image forming device is needed and hence, as such, no image is formed on the hologram. What essentially is obtained is the interference pattern due to the light reflected from the object and the reference beam. Secondly, for obtaining hologram, coherent light is used whereas in case of normal photography, no such source of tight is needed. The requirement of coherent light is due to the fact that the hologram is an interference pattern. Thirdly, in holography, a set of mirrors is used to render the reference and object beam on the photographic plate.

(b) Hologram has several interesting properties. Some of them are given below:

(i) The image obtained from the hologram has three-dimensional character unlike normal photographs which are two-dimensional. Due to the three-dimensional character of the image obtained in holography, you can observe different perspective of the object by changing the viewing position. Also, if a scene has beel recorded, you can locus at different depths.

(ii) We do not obtain negative in holography. Hologram itself, however, can be considered as negative in so far as obtaining the positive is concerned. **Otherwise,** there is no similarity between the typical negative of the ordinary photographs and the hologram. You may have noticed that when the negative of an ordinary photograph is seen through, we do get a feel of the object or the scene photographed. On the other hand, when we look at a hologram we observe a hodgepodge of speaks, blobs and whorls; it has no resemblance whatsoever with the original object.

2. Let amplitude of the signal (or the object wave) be A_1 and that of the reference wave be A_2, then, as per the problem

$$\frac{A_1}{A_2} = \frac{1}{10}$$

When these two waves are out of phase, their resultant amplitude will be (10 -1) = 9. On the other hand, when they are in phase, the resultant amplitude will be (10 + 1) = 11. Thus, the ratio of their intensities,

$$\frac{I_{min}}{I_{max}} = \frac{(9)^2}{(11)^2} = 0.67$$

3. The spacing of the fringes is given as

$$d = \frac{\lambda}{\sin\theta}$$

$$= \frac{492 \times 10^{-9}}{\sin 15^\circ}\ \text{m}$$

$$= 1.8\,\mu\text{m}$$

UNIT 15 FIBRE OPTICS

Structure

15.1 INTRODUCTION

You might have seen advertisement dispalys (made of glass or plastic rods) and illuminated fountains. While looking at these, you might also have noticed that light seems to travel along curved path. In the above mentioned cases, most of the incoming light is contained within the boundaries of the medium (glass or plastic or water) due to the phenomenon of total **internal reflection.** And since the medium itself has a curved shape, the light travelling through it appears to travel along a curved path. Optical fibre, which is made of transparent glass or plastic, also transmit light in a similar fashion. These fibres are thread like structure and a bundle of it can bc used to transmit light around corners and over long distances. Since optical fibrc can transmit light around corners, it is being used for obtaining images of inaccessible regions e.g. the interior parts of human body. The real potential of the optical fibrcs was, however, revealed only after the discovery of lasers.

You may recall from Unit 13 of this course that the discovery of lasers- a source of coherent and monochromatic light - raised the hope of realising communication at optical frequencies. Since increase in frequency of the carrier wave enables it to carry more information, communication at optical frequencies ($\sim 10^{15}$ Hz) has obvious advantages over communication at radio wave ($-\ 10^{6}$ Hz) and microwave ($-\ 10^{9}$ Hz) frequencies. But, early attempts at communication at optical frequencies faced a major problem. When optical radiation travles through the Earth's atmosphere, it is attenuated by dust particles, fog, rain etc. Thus, a need for an **optical waveguide** was felt and the answer was the optical fibres. Optical fibres are an integral part of optical communication – transmission of speech, data, picture or other information – by light. In this unit, you will study about the optical fibres, especially in the context of optical communication.

In Sec.15.2, you will learn the physical principles involved in transmission of light through fibres. Types of fibres used in optical communication has also been explained. General considerations about the optical communication through fibres has been discussed in Sec. 15.3. In the same section, you will also learn about the requirements which must be met by optical fibres so that efficient optical communication may take place. The area of optical fibre is relatively new and an exciting field of activity. A thorough understanding demands rather sophisticated mathematical background on the part of the student. It has, therefore, been attempted here to keep the mathematical aspects to a bare minimum and the underlying physical principles have been highlighted.

Objectives

After going through this unit, you should be able to

- explain light transmission through fibre
- distinguish between step-index and GRIN fibres
- derive expression for pulse dispersion in fibres, **and**
- solve simple problems on optical fibres.

15.2 OPTICAL FIBRES

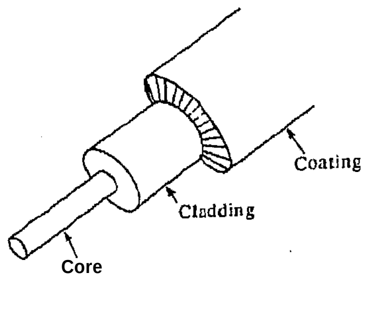


Fig. 15.1: Optical Fibre

An optical fibre consists of a cylindrical glass core surrounded by a transparent cladding of lower refractive index. This assembly is further covered by a plastic coating to protect it against chemical attack, mechanical impact and other handling damages. **Fig. 15.1** shows the geometry of a typical optical fibre. The core diamter is in the range 5 μm to 125 μm with the cladding diameter usually in the range 100 μm to 150 μm. The plastic coating diameter is around 250 μm.

