07/07/23

UNIT- IV

LASER

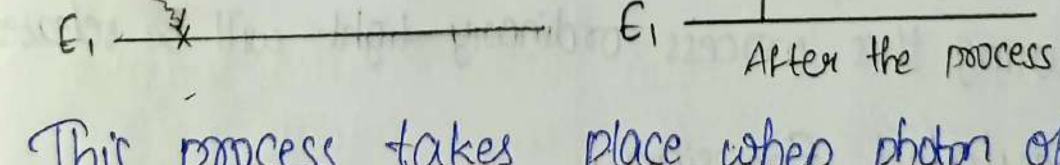
Light Amplification by Stimulated Emission of Radiation — Due to spontaneous Emission

Basic definitions of the laser

1. Stimulated Absorption
2. Stimulated Emission — LASER
3. Spontaneous Emission

Stimulated Absorption :

The process of particle transfer from lower energy level to higher energy level by using external energy is called stimulated absorption and the process is shown in the below diagram

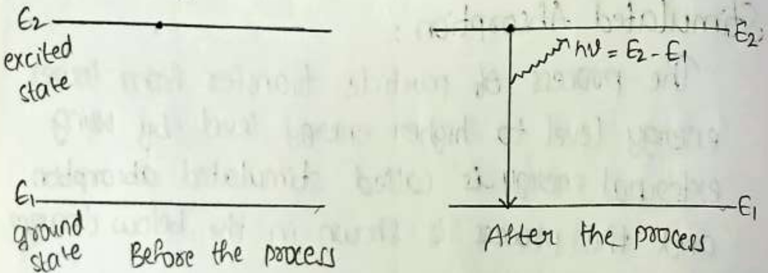


This process takes place when photon of energy $h\nu$ having energy difference between two energy levels $(E_2 - E_1)$ falls on an atom at ground state.

Spontaneous Emission :

The process of particles in an atom transfer from higher energy level to lower energy level without external energy is called "<u>spontaneous emission</u>."

- This process takes place naturally when particle moves from ~~higher~~ excited state to ground state after the lifetime in the excited state (10^{-8} secs) as shown in the below diagram.

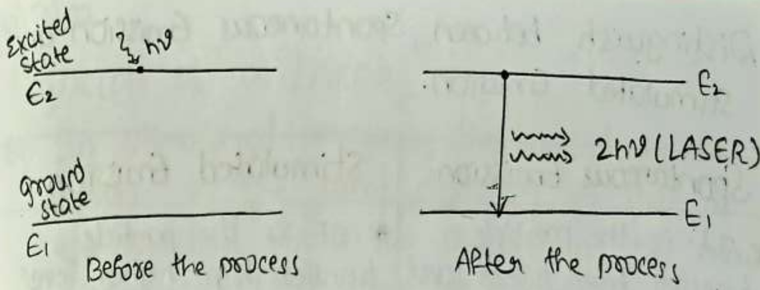


- During this process a photon having energy $h\nu$ which is equal to energy difference between E_2 & E_1 will be produced.
- During this process ordinary light will be released.

Stimulated Emission :

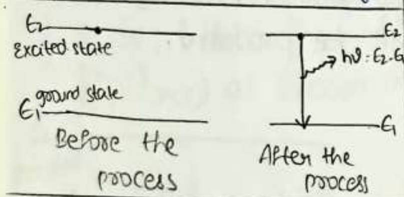
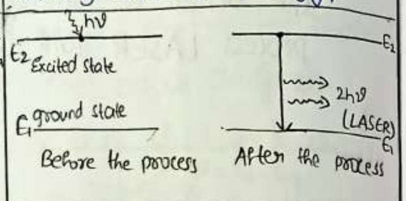
The process of particle in an atom from higher level to lower level with the help of external energy is called "<u>stimulated</u> <u>emission</u>."

- During this process two photons are produced as shown in the diagram



- Out of which one is stimulating photon and the other is stimulated photon. During this process LASER light will be produced.

Distinguish between Spontaneous Emission and Stimulated Emission.

Spontaneous Emission	Stimulated Emission
* It is the particle transfer from higher level to lower level without taking external energy.	* It is the particle transfer from higher level to lower level ~~with~~ by taking external energy.
	
* Single photon released during this process.	* Two photons releases during this process.
* Ordinary light will be produced.	* LASER light will be produced.
* The emitted photons travels all direction and they are random.	* The emitted photon travels in the direction of incident photons.
* The emitted radiation is less intense and is incoherent.	* The emitted radiation is more intense and is coherent.
* The photons are not in phase i.e., there is no phase relation between them.	* The photons are in phase i.e., there is constant phase difference between them.
* It is slow process when compared with stimulated emission.	* It is fast process when compared with spontaneous emission.

