# Communication Electronics

## 18KP3PELP3


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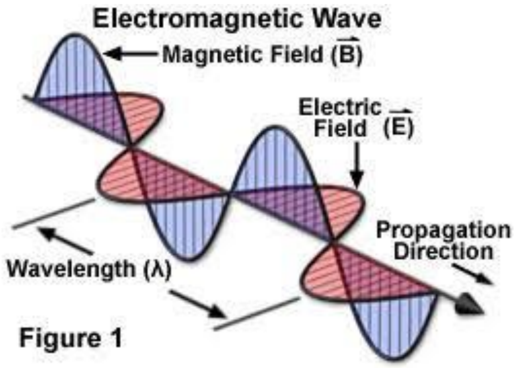
## Unit – 1

**Transmission System**

It transmits the signal from one place to another. The signal can be electrical or radio signal.

**Signal**

It is an electrical or electromagnetic current, carrying data from one device to another in any dimension and in any form.




**Transmission**

It is done at High voltage. At high voltage it increases the efficiency. Higher the voltage lowers the current. Lower the current, lower the resistance in the conductor. The Transmission Voltage is greater than 39,000 volts or 39Kv. Commonly used voltage are 69Kv and 138Kv.

**Antenna**

Device to transmit and receive the EM waves. The principle of antenna is to converts electrical currents into EM radiation. Antennas are normally directive, receiving more signals in one direction than another.

To ensure that the best performance is obtained, it is necessary to align or point the antenna in the right direction. This antenna alignment or orientation is a key part of any antenna installation.

An antenna is the interface between radio waves propagating through space and electric currents moving in metal conductors, used with a transmitter or receiver.

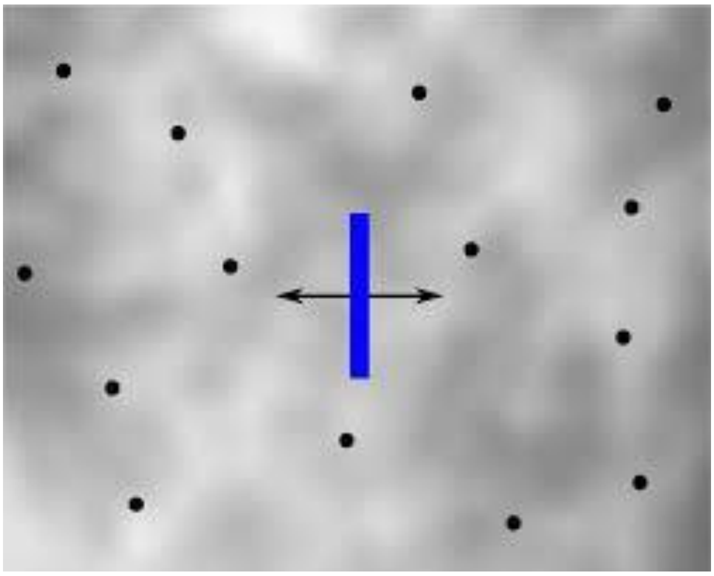
**Directions of an Antenna**

- Directional
- Semi Directional
- Omni Directional

A directional antenna usually is intended to maximize its coupling to the electromagnetic field in the direction of the other station. A vertical antenna radiates in all directions horizontally but sends less energy upward or downward.

**Radiation Field**

Field which is from the antenna. antennas are usually used to transfer signals at large distance. The condition of the field is distance from the antenna must be greater than the size of the antenna and the wavelength.

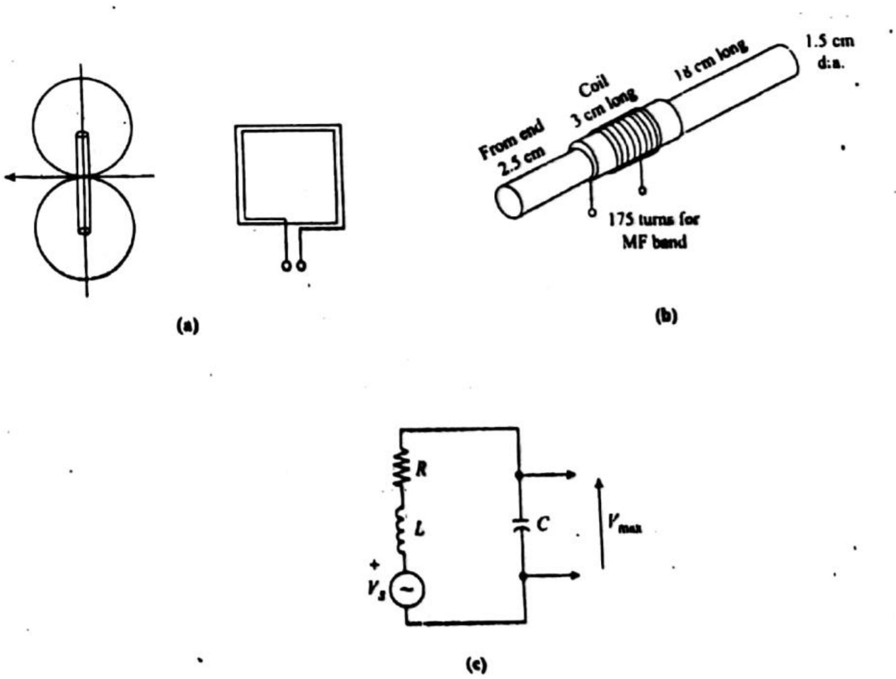


**Working of the Radiation field**

Current in a wire is surrounded by a magnetic field. Current is alternating then the electric charges in a Wires are accelerated. In that wire alternating EM field rise and travel away from the wire in the form of EM wave.

The radiations are produced in the coil of a wire. When the charges of the wire rise with the electromagnetic field the radiation increases. Depending upon the shapes of the wire the radiation can produced.

EM field in the phase of current deceases the amplitude as the Square of the distance. Increasing the distance, the EM field increase the current and decrease the amplitude.




The total field originating from an alternating current in a wire is complicated consisting of the following points:

Electric field component lags the current by 90 degree and decrease in amplitude. EM field in the phase of current deceases the amplitude as the Square of the distance. Increasing the distance, the EM field increase the current and decrease the amplitude.

**Polarization**

It is in the direction of the electric field vector to propagate the wave vector. It acts along the direction of the propagated wave. In transverse waves it specifies the geometrical Orientation of the oscillation.

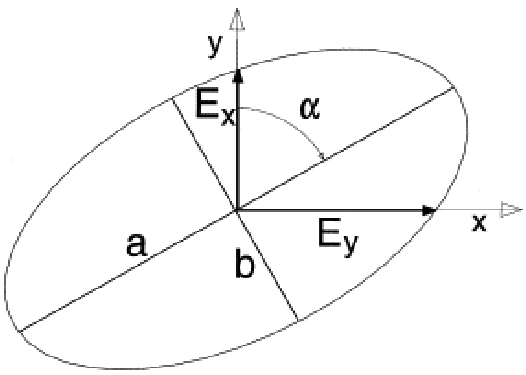
The polarized signal when hits on the earth and act as a linear polarized wave. It transmits only in the transverse region. The perpendicularly propagated waves are in different planes.

**Linear Polarization**

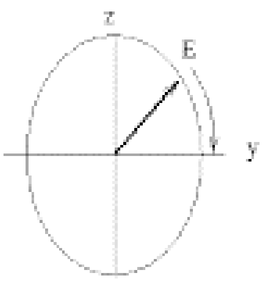
Electric field vector remains in the same plane. Field oscillate in a single direction. It also propagates across the earth's surface and it is said to be vertically polarized and horizontally polarized.

Elliptical Polarization

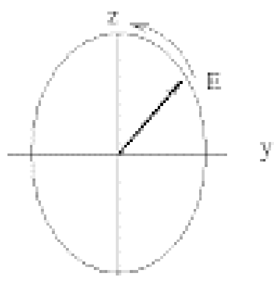
It travels in two planes. Two plane waves of different amplitude but same in phase by 90 degrees. Along the direction of the propagation when wave is in clockwise direction then it is called as Right handed polarization. When it is in anticlockwise direction then it is called as left handed rotation.



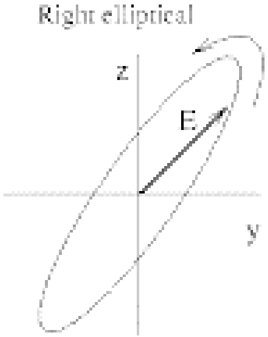

Linear polarization plays in two linear cases.




Right elliptical

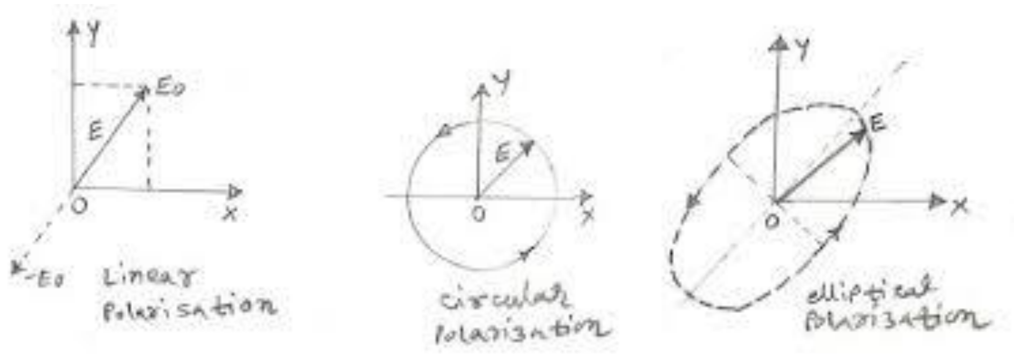



Left elliptical



**Circular Polarization**

It travels in two planes. Two plane waves of same amplitude but different in phase by 90 degree.




