Fiber Optics

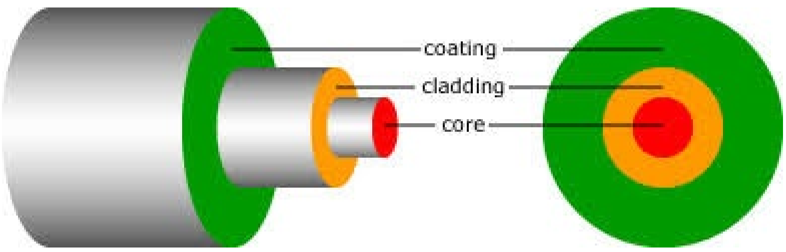
Classification, acceptance angle, numerical aperture, V-number, attenuation, ray dispersion in fibers, fiber optics sensors, optical fiber communication system.

Introduction

Fiber optics deals with light propagation through thin, transparent, flexible glass conduits. It plays an important role in today's communication to transmit voice, TV and data signals from one place to another. Though this technology was initially used for long distance communication, today fiber optics is the backbone of modern communication systems like campus wide LANs, FTTH (Airtel V-fiber, JIO-GIGAFIBER) etc. and almost all long route links.

Optical Fiber:

Optical fibers are circular dielectric wave-guides that can transport optical energy and information. They have a central core surrounded by a concentric cladding with slightly lower refractive index. These are typically made of silica with index-modifying dopants such as GeO_2. A protective coating of one or two layers of cushioning material (such as acrylate) is used to reduce cross talk between adjacent fibers and the bending loss.



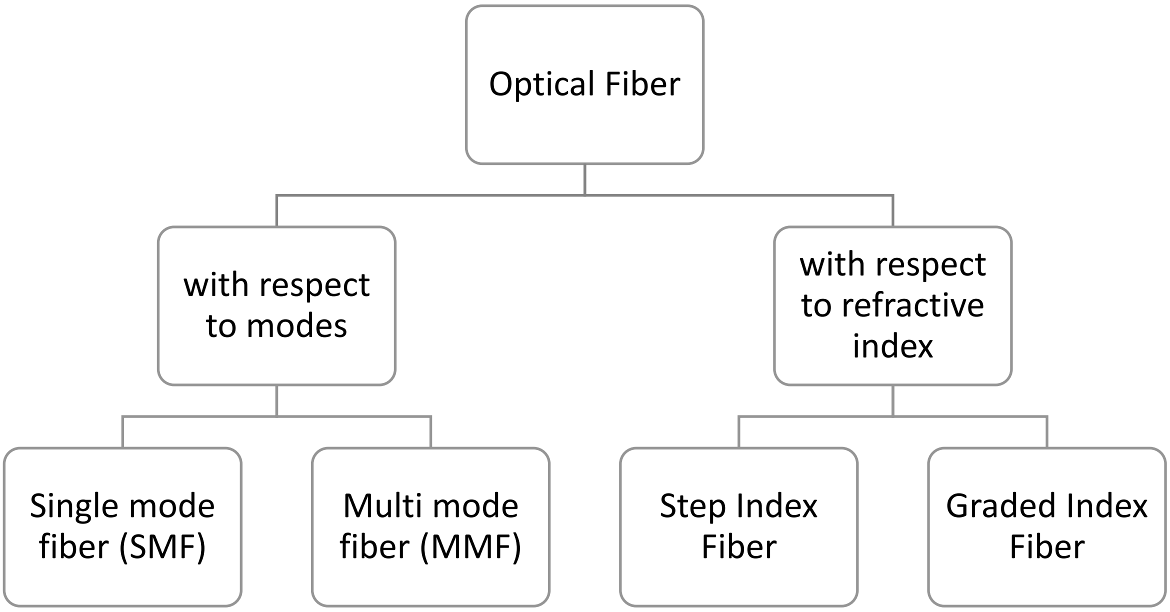
Light launched from one end of the fiber will be totally internally reflected throughout the core provided necessary conditions are met.

Fiber Modes:

Since the core has a higher index of refraction than the cladding, light will be confined to the core if the angular condition for total internal reflectance is met. The fiber geometry and composition determine the discrete set of electromagnetic fields, or fiber modes, which can propagate in the fiber.

Modes can be broadly categorized as: **radiation** modes and **guided** modes. Radiation modes carry energy out of the core; the energy is quickly dissipated. Guided modes are confined to the core, and propagate energy along the fiber, transporting information and power. If the fiber core is large enough, it can support many simultaneous guided modes. Each guided mode has its own distinct velocity and can be further decomposed into orthogonal linearly polarized components. When light is launched into a fiber, the modes are excited to varying degrees depending on the conditions of the launch — input cone angle, spot size etc.

Classification of fibers:

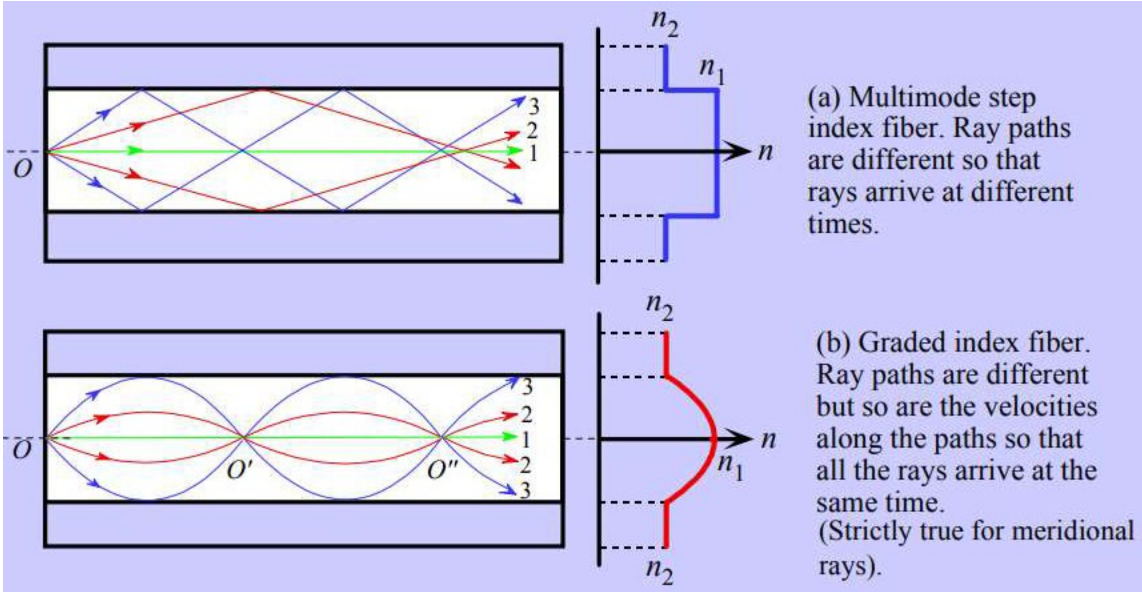


Single-mode fiber **(SMF):**
- Only one mode propagate i.e. fundamental mode
- core diameter 8 - 9 µm; cladding dia. ~ 125 µm
- Generally used for long haul communication.