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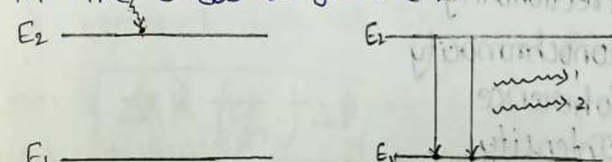
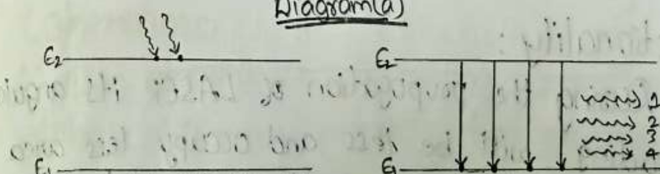
Principle of a LASER:

* In stimulated emission, the emitted light travels in the same direction as that of the incident photon as shown in the below diagram (a). Now these emitted two photons stimulate two more atoms (photon) from excited state to ground state as a result of that four photons will be released as shown in the below diagram (b).

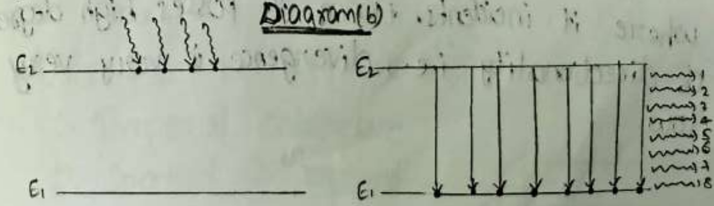
* These four photons again stimulates four more atoms in the excited state as a result of that eight photons will be produced as shown in the below diagram (c).



Diagram(a)



Diagram(b)



Diagram(c)

* Again these 8 photons stimulates 8 more atoms in the excited state as a result of that 16 photons will be released.
* These ~~multication~~ multiplication process continuous till the radiation produced in a laser device gets LASER properties. This process is called principle of LASER.

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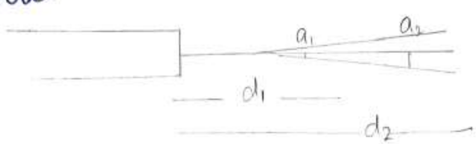
Characteristics of LASER

LASER light is different from conventional light source (ordinary light) in a number of ways. The following are the characteristics of the LASER beam they are:

1. Directionality
2. Monochromacity
3. Coherence
4. Intensity

Directionality:

During the propogation of LASER its angular spreading will be less and occupy less area where it incidents. Hence it posses high degree of directionality i.e., divergence is very very low.



As shown in the diagram if a_1 & a_2 are the diameters of LASER light after travelling a distance of d_1 & d_2, then the angle of divergence can be expressed as

$$\boxed{\phi = \frac{a_2 - a_1}{2(d_2 - d_1)}}$$

Monochromacity:

The property of exhibiting a single wavelength by a light is called "monochromacity".

- When it is sent through a prism then a single line will be appeared in the optical spectrum.
- The degree of a monochromacity of a LASER is expressed with the following equation

$$\boxed{\Delta\lambda = \left(\frac{-c}{\nu^2}\right)\Delta\nu}$$

Coherence:

The property of exhibiting zero (or) constant phase difference between two or more waves is known as "coherence".

- Coherence is of two types
  1. Temporal coherence
  2. Spatial coherence

① Temporal Coherence

If there exist either zero (or) constant phase difference between two light fields measured at two instants at same point then the wave is said to have temporal coherence.

② Spatial coherence

If there exist either zero (or) constant phase difference between two points on a wave front measured at single instant of time then the wave is said to have spatial coherence.

Intensity

LASER light is highly intense light source and also brighter. This is because of coherence and directionality. Due to negligible divergence LASERs are highly intense and are able to produce high temperatures.

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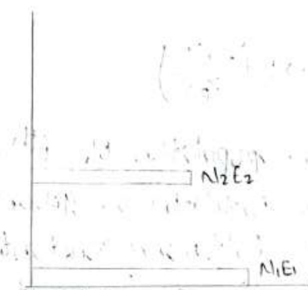
Population Inversion

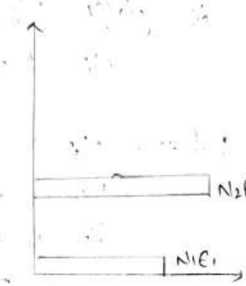
In general the number of atoms in lower energy level is always larger than the number of atoms in higher energy level i.e., $N_1 > N_2$.

- Actually to get a LASER beam from LASER device their should be more number of atoms in higher energy level when compared with number of atoms in the lower energy level i.e., $N_2 > N_1$.
- For this population of ground state and excited state should be inverted i.e., making more number of atoms in higher energy level when compared with lower energy level is known as population inversion.



$N_1 > N_2$

Before Population Inversion



$N_2 > N_1$

After Population Inversion

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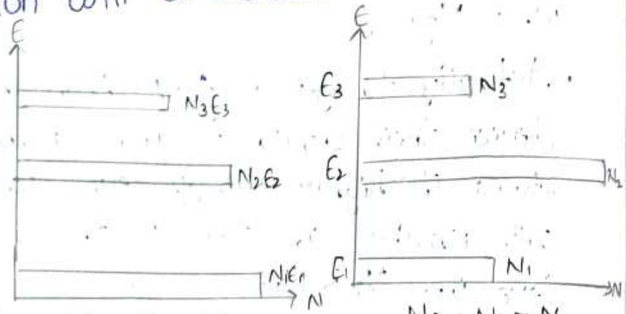
In three level energy scheme is shown in the below diagram, when we supply energy to the atoms it makes a transition from E_1 to E_2 as a result of that population inversion will be acheived.