**Effective parameter of an antenna**

Typical parameters of an antenna are Gain, bandwidth, radiation pattern, polarization, Impedance

**Effective area of an antenna:**

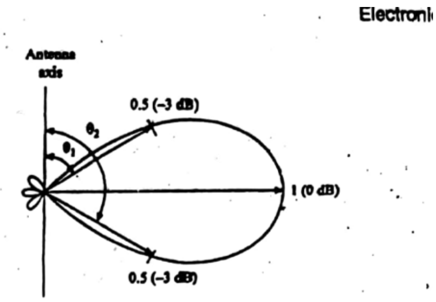
Calculate the area of an antenna in any type of an antenna. Calculating the collection of EM energy from the incident wave For the center of spherical co-ordinate is (θ,Φ)

$$P_R = P_D A(\theta, \phi)$$

$$\frac{A(\theta, \phi)}{A_{eff}} = g(\theta, \phi)$$

Effective area is calculated

$$\frac{A_{eff}}{G_M} = \frac{\lambda^2}{4\pi}$$




$$A_{eff} = \frac{\lambda^2 G_T}{4\pi}$$

**Effective length of an antenna**

At low frequency only the length can be calculated. When physical structure of antenna is a linear or Array conductor effective length is very effective Input terminal current and effective length is equal to the area under the actual current length

$$V_A = E\ell_{eff}$$

Effective length of an antenna is calculated by the voltage of the given antenna

$$I_0\ell_{eff} = \text{area under current–length curve}$$

**Power gain of an antenna**

It describes how much power is transmitted in the direction of peak radiation in an isotropic source. It is also called Directivity of an antenna. Antenna power gain will vary depending upon on the direction.

Expression for the power gain of an antenna

Function of the angular co-ordinates is θ and ф

Power gain of the antenna is defined as the ratio P (θ , ф)

Gain function of an antenna is G (θ, ф)

- Power gain G,

$$G = \frac{4\pi\,(\,maximum\,power\,radiated\,per\,unit\,solid\,angle)}{net\,power\,accepted\,by\,the\,antenna}$$

- Equivalent definition is

$$G = \frac{maximum\,radiation\,intensity\,\,from\,subject\,antenna}{radiation\,intensity\,\,from\,lossless\,isotropic\,ant\,with\,same\,input\,power}$$

- The power gain and directiven gain are related by radiation efficiency ($\rho_r$).

$$G = \rho_r G_D$$

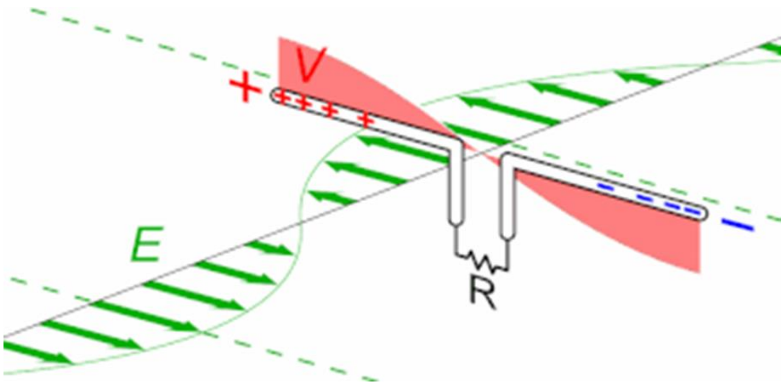
**Dipole Antenna**

It is the simplest type of antenna. Consist of two conductors of equal length oriented end to end. It is widely used in radio and telecommunication. It is a resonant antenna. It is omnidirectional.

Omnidirectional antenna can easily transmit and receives the signal in all direction. With the help of the two conductors the waves are propagated in both vertical and horizontal directions.

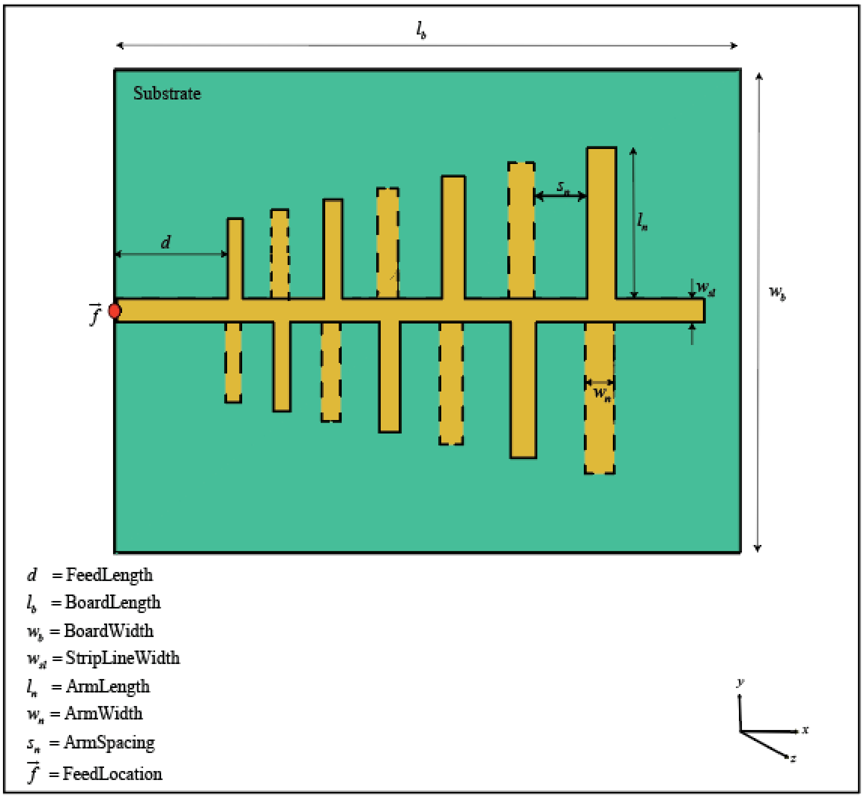
The pole strength of an antenna is maximum so that the gain and the impedance of the antenna is also very high. It is a type of RF antenna which is widely used for radio transmitting and receiving applications. The dipole is often used for on its own as an RF antenna.

The values of the real and imaginary input impedance are well known for a dipole antenna. The impedance varies with the frequencies. The half wavelength resonant frequency real part of the impedance should be 73ohms and the imaginary part should be 42.5ohms.




## Dipole Array Antenna

Group of dipole antennas are called as Dipole array antenna. Two conductors are phased with equal length. Distance between the two conductors are called as arm spacing. The length of the conductor is called as board length and the width as board width.



Advantages of Dipole array antenna

- The signal strength increases.
- High directivity is obtained.
- Minor lobes are reduced much.
- High signal o noise ratio is archived.
- High gain is obtained.
- Power wastage is reduced.
- Better performance is obtained.

**VHF AND UHF Antennas**

VHF AND UHF Antennas are used in very high signal. For example, in two-way radio, public safety and in commercial communications.

VHF --- Very high frequency antenna
UHF --- Ultra high frequency antenna

The Range of the vhf antenna is 30 to 300 MHZ. It is Suited for long distance in and outdoor use. It has Longer wavelength and lower frequency. The Range of the uhf antenna is 300 MHZ to 3 GHZ. Used in wireless communication because it easily penetrates through buildings, walls, concrete. It has High frequency and lower wavelength
The vhf and uhf antennas are three types.

Discone Antenna

Helical Antenna

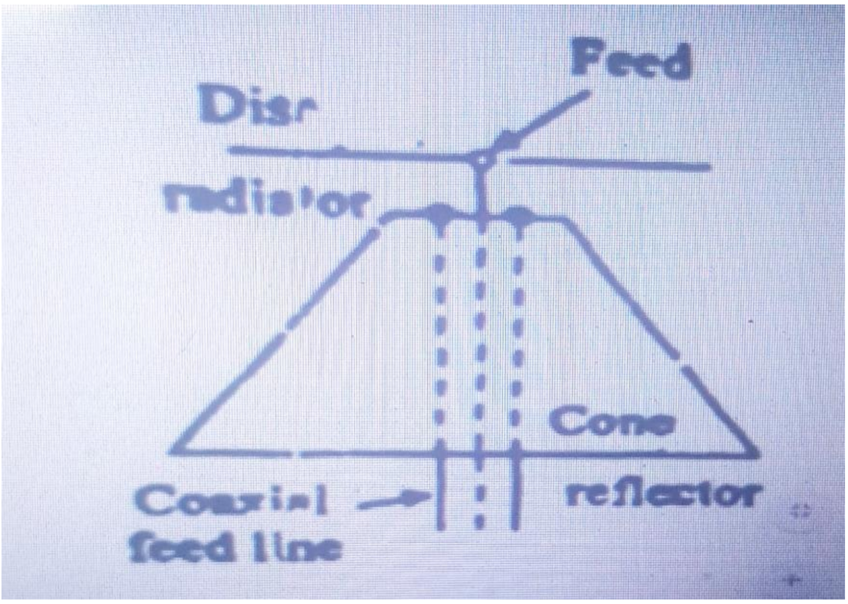
Yagi Uda Antenna

**Discone Antenna**

It radiates an Omni-directional pattern in the horizontal plane. It is a Broad band antenna with frequency range 10:1. It is Fed directly to the co-axial line of 50 ohms. Directly mounted at the end of the line

It is used in the urban mobile communication system. It is very compact and rugged. Because of less expensive to construct these types of antennas are used in densely populated communicational area. It is both act as a vhf and uhf antenna. The signal transmits uniformly as a co-axial line.