Multimode fiber **(MMF):**
- Many modes propagate, fundamental, lower order, higher order modes.
- Core diameter 50- 62.5 or 100 µm; cladding dia. ~ 125 µm
- Generally used for short distance communication.

Step index fiber:

The refractive index of the core material is constant throughout the length and diameter and an abrupt change occurs in step at the core cladding boundary as shown in the refractive index profile below:



Graded index fiber:

They 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.

$$n(r) = n_1[1-2\Delta(r/a)^{\alpha}]^{1/2}$$

α is the characteristic refractive index profile of the fiber core.

The refractive index is highest at the core center and decreases gradually with distance towards the outer edge. *Graded index fiber reduces the modal dispersion hence enhances the bandwidth*.

Light propagation through Optical fibers (Ray theory)

Considering the light propagation through a step index fiber with n1 and n2 being the refractive index of core and cladding resp.[refer fig. below]

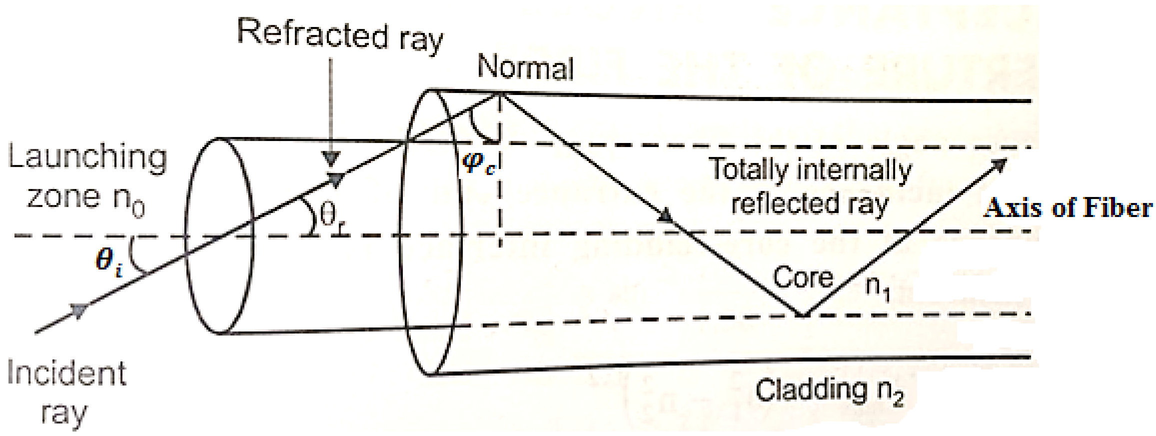
Let θi be the angle of incidence at the air/core interface w.r.t. the fiber axis, n0 is the refractive index of the outer medium and θr be the corresponding angle of refraction.

Applying Snell's law at Air/core interface yields:

$n_0.\sin\theta i = n1.\sin\theta r$

considering air as the launching/outer medium i.e. $n_0 = 1$, thus we have;

$$\sin\theta i = n1.\sin\theta r \quad (1)$$



Since from the above figure θr = 90 – ϕ [on extending the normal corresponding to the core cladding interface]. Thus eq. 1 can be modified as:

$$\sin\theta i = n1.\sin(90-\phi) = n1.\cos\phi \quad (2)$$

Our motive here is to findout the maximum value of angle θi for which the incident ray will be confined in the core. From our understanding of TIR we know that if θi approaches its maximum value, ϕ will tend toward its minimum i.e. ϕ_c (cutoff condition for TIR).

i.e. if $\theta i \longrightarrow \theta i_{max}$; $\phi \longrightarrow \phi_c$

Thus eq.2 w.r.t. θi_{max} can be modified as

$$\sin\theta i_{max} = n1.\cos\phi_c \quad (3)$$

Now applying Snells law again at Core/cladding ineterface,

$$n1.\sin\phi_c = n2.\sin.90 \text{ i.e. } \sin\phi_c = n2/n1$$

or $\cos\phi_c = [(n_1^2 - n_2^2)/ n_1^2]^{1/2}$

$$\text{Thus } \theta i_{max} = \sin^{-1}(n_1^2 - n_2^2)^{1/2} \quad (4)$$

θi_{max} is called as the **Acceptance angle** which is defined as the maximum angle an incident ray can have to undergo TIR/propagate through the fiber.

ACCEPTANCE ANGLE: Acceptance angle is the maximum angle to the fiber axis at which light may enter the fiber axis in order to undergo TIR.

ACCEPTANCE CONE: If all possible directions of acceptance angle are considered at the same time we get a cone corresponding to the surface called as acceptance cone. *Acceptance cone =* ***$2\,\theta i_{max}$.***

Numerical Aperture (NA):

NA gives the measure of light gathering ability of an optical fiber. It is also referred as figure of merit of the fiber. It is defined as:

$$NA = \sin \theta i_{max} = \sqrt{(n_1^2 - n_2^2)}$$

Fiber optic communication technology operates not with refractive indexes of the core and cladding themselves but with their difference index difference. Thus a relative refractive index parameter (Δ) can be defined as:

$\Delta = n1-n2/n1.$

NA can be written in terms of Δ as:

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

$$NA = n_1\sqrt{2\Delta}$$

Similarly Acceptance angle can also be given in terms of Δ.

V Number/V-parameter/ Normalized frequency parameter

The Normalized Frequency Parameter of a fiber, also called the V number, is a useful specification w..r.t. optical fiber. Many fiber parameters can be expressed in terms of V, such as: the number of modes at a given wavelength, mode cut off conditions, and propagation constants.