$N_1 > N_2 > N_3$ $\quad$ $N_3 < N_2 > N_1$

Before Population Inversion $\quad$ After Population Inversion

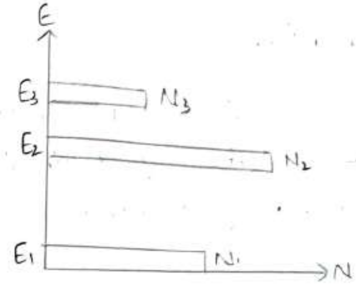
As we move from lower energy level to higher energy level, population decreases as per equation called Boltzmann Distribution law is given by

$$\boxed{N_i = N_0 \exp\left(\frac{-E_i}{K_B T}\right)}$$

where N_i is the population of i^{th} energy level
N_0 is the population of ground state.
K_B is the boltzmann constant
T is the absolute temperature
E_i is the energy of ith energy level

Metastable state

The excited state having longer life time is called "metastable state". It is the energy state which posses a lifelite of the order of 10^{-3} secs.



$N_3 < N_2 > N_1$

- The role of metastable state is very important in achieving population inversion which is essential to get a beam from a LASER device. In the diagram, E_1 is the ground state, E_2 is the first excited state (meta stable state) and E_3 is the second excited state.
- Population inversion is acheived always in metastable state and its lower energy state.
- Because of its longer life time meta stable state accomodates more number of atoms and it recollects the more and more photons.
- At one moment population of metastable state increases when it compares with its lower energy state.

- As soon as population inversion condition is acheived between metastable state and its lower energy state, all the atoms makes transition and emits the LASER beam.

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Pumping Mechanism

The process of raising more number of atoms to excited state by artificial sources is called as pumping process.

(or)

The process of achieving population inversion is called pumping process.

- There are several methods by means of which population inversion can be achieved.
- Some of the most common methods are:
  1. Optical Pumping
  2. Electric Discharge Pumping.
  3. Inelastic atom - atom collision
  4. Direct conversion
  5. Chemical reaction

Optical Pumping:

Here the atoms are excited with the help of photons emitted by an external optical source. The atoms absorbs energy from the photons and rises to excited state.

- These types of pumping mechanisms are used in solid state LASERs.

Eg: Ruby LASER, Nd-YAG LASER

Electric Discharge Pumping:

Here the electrons are accelerated to very high velocities by strong electric field and they collides with gas atoms, so that they will raised to excited states.

- These types of pumping mechanisms are generally used in gas LASERs.

Eg: He-Ne LASER, CO_2 LASER

Inelastic atom - atom collision:

In this method a combination of two types of gases are used, i.e., A and B. Both moving nearly coinciding excited states i.e., A* & B*.

- During electric discharge method 'A' atoms gets excited due to collision with electrons i.e., $\bar{e} + A \longrightarrow A^*$

- This excited A^* atoms now collides with 'B' atoms, so that B goes to excited states and become B^*.

  i.e., $A^* + B \longrightarrow B^*$

- These type of pumping mechanisms is generally used in gas LASERs only.

  Eg: He-Ne LASER, CO_2 LASER

Direct conversion:

Due to electrical energy applied in direct band gap semiconductors like GaAs etc., the combination of electrons and holes takes place hence electrical energy is converted into light energy directly.

Eg: Semiconductor LASER

Chemical Reaction:

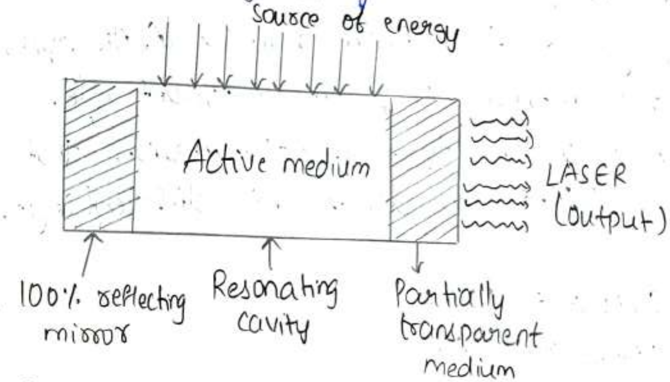
Due to some chemical reactions the atoms may be raised to excited states.

Eg: Dye LASERs

Block Diagram of a LASER

Block diagram of a LASER consist of three parts. They are:

1. Source of Energy
2. Active medium
3. Resonating cavity



Source of energy

In order to send particles from lower energy level to higher energy level i.e., to acheive the process of population inversion, source of energy is required.

- Using source of energy we can supply the energy to the particles (atoms) to the ground state, like this so many ways using different pumping mechanisms.

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Active Medium:

The medium in which population inversion takes place is called active medium.

