G.PULLAIAH COLLEGE OF ENGINEERING AND TECHNOLOGY: KURNOOL

DEPARTMENT OF ECE

OFC LECTURE NOTES

UNIT-1

BASIC TERMS AND DEFINITIONS:

Fiber	A single optical transmission element characterized by a core, a cladding, and a coating. Two common structures, single-mode (with a step-index profile) or multimode (with a graded-index profile) are used for fiber optic communication systems. Different variations are made depending on the attenuation, bandwidth, dispersion, wavelengths, and mechanical requirements.
Fiber amplifier	Most common are the erbium doped fiber amplifiers (EDFAs), semiconductor optical amplifiers (SOAs), and Raman amplifiers, which are used to increase signal gain without electrical conversion.
Fiber break locator	A low-cost OTDR used to locate breaks in optical cables.
Fiber optic cable	A communications cable that consists of one or more optical fibers, each capable of transmitting data via modulated light waves. Loose buffered types for outside plant applications can be armored or dielectric stranded or central tube designs. Applications include aerial figure-8, ducted, direct buried, all dielectric self-supporting (ADSS), and optical power ground wire (OPGW). Indoor designs are tight buffered breakout or distribution types with cable jackets designed to meet building codes for use in plenum, riser, and low smoke zero halogen environments.
Fiber coating	A UV-cured material immediately surrounding the glass cladding that serves to protect the integrity of the fiber from surface damage and stresses. Normally 250 µm for outside plant cables and 900 µm for indoor cables.
Fiber connector (FC)	A keyed connector with threaded coupling mechanism that has 2.5-mm ferrule. Mostly used in single-mode systems and test equipment.
Fiber optics	The links used for voice, video, data, medical, sensing, and illumination applications. All use optical fibers to transmit or receive optical signals or power.
Fiber sensor	A sensing device in which the active sensing element is an optical element attached directly to an optical fiber. The measured quantity changes the optical properties of the fiber so that it can be detected and measured.
Cladding	The low refractive index material, usually glass, that surrounds and protects the core and provides the optical refractive barrier.
Cable rack	Vertical or horizontal open support attached to a ceiling or wall.
Cable tray	A ladder, trough, solid bottom, or raceway intended for, but not limited to, the support of telecommunications cable.
Core	The light guiding part of the fiber with a refractive index higher than

	that of the cladding.
Critical angle	The minimum angle at which light can be propagated within a fiber. Sine critical angle equals the ratio of the numerical aperture to the index of refraction of the fiber core.
Graded-index multimode fiber (GI-MMF)	A type of multimode fiber where the refractive index of the fiber core decreases radically towards the outside of the fiber. Four types of GI-MMF have been specified in IEC 60793-2: legacy OM1 (62.5/125) and OM2 (50/125) fibers and the newer, high bandwidth, laser-optimized OM3 and OM4 fiber (both 50/125), designed for VCSEL lasers and Gigabit data rates.
Index of refraction (IOR)	The ratio of the speed of light in a vacuum to the speed of light in a material. When light strikes the surface of a transparent material, some light is reflected while some is bent (refracted) as it enters. The IOR is used to calibrate OTDRs for measuring fiber length.
Mode	A light path.
Multimode fiber (MMF)	An optical waveguide that allows more than one mode to be guided. 50/125, 62.5/125 and 100/140 are the most common. Graded-index types are used in fiber optic communication systems.
Reflectance	The percentage of light reflected from a component, such as a connector, splice, splitter, or WDM.
Reflection	The abrupt change in direction of a light beam at an interface between two dissimilar media that returns the beam into the medium where it originated, i.e., a mirror.
Refraction	The bending of a beam of light in transmission between two dissimilar materials or in a graded index fiber where the refractive index is a continuous function of position.
Refractive index	The ratio of light velocity in a vacuum to its velocity in the transmitting medium.
Single-mode	A step-index waveguide in which only one mode will propagate above the cutoff wavelength at a single wavelength.
Step-index fiber	A type of fiber where the refractive index of the core is uniformly higher than that of the surrounding cladding.
Absorption	Caused by impurities introduced during the manufacturing process, absorption creates loss in a fiber by turning light energy into heat. The amount of absorption is determined by the wavelength and depends upon the composition of the glass or plastic. Absorption and scattering are the two causes of intrinsic attenuation in an optical fiber.
Acceptance Angle	The maximum angle Φ_{max} with which a ray of light can enter rough the entrance end of the fibre and still be totally internally reflected is called acceptance angle of the fiber.
Snell's law	The relationship at the interface is called Snell's Law. It is given by the equation $n_1 \sin\varphi_1 = n_2 \sin\varphi_2$
Mode coupling	The effect of coupling energy from one mode to another mode is known as mode coupling. The cause of mode coupling is due to waveguide perturbations such as deviations Of the fiber axis from straightness variations in the core