The discone type antenna is usually a cone type antenna. It also called as a cone reflector.




**Advantages of discone antenna**

It can operate over frequency ranges upto 10:1and also in the low angle of radiation .

It is a unity gain antenna.

It is a best base scanner antenna

**Helical Antenna**

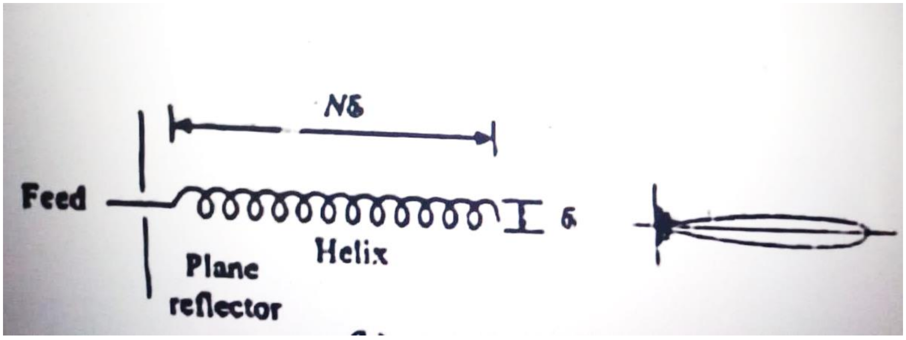
It is a coil of a wire. When the diameter of the helix is lesser than the wavelength, then it is act like a compact dipole antenna. It is a Circular polarized wave. So it travels in two planes. Transmitted along two plane waves of same amplitude but different in phase by 90 degrees.

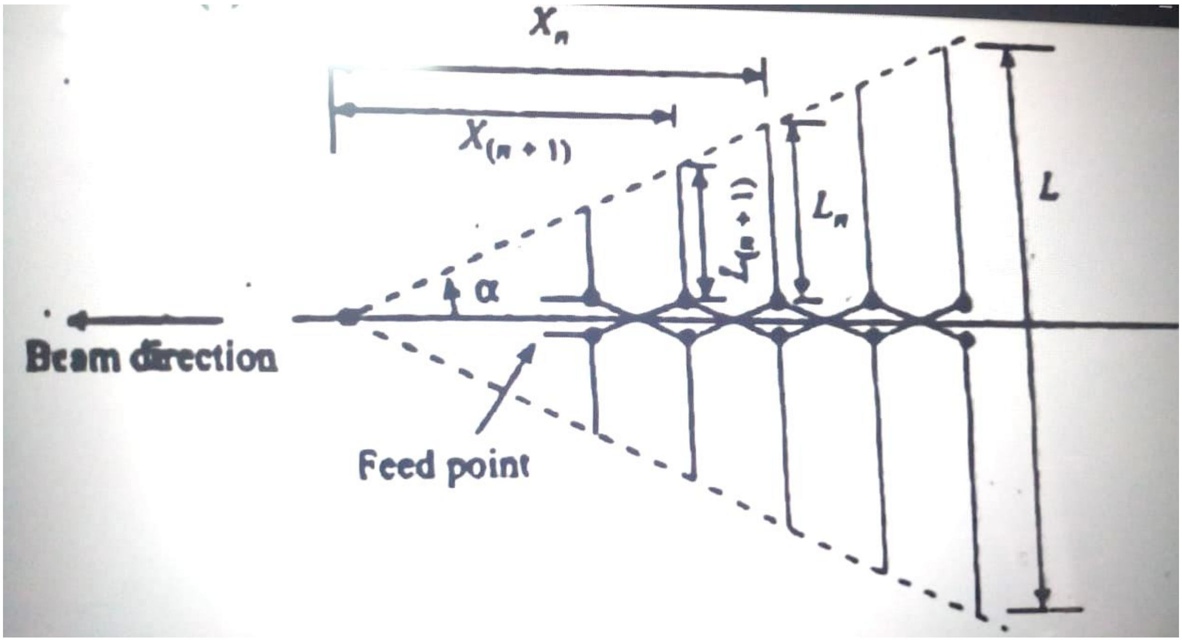
When plane reflector is kept at the end, it results as a high directional antenna. The bandwidth of the antenna is represented as $L_{n.}$ In an antenna the helix is surrounded at the center of the conductors. It works under the beam of the transmitted line.

It also circulated at the director element to easily transmit and receive the signals. Gain or impedance shows a periodic variation with log of input frequencies.

It is a broad band. Directional antennas are used for mobile base operations. Many channels are handled over a single antenna system with good directive characteristics.

omnidirectional antenna can easily transmit and receives the signal in all direction. With the help of the two conductors the waves are propagated in both vertical and horizontal directions.




**Advantages of helical antenna**

- It is used for transmission and reception of VHF signals.
- It is used for satellite and radiometry applications.
- It is the simplest antenna which provides circularly polarised waves.
- It is used in extra-terrestrial communications in which satellite relays

**Yagi Uda Antenna**

It is a directional antenna. Consist of multiple parallel elements in a single line is called as a Yagi uda antenna. It is made up of metal rods. It is a **parasitic array**, usually half wave dipole.

Consist of single parasitic reflector and **thirteen director element.** Uda antennas are mounted on the Ground with the central support rod. It is Fed directly to the co-axial line of 200 to 300 ohms. Instead of thirteen elements three, five, seven, eleven elements are also used.

Most of the communication systems are used in three and five elements only. Three element yagi gives 7db. Five element yagi give 15db. Log periodic antenna

It is an array of dipoles. Fed with alternating phase. Lined up along the axis of the radiation. Length of the elements and their spacing are calculated by the given formula

$$\tau = \frac{L_{(n+1)}}{L_n} = \frac{X_{(n+1)}}{X_n}$$

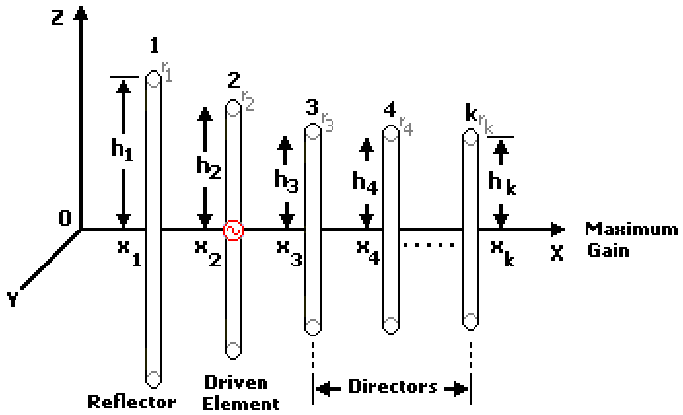
Angle of divergence

$$\alpha = \tan^{-1}\left(\frac{L_n}{X_n}\right)$$

$L_n$ is the length of an antenna and $X_n$ is the distance between the directive elements. The gain of an antenna is calculated by the angle of the divergence. It is a directional antenna. So it receives and also transmit the signals using the two conductors.

**Unique features of an antenna**

Gain or impedance shows a periodic variation with log of input frequencies. It is a broad band. Directional antennas are used for mobile base operations. Many channels are handled over a single antenna system with good directive characteristics.




Geometry of a K elements Yagi-Uda

The above diagram shows the geometry elements of a yagi uda antenna.h1 is the reflector, which transmits and receive signals from the antenna. The length of the reflector should be high than the other element. After the reflector the driven element should be fixed with high length next to reflector. Then the directors are obtained with equal or unequal lengths.

**Advantages of Yagi -uda antenna**

It is a highly directional antenna.

It is widely used in to receive TV signals.

It is used in the fields of RADARs, satellites and RFID applications.

**Microwave Antenna**

It is an Electromagnetic radiation with wavelength. Ranging between 300MHZ to 300GHZ. It has shorter wavelength. Communicate in two or more locations. It is a physical transmission device. Antennas are also used in radar, radio astronomy. For high gains are two or more planes are required.

Two types of microwave antenna:

1. Horn
2. Parabolic reflector antenna

***1.Horn***

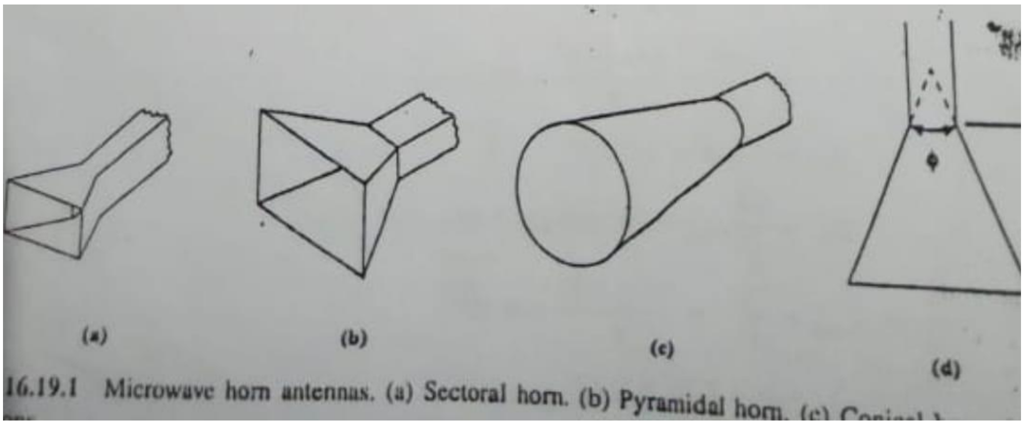
The following diagrams are given below are for horns.

a. Sectoral horn
b. Pyramidal horn
c. Conical horn
d. Microwave horn

The frequency of the wave depends on the types of the horn. when the waves are wants to be circulated like a rectangular wave is called sectoral horn. Depending upon the transmission of the frequencies the type of horns is differ with their types. The different types of horns are fixed in the antenna to get microwave signals.