- Active medium provides required energy levels for lasing action. To get the LASER beam from the lasing action.
- To get a LASER beam from a LASER system, active medium plays an important role.
- Based on the type of active medium that is used, LASERs are divided into different types like
  (i) Solid state LASER
  (ii) Liquid state LASER
  (iii) Gas LASERs
  (iv) Semiconductor LASERs
  (v) DYE LASERs

Resonating Cavity (or) Optical Resonator

The optical resonator constitutes an active medium kept in between 100% reflecting mirror and partially reflecting mirror as shown in the diagram.

- The optical resonator acts as a feed back system in amplifying the light which is emitted from the active medium by making it to undergo multiple reflections between 100% reflecting mirror and the partially reflecting mirror.
- Here the light bounces between the two mirrors and hence the intensity of light increases enormously. Finally, the intense amplified light is called LASER, which is allowed to come out through the partially reflecting mirror as shown in the diagram.

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Nd - YAG LASER

- Nd - YAG is a Neodinum based LASER. It is called Neodinum - Yitrium Aluminium Garnet ($Y_3 Al_5 O_{12}$). It is a four level solid state LASER.

Principle

The active medium in this case is Nd-YAG material, which is optically pumped by crypton flash tube. The neodinum ions (Nd^{3+}) are raised to excited state with the help of crypton flash tube.

- During the transition from metastable state to ground state a LASER beam of wavelength 1.063μm is emitted.

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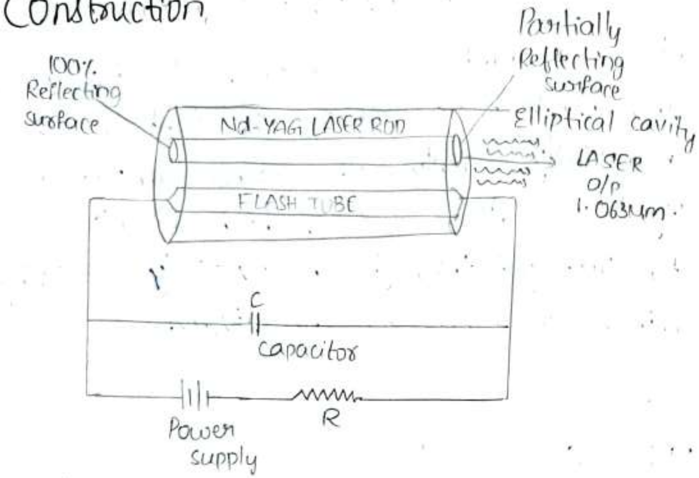
Construction



ND-YAG LASER is as shown in the above diagram, small amount of Yitrium ions (Y^{3+}) is replaced by neodium in the active element of Nd-YAG crystal. The active element is cut into a cylindrical rod, the ends of the cylindrical rod are highly polished and they are made optically flat and parallel to each other.

- This cylindrical rod and pumping source are placed inside an elliptical cavity.
- In this LASER the optical resonator is formed by a Nd-YAG LASER ROD only. Crypton flash tube is connected to power supply.

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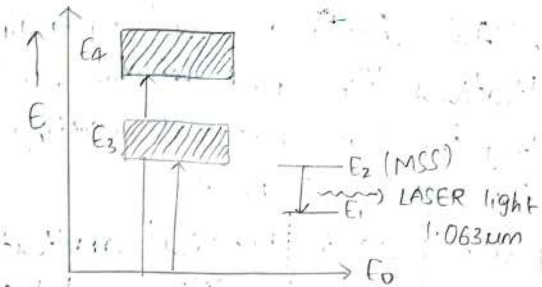
Working



- When crypton flash tube is switch on it emits white colour radiation. By receiving energy from crypton flash tube neodium atoms are raised to energy levels i.e., E_3 & E_4.
- In this case radiation of wavelength 0.73um & 0.8um is ~~observed~~ absorbed, Now Nd^{3+} ions makes a transition from these energy levels (E_3 & E_4) to metastable state E_2 by non-radiative transitions.
- The Nd^{3+} ions are collected in E_2 and population inversion is acheived between E_2 & E_1. LASER transition takes place between E_2 & E_1, that emitting light of wavelength is 1.063um that means after getting sufficient strength in the resonating cavity.

Applications

1. Nd-YAG LASER are used in engineering applications like speed detectors, welding, drilling the hard materials, cutting based on the required shape etc.
2. They are used in medical applications such as endoscopic, ENT, dental surgery and cosmotology etc.

20/7/23 CO_2 LASER

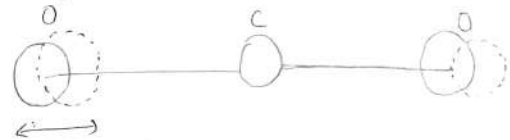
Introduction

- CO_2 LASER is a gas LASER, in this molecular gas LASER transition is acheived between vibrational states of CO_2 molecule.
- It is a four energy level LASER which gives continuous output. This LASER operates at 10.6μm IR region and it is a very efficient LASER.
- This is the first molecular LASER developed by indian born american scientist. professor ~~CKN PILLAI~~ "C.K.N Pillai"

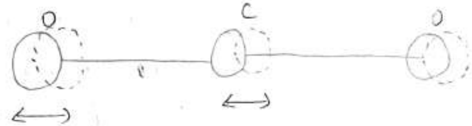
Energy state of CO_2 molecule

- A CO_2 molecule has a carbon atom at the center with two oxygen atoms are attached, one at both sides. This molecule exhibits 3 independent mode of vibrations.