Mathematically, $$V=2\,\pi \cdot a.NA/\lambda$$

where ‘a’ is the fiber core radius, ‘λ’ is the operating wavelength.

Number of Modes: V parameter is used to approximate the number of modes of an optical fiber. If N_m denotes the number of guided modes in a step index multimode fiber then:

$N_m = V^2/2$ for step index MMF

$N_m = V^2/4$ for graded index fiber

Cutoff condition: The modal cutoff condition in term of V (a step index fiber becomes single-mode for a given wavelength) is

$0 < V < 2.405$

Solve the following

1. Numerical aperture (NA) describes the ability of:
    a. Light Scattering
    b. Light Attenuation
    c. Light Collection
    d. Light Dispersion
2. For a glass rod (refractive index 1.5) surrounded by air, the value of critical incident angle is :
    a. 38.68^o
    b. 30.08^o
    c. 81.25^o
    d. 12.15^o
3. The numerical aperture of the silica fiber with core and cladding refractive index of 1.48 and 1.46 resp.:
    a. 0.17
    b. 0.24
    c. 0.46
    d. 0.82
4. The value of V-parameter of fiber with core and cladding refractive index of 1.5 and 1.49 resp., operating at 1550 nm and core diameter of 10 μm:
    a. 3.5
    b. 28.4
    c. 2.2
    d. 14.2
5. The core radius required for single mode operation of a fiber at 1550 nm having $n_1 = 1.52$, $n_2 = 1.51$ is:
    a. 6 μm
    b. 3.41 μm
    c. 9.8 μm
    d. 22 μm
6. V-number of a step index fiber determines the number of:
    a. Leaky modes
    b. Radiation modes
    c. Guided modes
    d. Unguided modes
7. Identify the incorrect statement(s) with respect to V-number:
    a. V-no. increases on lowering the operating wavelength.

   b. V-no. decreases on lowering the operating wavelength.
   c. V-no. doesn't depend on wavelength.
   d. V-no. increases on increasing the core radius.

8. Which among the following is/are responsible for attenuation of optical power in fiber ?
   a. Absorption
   b. Scattering
   c. Dispersion
   d. All the above
9. Identify the correct statement(s) w.r.t. standard optical fibers:
   a. Single mode fibers are used for long haul communication.
   b. Core diameter of multi-mode fibers is less than that of single mode.
   c. Single mode and multi-mode fibers have different cladding diameters.
   d. Cladding diameter of both single mode and multi-mode is same.
10. Which one of the following is/are true:
   a. Graded index fiber has better bandwidth as compared to Step index.
   b. Step index fibers show no intermodal dispersion.
   c. Graded index geometry reduces intermodal dispersion.
   d. Step index and graded index fibers offers similar bandwidths.

ATTENUATION

When an optical signal propagates through an optical fibre, its power decreases exponentially with distance. **The loss of optical power as light travels down a fiber is known as attenuation**. The attenuation of optical signal is defined as the ratio of the optical input power to the output power from a fibre of length L. If P_i is the optical power launched at the input end of the fibre, then the power P_o at a distance L down the fibre is given by

$$P_o = P_i e^{-\alpha L} \qquad (1)$$

where α is called the fibre attenuation coefficient expressed in units of km^{-1}
Taking logarithms on both the sides of the above equation, we obtain

$$\alpha = \frac{1}{L} \ln \frac{P_i}{P_o} \qquad (2)$$

In units of dB/km, α is defined through the equation

$$\alpha_{dB/km} = \frac{10}{L} \ln \frac{P_i}{P_o} \qquad (3)$$

DIFFERENT MECHANISMS OF ATTENUATION

Absorption:-

Absorption is a phenomenon in which the energy of light wave is absorbed by the matter. Thus the light energy is transformed to other form of energy for example to heat. Absorption is of two types:-

Intrinsic absorption:-

If an optical fibre is truly pure with no impurities or imperfections then absorption is intrinsic. The intrinsic absorption occurs in ultraviolet region and Infrared region .

Intrinsic absorption in the ultraviolet region is caused by electronic absorption bands. Basically, absorption occurs when a photon of optical signal interacts with an electron and excites it to a higher energy level. Silica molecules used in general fibers form an electronic resonance with ultraviolet wavelengths <0.4 μm.

The main cause of absorption in the infrared region is the characteristic vibration frequency of atomic bonds. In silica glass, absorption is caused by the vibration of silicon-oxygen (Si-O) bonds. The interaction between the vibrating bond and the electromagnetic field of the optical signal causes intrinsic absorption. Light energy is transferred from the electromagnetic field to the bond and generate vibrational resonance with infrared wavelengths > 7μm. The resonance produced by the silica molecules is very small for wavelengths between 1.3μm and 1.6μm.

Extrinsic absorption :

It is caused due to the impurities in the fiber material. Metal impurities such as iron, nickel and chromium are introduced in the fibre during fabrication. When the light passes through the fiber these impurities in the glass absorb light energy which causes electronic transition in these metal ions from one energy level to another. Extrinsc absorption also occurs due to the presence of hydroxyl ions in the fiber.

Rayleigh Scattering loss : -

Rayleigh scattering accounts for the majority (about 96%) of attenuation in optical fiber. The local microscopic density variation in glass causes local variations in refractive index. These variations which are inherent in the manufacturing process cannot be eliminated and act as obstructions and scatter propagating light in all directions. This is known as Rayleigh scattering. The Rayleigh scattering loss greatly depends on the wavelength. It varies as $1/\lambda^4$ and becomes important at lower wavelengths.

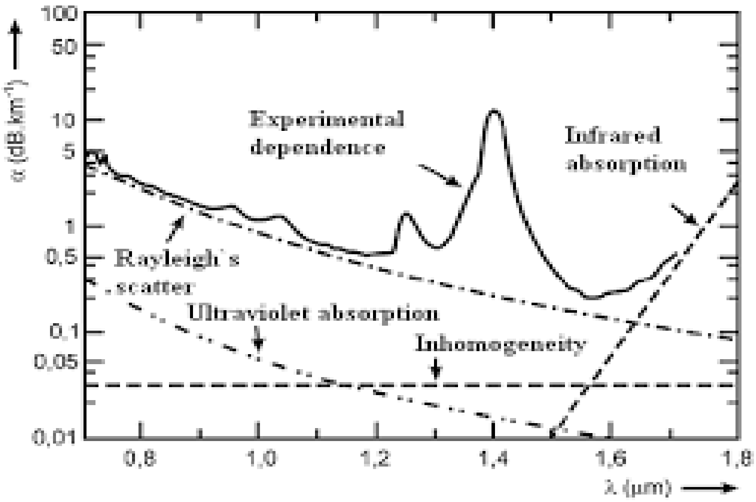


Fig. Absorption & Scattering losses as a function of Wavelength

BENDING LOSS:-

Bending losses also called radiative losses occur whenever an optical fiber undergoes a bend of finite radius of curvature. When a bend is imposed on an optical fiber, strain is placed on the fiber along the region that is bent. The bending strain affects the reactive index and the critical angle of the light ray in that specific area, as a result the condition of total internal reflections no longer satisfied. Hence, light traveling in the core can refract out and loss occurs. Fibers can be subjected to two types of bends:

Macroscopic bend:-

Macroscopic bend is a large – scale bend that is visible. Its radius of curvature is approx. of the order of cm and large as compared with the fiber diameter.