	diameter, irregularities at the Core- cladding interface and refractive index variations.
linearly polarized mode	The field components HE, EH, TE, TM forms linearly polarized modes. Linearly polarized Modes are labeled LP_{jm} where j and m are integers designation mode solutions.
Birefringence	Manufactured optical fibers have imperfections such as asymmetrical lateral stresses, non - circular cores and variations in refractive index profiles. These imperfections break the circular symmetry of the ideal fiber and lift the degeneracy of the two modes. These modes propagate with different phase velocity and it is called as fiber birefringence.
Mode-Field Diameter	The fundamental parameter of a single mode fibre is said to be the mode field diameter. It is possible to determine the mode-field diameter with the help of the fundamental LPo1 mode.

Concepts

Step Index (SI) Fiber

The step index (SI) fiber is a cylindrical waveguide core with central or inner core has a uniform refractive index of n_1 and the core is surrounded by outer cladding with uniform refractive index of n_2. The cladding refractive index (n_2) is less than the core refractive index (n_1). But there is an abrupt change in the refractive index at the core cladding interface. Refractive index profile of step indexed optical fiber is shown in Fig.1.6.13. The refractive index is plotted on horizontal axis and radial distance from the core is plotted on vertical axis.

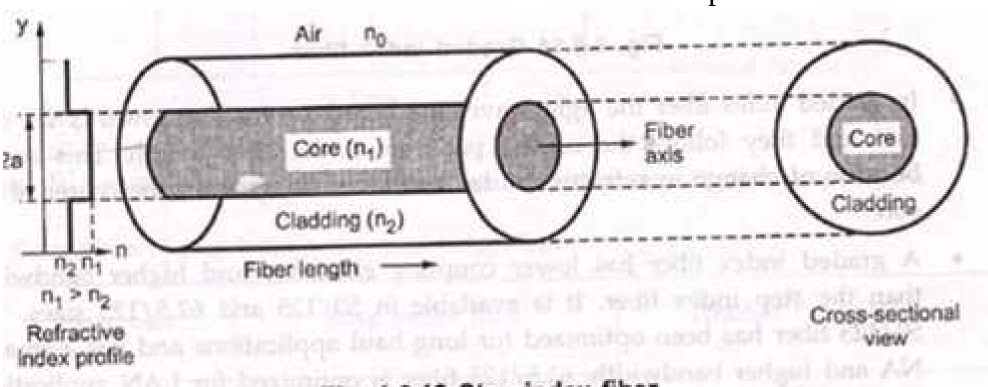


Fig. 1.6.13 Step index fiber

The propagation of light wave within the core of step index fiber takes the path of meridional ray i.e. ray follows a zig-zag path of straight line segments.

The core typically has diameter of 50-80 µm and the cladding has a diameter of 125 µm.

The refractive index profile is defined as –

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

Graded Index (GRIN) Fiber

The graded index fiber has a core made from many layers of glass.

In the **graded index (GRIN)** fiber the refractive index is not uniform within the core, it is highest at the center and decreases smoothly and continuously with distance towards the cladding. The refractive index profile across the core takes the parabolic nature. Fig.1.6.14 shows refractive index profile of graded index fiber.