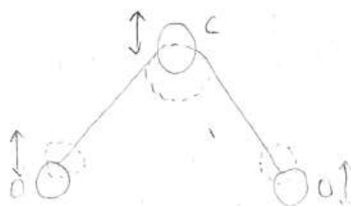
a) Symmetric mode of Vibrations



b) Assymetric mode of vibrations



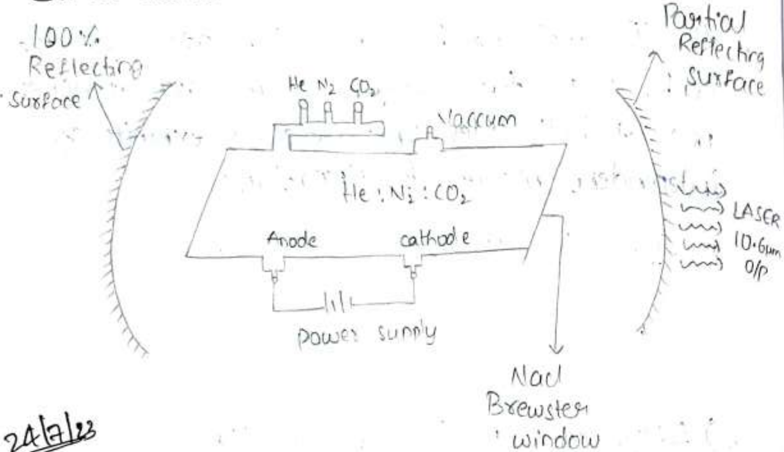
c) Bending mode of vibrations



Principle

The active medium is a gas mixture of CO_2, He and N_2. The LASER transition takes place between the vibrational states of CO_2 molecule.

Construction



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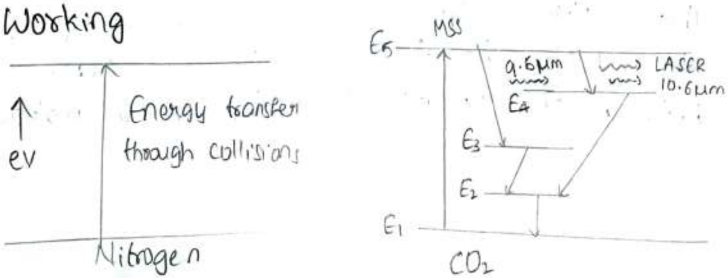
- It consists of quartz tube of 5m long and 2.5 cm wide in the diameter, the discharge tube is filled with gaseous mixture of CO_2-active medium, He and N_2 with suitable partial pressures.
- The terminal of discharge tube is connected to a DC power supply. The ends of the discharge tube is fitted with Nacl brewster's window, so that the light generated will be polarized, two concave mirrors are (One is fulling reflecting and other one is partially reflecting) form an optical resonator.

Working



- The diagram shows energy levels of nitrogen and carbon dioxide molecules. When discharge occurs in the gas molecule the electrons are moves from cathode to anode and they collide with nitrogen molecule and they are raised to excited state

$$e_1 + N_2 \longrightarrow N_2^* + e_2$$

- Now N_2 molecule in the excited state collides with the CO_2 molecules in the ground state and excites them to higher vibrational states and it can be represented as

$$N_2^* + CO_2 \longrightarrow CO_2^* + N_2$$

- Since the excited ~~state~~ levels of nitrogen is very close to the E_5 level of the CO_2 molecule, which results population in the E_5 level increases
- As soon as population inversion is achieved the transition takes place from E_5 to E_4 and E_5 to E_3 out of these two transitions E_5 to E_4 will produce a LASER beam of wavelength 10.6μm.

Advantages

1. Its efficiency is better than He-Ne LASER and other gas LASERs.
2. Long life of 20,000 hours.

Disadvantages

1. It requires cooling system
2. More cost when compared to other LASER systems.

Applications:

1. High power CO_2 LASERs finds applications in industries, for various purpose like welding, drilling, cutting, soldering.
2. It is used for micro surgery and Blood less surgeries.

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Applications of LASER in different fields

1. Scientific field

- They are used for isotopes separations.
- They are used to create plasma.
- They are used to produce chemical reactions.
- They are used to study the internal structure of micro-organisms.

2. Medicine

- They are used in bloodless surgery.
- They are used in Angioplastery for removal of blocks.
- They are used in cancer diagonsis and therapies.
- They are used in destroying kidney stones.
- They are used in asthamology, to attach the deattached retina.

3. Industries

- They are used to drill holes in ceramics.
- They are used for heat treatment in the tooling and automotive industries.

