- **Depressed cladding** means that the fiber cladding consists of two regions: the inner and outer cladding regions.
  - **Core of radius a and RI n_1**
  - **Inner cladding having RI n_2 where $n_1 > n_2$**
  - **Outer cladding having RI n_3 where $n_1 > n_3 > n_2$**



Dispersion Shifted & Dispersion Flattened Single Mode Fibers

Dispersion Shifted Fibers

- ✓ By changing the design parameters in matched or depressed cladding, dispersion can be shifted to a longer wavelength. The optical fibers thus designed are called **Dispersion Shifted Fibers**
- ✓ Also called as **Dispersion Modified Fibers**



Dispersion Flattened Fibers

- ✓ When the dispersion is distributed over a wide spectral range as shown, such fibers are called as **Dispersion Flattened Fibers**

Multi-mode Optical Fiber

- **Multi-mode optical fiber** is a type of optical fiber mostly used for communication over short distances, such as within a building or on a campus.
- Typical multimode links have data rates of 10 Mbit/s to 10 Gbit/s over link lengths of up to 600 meters.

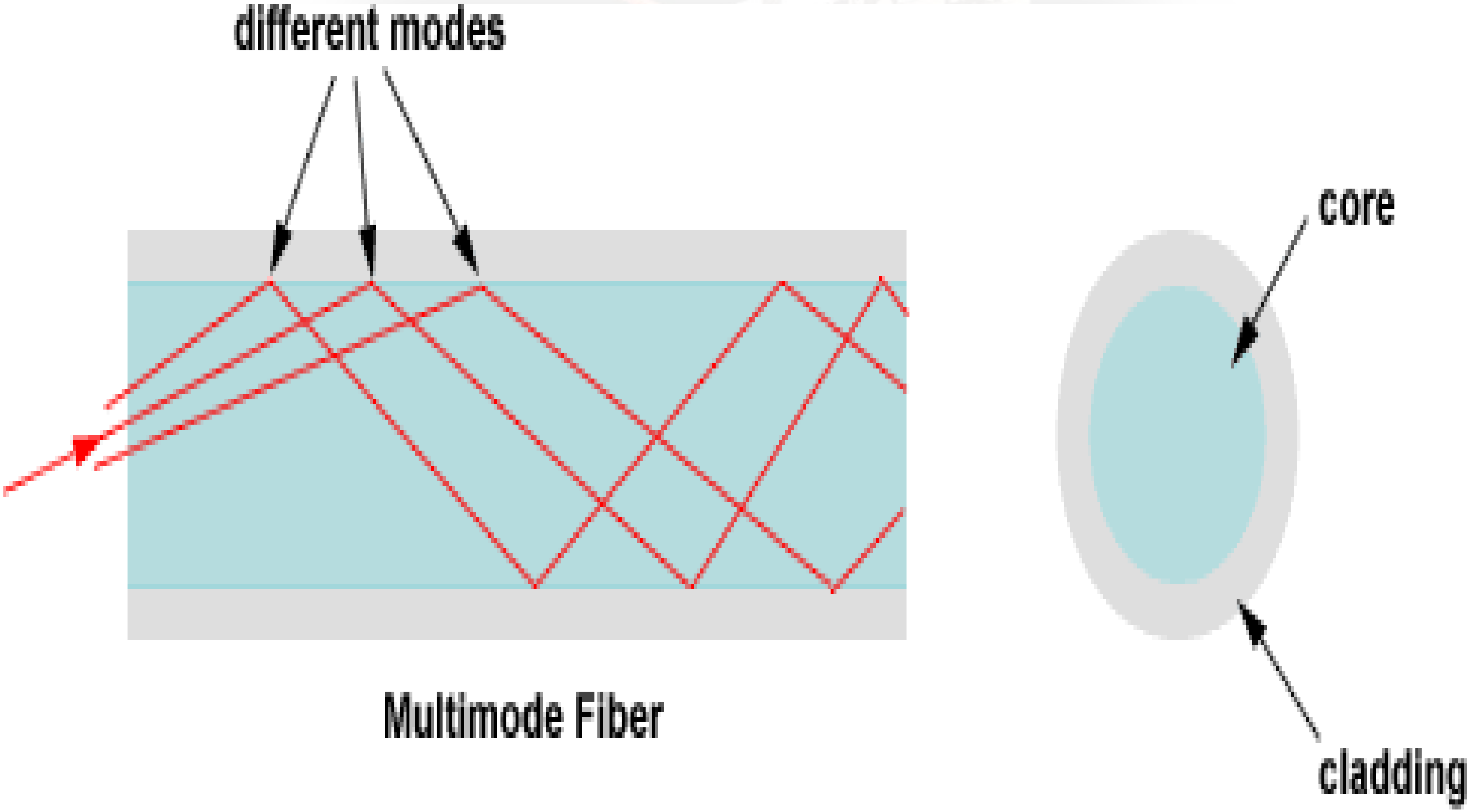
About Multi-Mode Fiber

- Multi-mode fibers are described by their core and cladding diameters. example: 62.5/125 µm multi-mode fiber.