In order to understand why the incoming light does not come out through the cylindrical surface of the fibre, you should recall the phenomenon of total internal reflection. You are aware that when light travels from an optically denser medium to a rarer medium, it bends away from the normal as shown in Fig.15.2(a). If the refractive indices of the two media are n_1 and n_2 such that $n_1 > n_2$, and θ_1 and θ_2 are the angle of incidence and angle of refraction respectively, then, from Snell's law

$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} \tag{15.1}$$

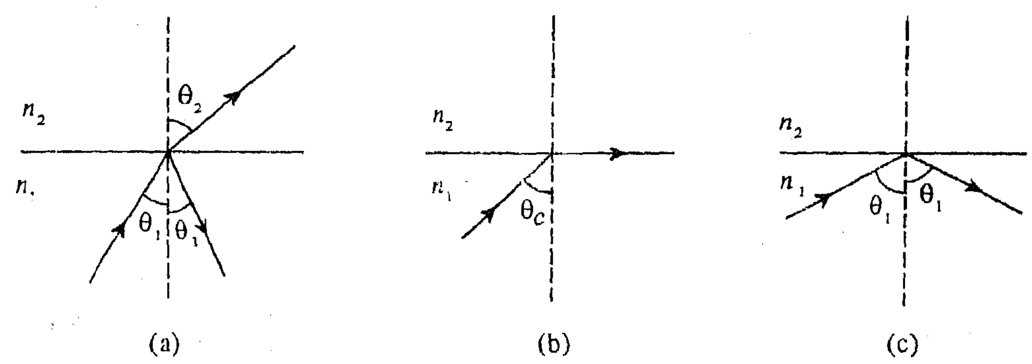
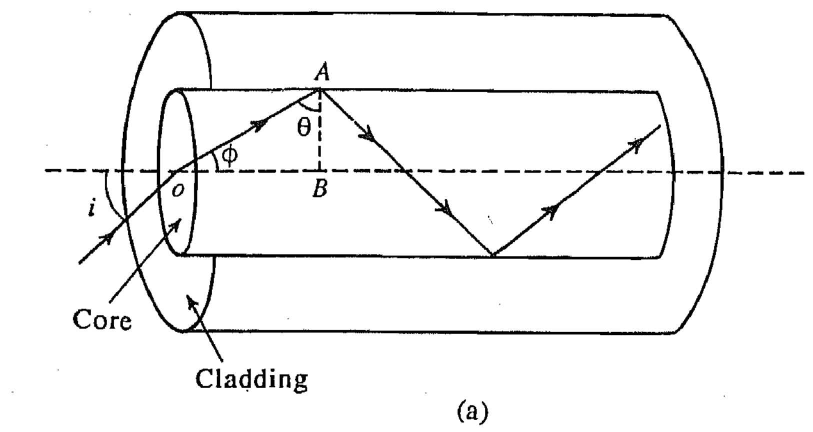


Fig. 15.2: Total internal reflection

As the angle of incidence is increased, the refracted ray will further bend away form the normal. Ultimately, when the angle of incidence reaches the critical value - known as critical angle, θ_c - the refracted ray travels along the interface separating the two media, as shown in Fig. 15.2 (b). And, when the angle of incidence is increased beyond θ_c, there is no refracted ray and the incident ray undergoes total internal reflection into the optically denser medium, Fig.15.2(c). This phenomenon is known as total internal reflection and the critical angle, θ_c is given as, from Eq.(15.1)

$$\frac{n_1}{n_2} = \frac{\sin(\pi/2)}{\sin\theta_c} \Rightarrow \theta_c = \sin^{-1}(n_2/n_1) \tag{15.2}$$

Transmission of light, based on above principle, through an optical fibre of core refractive index n_1 and cladding refractive index n_2 with $n_1 > n_2$ is shown in Fig.15.3(a).



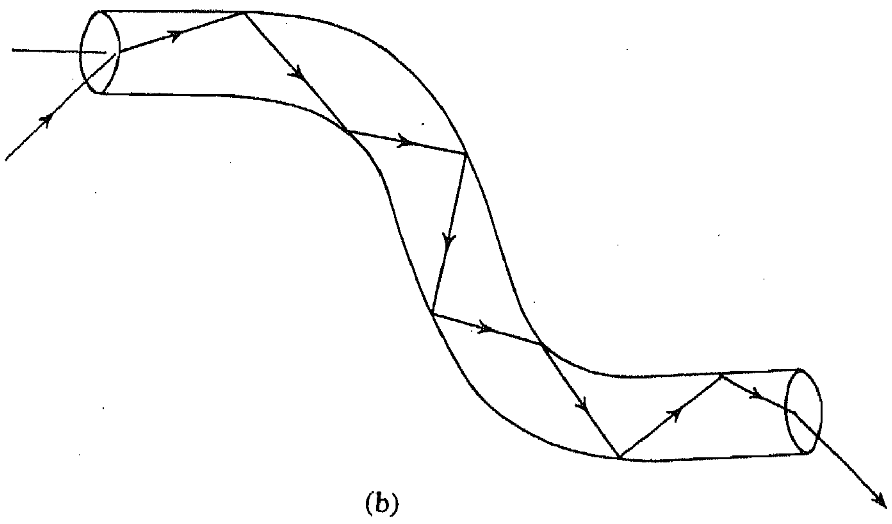


Fig.15.3: (a) Light propagation through a fibre by total internal reflection.
(b) Light propagation through a bent fibre.