4. Communication

- Due to narrow band width LASERs are used in microwave communication systems.
- Due to narrow angular spread they are used in long distance communication.
- By the use of LASERs the storage capacity is gradually improved.

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OPTICAL FIBRE

INTRODUCTION

Generally communication is transferred through carrier waves in any communication system. When the frequency of carrier waves are high then the information carrying capacity also enhances.

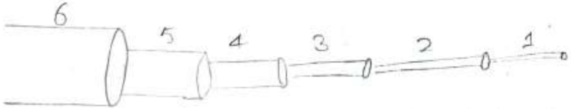
- As the propogation of light takes place in the form of high frequency waves, then these light waves can be used to carry the information i.e., as carrier waves.
- For proper guiding of information with carrying light waves, we need a proper guiding medium (or) material - that material is the optical fibre.

Optical fibre

Optical fibre is a thin and transparent guiding medium (or) material which guides the information carrying light waves.

- A single optical fibre can carry 140MB of information upto 220km in 1 second.

Structure of optical fibre



1. Core
2. Cladding
3. Silicon coating - quality of transmission of light
4. Buffer Jocket - moisture and absorption of external light
5. Strengthen member - toughness and tensil strength
6. Outer Jocket

- Optical fibre consist of central cylindrical layer known as core, surrounded by a second layer called cladding - light is transmitted with in the core.
- The cladding keeps the light with in the core because the refractive index of the cladding is less than that of the core i.e., core acts as denser medium and cladding acts as a rarer medium.
- Silicon coating is provided between buffer jocket and cladding, in order to improve the quality of transmission of light.
- The buffer jocket protects the fibre from moisture and absorption. To provide necessary toughness and tensil strength.
- A layer of strengthen member is arranged surrounding the buffer jocket - finally it is covered with a black poly urethan outer jocket.

Total Internal Reflection - Principle of the optical fibre

- In order to understand the principle of optical fibre let us consider core and cladding having refractive indices are n_1 & n_2. Here core is the denser medium and cladding is the rarer medium.
- Let us consider a ray of light is moving from core to cladding medium with an angle of incidence 'i'. As it is moving from denser medium to rarer medium, it deviates away from the normal. Here the angle of refraction is 'r'.
- As the angle of incidence increases, angle of refraction also increases. At a particular angle of incidence i.e., at $\boxed{i = \theta_c}$, the refracted ray simply grazes along the boundary as shown in the diagram '2', in this case angle of refraction is 90°.

- When the angle of incidence is greater than critical angle i.e., $\boxed{i > \theta_c}$, in that case the light beam simply reflects into the same medium as shown in the below diagram '3'.

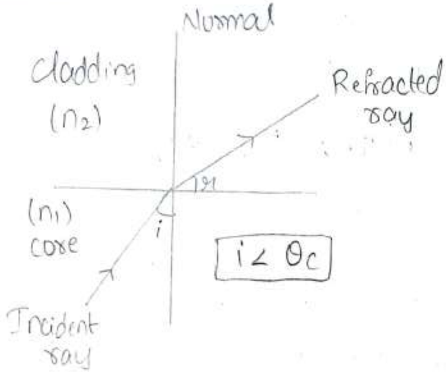


diagram (1)

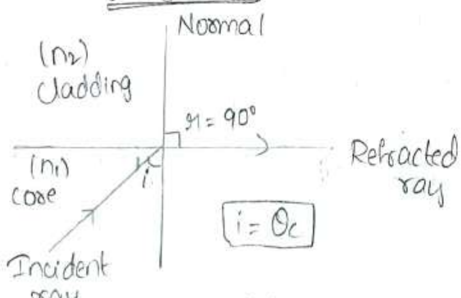


diagram (2)

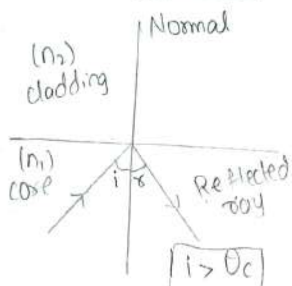


diagram (3)

where n_1 is the refractive index of the core, n_2 is the refractive index of the cladding.

Now applying snell's law of refraction for the second case (diagram 2)

i.e., $\dfrac{n_1}{n_2} = \dfrac{\sin r}{\sin i}$

$$n_1 \sin i = n_2 \sin r$$

from the above diagram 2, $i = \theta_c$ and $r = 90^\circ$

using this condition, the above equation can be written as

$$n_1 \sin \theta_c = n_2 \sin 90^\circ$$

$$n_1 \sin \theta_c = n_2$$

$$\sin \theta_c = \frac{n_2}{n_1}$$

$$\boxed{\theta_c = \sin^{-1} \frac{n_2}{n_1}}$$

where θ_c is critical angle

Critical angle : The angle of incidence for which angle of refraction is 90° is called "critical angle" (θ_c)

Conclusion

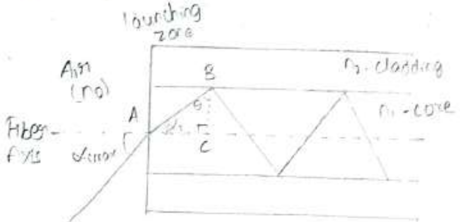
Hence for a light beam to ~~understand~~ undergo total internal reflection the following two conditions are required:

1. Refractive index of core should be greater than refractive index of cladding
   i.e., $\boxed{n_1 > n_2}$
2. Angle of incidence at core-cladding boundary should be greater than critical angle.
   i.e., $\boxed{i > \theta_c}$

31/7/23 **Acceptance angle and Acceptance Cone**

Acceptance angle :

The maximum angle of launch (α_{imax}) at one end of the optical fibre for which total internal reflection takes place at core-cladding boundary is called acceptance angle.