Microscopic bend: -

Random microscopic bends of fiber axis of very very small radius of curvature of the order of mm are called microscopic bends. Microbending might be related to temperature, tensile stress, or crushing force occurring during the manufacturering processes or installation processes. The bend may not be clearly visible upon inspection. Light rays get scattered at the small bends and escape in the cladding. Such losses are known as microbend losses.

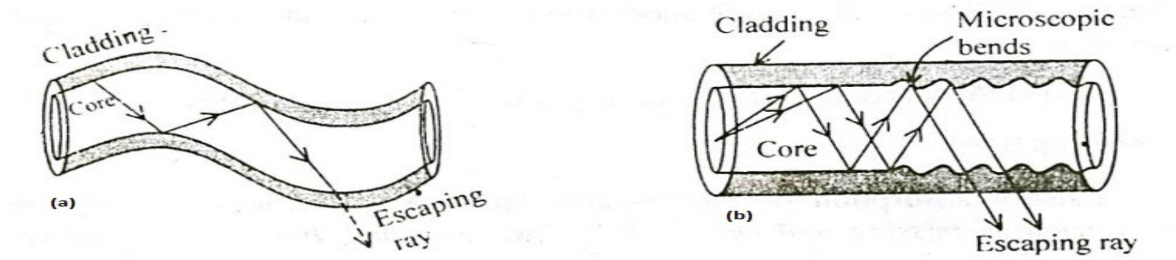


Fig. (a) Macrobend Losses & (b) Microbend Losses

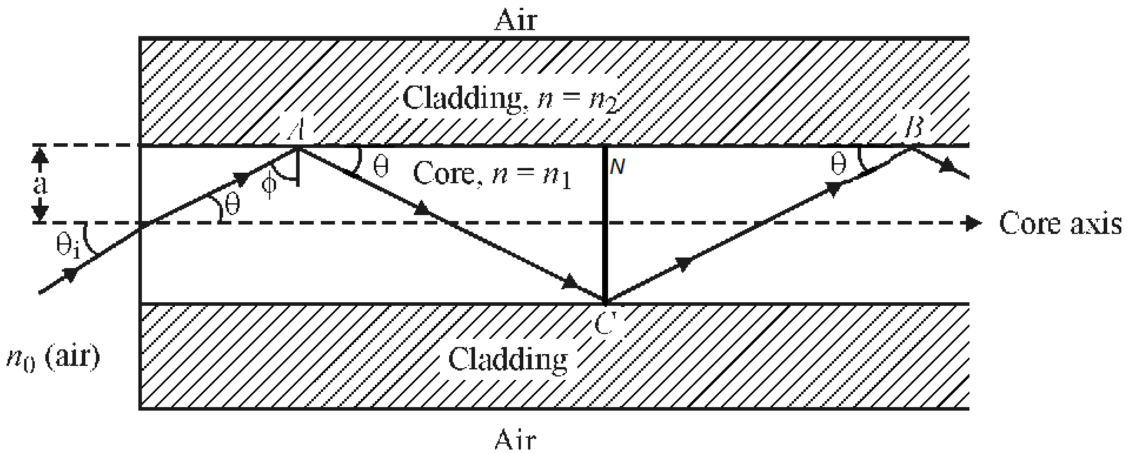
PULSE DISPERSION IN OPTICAL FIBER

In optical fiber communication system, the information is coded in the form of discrete pulses of light, which are transmitted through the fire. These pulses are of a given width, amplitude and time interval .The number of pulses that can be sent per unit time will determine the information capacity of the fiber. More information can be sent by optical cable when distinct pulses can be transmitted in rapid succession. The pulses travel through the transmitting medium i.e.; optical fiber and reach the detector at the receiving end. For the information to be retrieved at the detector, it is necessary that the optical pulses are well resolved in time. **However, the light pulses broaden and spread to a wider time interval, because of the different times taken by different rays propagating through the fiber**. **This phenomenon is known as distortion or pulse dispersion.** Hence, even though two pulses may be well resolved at the input end, they may overlap on each other at the output and as shown in figure below. It is obvious that the pulse broadening depends on the length of the travel of the pulses through the fiber. Hence, dispersion is expressed in units of ns/km (time/distance).

Fig. Pulse Dispersion

Determination of Pulse Dispersion in Optical Fiber (Ray Analysis)

Let us consider propagation of two rays of light through an optical fiber. One ray is incident at an angle of θ_i at the input end and refracts at an angle θ in the fiber core and



travels through the path ACB obeying the phenomenon of total internal reflection at core – cladding interfaces. Another ray which has normal incidence travels along the axis of the fiber. As, path lengths of both the rays are different, they reach to the output end of the fiber at different times.

Referring to the figure given above the time taken by the refracted ray to traverse the length AB of the fiber is,

$$t = \frac{AC+CB}{v} = \frac{n_1 AN}{c\ \cos\theta} + \frac{n_1 NB}{c\ \cos\theta} = \frac{n_1 AB}{c\ \cos\theta} \qquad (1)$$

where, $v = \frac{c}{n_1}$ is the velocity of light in the fiber core.