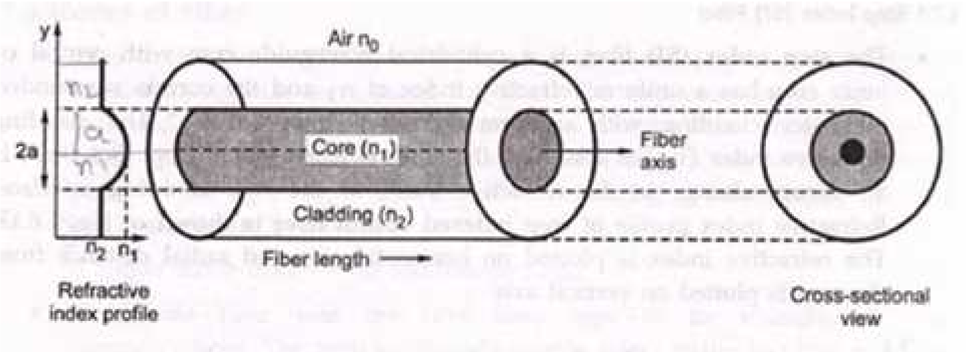


Fig. 1.6.14 Graded index fiber

In graded index fiber the light waves are bent by refraction towards the core axis and they follow the curved path down the fiber length. This results because of change in refractive index as moved away from the center of the core.

A graded index fiber has lower coupling efficiency and higher bandwidth than the step index fiber. It is available in 50/125 and 62.5/125 sizes. The 50/125 fiber has been optimized for long haul applications and has a smaller NA and higher bandwidth. 62.5/125 fiber is optimized for LAN applications which is costing 25% more than the 50/125 fiber cable.

The refractive index variation in the core is giver by relationship

$$n(r) = \begin{cases} n_1\left(1 - 2\Delta\left(\frac{r}{a}\right)^{\alpha}\right) & \text{when } r < a \text{ (core)} \\ n_1(1 - 2\Delta)^{\frac{1}{2}} \approx n_2 & \text{when } r \geq a \text{ (cladding)} \end{cases}$$

where,

r = Radial distance from

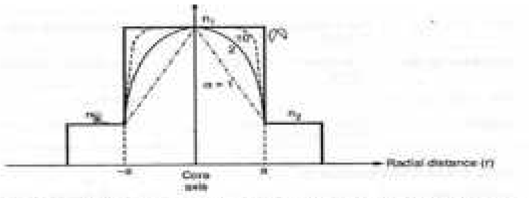
fiber axis a = Core radius

n_1 = Refractive index of core

n_2 = Refractive index of cladding

α = Shape of index profile.

Profile parameter α determines the characteristic refractive index profile of fiber core. The range of refractive index as variation of α is shown in Fig. 1.6.15.



1.6.15 Possible fiber refractive index profiles for different values of α

NUMERICAL APERTURE:

The **numerical aperture** (NA) of a fiber is a figure of merit which represents its light gathering capability. Larger the numerical aperture, the greater the amount of light accepted by fiber. The acceptance angle also determines how much light is able to be enter the fiber and hence there is relation between the numerical aperture and the cone of acceptance.

$$\text{Numerical aperture (NA)} = \sin \phi_{0(max)}$$

$$NA = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

For air $\quad n_0 = 1$

$$NA = \sqrt{n_1^2 - n_2^2}$$

V –number

Normalized frequency or V number is a dimensionless parameter and represent the relationship among three design parameters variables of the fiber viz core radius a, relative refractive index Δ and the operating wavelength λ.

It is expressed as V = (2*π* Numerical aperture(a)) / λ.

Types of Rays:

If the rays are launched within core of acceptance can be successfully propagated along the fiber. But the exact path of the ray is determined by the position and angle of ray at which it strikes the core.

There exists three different types of rays.

i) Skew rays ii) Meridional rays iii) Axial rays.

The skew rays does not pass through the center, as show in Fig. 1.6.11 (a). The skew rays reflects off from the core cladding boundaries and again bounces around the outside of the core. It takes somewhat similar shape of spiral of helical path.