The above diagram shows longitudinal crossection of launch at an end of a optical fibre with a ray of light entering into it. The light is launched from a medium of refractive index n_0 ($n_0 = 1$ for air medium) to the core of refractive index n_1. The ray enter with an angle of incidence α_i to the fibre end phase. This particular ray entering the core at its optic axis point 'A' and proceeds after refraction at the angle of α_r from the axis. It then undergoes total internal reflection at 'B' on core and cladding boundary ; at an internal incident angle 'θ'.

- Let us now find upto what value of α_i at 'A', total internal reflection at 'B' is possible.
- From right angled triangle ΔABC

$$\boxed{\alpha_r = 90 - \theta} \rightarrow (1)$$

Using Snell's law of refraction at air - core interface

i.e., $$\frac{\sin \alpha_i}{\sin \alpha_r} = \frac{n_1}{n_0}$$

$$\boxed{\sin \alpha_i = \frac{n_1}{n_0} \sin \alpha_r} \rightarrow (2)$$

Using the value of α_r from eq (1) substitute in eq (2)

$$\sin \alpha_i = \frac{n_1}{n_0} \sin(90 - \theta)$$

$$\boxed{\sin \alpha_i = \frac{n_1}{n_0} \cos\theta} \rightarrow (3)$$

If $\alpha_i = \alpha_{imax}$ and $\theta = \theta_c$

Now eq ③ becomes

$$\boxed{\sin\alpha_{imax} = \frac{n_1}{n_0}\cos\theta_c} \rightarrow ④$$

$$= \frac{n_1}{n_0}\sqrt{1-\sin^2\theta_c} \quad \left[\because \sin\theta_c = \frac{n_2}{n_1}\right]$$

$$= \frac{n_1}{n_0}\sqrt{1-\left(\frac{n_2}{n_1}\right)^2}$$

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

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

$$\sin\alpha_{imax} = \frac{\sqrt{n_1^2-n_2^2}}{n_0}$$

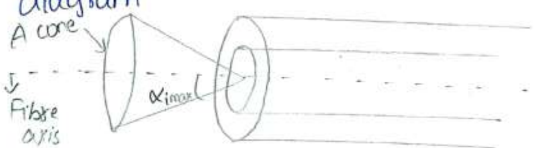
$$\boxed{\alpha_{imax} = \sin^{-1}\left(\frac{\sqrt{n_1^2-n_2^2}}{n_0}\right)}$$

If $n_0 = 1$

$$\boxed{\alpha_{imax} = \sin^{-1}\sqrt{n_1^2-n_2^2}}$$

This maximum angle is called "acceptance angle".

Rotating acceptance angle about the fibre axis will get acceptance cone as shown in the below diagram



Conclusion:

Light launched into the optical fibre end within this acceptance cone alone will be accepted and propogated to other end of the optical fibre by "total internal reflection".

Larger acceptance angle makes launching easier.

Numerical Aperature (NA)

Light collecting capacity of an optical fibre is called numerical aperature.

(or)

Sign of the acceptance angle is called numerical aperature.

i.e., $NA = \sin\alpha_{imax}$

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

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

if $n_0 = 1$

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

From these we can say that the numerical aperature is effiectively dependent only on the refractive indices of the core and cladding materials and it is not a function of a fibre dimensions.

Numerical aperature in terms of a 'Δ'

Delta (Δ) is the fractional difference in the refractive index, it defines

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2} \rightarrow (1)$$

$$\Delta = \frac{(n_1 + n_2)(n_1 - n_2)}{2n_1^2} \quad [\because n_1 \cong n_2]$$

$$= \frac{\cancel{2}\cancel{n_1}(n_1 - n_2)}{\cancel{2}n_1^{\cancel{2}}}$$

$$\boxed{\Delta = \frac{n_1 - n_2}{n_1}} \rightarrow (2)$$

$$\boxed{\Delta = 1 - \frac{n_2}{n_1}}$$

from eqn (1)

$$\Delta 2n_1^2 = n_1^2 - n_2^2$$

Square root on both sides

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

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

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

$$\Rightarrow \boxed{NA = n_1\sqrt{2\Delta}} \rightarrow (3)$$

01/8/23

Types of Optical fibres

Optical fibres are divided into different types based on different parameters

a. Based on the number of modes -
   1. Single Mode Optical Fibre (SMOF)
   2. Multi Mode Optical Fibre (MMOF)

b. Based on the refractive index profile -
   1. Step Index Optical Fibre (SIOF)
   2. Graded Index Optical Fibre (GIOF)

c. Based on the material used -
   1. Glass fibre
   2. Plastic Fibre

a. Based on the number of modes

'MODE' is the one which describes the nature of propogation electromagnetic waves in a waveguide. ~~(or~~

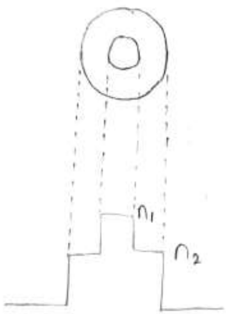
(or)

It describes about the number of light paths travelling in a waveguide.