When the ray of light is incident at angle $\theta(>\theta_c)$ at the core - cladding interface, it undergoes total internal reflection. Due to cylindrical symmetry of the fibre, the ray undergoes total internal reflection at subsequent incidences at the core -cladding interface and hence gets trapped inside the fibre. Due to this "guiding" properly, optical fibres are also called "**Optical Waveguides**". Fibres in the bent form can also guide the light, as indicated in Fig.15.3(b), provided that, even at curved portion, the angle of incidence is greater than θ_c. Do you know why cladding material is needed? The need for a cladding material of lower refractive index is due to two reasons. Firstly, to achieve total internal reflection at the core -cladding interface. Secondly, when light undergoes total internal reflection, a part of it penetrates into the cladding material (region of lower refractive index). This may lead to leakage of light, and it may also couple with the light travelling in adjacent fibres. The use of sufficiently thick cladding material prevents this type of loss.

You may note, from Eq. (15.2), that the critical angle for the incident ray depends on the refractive indices of the core and the cladding material. In Fig. 15.3(a), θ is the angle at which incident light falls on the core - cladding interface and this angle is different from the angle, i, at which light is incident at the entrance aperture of the fibre. It is so because the entrance aperture is an air (refractive index $n_0 \sim 1$) - glass (refractive index n_1) interface. Thus, according to Snell's law, (refer to Fig.15.3(a))

$$n_0 \sin i = n_1 \sin \phi \qquad (15.3)$$

Now, if this ray has to undergo total internal reflection at the core - cladding interface, from **Eq.(15.2)**

$$\sin \theta \geq n_2/n_1$$

from Δ OAB,

$$\sin \phi = \sin (90 - \theta) = \cos \theta$$
$$= (1 - \sin^2\theta)^{1/2}$$
$$= [1 - (n_2/n_1)^2]^{1/2}$$

Hence, Eq. (15.3), taking $n_0 = 1$, may be written as,

$$\sin i_{max} = n_1 \sin \varphi$$
$$= n_1 \left[\frac{n_1^2 - n_2^2}{n_1^2}\right]^{1/2}$$
$$= \left(n_1^2 - n_2^2\right)^{1/2}$$
$$i_{max} = \sin^{-1} \left[n_1^2 - n_2^2\right]^{1/2}$$

(15.4)

The angle of incidence, i_{max}, given by **Eq.(15.4)** is a measure of the light gathering capacity of the fibre. You should convince yourself that if the incidence angle is greater than i_{max}, the light will be refracted into the cladding material. All the light incident on the fibre aperture along the core formed by $i = 0$ to $i = i_{max}$ will undergo total internal reflection in the fibre. The quantity $(n_1^2 - n_2^2)^{1/2}$ in Eq. (15.4) is called the numerical aperture of the fibre.

15.2.1 Types of Fibres

As mentioned above, in its simplest form, an optical fibre consists of a glass core and a cladding (also of glass) of lower refractive index. This type of fibre in which there is a sudden change in the refractive index at the core-cladding interface is called Step-index fibre. The variation of the refractive index with the radius of such a fibre is shown in

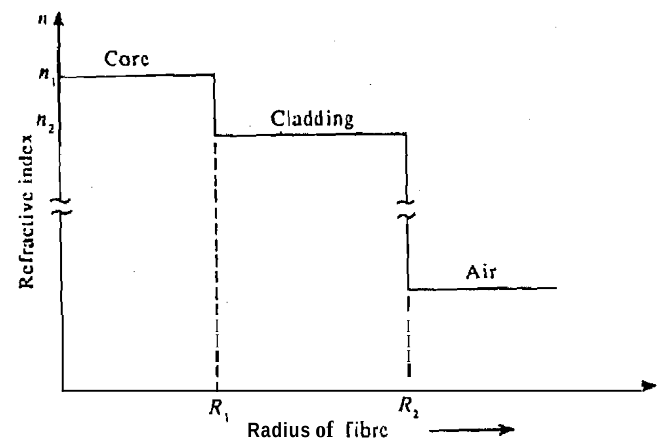


Fig.15.4: Refraclive index profile of a step-index fibre.

In optical communication, signal is transmitted through the fibre in the form of pulses.

Fig, 15.4.