The **meridional** ray enters the core and passes through its axis. When the core surface is parallel, it will always be reflected to pass through the enter. The meridional ray is shown in fig. 1.6.11 (b).

The **axial ray** travels along the axis of the fiber and stays at the axis all the time. It is shown in fig. 1.6.11 (c).

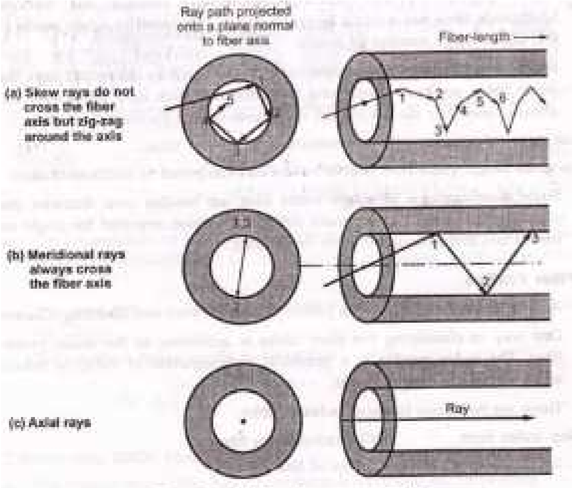


Fig. 1.6.11 Different ray propagation

Distinguish between optical fiber communication system and conventional communication system? And List out the advantageous and disadvantage of optical fiber communication?

Ans:

ptical Fiber Communication System	Conventional Communication System
Requires a bandwidth of 10^{13} to 10^{16} Hz.	1. Requires a bandwidth of 500 MHz
Light weight	2. Heavier in weight.
Immune to R.F. interference	3. Needs external shielding.
Electrical isolation.	4. Exhibits earthing problems.
Low loss of about **0**.2 dB/km.	5. Loss of about 10dB/km.
Secure signal propagation.	6. Signal can be tapped easily.
Due to increased bandwidth higher data	7. Low data rates compared to optical fiber.

Advantageous Of Optical Fibers Communication:

1. Information bandwidth is more.
2. Optical fibers are small in size and light weighted.
3. Optical fibers are more immune to ambient electrical noise, electromagnetic interference.
4. Cross talk and internal noise are eliminated in optical fibers.

5. There is no risk of short circuit in optical fibers.
6. Optical fibers can be used for wide range of temperature.
7. A single fiber can be used to send many signals of different wavelengths using Wavelengths Division Multiplexing (WDM).
8. Optical fibers are generally glass which is made up of sand and hence they are cheaper than copper cables.
9. Optical fibers are having less transmission loss and hence less number of repeaters are used.
10. Optical fibers are more reliable and easy to maintain.

Disadvantageous Of Optical Fibers Communication:

1. Attenuation offered by the optical fibers depends upon the material by which it is made.
2. Complex electronic circuitry is required at transmitter and receiver.
3. The coupling of optical fibers is difficult.
4. Skilled labors are required to maintain the optical fiber communication.
5. Separated power supply is required for electronic repeaters at different stages.