A horn antenna is used to transmit radio waves from a waveguide (a metal pipe used to carry radio waves) out into space, or collect radio waves into a waveguide for reception. The waves then radiate out the horn end in a narrow beam.

The radiation pattern of a horn antenna is a Spherical Wave front. ... The wave radiates from the aperture, minimizing the diffraction of waves. The flaring keeps the beam focussed. The radiated beam has high directivity. A horn antenna or microwave horn is an antenna that consists of a flaring metal waveguide shaped like a horn to direct radio waves in a beam. ... Conical horn A horn in the shape of a cone, with a circular cross section. They are used with cylindrical waveguides




16.19.1 Microwave horn antennas. (a) Sectoral horn. (b) Pyramidal horn.

**2.Parabolic reflector antenna**

Most widely used antenna in microwave is parabolic reflector antenna. It consists of many antennas such as dipoles or horns situated at the focal point of the reflector

Gain or impedance shows a periodic variation with log of input frequencies. It is a broad band. Directional antennas are used for mobile base operations. Many channels are handled over a single antenna system with good directive characteristics.

When plane reflector is kept at the end, it results as a high directional antenna. The bandwidth of the antenna is represented as $L_n$. In an antenna the helix is surrounded at the center of the conductors. It works under the beam of the transmitted line.

The main advantage of a parabolic antenna is that it has high directivity. It functions similarly to a searchlight or flashlight reflector to direct the radio waves in a narrow beam, or receive radio waves from one particular direction only.

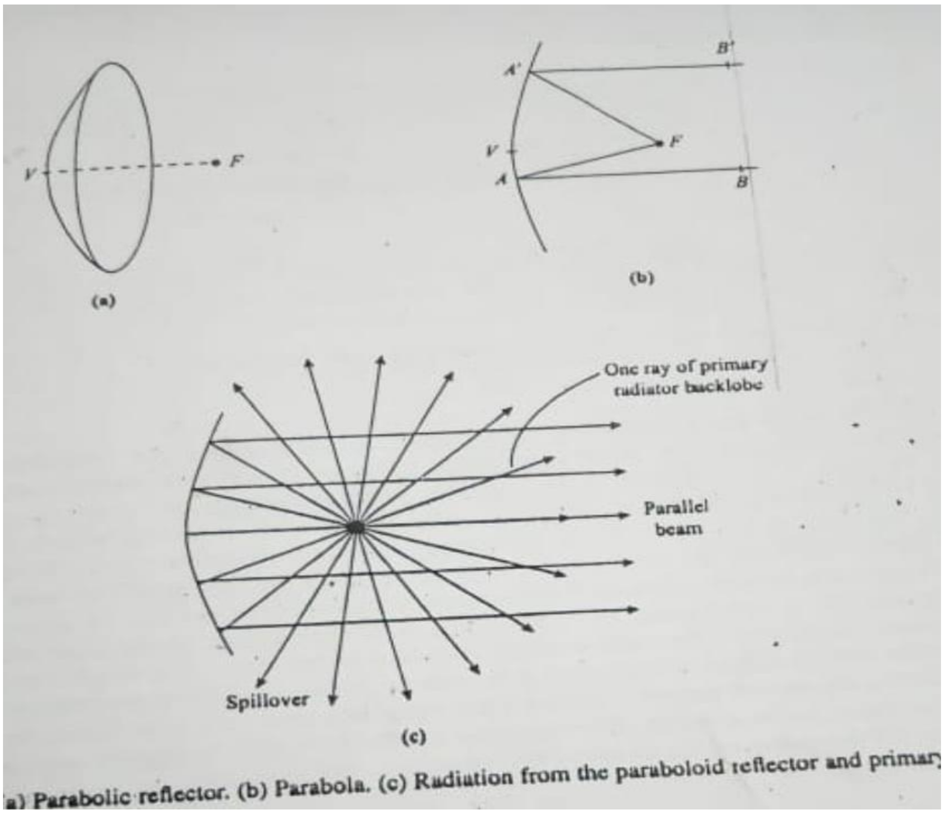
The high level of gain is one of the main reasons for the more use of the parabolic reflector. In fact, the parabolic reflector antenna gain can be as high as 30 to 40 dB These figures of gain are not easy to achieve using other forms of antenna.

$$f/D = 0.25 \cot(\psi/2)$$

For an angular aperture of 55°, the aperture number is

$$f/D = 0.25 \times 1.92 = 0.48$$

$$G = I(0)\left[\frac{\pi D}{\lambda}\right]^2$$

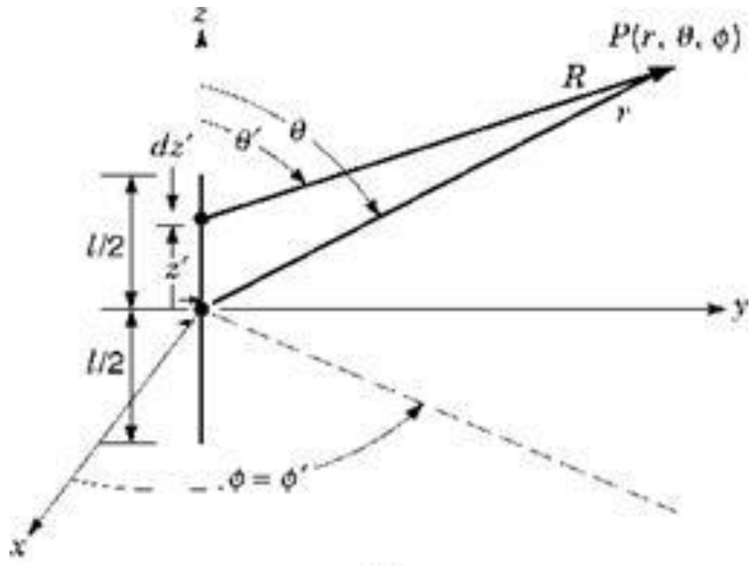


a) Parabolic reflector. (b) Parabola. (c) Radiation from the paraboloid reflector and primary

**Thin linear antenna**

Thin antenna means its diameter is small compared to its wave length, i.e. Where d= diameter of the antenna and $\lambda$= wavelength. Antenna is fed at the centre by a balanced two wire transmission line and. assuming sinusoidal current distribution along various length of line as.

Linear antennas are considered to be those antennas that imply the use of electrically thin conductors (wavelength >>conductor diameter). ... In order to calculate radiated fields in these antennas, conductors are modelled as if they were current lines with no diameter.




(a)

(a) A thin linear antenna of length $L$ carries an oscillating current

$$I(z,t) = I_0 \sin(2\pi z/L)e^{-i\omega t}, \quad |z| < L/2.$$

Find the quadrupole moment ($Q_0$) of the antenna.

(b) Find the quadrupole radiation pattern. Sketch the angular distribution.

(c) Find the maximum intensity and the angle for which it occurs for the quadrupole.

. A thin linear antenna of length $L$ carries an oscillating current

$$I(z,t) = I_0 \sin(2\pi |z|/L)e^{-i\omega t}, \quad |z| < L/2.$$

(a) Sketch this current as a function of $z$.

(b) Find the radiation pattern for this antenna for $kL = 2\pi$, and for $kL = \pi$.

(c) Plot the angular distribution for each of the above cases.

. For the antenna in the previous problem:

(a) Find the maximum $\frac{dP}{d\Omega}$, and the angle for which this occurs.

(b) Find the total power radiated by this antenna, and the formula for its radiation resistance (in ohms).

- Radiation Resistance and Input Radiation Resistance

$$R_r = \frac{2P_{\text{rad}}}{|I_0|^2} = \frac{\eta}{2\pi}\{C + \ln(kl) - C_i(kl) + \frac{1}{2}\sin(kl) \times [S_i(2kl) - 2S_i(kl)] + \frac{1}{2}\cos(kl) \times [C + \ln(kl/2) + C_i(2kl) - 2C_i(kl)]\}$$

$$R_{in} = \frac{R_r}{\sin^2\left(\frac{kl}{2}\right)}$$

- Directivity and Effective Aperture

$$D_0 = \frac{2F(\theta)|_{\max}}{Q}$$

$$A_{em} = \frac{\lambda^2}{4\pi} D_0$$

**Advantages of Thin linear antenna**

- Antenna Radiation Pattern.
- Radiation Intensity.
- Directivity and Gain.
- Radiation Efficiency and Power Gain.
- Input Impedance.
- Effective Length.
- Bandwidth.
- Effective Aperture

# UNIT – 3

## Optical Fibre

It refers the medium and the technology associated with the transmission of information as light pulses along a glass or plastic strand or fibre. It is used in the long distance and high performing data networking. It is flexible, transparent fibre made by drawing glass. It is thicker than the human hair.