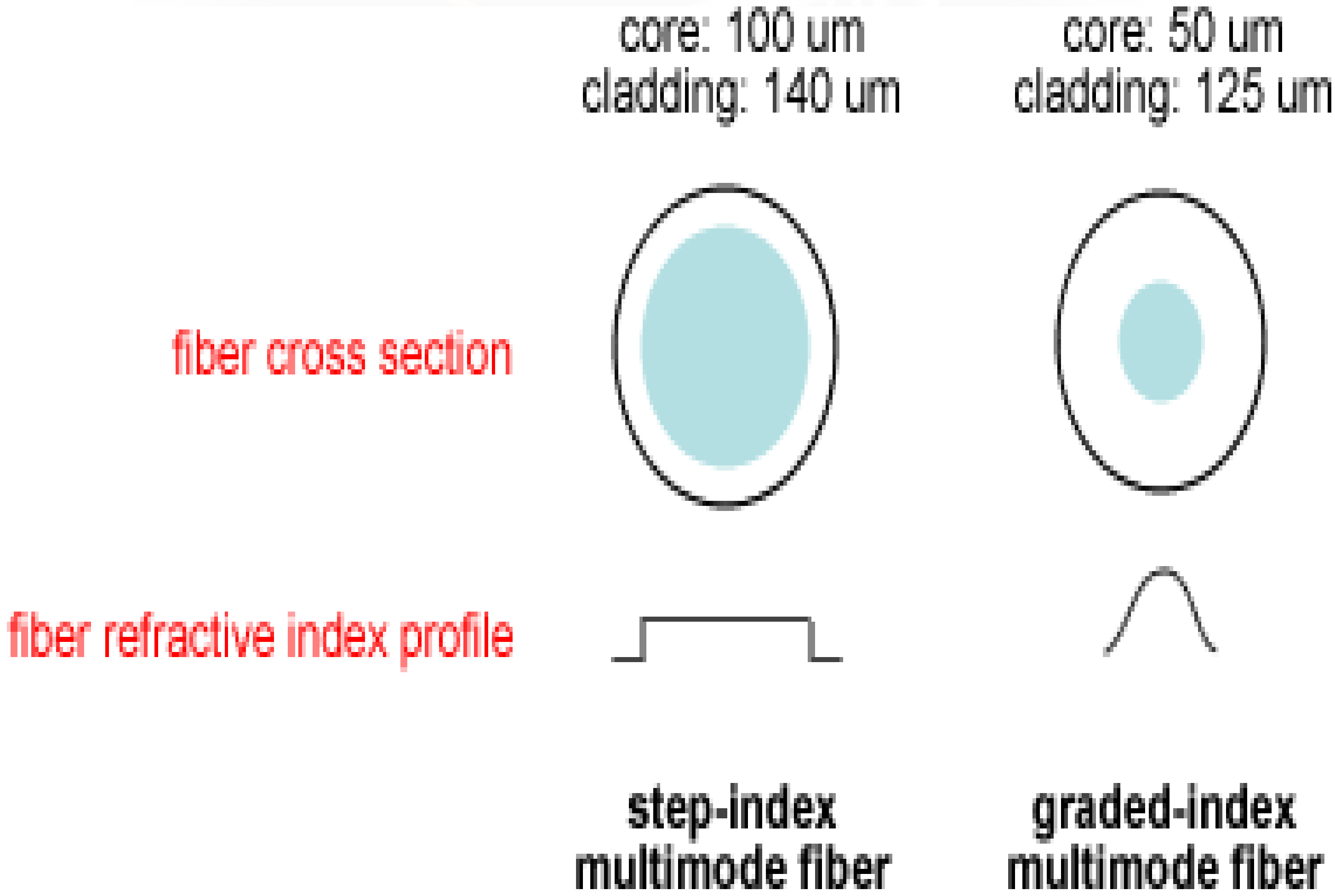
- The two types of multi-mode optical fibers are:
  - **Step index multi-mode optical fibers**
  - **Graded index multi-mode optical fibers**

- The transition between the core and cladding can be sharp, which is called a **step-index** profile, or a gradual transition, which is called a **graded-index** profile.