Let $AB = L$, then $t = \frac{n_1 L}{c\cos\theta}$ (2)

For the axial ray θ= 0 , hence , $t_{min} = \frac{n_1 L}{c}$ (3)

In case the ray traverse the longest path, θ= θ_c and,

$$t_{max} = \frac{n_1 L}{c\cos\theta_c} \qquad (4)$$

As, $\cos\theta_c = \frac{n_2}{n_1}$,

$$t_{max} = \frac{{n_1}^2 L}{n_2} \qquad (5)$$

Thus, time delay

$$\Delta t = t_{max} - t_{min} = \frac{{n_1}^2 L}{n_2} - \frac{n_1 L}{c} = n_1\left(\frac{n_1}{n_2} - 1\right)$$

Or $\Delta t = \frac{n_1 L}{c}\Delta$ (6)

where, $\Delta = \frac{n_1 - n_2}{n_2}$ is the index gradient

Finally, **Pulse Dispersion** $= \frac{\Delta t}{L} = \frac{n_1}{c}\Delta$ ns/km (7)

Solve the following

Q1.. What is the unit of measurement of the optical attenuation per unit length?

a. dB-km
b. dB/km
c. km/dB
d. V

Q2. The dominant loss mechanisms in silica fiber are

a. Absorption and radiation losses
b. Absorption and Rayleigh scattering
c. Coupling and radiation losses
d. Radiation and modal dispersion

Q3. Which among the following reasons is/ are responsible for an extrinsic absorption in optical fiber

a. Atomic defects in the composition of glass
b. Basic constituent atoms of fiber material
c. Impurity atoms in glass material
d. All of the above

Q4.The loss in signal power as light travels down the fiber is called

a. Attenuation
b. absorption
c. propagation
d. scattering

Q5.If 15% of the power fed at the launching end of ½ km optical fiber is lost during propagation then attenuation in dB/km is

a. 6.66 db/km
b. 1.648 db/km
c. 16.48 db/km
d. 3.33 db/km

Q6.. A 3-km fiber optic system has an input power of 2 mW and a loss characteristic of 2 dB/km. The output power of the fiber optic system is

a. 1.5 mW
b. 0.15
c. 2 mW
d. 0 .5 mW

Q7. Delay caused by the difference in the propagation times of light rays that take different paths down a fiber is called

a. Pulse dispersion
b. Attenuation
c. Rayleigh Scattering
d. none of the above

Q8. What is the pulse dispersion per unit length if for an optical fiber, 0.1μs pulse broadening is seen over a distance of 13 km?

a. 6.12 ns/km
b. 7.69 ns/km
c. 10.29 ns/km
d. 8.23 ns/km

Q9. The dispersion is expressed in units of

a. sec.
b. ms/km
c. km
d. ns/km

Q10. Pulse dispersion in optical fiber affects

a. Information carrying capacity of optical communication system
b. strength of optical fiber
c. strength of signal
d. Light propagation in optical fiber.

Fiber Optic Sensors

Fundamentally, a fiber-optic sensor works by modulating one or more properties of a propagating light wave, including intensity, phase, polarization and wavelength, in response to the environmental parameter being measured. Today fiber optic based devices play a major role in optical sensor and optical communication applications. These applications include civil, mechanical, electrical, aerospace, automobile, nuclear, biomedical and chemical sensing technologies.

Fiber Optic Sensors (FOS)

Optical fiber as the light wave guiding media has been proposed and developed since 1960s. But it is not until 1980s that the first silica based low loss fiber was fabricated for optical communication system. Since then, there has been an explosive development in fiber optical communication and fiber based systems have become the backbone of the information age. In parallel with these developments, optical fiber sensors, which have been a major user of the technology associated with the optoelectronics and fiber optic communications industries, have fascinated the researchers and tantalized the application engineers for over past three decades.

Many components associated with optical fiber communications and optoelectronic industries have been developed for optical fiber sensor applications nowadays. The capability of optical fiber sensors to displace traditional sensors for sensing applications has been increased, since component prices have fallen and the component quality has been improved greatly.

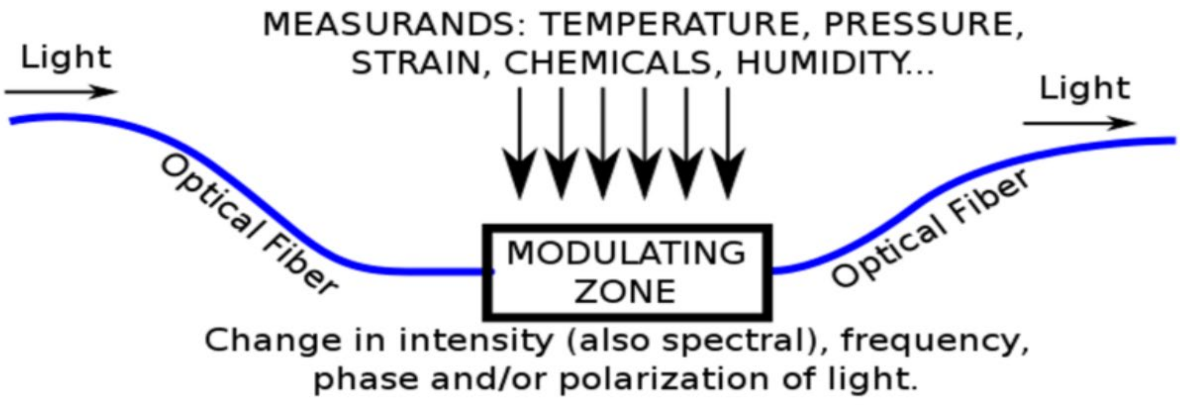


Figure : A basic fiber optic sensor system consists of an optical fiber and a light modulating arrangement.

In the 21st century, photonics technology has turned into one of the primary research fields. Fiber optic sensors have been used in diverse applications ranging from monitoring of natural structures for prediction of earthquakes and volcanic activity to medical systems like blood oxygen monitoring. For structural applications, fiber optic sensors are used for strain sensing and damage detection. These sensors have also been used for sensing temperature, pressure, rotation, velocity, magnetic field, acceleration, vibration, chemical and biological species, pH level, acoustic waves, environmental sensing and many other physical parameters.

Optical fiber sensors may be defined as a means through which a physical, chemical, biological or other measure and interacts with light guided in an optical fiber or guided to an interaction region by an optical fiber to produce an optical signal related to the parameter of interest. The fiber sensor is illustrated diagrammatically in Fig. \ref{fig:1} where light is taken to a modulation region using an optical fiber and modulated therein by physical, chemical or biological phenomena. The modulated light is transmitted back to a receiver, detected, and demodulated. The advantages of fiber-optic sensing are well known and have been widely presented. Comparing with the conventional electrical and electronic sensors, fiber-optic sensors have inherent superiority that others cannot or difficult to achieve, such as:

Perfect insulation: insensitivity to EMI (electro magnetic interference) and inability to conduct electric current.