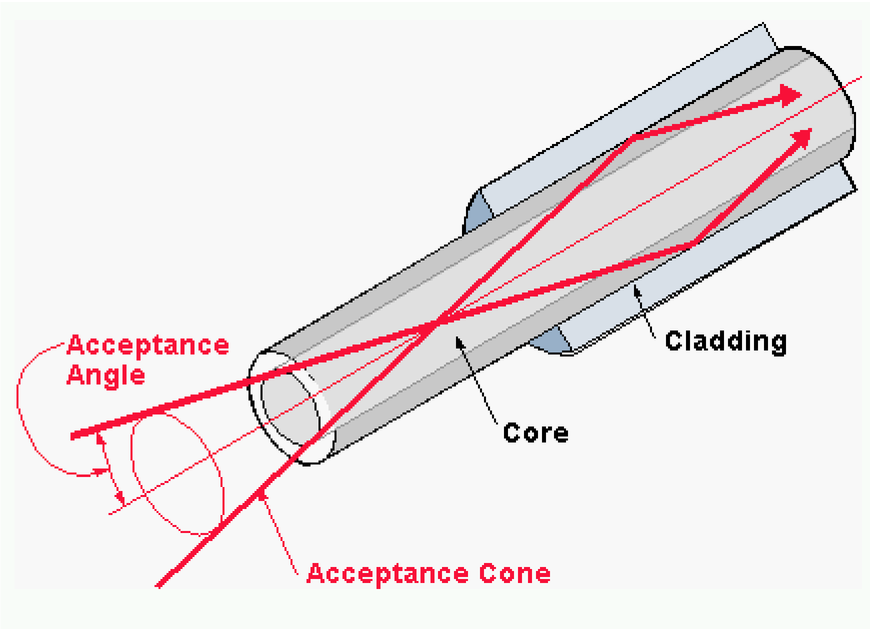
An Optical fiber is a flexible, transparent fiber made of high quality glass (silica) or plastic, slightly thicker than a human hair. It either functions as a waveguide or light pipe that transmits light between two ends of the fiber or fiber cable. Optical fibers are widely used in fiber-optic communications, which permits transmission over longer distances and at higher bandwidths (data rates) than other forms of communication

Fibers are used instead of metal wires because signals travel along them with less loss and are also safe to electromagnetic interference. The field of applied science and engineering concerned with the design and application of optical fibers is known as fiber optics.

## Structure of optical fibre

Optical fiber is comprised of a light carrying core surrounded by a cladding which traps the light in the core by the principle of total internal reflection. Most optical fibers are made of glass, although some are made of plastic.

The core and cladding are usually fused silica glass which is covered by a plastic coating called the buffer or primary buffer coating which protects the glass fiber from physical damage and moisture. There are some all plastic fibers used for specific applications. Glass optical fibers are the most common type used in communication




**Types of optic cable**

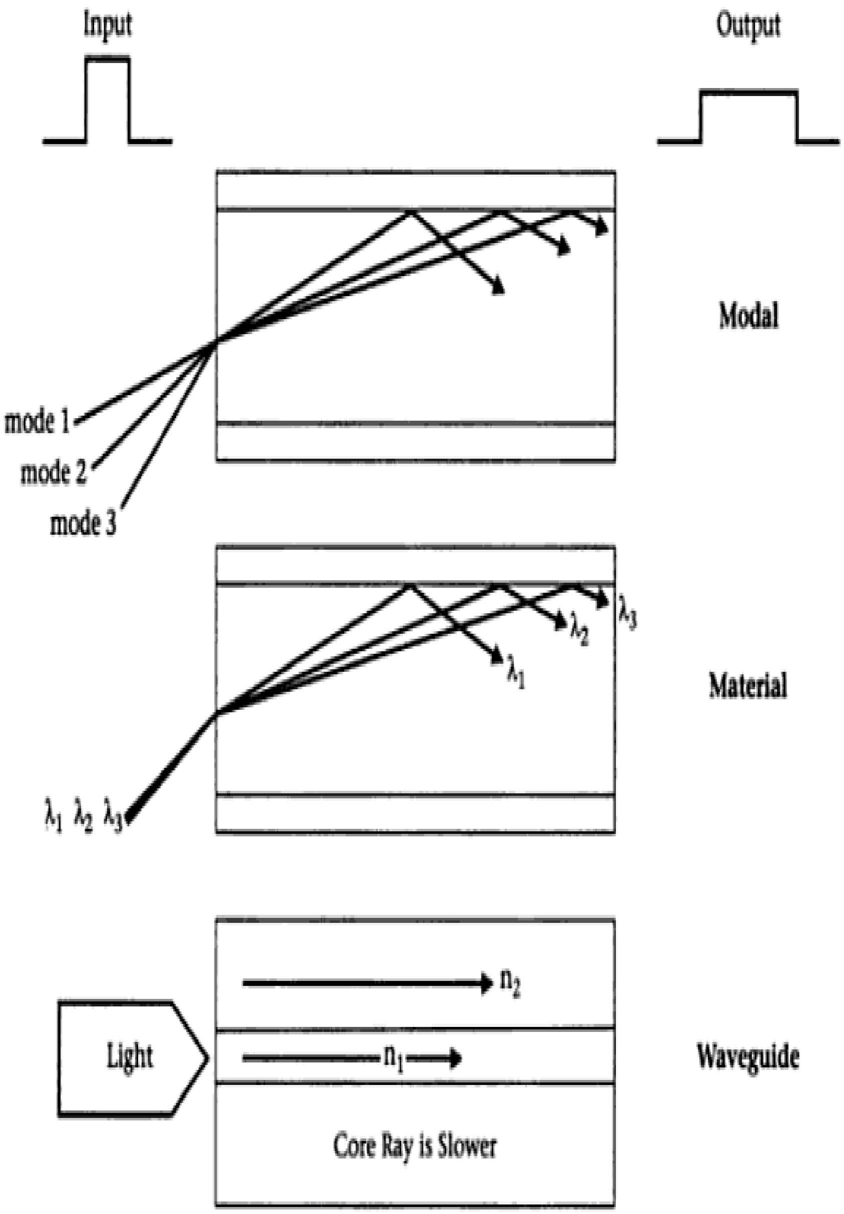
Three types of cable are

1.Single mode

2. Multimode

3. Plastic optical fibre

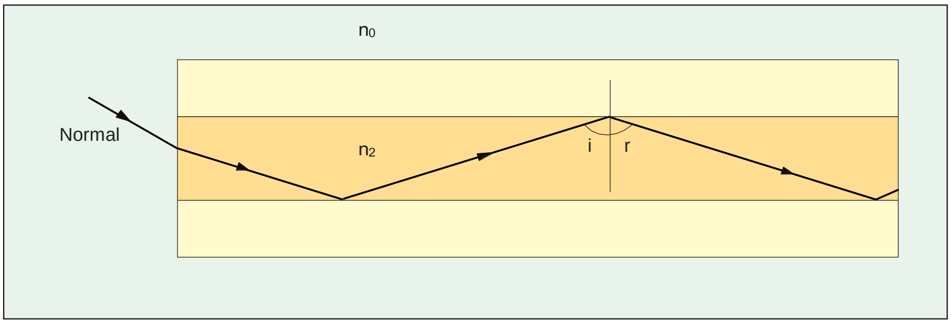
Optical fibre is used in telecommunications companies to transmit telephone signals, internet communication and cable television. It is also used in a multitude of other industries and also in defence.




**Total reflection in a fiber**

Total reflection can easily be observed in a prism or in a transparent glass filled with water. The principle of light propagation in an optical fiber is based on the principle of total reflection. In an optical fiber, there are two media (two different types of quartz glass) with a small difference in refractive index.

Typical values are $n_2$ =1.47 and $n_1$ = 1.46, which gives a critical angle i = 83.3°. For light propagating in a fiber, the largest possible angle of incidence of light into the fiber



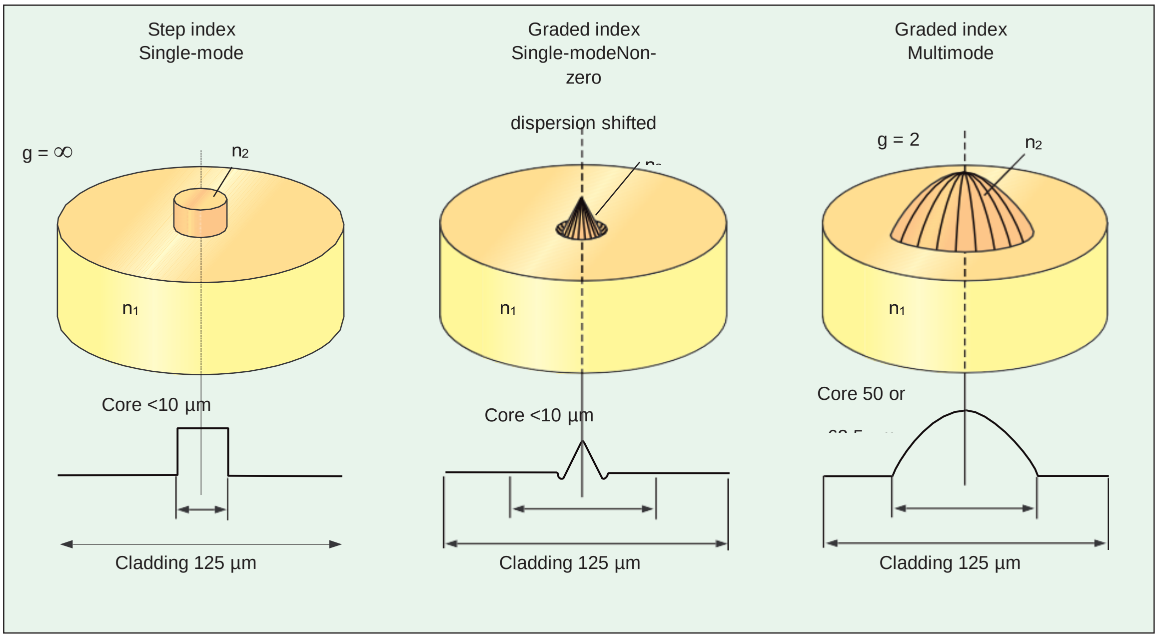

from the normal is considered. This is called the numerical aperture and is dealt with in the chapter entitled "Optical fiber and their parameters". We will later make a distinction between single-mode and multimode fiber. To properly describe single-mode fiber a treatment including the Maxwell equations is needed.