Further, when light travels through the optical fibres, there are different types of losses as well as a broadening of **the** pulse. These aspects of the optical fibres are of vital importance for optical comunication and have been discussed in the next section. In order to overcome some of the inherent deficiencies of the step - index **fibres,** another type of fibre in use is called **GRadient - INdex Fibre (or GRIN** - fibre). In the GRIN

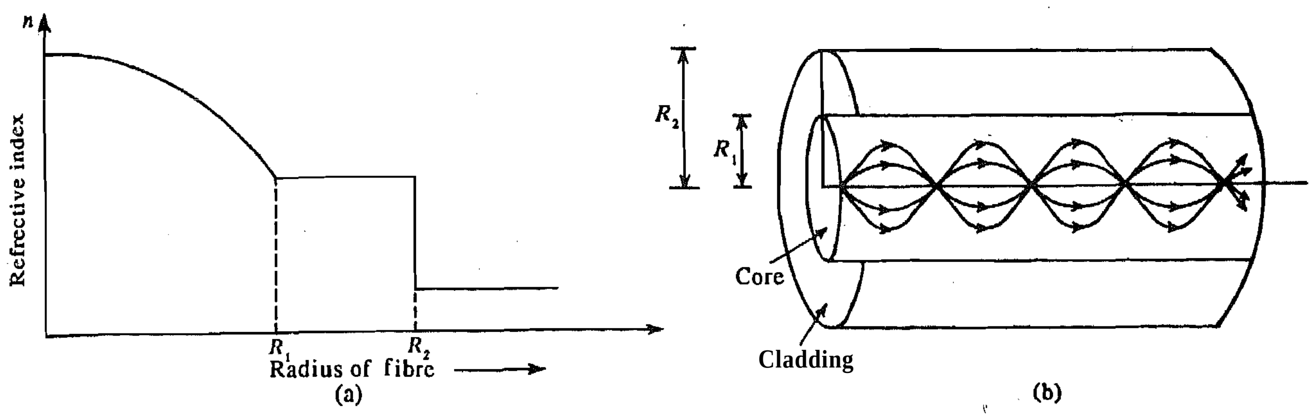


Fig.15.5: (a) The refractive index profile of a Gradient - index fibre; (b) Ray paths in such a fibre.

fibre, the refractive index of the core material decreases continuously along the radius, nearly in parabolic manner, from a maximum value at the center of the core to a constant value at the core - cladding interface. The variation of the refractive index, with radius, of a GRIN - fibre is shown in Fig.15.5(a).

Since the refractive index gradually decreases as one moves away from the axis of the fibre, a ray that enters the fibre is continuously bent towards the axis of the fibre as shown in Fig.15.5(b). Can you explain why does this happen? This smooth bending of the ray towards the axis is again a consequence of Snell's law. As the ray moves away from the centre, it encounters media of lower and lower refractive indices and hence bends towards the axis of the fibre. Can you name a natural phenomenon which results due to the atmospheric gradient of refractive index? You guessed rightly - the Mirage, which is observed while looking across on expanse of hot desert is one such example.

SAQ 1

Spend 2 min

What will happen if the refractive index of the cladding material is higher than that of the core?

Having learnt about the basic principles involved in transmission of light in optical fibres, let us study some of its important features as a component of optical communication system. But before we do that, let us see what are the uses to which optical fibres has been put to.

15.2.2 Applications of Optical Fibres

The most elementary application of the optical fibres is the transmission of light either

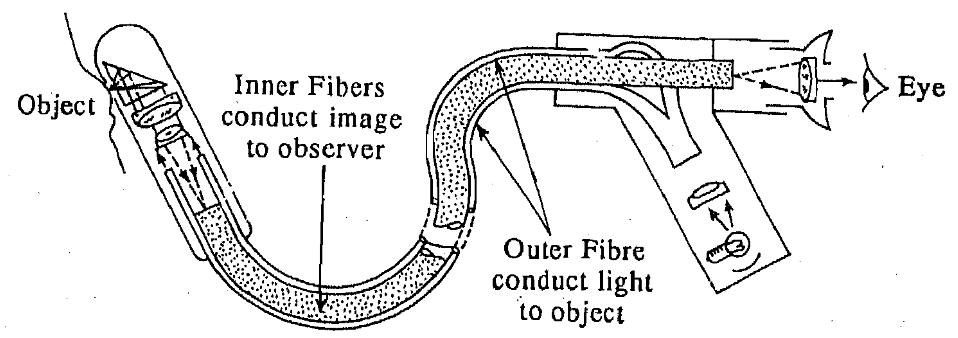


Fig.15.6: Flexible fibrescope

example of transmission of images using optical fibres is the flexible **fibrescope.** As shown in Fig. 15.6, some of the fibres conduct light into the cavity to be examined, while the others carry the image back to the observer. The image conducting fibres, **upto** 140000 of them, are by necessity very thin, often no more than **10 μm** in diameter, and the entire fibre-bundle has diameter of the order of a few mm. Fibrescope are used extensively in medicine and engineering. They make it possible to inspect a cavity in the human body and to look inside the heart while it beats.