Remote sensing: it is possible to use a segment of the fiber as a sensor gauge with a long segment of another fiber (or of the same fiber) conveying the sensing information to a remote station. Optical fiber transmission cables offer significantly lower signal loss, as compared to signal transmission in other sensors, and can maintain a high signal-to-noise ratio (SNR).

Small size and light weight: optical fibers are intrinsically small-size, which helps when building a compact measurement and acquisition system and suitable for installing or embedding into structures.

Operation in hazardous environments: optical fiber sensors have been proven to be able to work under extreme conditions, such as high temperature, high pressure, corrosive and toxic environments, high radiation, large electromagnetic fields and other harsh environments;

High sensitivity and wide bandwidth: a FOS is sensitive to small perturbations in its environment.

Distributed measurement: an optical fiber communication network allows the user to carry out measurements at different points along the transmission line without significant loss when the signal passes through it. This provides a method to monitor, control, and analyze the parameter being monitored over an extended length or area.

General classification of fiber optic sensor

Generally, optical fiber sensors may be categorized under two headings according to their operation:

- Extrinsic Fiber Optic Sensor

- Intrinsic Fiber Optic Sensor

Extrinsic optical fiber sensors are distinguished by the characteristic that the sensing takes place in a region outside the fiber as shown in Fig. \ref{fig:2}(a). The optical fiber is only used as the means of light delivery and collection. The propagating light leaves the fiber in a way that can be detected and collected back by another or the same fiber. Extrinsic FOSs can be found in schemes such as Fabry-Perot interferometers which utilize only some of the advantages optical fibers offer over competing technologies.

Intrinsic optical fiber sensors differ from extrinsic sensors, where light does not have to leave the optical fiber to perform the sensing function as shown in the figure given below. In intrinsic FOSs, the optical fiber structure is modified and the fiber itself plays an active role in the sensing function, i.e. modulation of light takes place inside the fiber to measure a particular parameter. So they are also called all-fiber sensors. Intrinsic FOSs such as fiber optic gyroscope, fiber Bragg gratings, long period gratings, microbend and coated or doped fiber sensors utilise most of the advantages offered by the technology. Intrinsic systems have attracted many researchers mainly due to their ability to be embedded into composite structures.

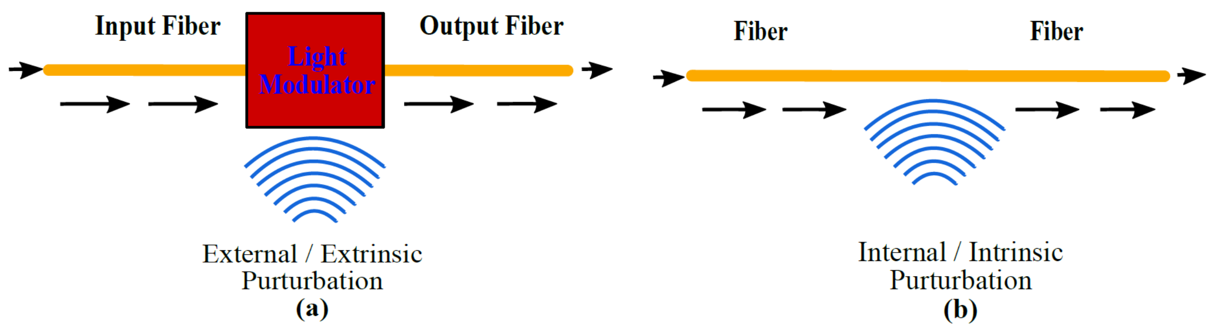


Figure : A basic fiber optic sensor system consists of an optical fiber and a light modulating arrangement

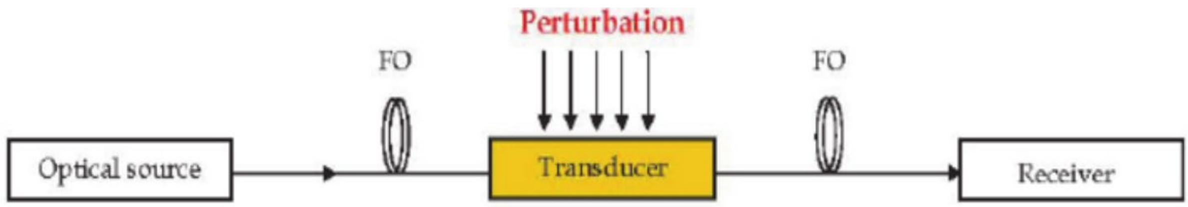
Classification of fiber optic sensor based on modulation techniques

Optical fiber sensors act as transducers and convert measurands such as temperature, strain and pressure into a corresponding change in the optical radiation. According to the general equation of an EM wave, as given by equation (1), light wave propagating along the optical fiber could be characterized in terms of four factors, which are intensity (amplitude), phase, wavelength (frequency) and state of polarization.

$$\underbrace{\vec{A}}_{\text{Filed}} = \underbrace{\vec{A}_o}_{\text{Ampl.}} \, sin \underbrace{(\vec{k}.\vec{r} - \overbrace{\omega}^{\text{Freq.}} t)}_{\text{Phase}}$$

where, $\vec{A}$ is electric or magnetic field vector of EM wave, $\vec{k}$ is the propagation vector, $\vec{r}$ is position vector, ω angular frequency of radiation and t is the time. When the surrounding environment has certain perturbation on the sensing head, at least one of the four factors change according to the influence. By measuring the light signal variation, one could obtain useful information of the

change in surrounding environment. Thus the effectiveness of the optical fiber sensor depends on its ability to convert the measurands into these parameters reliably and accurately. Following are the modulation technique based classification of FOSs also depicted in the following figure.