Multimode Fibers

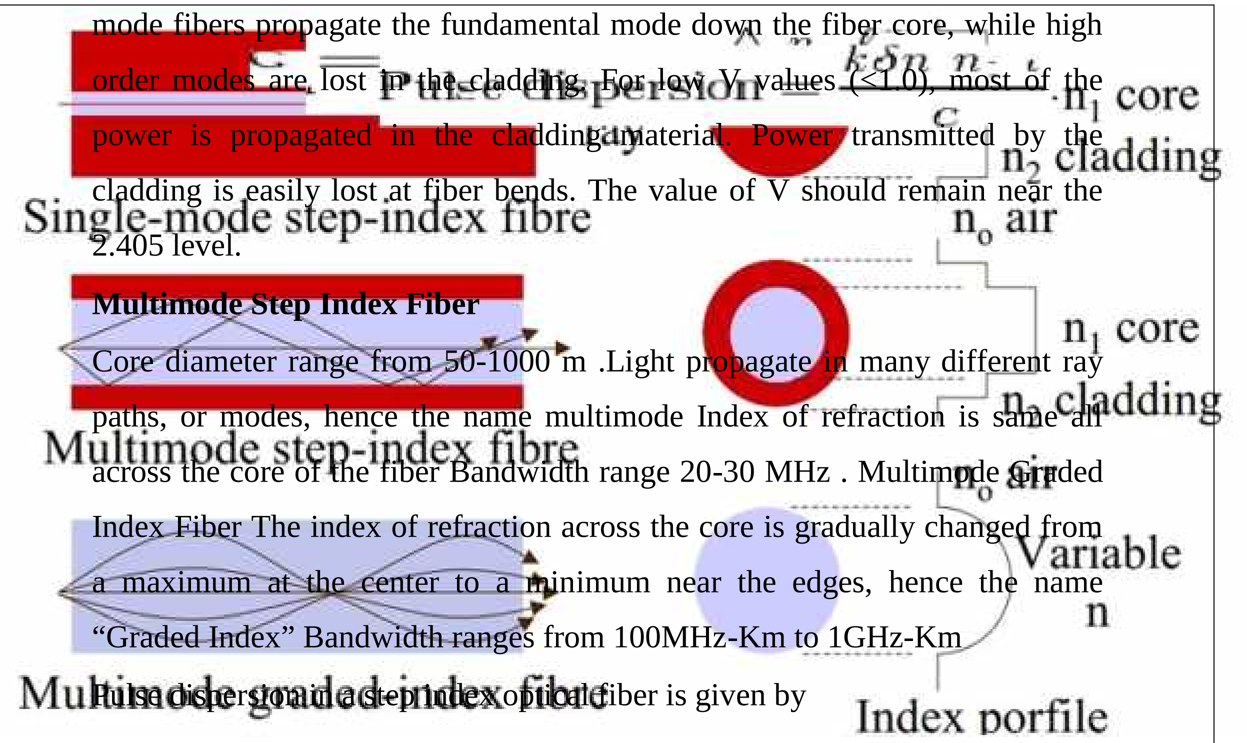
As their name implies, multimode fibers propagate more than one mode. Multimode fibers can propagate over 100 modes. The number of modes propagated depends on the core size and numerical aperture (NA).

As the core size and NA increase, the number of modes increases. Typical values of fiber core size and NA are 50 to 100 micrometer and 0.20 to 0.29, respectively.

Single Mode Fibers

The core size of single mode fibers is small. The core size (diameter) is typically around 8 to 10 micrometers. A fiber core of this size allows only the fundamental or lowest order mode to propagate around a 1300 nanometer (nm) wavelength. Single mode fibers propagate only one mode, because the core size approaches the operational wavelength. The value of the normalized frequency parameter (V) relates core size with mode propagation.

In single mode fibers, V is less than or equal to 2.405. When V = 2.405, single mode fibers propagate the fundamental mode down the fiber core, while high order modes are lost in the cladding. For low V values (<1.0), most of the power is propagated in the cladding material. Power transmitted by the cladding is easily lost at fiber bends. The value of V should remain near the 2.405 level.



Multimode Step Index Fiber

Core diameter range from 50-1000 m .Light propagate in many different ray paths, or modes, hence the name multimode Index of refraction is same all across the core of the fiber Bandwidth range 20-30 MHz . Multimode Graded Index Fiber The index of refraction across the core is gradually changed from a maximum at the center to a minimum near the edges, hence the name "Graded Index" Bandwidth ranges from 100MHz-Km to 1GHz-Km

Pulse dispersion in a step index optical fiber is given by

where

Δ is the difference in refractive indices of core and cladding.

n_1 is the refractive index of core

ℓ is the length of the optical fiber under observation

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. Due to the graded index, light in the core curves helically rather than zigzag off the cladding, 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: digital pulse suffers less dispersion. This type of fiber is best suited for local-area networks.