Of increasing interest is the use of fibre guides for communication. Compared to electrical conductors, optical fibres are lighter in weight, less expensive, equally flexible, not subject to electrical interferences and more secure to interceptions. Fibres **can** now be made which has losses as low as **0.2dBkm^{-1}**. This is a remarkable achievement considering that only a decade ago the best fibres had losses in excess of **1000 dBkm^{-1}** and 20 **dBkm^{-1}** was thought to be the **limit.**

15.3. OPTICAL COMMUNICATION THROUGH FIBRE

As mentioned earlier, optical communication refers to the transmission of speech, data, picture or other information by light. You may recall from Unit 13 that the replacement of radiowaves and microwaves by light waves is especially attractive because of the enhanced information carrying capacity of the latter. Optical frequencies are some five orders of magnitude higher than, say, microwave frequencies. Therefore, larger volume of information can be transmitted through fibre cable compared to that through copper coaxial cable (used for microwave communication) of similar size. Further, in contrast with metallic conduction techniques (**e.g.** through copper cables), communication by light offers the possibility of complete electrical isolation, immunity to electromagnetic interference and freedom from signal leakage. In a typical optical communication system, the information carrying signal originates in a transmitter, passes through an optical fibre link or an optical channel and enters a receiver which reconstruct the original information. In order to minimize the distortion, the signal is encoded into digital form before transmission. In this way, retrieval of the signal at some distance down the line depends only on the recognition of either the presence or the absence **of** a pulse **representing** a binary **(0** or 1**)** digit, Minor distortion and noise may therefore be tolerated as long as pulses can be detected and regenerated, free from distortion.

You may be wondering that with above advantages, why light was not used for communication purposes. It is not as if these advantages of using tight as carrier of information were not known. Rather, it was the unavailability of a suitable source of **light** which could be modulated. Light from lasers, being highly monochromatic, can effectively be modulated by the information carrying signals. The laser light, acting as the carrier wave, respond, either directly or indirectly, to the electrical signal say, from telephone. These signals can, therefore, modulate the carrier wave which then travel through tbe optical fibre (the optical waveguide). At the receiving end of the fibre, a **photodetector** receives and demodulate these optical signal into sound waves. For long distance optical transmission line, yet another component, called **repeater** is used in optical communication system. Repeater essentially amplify and reshape the signal and retransmit it along the fibre.

Optical **communication,** as such, can be carried out thorugh open space. Then why do we need fibres to carry optical signals? The reason lies in substantial attenuation (or damping) of the signal while it travels in open space between the information source and information use. For example, communication between one sattelite to another is carried out through open space because the intervening region is essentailly vacuum. However, similar open space optical communication will not be feasible between a **satallite** and the earth or between two places on the earth because earth's atmosphere strongly influences the light transmission. Hence, the need for an optical waveguide (fibres) for terestrial optical communication.

Well, you have **learnt** in the previous section how light is transmitted through optical fibres. But, is this property of fibres enough for transmitting information carrying signals from one point to another? No, the optical fibre must have some additional characteristics if at all it has to serve as an effective optical signal carrying medium. The optical fibre should be, as much as possible, free from pulse dispersion in order to carry large volume of information. Pulse dispersion arises because different light rays take different times to travel a fixed length in the fibre. Secondly, as we know, even the light from lasers may have a spread in its wavelength. That is, even laser light is not completely monochromatic. And since the refractive index of fibre material is a function of wavelength, light of different wavelengths will travel with different velocities. This inherent property of material is yet another cause of pulse dispersion and is known as material dispersion. Further, the optical radiation will be attenuated by the material of the fibre due to scattering and other phenomenon. In the following you will learn how these problems can be tackled.

15.3.1 Pulse Dispersion in Fibres

You may recall from Sec. 15.2 that rays of light incident at the core - cladding interface at an angle greater than the critical angle θ_c undergoes total internal reflection and propagate through the fibre as shown in Fig. 15.7.

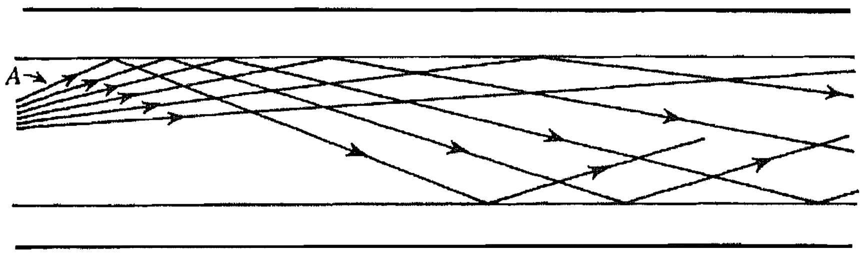


Fig.15.7: Rays of light passing through a fibre

However, the ray, marked A in Fig. 15.7, which is incident on the core-cladding interface at the largest angle will travel a longer optical path as compared to other rays incident at smaller angles. As a result, different rays will take different times in traversing a given length of the fibre. This causes broadening of the information carrying pulses, as shown in Fig. 15.8. What effect the pulse broadening has on the signal transmission capacity of

The transmission capacity of the fibre is determined by the number of pulses transmitted per unit time. For correct information retrieval, the pulses must remain resolvable i.e. they should not overlap each other.