- Intensity modulated FOS
- Phase modulated FOS
- Polarization modulated FOS
- Wavelength modulated FOS

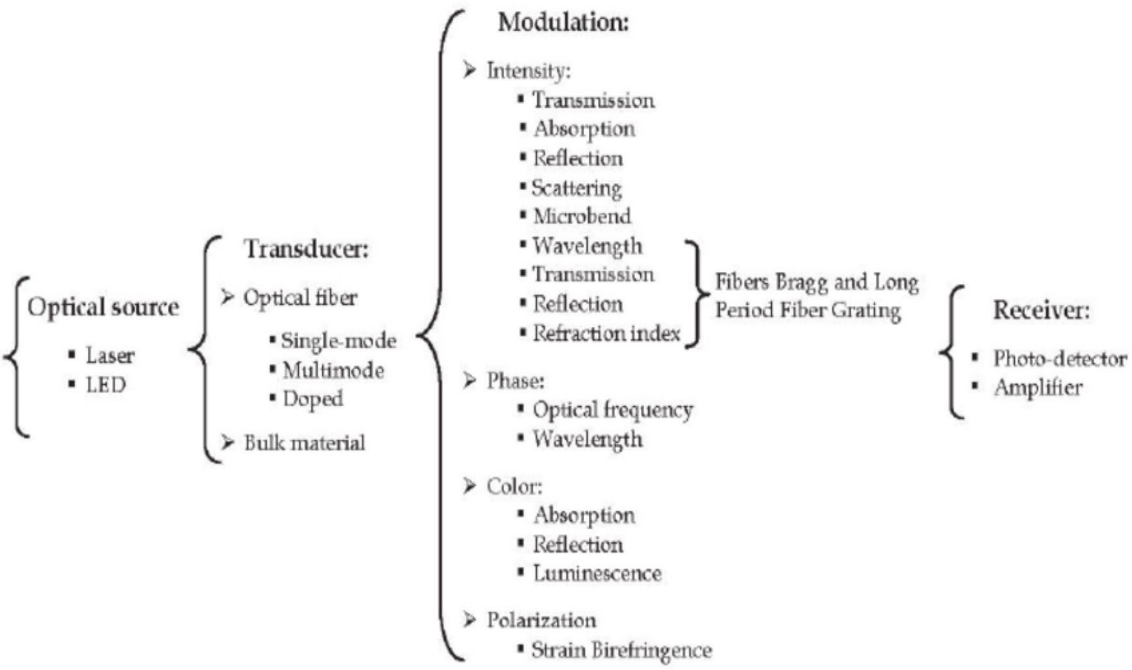


Figure: Diagram for the classification of fiber optic sensors based on different modulation techniques.

Intensity sensors are basically incoherent in nature and are simple in construction and handling, while the interferometric sensors are quite complex in design and handling but offer better sensitivity and resolution compared to intensity modulated sensor. Phase-modulated sensors usually use an interferometer and sense the output signal by comparing the phase of the received signal with a reference signal. Generally, this sensor employs a coherent light source such as a laser and two single mode fibers. In the polarization modulation based sensors, a plane polarized light is launched in the fiber and the change in the state of polarization is measured as a function of the perturbing parameter of interest.

In the case of commonly used wavelength modulated sensors, light from a broad band source is launched from one side of the fiber and the variation is sensed in terms of change in wavelength of reflected or transmitted spectrum.

Intensity modulated sensors

In an intensity modulated FOS, the measurand modulates the intensity of transmitted light through the fiber and these variations in output light is measured using a suitable detector. Measurements of optical power are easier than measurements of complicated optical properties like wavelength shift, polarization state or phase interference. Various mechanisms such as transmission, reflection, micro-bending, or other phenomenon such as absorption, scattering, or fluorescence can be associated with light loss. Depending upon which mechanism changes the intensity of a signal, a wide variety of architectures are possible for these sensors. Two of the basic configuration of intensity modulated fiber optic sensors are shown in fig \ref{fig:3}. Optical fiber intensity-based reflective sensors represent one of the initial, straightforward and, maybe, the most widely used sensors.

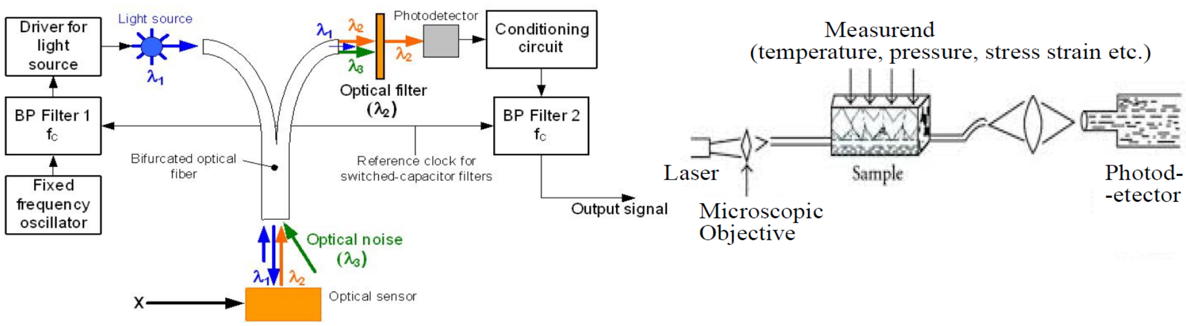


Figure: Two basic schematic of intensity modulated fiber optic sensors with the light modulating arrangement.

The intensity modulated based sensor requires more light and therefore usually uses multimode large core fibers. The popularity of these sensors is related to their simple configuration, low fabrication cost, possibility of being multiplexed, robustness and flexibility because no speciality components or fibers are required except a stable optical source, a reasonable photo-detector and signal processing unit. However, by adding suitable components to the architecture of these sensors, performance can be enhanced and sensing at multiple points becomes possible. Intensity-based fiber optic sensors have a series of limitations imposed by variable losses in the system that are not related to the environmental effect to be measured. Potential error sources include variable losses due to connectors and splices, micro bending loss, macro bending loss, deterioration of optical fiber and misalignment of light sources and detectors. Variations in the intensity of the light source may also lead to false readings, unless a referencing system is used. Intensity modulated FOS can be found in a variety of intrinsic and extrinsic configurations.

Phase modulated sensors

Phase modulated sensors use changes in the phase of light for detection. The principle attraction of optical phase modulation is its intrinsically high sensitivity to environmental modulation, so that very high resolution measurand are feasible. The optical phase of the light passing through the fiber is modulated by the field to be detected. This phase modulation is then detected interferometrically, by comparing the phase of the light in the signal fiber to that in a reference optical fiber. In an interferometer, the light is split into two beams, where one beam is

exposed to the action of the measurand and undergoes a phase shift and the other is isolated from the sensing environment and is used as a reference. Once the beams are recombined, they interfere with each other. These are used to measure pressure, rotation and magnetic field, etc. Mach-Zehnder, Michelson, Fabry-Perot, Sagnac, polarimetric, and grating interferometers are the commonly used Introduction to fiber optic sensors intereferometers. These interferometric sensors have wide applications in science, engineering and technical field. Mach-Zehnder interferometer is the most commonly used phase-modulated sensor. These sensors give a change in phase depending upon the change in length of an arm of interferometer or change in RI, or both. In general, the phase-based fiber optic sensor is more sensitive than the intensity-based fiber optic sensors.