Multi-mode Optical Fiber



Types of multi mode fiber



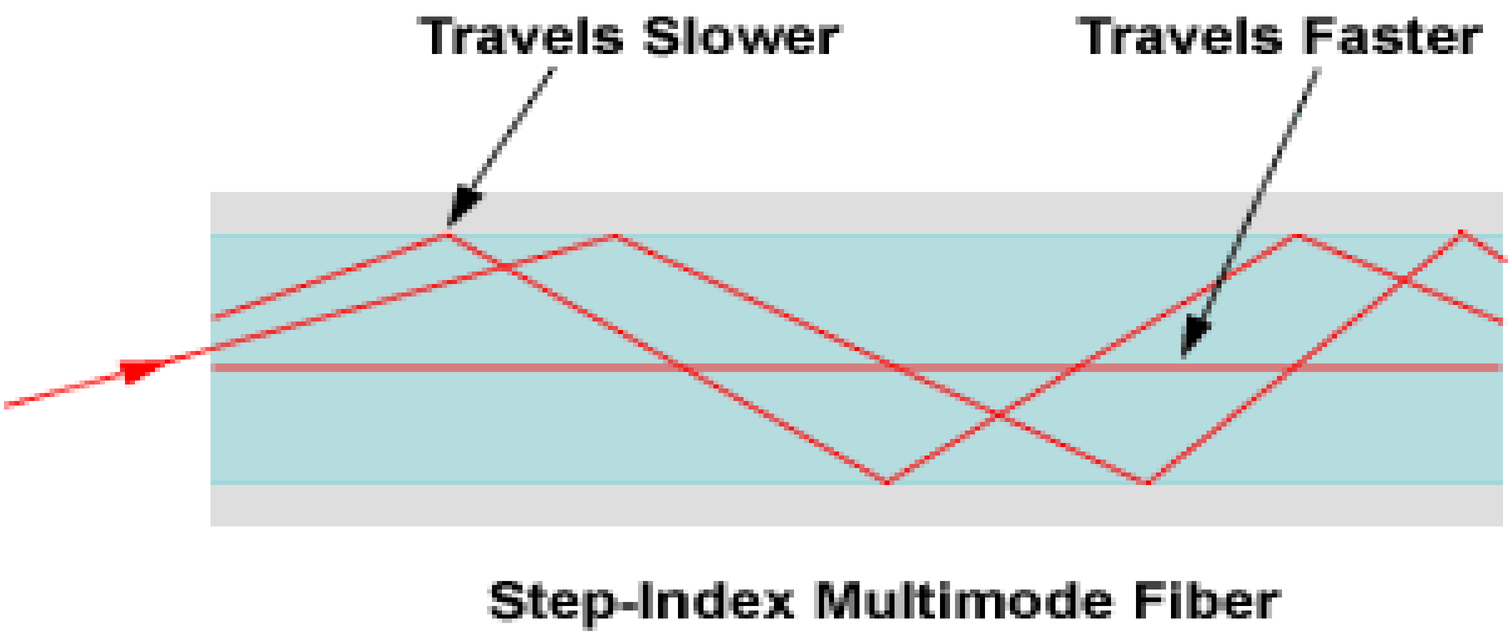
Step Index Fiber

- **Step-index multimode fiber** has a large core, up to 100 microns in diameter.
- As a result, some of the light rays that make up the digital pulse may travel a direct route, whereas others zigzag as they bounce off the cladding.
- These alternative pathways cause the different groupings of light rays, referred to as **modes**, to arrive separately at the receiver.

Step Index Fiber

- ✓ The pulse begins to spread out, thus losing its well-defined shape.
- ✓ The need to leave spacing between pulses to prevent overlapping limits bandwidth that is, the amount of information that can be sent.
- ✓ Consequently, this type of fiber is best suited for transmission over short distances, in an endoscope, for instance.

Light Propagation in Step Index Fiber



Modal Dispersion

- The arrival of different modes of the light at different times is called **Modal Dispersion**.
- Modal dispersion causes pulses to spread out as they travel along the fiber, the more modes the fiber transmits, the more pulses spread out.
- This significantly limits the bandwidth of step-index multimode fibers.
- For example, a typical step-index multimode fiber with a 50 µm core would be limited to approximately 20 MHz for a one kilometer length, in other words, a bandwidth of 20 MHz·km.