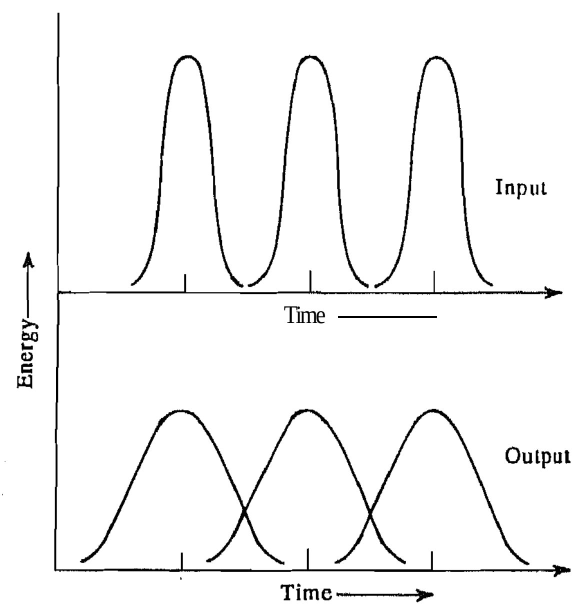


Fig.15.8: Pulse dispersion: (a) At the input, the information carrying pulses are well resolved. (b) At the output, due to brondening, pulses overlap nnd are unresolvable.

the fibre? Well, pulse broadening severely restricts the transmission capacity of the fibre. It is so because the pulses which are well resolved (Fig. 15.8a) at the input may overlap at the output (Fig. 15.8b) due to pulse broadening. To avoid this overlap, the time delay between two consecutive pulses must be increased. Therefore, the number of pulses that can be transmitted per unit time through the fibre will go down, that is, the transmission capacity of the fibre will be reduced.

To have a quantitative idea about the pulse dispersion in case of propagation through step - index fibre, refer to Fig. 15.9. Let a ray of light be incident at an angle i with the axis of the fibre. The time taken by this ray to travel a distance PR

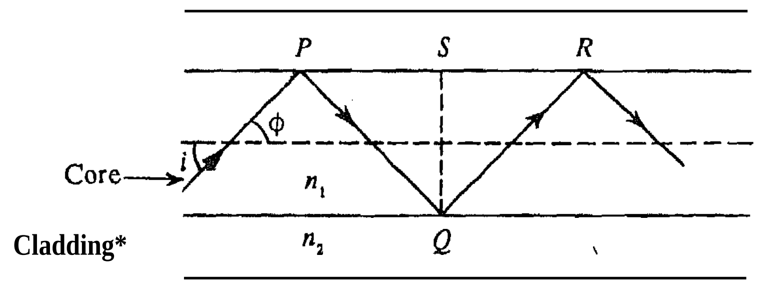


Fig. 15.9: Ray of light passing through step - index fibre.

$$t = \frac{PQ + QR}{c/n_1}$$ where c/n_1 = velocity of light in the core medium (refractive index n_1)

$$= \frac{n_1}{c} \frac{1}{\cos\varphi} (PS + QR)$$

$$= \frac{n_1 (PR)}{c \cos\varphi}$$

What does this relation indicate? It indicates that the time taken by the ray of light in travelling a distance through the fibre depends on the angle it makes with the axis of the fibre. Thus, for a fixed length L of the fibre, minimum time will be taken by a ray which travel along the axis of the fibre (ϕ =0) i.e.

$$t_{min} = n_1 L/c$$

and the maximum time will be taken by the ray for which ϕ is equal to $(\pi/2 - \theta_c)$; where θ_c is the critical angle at the core - cladding interface. Thus, $\phi = \cos^{-1}(n_2/n_1)$ and the maximum time

$$t_{max} = \frac{n_1 L}{c\,(n_2/n_1)} = \frac{n_1^2 L}{c\, n_2}$$

Thus, if all the input rays travel along the fibre simultaneously, the spread in time in traversing a distance L will be

$$\Delta t = t_{max} - t_{min}$$

$$= \frac{n_1 L}{c\, n_2} (n_1 - n_2) \quad (15.5)$$

SAQ 2

Spend 3 min

If the core and cladding refractive indices for a step - index fibre is 1.47 and 1.46 respectively, what will be the broadening of a pulse after a distance of 5 km?

Due to the pulse dispersion represented by Eq. (15.5), the signal transmission capacity of optical fibres is severly restrained. Therefore, an efficient optical fibre should have least possible pulse dispersion so that it can carry larger number of pulses per unit time.

Now the question is: Do we have any method to minimize the pulse broadening in optical fibres? Yes, there are methods by which we may minimize the pulse broadening. One of them is to use gradient - index (GRIN) fibre. In the following, you will learn how GRIN-fibres help in reducing the pulse broadening.