**Parameters of the Optical fibres**

When the refractive index for an optical waveguide is seen as a function of the waveguide's radius, the expression "index profile" can be used to describe how light is conducted through the waveguide. The index profile indicates how the refractive index changes from the waveguide's central axis to its periphery, or cladding. Light will be conducted and/or refracted in accordance with this profile. The refractive index is given as a function of the radius:

$$n = n(r)$$

The propagation of the light's modes in a waveguide is dependent on the index profile.




The above figure shows the graphical representation of the refractive index of the core in optical fibre. The index profile can be mathematically described by the formula below. Its main significance is for practical applications, particularly the use of multimode fibre.

where for the cladding

$$n(r) = n_1 = \text{constant}$$

## Numerical aperture

When light is injected into a fiber opening it is refracted in relation to the normal, producing a somewhat higher value for this incident angle, the acceptance angle. The sine value of the acceptance angle is defined as the numerical aperture (NA) and is calculated by means of the refractive index of the two materials involved

## Numerical aperture for a fibre with graded index profile

Because the refractive index of a fiber with a graded index profile varies with the distance from the fiber center n(r), the acceptance angle also varies for light entering the fiber. The acceptance angle is therefore a function of r as shown in the following formula:

$$\sin \beta(r) = \sqrt{n_2^2(r) - n_1^2} = NA \sqrt{1 - \left(\frac{r}{a}\right)^2} \leq NA$$

This means that the acceptance angle is greatest close to the center of the fiber, with a gradual reduction of the value towards On closer analysis, it can be seen that a graded index fiber with a core diameter of 50 µm accepts only half of the light that a step index fiber with the same core diameter will accept.

The distribution of modes is such that lower-order modes propagate along the fiber's central axis, higher-order modes propagate closer to the cladding, and some modes disappear into the cladding. The latter are termed leaky modes. Leaky modes are radiated to some extent and propagated in the fiber to some extent.

$$NA = n_2 \; 2 \cdot \Delta = 1.46 \qquad 2 \cdot 0.01 \approx 0.$$

**Modified Chemical Vapor Deposition (MCVD)**

The MCVD method for producing preforms for fibre manufacture was first describe by Mac Chesney at AT&T Bell's laboratories in 1974. MCVD has become one of the most tried and tested methods used for manufacture of fibre optic preforms. The process is simple, flexible and thus easy to emulate. Its simplicity has made the process.

Suitable for basic research in the field of optical waveguides. Large-scale utilization of this method is practised at AT&T Technologies in the USA, and by many other manufacturers in the USA, Japan and Europe. The method permits the variation of a number of parameters, e.g., multimode or single- mode, the finished fiber diameter, numerical aperture (NA), and refractive index profile.

These parameters are varied by varying the vapour flow of silicon dioxide and the doping substances, all controlled and supervised by computers. This makes it relatively easy for manufacturers to produce fibres according to a variety of requirements specifications

**Outside Vapor Deposition (OVD)**

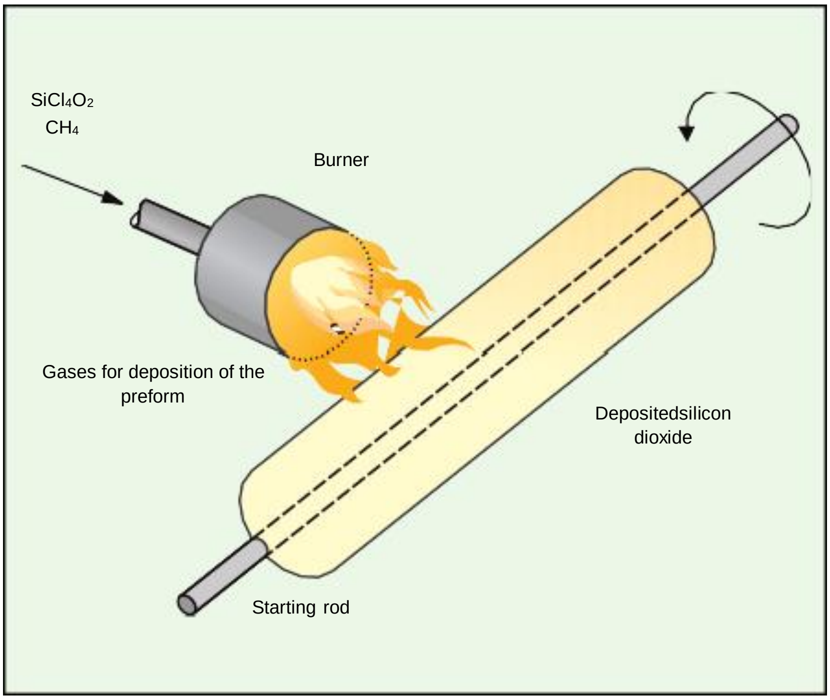
The description of this method will be much shorter than the preceding process description, since the basic chemical conditions are largely the same. Compared to MCVD, OVD is significantly more complex. Its complexity, and comprehensive patent protection, have meant that this process is used exclusively by Corning Glass Works (which developed the process) and their licensees. However, the total volume of OVD fiber produced today is probably as large or even larger than the volume of MCVD fiber. This is due to the fact that, in large-scale production, the OVD method is more efficient than the MCVD method. As mentioned earlier the MCVD-method has been improved to increase the efficiency.

**Process description**

The OVD process is divided into three phases.

**Phase 1, deposition**

Phase 1 involves deposition of the silicon dioxide powder (often referred to as soot particles) with or without doping substances onto a thin rod. A hot stream of soot




**Vapor-Phase Axial Deposition (VAD)**

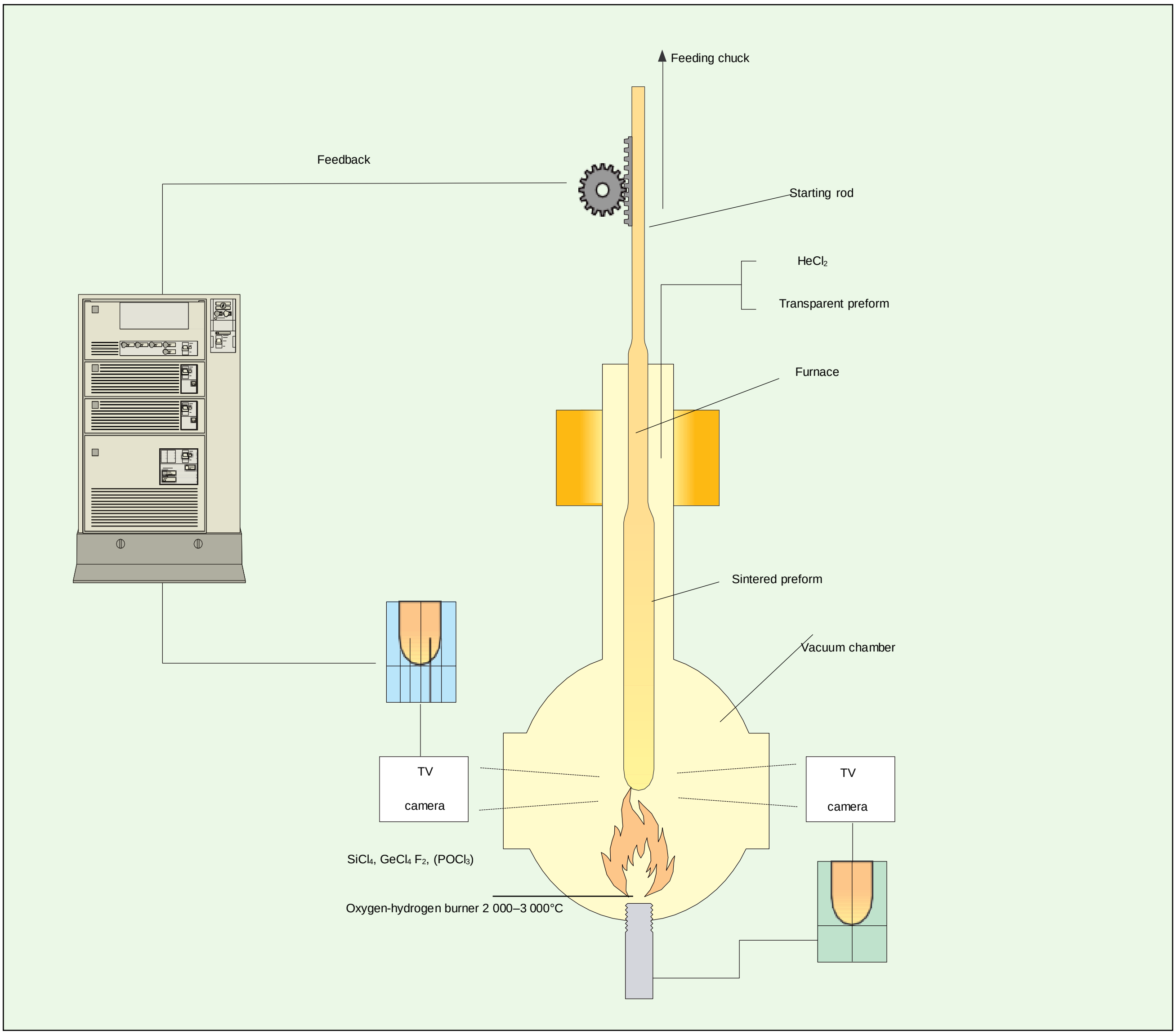
The Vapor-Phase Axial Deposition (VAD) method was developed in Japan in order to circumvent patent infringement of Corning's OVD method, and to permit continuous manufacture of preforms for the production of phase axial deposition.