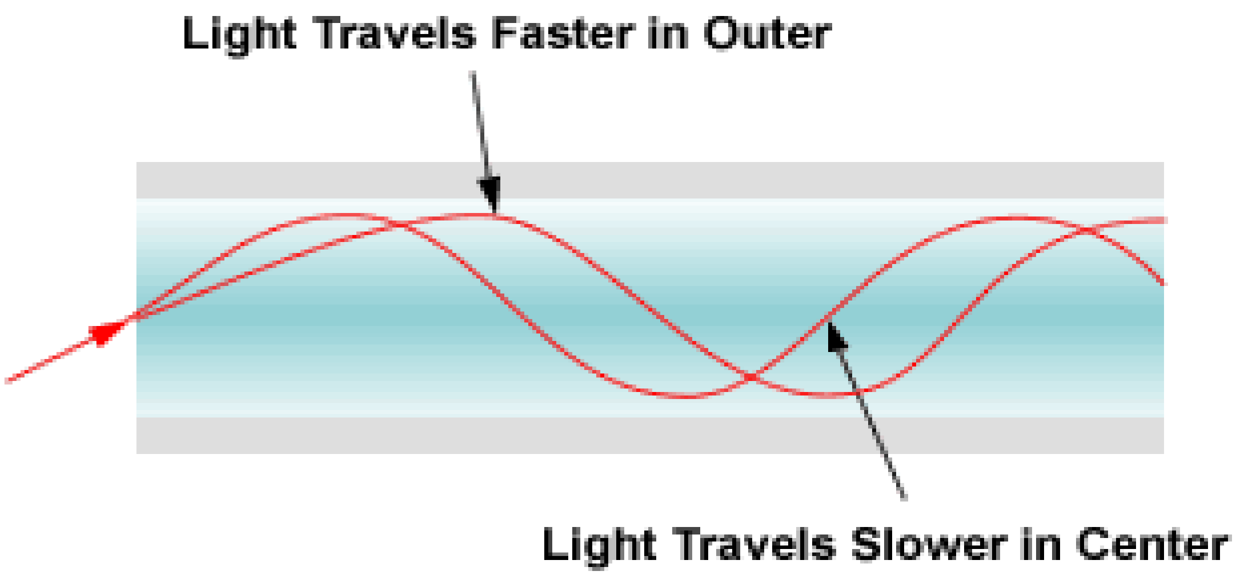
Graded-Index Multimode Fibers

- **Graded-index** multimode fibers solves the problem of modal dispersion to a considerable extent.
- Graded-index multimode fiber contains a core in which the refractive index diminishes gradually from the center axis out toward the cladding.
- The higher refractive index at the center makes the light rays moving down the axis advance more slowly than those near the cladding.

Graded-Index Multimode Fibers

- Also, rather than moving in a zigzag fashion off the cladding, light in the core curves helically because of the graded index, reducing its travel distance.
- The shortened path and the higher speed allow light at the periphery to arrive at a receiver at about the same time as the slow but straight rays in the core axis.
- The result: a digital pulse suffers less modal dispersion.

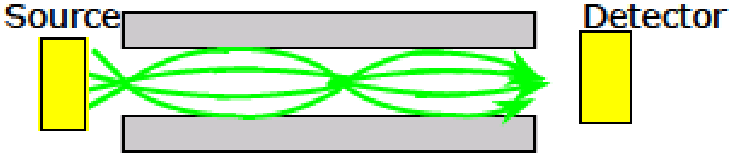
Light Propagation in Graded-Index Multimode Fiber



Graded-Index Multimode Fiber

Multi-mode v/s Single mode

Multimode

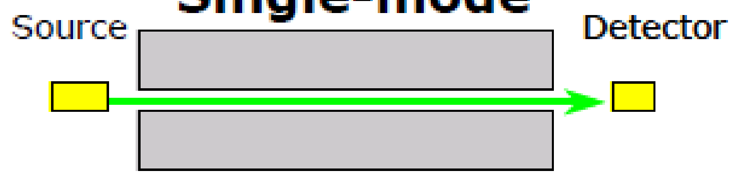


+ Low cost sources
    + 850 nm and 1310 nm LEDs
    + 850 nm lasers at 1 & 10 Gb/s
    + Low precision packaging
+ Low cost connectors
+ Lower installation cost
- Higher fiber cost
+ **Lower system cost**
- Higher loss, lower bandwidth
- Distance up to 2 km

Best for:

- ***LAN, SAN, Data Center, CO***

Single-mode



- High cost sources
    - 1310+ nm lasers 1 and 10 Gb/s
    - 1 Gb/s + w/ DWDM
    - High precision packaging
- Higher cost connectors
- Higher installation cost
+ Lower fiber cost
- **Higher system cost**
+ Lower loss, higher bandwidth
+ Distance to 60 km+

Best for:

- ***WAN, MAN, Access, Campus***

Advantages of Multi-mode Fiber

- ✓ easily supports most distances required for premises and enterprise networks
- ✓ can support 10 Gb/s transmission upto 550 meters
- ✓ easier to install and terminate in the field
- ✓ connections can be easily performed in the field, offering installation flexibility and cost savings
- ✓ have larger cores that guide many modes simultaneously.

Applications

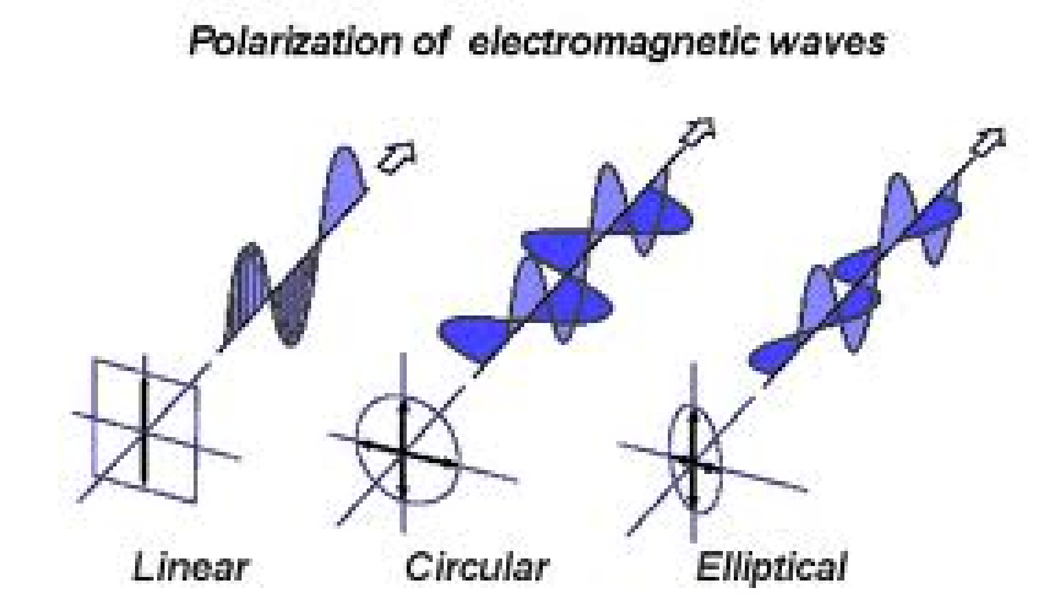
- **Step-index** multimode fibers are mostly used for imaging and illumination.
- **Graded-index** multimode fibers are used for data communications and networks carrying signals for typically no more than a couple of kilometers.

Polarization and its types

The orientation of the electric field vector at a fixed point in space is defined as polarization of a EM wave

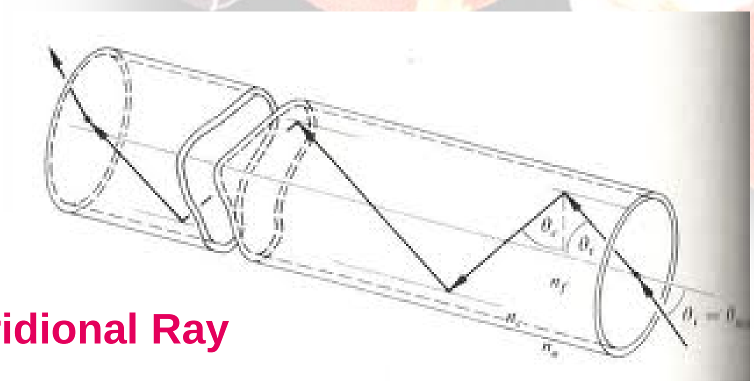
Types of polarization:

- ✓ Elliptical Polarization
- ✓ Circular Polarization
- ✓ Linear Polarization

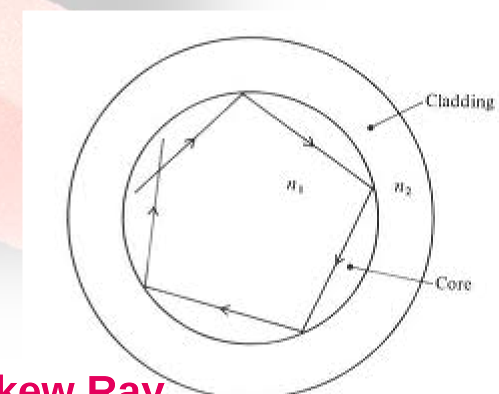


Polarization (contd.)