15.3.2 Pulse dispersion: GRIN Fibres

You may recall form Sec. 15.2 that core of the GRIN-fibre offers gradually decreasing refractive index environment to light rays as it moves away from the axis of the fibre. Let us see how this parabolic refractive indcx profile of the GRIN - fibre (Fig.15.5(a)) helps in reducing the pulse dispersion. Refer to Fig.15.10 in which two rays A and B are shown to enter the core axis at differnt angles. As the rays move towards the core - cladding interface, they encounter decreasing refractive index environment. As a result, both of them will bend away from the normal and hence towards the axis of the core. The paths taken by rays arc not straight lines as in the case of step - index fibre; rather, it is sinusoidal. It is because in the core, refractive index is a continuously decreasing function of the core radius. Now, ray A which makes the smaller angle with the axis travels smaller distance through tlic core whereas ray *B* travels a longer distance. However, the time taken by both of them, seperately, in traversing a fixed distance along the fibre will be same. Can you say why? It is so because ray A which travels a shorther

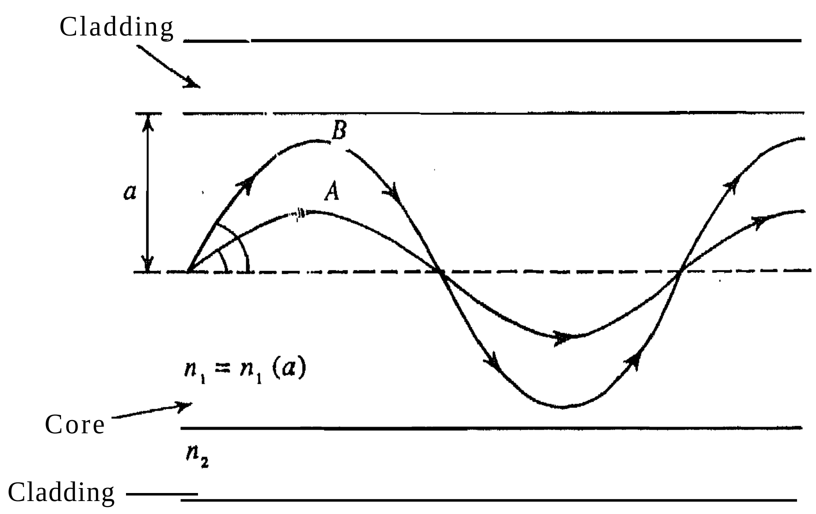


Fig.15.10: Two rays Annd B travelling through a GRIN- fibre.

distance, does so in the region of higher refractive indcx. Hence the velocity of light along the path taken by ray A will be smaller (velocity of light $= c/n$). On the other hand, ray *B* which travels a relatively larger distance, does so in the region of lower refractive index and hence with higher velocity. The net result is that the rays making different angles with the core axis take equal time in propagating through the fibre. Due to this reason, the pulse broadening is reduced in GRIN-fibre.

The volume of information which may be transmitted through GRIN - fibre is more or less free from pulse broadening due to above reason. The information carrying capacity of such fibre is only limited by material dispersion about which you will learn in the following.

1533 Material Dispersion

Above we discussed about the pulse broadening in optical fibres arising because of the fact that light rays incident at different angles at the core-cladding interface take different times to traverse a fixed length of fibre. We also discussed how to reduce this dispersion by using GRIN-fibre. Now, suppose that the light beam travelling through the fibre is free from the pulse broadening due to above mentioned reason. Does it mean that the beam is free from pulse broadening? No, there is yet another source of pulse broadening known as material dispersion. Material dispersion arises due to the variation of refractive index with wavelength, i.e. the velocity of light in the medium is dependent upon its wavelength. You are aware that light even from a highly pure source (like laser which give highly monochromatic light) will have a spread in its wavelength. Therefore, different wavelengths, with in the range, will travel with different velocities and hence will arrive at the end of the fibre at different times and cause broadening of the pulse. You may note that the material broadening is an intrinsic physical property of the fibre material.

Although glass is transparent to electromagnetic radiation in the visible range, it does absorb a part of it due to several processes. As a result, the input power of the light beam will suffer a loss while traversing the length of the fibre. In the following, we briefly discuss some of these processes causing power loss in fibres.

15.3.4 Power Loss

When electromagnetic radiation interacts with matter, it may lose energy via different mechanisms. In case of optical fibre material, silica, major loss in energy or power is caused due to absorption of photons by impurity atoms. Therefore, to minimize this loss, the fibre material should be of high purity. Secondly, the photons may also lose energy by exciting the atoms of oxygen and silicon (the building blocks of silica, SiO_2). Thirdly, silica being amorphous material, it offers randomely varying refractive index. Due to this, the propagating light beam may get scattered and its direction of propagating may change drastically. These loss causing mechanisms are taken care of by proper design and synthesis technique of the fibres.

The power loss we are talking about is expressed in terms of bel or decibel which are comparable units. One bel means that power in one channel or at one time is 10 times that in another channel, or at another time. 2 bel means 100x, 3 bel means 1000x and so on. For practical use, the unit bel is too large. Hence the decibel, dB, is used. 1 bel = 10 dB. A decibel (dB) is equal to $10\log_{10}(p_2/p_1)$ where p_1 and p_2 are input and output powers levels. Thus, if the power level of an optical signal reduces by half, the power loss in decibels will be $10\log_{10}(1/2) = -3dB$. In optical fibre communication, the power loss is expressed as $dBkm^{-1}$. In long distance optical communication through fibres, the permissible loss is $20dBkm^{-1}$. With modern techniques of synthesis, optical fibres with power loss as low as $\sim 0.2dBkm^{-1}$ can be produced.