Production process

The VAD method is similar to the OVD method insofar as deposition is external rather than internal, and a porous preform is formed which is then dehydrated and sintered. However, soot particles are deposited axially in this method, not radially as in the OVD method. This makes it more difficult to modify the index profile, but easier to make longer preforms.

The manufacturing system consists of a mechanism for axial movement of the preform, reaction chamber, burner, vaporizing unit for the constituent raw material, and a control unit. The preform is drawn slowly, vertically, upwards through the manufacturing equipment. The raw materials ($SiCl_4$, $GeCl_4$ and $POCl_3$) are injected in the same way as in the OVD method; an oxygen-hydrogen gas burner is used and extremely fine glass particles formed in flame-hydrolysis reactions are deposited on the end surface of an already de- posited preform, which functions as a growth substrate. The porous preform grows axially and is moved axially at the rate of growth.

The preform is dehydrated and consolidated into a transparent rod in an electrically heated ring-shaped graphite resistance furnace.




Variations in the position of the growth zone give fluctuations in the index profile of the finished preform. The axial speed (= rate of growth) is approximately 40–60 mm/hour.

One to three burners are used for deposition. Different index profiles can be obtained by varying the number of burners and the content and proportions of the raw materials. During consolidation, the preform is dehydrated in an atmosphere of chlorine gas. To obtain a thicker cladding, an additional deposition can be made on the surface of the sintered preform rod. This means that very large preforms can be produced.

**Dispersion**

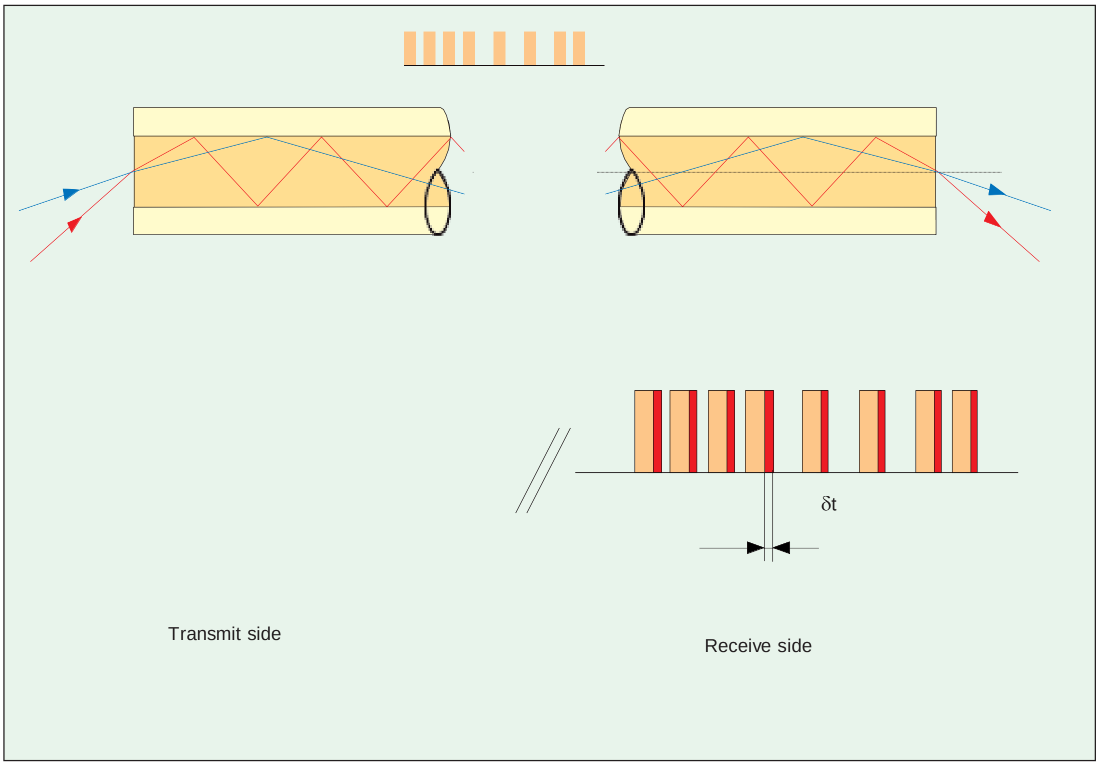
Light travelling through a waveguide will be subjected to distortion. The emitted light will be spread out in time. In the field of fiber optics this is called dispersion. There are two different kinds of dispersion:

- Intermodal dispersion occurs in a multimode fibre
- Intermodal dispersion (chromatic) occurs in the single-mode fibre and also in the multimode fibre

**Intermodal dispersion**

A light pulse that propagates in a multimode fiber should be seen as a large number of sub pulses, each with its own angle of incidence into the fiber. The light pulses will thus follow different ray paths through the fiber. The length of the ray path varies due to the incident and reflection angles. The simultaneously emitted light pulses will thus reach the end of the fiber at slightly different times.

It may be described as a broadening of the pulse (during its propagation through the fiber) due to an increase in pulse duration. The phenomenon is highly detrimental to fiber optic communication.




**Modal dispersion causes:**

- a reduction of the transmission capacity (Mbit/s)
- a reduction of the transmission distance

There is a certain "natural" reduction of the effects of modal dispersion in a fiber. The individual modes cooperate and transfer energy to and from each other. Modes of a lower order (modes with a smaller angle to the fiber axis) become higher-order modes (modes with a larger angle to the fiber axis) after energy transfer.

Mode coupling, as this is termed, occurs at points of impurities in the core, at splices, and at sharp bends in the fiber. In modern fibers, it has been possible to reduce mode coupling by increasing the quality of the fiber. The result is a certain neutralization of the time difference it. This difference does not increase linearly with the length of the fiber but as follows:

$$\delta t \approx \sqrt{\text{fiber}}$$

Modal dispersion can be eliminated entirely by reducing the core diameter so that only one mode, the $LP_{01}$ mode, can propagate in the fiber, a single-mode fiber

**Intermodal dispersion or chromatic dispersion**

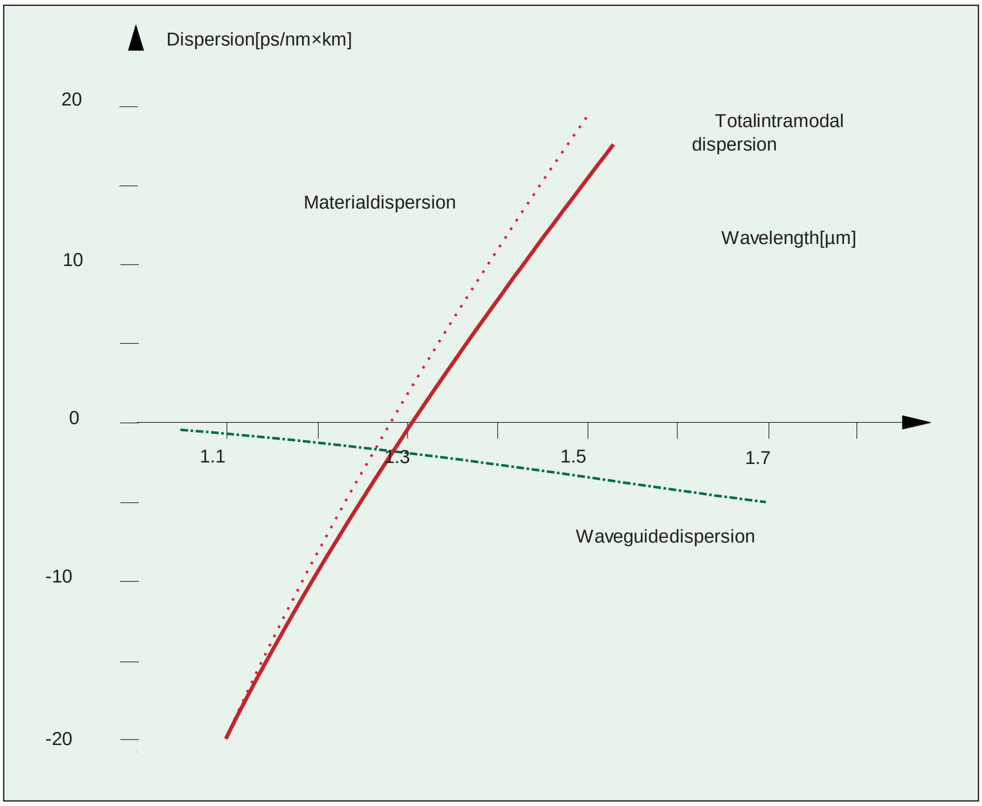
Even if intermodal dispersion is completely eliminated by permitting only the fundamental mode to propagate in the single-mode fiber, there still will be dispersion of this mode as well. Distortion of this type is called intermodal dispersion and polarization mode dispersion. The intermodal dispersion or chromatic dispersion in a single-mode fiber consists of material dispersion and of waveguide dispersion.