Polarization modulated sensors

Optical fiber is made of glass. The refractive index of the fiber can be changed by the application of stress or strain. This phenomenon is called a photo elastic effect. In addition, in many cases, the stress or strain in different directions is different, so that the induced refractive index change is also different in different directions. Thus, there is an induced phase difference between different polarization directions. In other words, under the external perturbation, such as stress or strain, the optical fiber works like a linear retarder. Therefore, by detecting the change in the output polarization state, the external perturbation can be sensed. Polarization plays an important role in a system using single mode fiber. A variety of physical phenomena influence the state of polarization of light. They are Faraday rotation, electrogyration, electro-optic effect and photo elastic effect. Polarization modulation may also be introduced by a number of other means, such as mechanical twisting or by applying stress on the fiber. We can measure magnetic field, electric field, temperature and chemical species based on polarization effect. For example, magnetic field causes Faraday rotation of the plane polarized light by an angle proportional to the strength of the magnetic field. Liquid crystals (LCs) have polarization effects, so sensors based on LCs also exhibit polarization effects.

Wavelength modulated sensors

Wavelength modulated sensors use changes in the wavelength of light for detection. Truly wavelength-modulated sensors are those making use of gratings inscribed inside the optical fiber. A grating is a periodic structure that causes light or incident electromagnetic energy to behave in a certain way dependent on the periodicity of the grating. The following section will give a brief introduction to fiber grating based sensors. Fiber sensors based on intensity modulation and phase modulation principle have some problems that need to be solved in practical applications. The problems associated with source power fluctuations, coupler losses, bending losses, mechanical losses due to misalignment and absorption effects will significantly influence measurement performance of intensity based fiber sensors. Measurement accuracy of phase-based fiber sensors is often compromised due to the existence of temperature drifts and vibration.

Sample Questions

1. Design a suitable Fiber optics sensor system to use in (a) Chemical Industry (b) Mechanical Vibration measurements (c) Non-contact measurement of high current/high voltage (d) Civil structure monitoring
2. How FO sensors could be used for ``Load based traffic signal control''?
3. Discuss suitable distributed sensors for aircraft health monitoring, while flying.
4. Classify fiber optic sensors.

Fiber Optic Communication System

An optical fiber communication system is similar in basic concept to any type of communication system. A block schematic of a general communication system is shown in the figure (a) given below, the function of which is to convey the signal from the information source over the transmission medium to the destination. The communication system therefore consists of a transmitter or modulator linked to the information source, the transmission medium, and a receiver or demodulator at the destination point. In electrical communications the information source provides an electrical signal, usually derived from a message signal which is not electrical (e.g. sound), to a transmitter comprising electrical and electronic components which converts the signal into a suitable form for propagation over the transmission medium. This is often achieved by modulating a carrier, which, as mentioned previously, may be an electromagnetic wave. The transmission medium can consist of a pair of wires, a coaxial cable or a radio link through free space down which the signal is transmitted to the receiver, where it is transformed into the original electrical information signal (demodulated) before being passed to the destination. However, it must be noted that in any transmission medium the signal is attenuated, or suffers loss, and is subject to degradations due to contamination by random signals and noise, as well as possible distortions imposed by mechanisms within the medium itself. Therefore, in any communication system there is a maximum permitted distance between the transmitter and the receiver beyond which the system effectively ceases to give intelligible communication. For long-haul applications these factors necessitate the installation of repeaters or line amplifiers at intervals, both to remove signal distortion and to increase

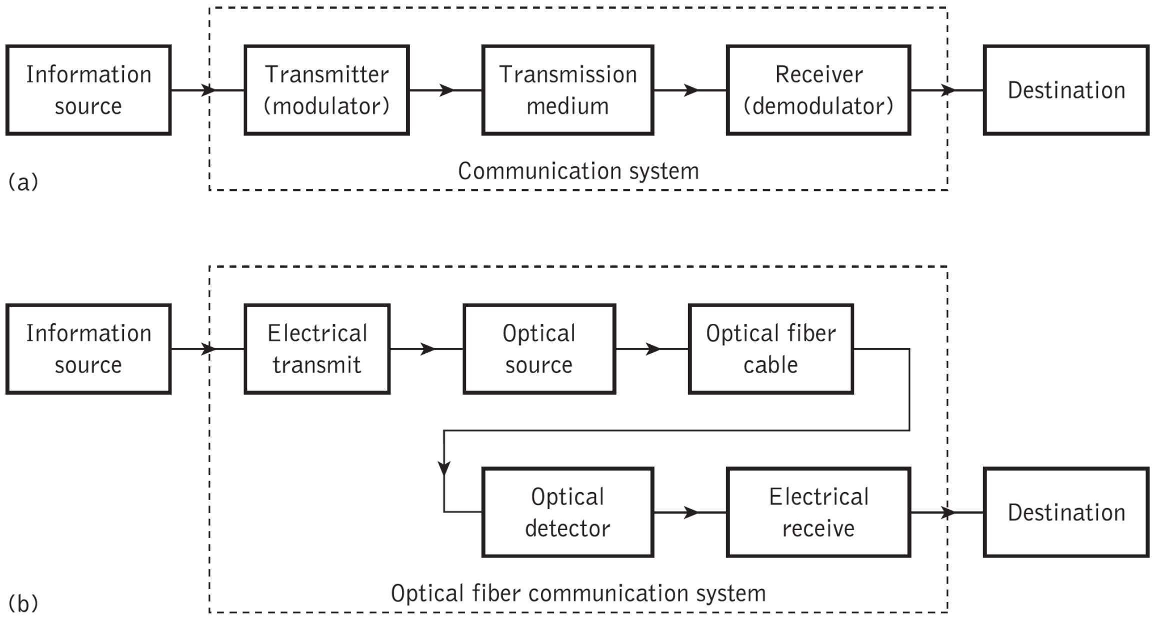


Figure : (a) The general communication system. (b) The optical fiber communication system