15.4 SUMMARY

- An optical fibre consists of a transparent glass core and a cladding of lower refractive index. Since the refractive index of the cladding material is lower than that of the core, much of the light launched into one end will emerge from the other end due to a large number of total internal reflections.
- In the step-index fibre, the refractive index changes suddenly at the core-cladding interface. On the other hand, in the gradient-index (GRIN-) tibres, the refractive index decreases continuously from the core a& as a function of radius.
- The maximum entrance core angle, also known as acceptance angle, is a measure of the light gathering capacity of the fibre and is given as

$$\sin i_{max} = \frac{1}{n_0}\left[n_1^2 - n_2^2\right]^{1/2}$$

The term $\left(n_1^2 - n_2^2\right)^{1/2}$ is known as the **numerical** aperture of the fibre.

- **In** optical communication, information is transmitted in the form of pulses. While travelling through the fibres, these pulses broaden because rays incident at different angles at the core- cladding interface take different times in traversing a fixed length of the fibre. Pulse broadening due to this reason in a step-index fibre of length L is given as,

$$\Delta t = \frac{n_1 L}{c\, n_2}\left[n_1 - n_2\right]$$

- Pulse broadening can be greatly reduced if, instead of step-index fibre, we use a GRIN- fibre. It is so because in GRIN-fibre, though different rays traverse different optical paths in the core, they all take same time in travelling through a given length of the fibre.
- Material dispersion is yet another cause of pulse broadening. Material dispersion arises because the refractive index (and hence the velocity of light) a medium is a function of wavelength of light. And, even highly monochromatic light has a spread in its wavelength.

15.5 TERMINAL QUESTIONS

1. Suppose you have two optical fibres A and B. The refractive indices of the core (n_1) and the cladding (n_2) materials is

   $(n_1)_A = 1.52$, $(n_2)_A = 1.41$, $(n_1)_B = 1.53$, $(n_2)_B = 1.39$

   Which of the two fibres will have higher light gathering capacity?

2. A step-index fibre 6.35×10^{-5} m in diameter has a core of refractive index 1.53 and a cladding of refractive index **1.39.** Determine (a) the numerical aperture for the fibre; (b) the acceptance angle (or **maximum** entrance cone angle).

15.6 SOLUTIONS AND ANSWERS

SAQs

1. If the refractive index of the cladding material is higher than that of the core material of the fibre, the incoming light will not undergo total internal reflection. It is so because when the light travels from a rarer to denser medium, it bends towards the surface normal. Thus, the light ray incident on the core-cladding interface will, instead of coming inside the core, get refracted in the cladding material (refer to Fig. 15.2).

2. The pulse broadening is given as

$$\Delta t = \frac{n_1 L}{c\, n_2}(n_1 - n_2)$$

As per the problem,

$L = 5 \times 10^3$ m, $n_1 = 1.47$, $n_2 = 1.46$ and $c = 3 \times 10^8$ ms^{-1}

So,

$$\Delta t = \frac{1.47 \times 5 \times 10^3\,(\mathrm{m})}{3 \times 10^8\,(\mathrm{ms}^{-1}) \times 1.46}(1.47 - 1.46)$$

$$= \frac{7.35 \times 10^3\,(\mathrm{m})}{4.38 \times 10^8\,(\mathrm{ms}^{-1})}(0.01)$$

$$= 0.17\,\mu\mathrm{s}$$

TQs

1. Refer to Fig. 15.3. The maximum angle of incidence, i_{max}, of the light beam at air-core interfacc is the measure of the light gathering capacity of the fibre. The sine of this angle of incidence is given as

$$\sin i_{max} = \frac{1}{n_0}\left[n_1^2 - n_2^2\right]^{1/2}$$

where, n_0, n_1 and n_2 arc the refractive indices of air, core and cladding respectively.

n_o = refractive index of air = 1.

For the fibre A,

$n_1 = 1.52$ and $n_2 = 1.41$

$\sin i_{max} = [(1.52)^2 - (1.41)^2]^{1/2}$

$= [0.3223]^{1/2}$

$(i_{max})_A = \sin^{-1}[0.57] \cong 35°$

For the fibre B,

$n_1 = 1.53$ and $n_2 = 1.39$

$\sin i_{max} = [(1.53)^2 - (1.39)^2]^{1/2}$

$(i_{max})_B = \sin^{-1}[0.64] \cong 40°$

Hence, the light gathering capacity of fibre B is greater than fibre A.

2.a) The numerical aperture of the fibre is given as,

N.A. $= [n_1 - n_2]^{1/2}$

$= [(1.53)^2 - (1.39)^2]^{1/2}$

$= 0.64$

b) The acceptance angle or the maximum entrance angle, i_{max}, corresponds to θ_c, the critical angle for total internal reflection at the core-cladding interfacc.

$$\sin i_{max} = \frac{1}{n_0}[\text{N.A.}]$$

$= 0.64$

$\Rightarrow i_{max} = \sin^{-1}[0.64]$

$\cong 40°$

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