**Material dispersion**

Material dispersion and waveguide dispersion tend to cancel each other out in wavelengths close to 1310 nm where the chromatic dispersion is zero. For shorter wavelengths, the chromatic dispersion is negative, and for longer wavelengths, it is positive.

Material dispersion can only be changed by varying the composition of the glass in the fiber core and cladding. Waveguide dispersion is caused by the profile of the waveguide and can only be changed by changing the refractive index profile.

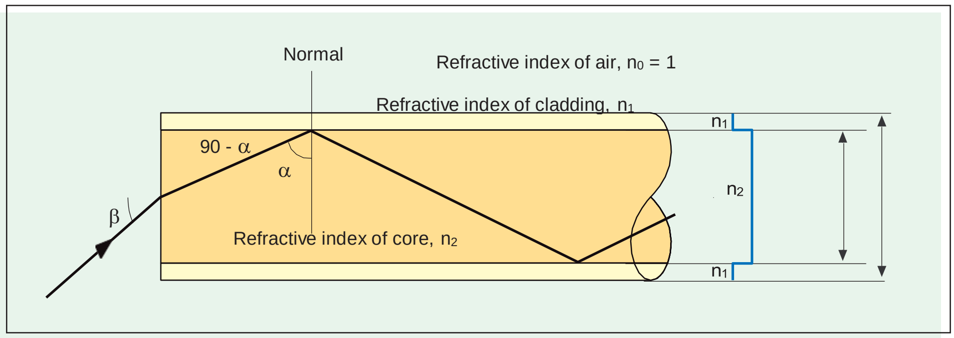
The primary reason for chromatic dispersion is the transmitting light source. A laser is not entirely monochromatic, which means that each light pulse emitted contains light that isboth somewhat towards the red




**Multimode fiber with rectangular index profile**

If a fiber with a rectangular index profile (plastic fiber, or simple glass fiber with quartz core and plastic cladding) is to be used to transmit light utilizing the principle of total reflection, the refractive index ($n_2$) of the core must be higher than the refractive index ($n_1$) of the cladding. If the refractive index of the core is constant over the entire core radius, the fiber is called a step index fiber. The index profile (blue) and light refraction of a fiber with a step index profile.

This type of fibre is easy to manufacture, but because of its relatively poor trans- mission capabilities, it is only used for information transfer over very short distances



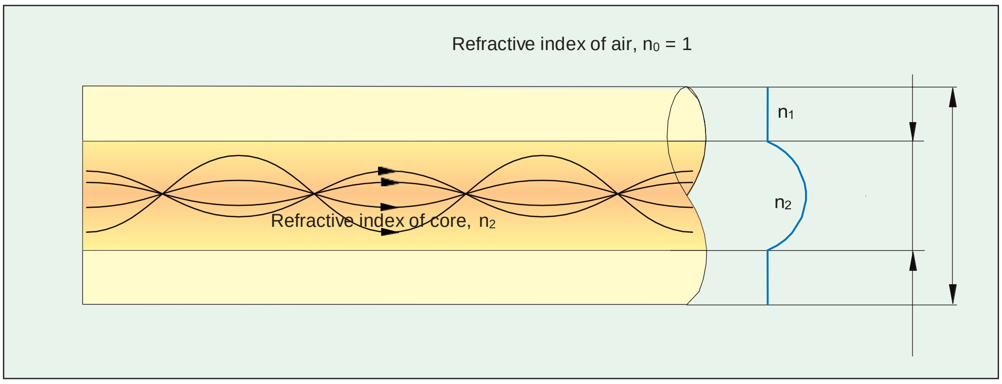

**Multimode fiber with graded index profile**

As previously outlined, a multimode fiber with a rectangular index profile transmits a large number of modes. Each one of these modes has a different path length through the fiber and, hence, each arrives at a slightly different time (termed modal dispersion) at the other end of the fiber. Modal dispersion can be reduced considerably if the refractive index can be made to vary from the core's center to- wards the cladding.

The refractive index is permitted to vary parabolic ally so that the refractive index is at a maximum ($n_2$) at the center of the fiber and drops to a minimum ($n_1$) at the point of coupling to the cladding. A fiber which has an index profile that varies quadratic ally with an exponent g = 2 is thus called a graded index fiber.

In four light waves (modes) have been drawn: one which passes along the fiber's central axis where the refractive index is at the maximum; one lower-order light wave (mode); and two higher-order waves (modes).

The light travelling the longer path through the fiber is actually travelling through glass with a lower refractive index and consequently travels faster despite the longer path. If the fiber's variation in refractive index can be made as close to a parabolic variation as possible, the modal dispersion will be very small. Dispersion in a multi-mode graded index fiber causes a time difference less than 1 ns over 1 km of fiber.




Light waves propagate through the fiber in a helical motion. Modal dispersion is caused by variations from the ideal parabolic profile in a fiber. Variations such as the relative differential in the refractive index and the profile exponential g are dependent on wavelength.

Multimode fibers are generally used in indoor networks. The larger core diameter allows simpler connection to transmission equipment. The fiber is used in data networks, sensor applications and it fulfills the requirements for FDDI. Generally speaking, multimode fiber means graded index multimode fiber. These fibers can be used at both 850 nm and 1300 nm or in dual window applications.

**Standard single-mode fiber with rectangular index profile**

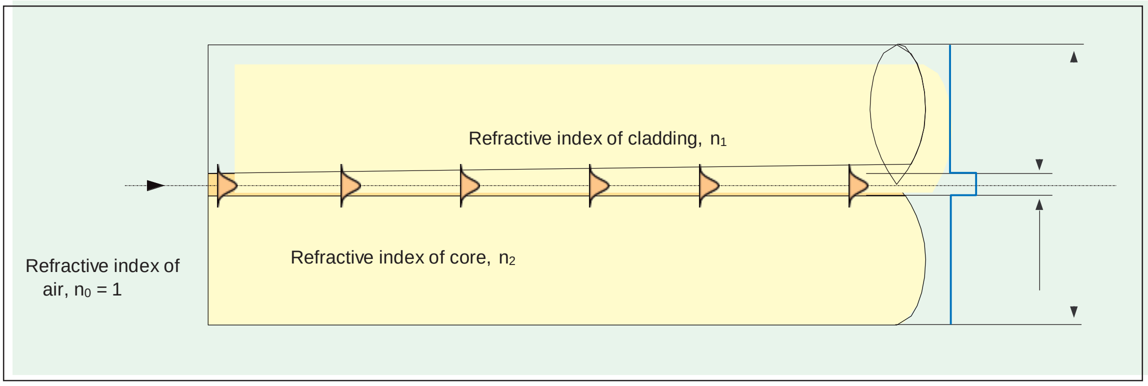
Single-mode fibers are normally used in long distance telecommunication links. For standard single-mode the lowest dispersion is around 1310 nm and the lowest attenuation is found around 1550 nm.

If the cut-off value and the mode field diameter are combined, an estimate of the fiber bend sensitivity can be obtained. High cut-off and a small mode field diameter will give a more bend resistant fiber.
The passage of light through a standard single-mode fiber, and the refractive index profile of the fiber. A fiber with the above parameters has a numerical aperture NA = 0.11 which gives an acceptance angle

It is not only the core diameter of a single-mode fiber that is significantly smaller than the core of a multimode step index fiber; the numerical aperture and acceptance angle are also considerably smaller. These three factors taken together make it more difficult to couple light into the fiber.
The cut-off wavelength for the fiber in the example above can be calculated using the following formula:

$$\lambda_c = \pi \frac{2\,a}{V_c} NA = \pi \frac{9.2}{2.405} \cdot 0.11 \approx 1322 \; [nm]$$

This calculation indicates the fiber cut-off. Fibers installed in a fiber optic cable will always have lower cut-off wavelength, the cable cut-off.




Light of this or a longer wavelength can only propagate through the fiber in the fiber's fundamental mode ($LP_{01}$ mode). The fiber is thus a single-mode fiber. The dispersion un-shifted fiber (standard single-mode fiber) where introduced commercially 1983 and the transmission and geometrical properties has since then been more and more refined by the manufacturers. All high quality fibers manufactured today easily fulfil the specifications stated in the ITU recommendation G.652. See chapter 14 "Tables" for technical specification.

# Uses of Fibre Optics

Optical fiber can be used as a medium for telecommunication and computer networking because it is flexible and can be bundled as cables

Fibers have many uses in remote sensing. In some applications, the sensor is itself an optical fibre

Optical fiber can be used to transmit power using a photovoltaic cell to convert the light into electricity

Optical fiber lamps are used for illumination in decorative applications, including signs, art, toys and artificial Christmas trees

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