Pulse dispersion in a graded index optical fiber is given by

$c \approx 3 \times 10$

where

δn is the difference in refractive indices of core and cladding,

n is the refractive index of the cladding,

l is the length of the fiber taken for observing the pulse dispersion,

m / s is the speed of light, and

K = is the constant of graded index profile

Historical Development

Fiber optics deals with study of propagation of light through transparent dielectric waveguides. The fiber optics are used for transmission of data from point to point location. Fiber optic systems currently used most extensively as the transmission line between terrestrial hardwired systems.

The carrier frequencies used in conventional systems had the limitations in handling the volume and rate of the data transmission. The greater the carrier frequency larger the available bandwidth and information carrying capacity.

First generation

The first generation of light wave systems uses GaAs semiconductor laser and operating region was near 0.8 µm. Other specifications of this generation are as under:

i) Bit rate : 45 Mb/s

ii) Repeater spacing : 10 km

Second generation

i) Bit rate: 100 Mb/s to 1.7 Gb/s

ii) Repeater spacing: 50 km

iii) Operation wavelength: 1.3 µm

iv) Semiconductor: In GaAsP

Third generation

i) Bit rate : 10 Gb/s

ii) Repeater spacing: 100 km

iii) Operating wavelength: 1.55 µm

Fourth generation

Fourth generation uses WDM technique.

i) Bit rate: 10 Tb/s

ii) Repeater spacing: > 10,000 km

Iii) Operating wavelength: 1.45 to 1.62 µm

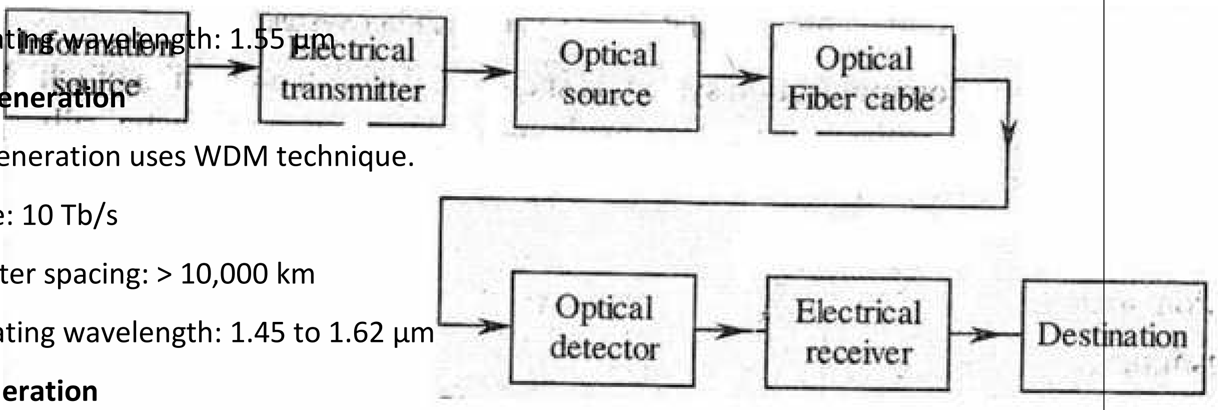
Fifth generation

Fifth generation uses Roman amplification technique and optical solitiors.

i) Bit rate: 40 - 160 Gb/s

ii) Repeater spacing: 24000 km - 35000 km

iii) Operating wavelength: 1.53 to 1.57 µm



1.1 General Block Diagram of a Optical Communication System

Optical Fiber Communication System:

The figure 1.1 shows a block schematic of the different elements in an optical fiber communication system. The carrier is modulated using analog information signal. The variation of light emitting from the optical source is a continuous signal. The information source provides an electrical signal to the transmitter. The transmitter comprises electrical stage. The electrical stage (circuits) drives an optical source. The optical source output is a light which is intensity modulated by the information. The optical source converts the electrical signal into an optical signal. The source may be either semiconductor laser or Light Emitting Diode (LED). The intensity modulated light signal is coupled to fiber. The fiber which is made up of a glass acts as a channel between the transmitter and receiver.

At the receiver the optical signal is detected by the optical detectors such as PIN diode and Avalanche photodiode. Sometimes photo transistors and photo conductors are used for converting an optical signal into electrical signal. The electrical signal is again processed and given to the transducer to get the original information.