- Circular Polarization is a limiting case of Elliptical polarization
- If the wave is frozen in time, the E vector will seem to move in a helical form
- Unlike waveguides, in optic fiber if the plane of symmetry is Z axis then E_z and H_z maybe non zero and give rise to EH, HE modes apart from TE and TM modes



Meridional Ray



Skew Ray

Linearly Polarized Modes

- ✓ Confinement of the Electric field in only one direction is linear polarization
- Azimuthal Variations give rise to hybrid modes
- $V = k_f \, a \, NA$

  where Numerical Aperture $NA = (n_{core}{}^2 - n_{cladding}{}^2)^{1/2}$

  $\Delta = (n_{core} - n_{cladding}) / \, n_{core}$

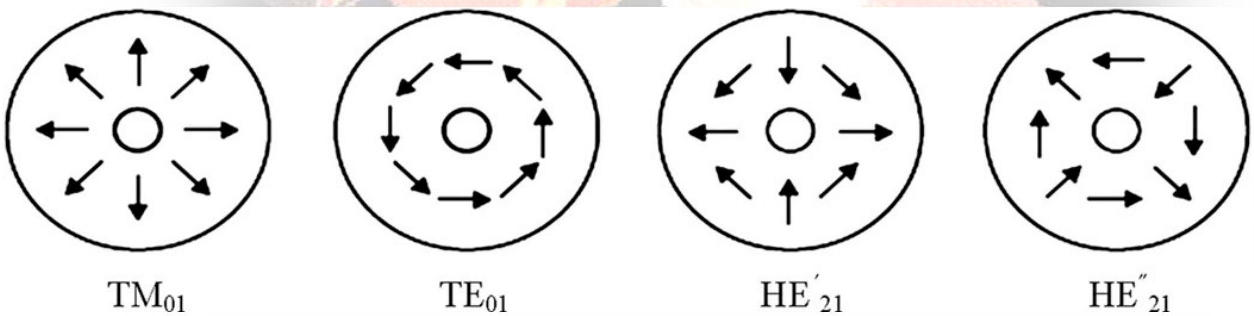
  Free space wave number $k_f = 2\frac{\pi}{Lambda}$

  where a is radius of the core
- For 0<V< 2.405 it is single mode and only HE_{11} mode exists

Linearly Polarized modes (contd.)

- ✓ For $\Delta \ll 1, HE_{11}$ becomes LP_{01} only one mode exists and the fiber itself is called single mode
- ✓ For V>2.405 both LP_{01} LP_{11} exist thus many modes exist and the fiber is called multi-mode

LP_{11} Mode Propagation



Mathematical Derivation

- In general the mode as represented by LP_{mn}, where m refers to no. of azimuthal nodes and n refers to no. of radial nodes
- When the propagating media is made of homogeneous layers then wave equation with approximations is valid as follows:

$$\Delta E - \left(\frac{1}{C^2}\right)\frac{(\delta^2)E}{\delta t^2} = 0$$

- Solving the above using Helmholtz's equation will yield the possible Linearly polarized modes.

Mathematical Derivation (contd.)

- ✓ Helmholtz's Equation:

$\Delta_t e + (k^2 n^2 \text{-} \beta^2)c = 0$

Where n=n(r) is constant for each layer and

$\Delta_t = \frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + \frac{1}{r^2}\frac{\partial^2}{\partial \emptyset^2}$

Also the solutions must have separable radial and azimuthal dependencies, i.e.

$$c(r,\varphi) = \omega(r)\begin{cases}\cos l\varphi \\ \sin l\varphi\end{cases}$$

When l=0. no azimuthal component exists.

Summary

- ✓ The classification of modes depends on light intensity distribution rather than electric field pattern
- ✓ LP modes are valid only for n_1-n_2<<1 i.e. weak guiding approximation
- ✓ A single LP mode may have various exact modes
- ✓ Different exact modes can be obtained by assuming different direction of polarization
- ✓ Lastly, LP modes are important in analyzing the characteristic of optic fiber

Thank You