. Based on the number of modes of propogation optical fibres are classified into two types, they are :

1. Single Mode Optical Fibre (SMOF)

- This fibres are made from doped silicon materials, it has very small core diameter. So that it can allow only one mode of propogation. The cladding diameter is very large when compared to core.
- Thus in the case of single mode optical fibres optical loss is very much reduced. The structure of single mode optical fibre is shown in the below diagram, it is available only for step index only.



Core Diameter - 5-10 μm

Cladding Diameter - 125 μm

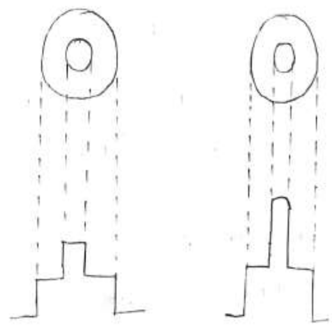
NA - 0.08 to 0.1

Band width > 50MHZ

- Because of their higher bandwidth they are used in long distance communication.

2. Multi Mode Optical fibre (MMOF)

- Here the core diameter is very large when compared with single mode optical fibres, so that it allows many modes to pass through it. The cladding diameter is very large when compared with single mode optical fibre.
- It is available for both step index and graded index optical fibre. The structure of multi mode optical fibre is shown in the below diagram



Core Diameter - 50-350 μm

Cladding Diameter - 125 μm to 500 μm

NA - 0.12 to 0.5

Band width < 50MHz

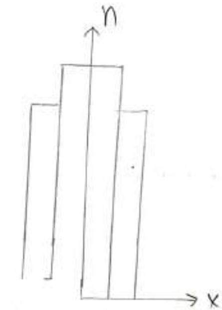
- Because of the less bandwidth multi mode optical fibres are used for short distance communication.

Distinguish between Single Mode Optical Fibre and Multi Mode Optical Fibre

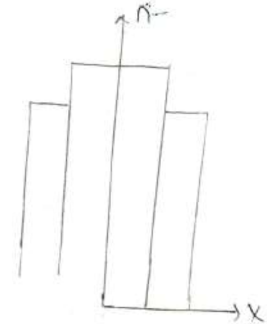
Single Mode Optical fibre	Multi Mode Optical Fibre
* They allows only one light ray path	* They allows more number of light ray paths
* They have small core diameters.	* They have more core diameters.
* $n_1 \cong n_2$ is small	* $n_1 \cong n_2$ is large
* No dispersion	* Dispersion is more
* Used for long distance communications.	* Used for short distance communications.
* Fabrication is difficult and more installation cost.	* Fabrication is easy and less installation cost.
* Launching of light and connecting to fibres is very difficult.	* Launching of light and connecting to fibres is very easy.

b. Based on the refractive index profile.

1. Step Index Optical Fibre



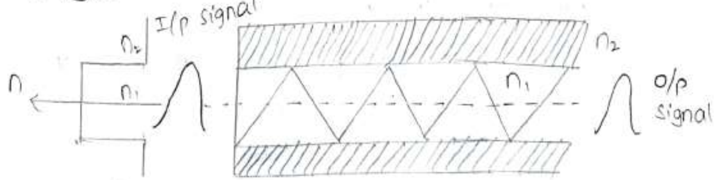
RI profile for SMSIOF



RI profile for MMSIOF

- In step index optical fibre the entire core has uniform refractive index n_1, which is slightly greater than refractive index of the cladding n_2. Since index profile is in the form of a step, these fibres are called "Step Index Optical fibre".

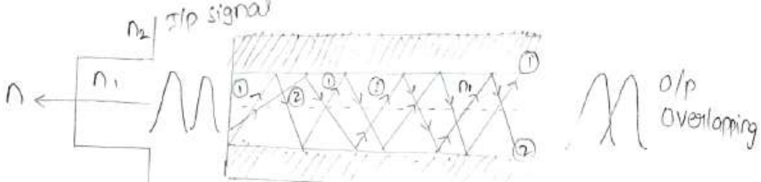
Transmission of signal in Step Index Optical Fibre



RI profile

Signal Propagation in SMSIOF

diagram (a)



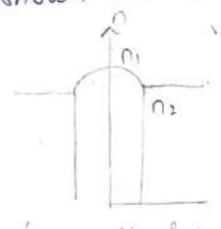
RI profile   Signal Propagation in MMSIOF

diagram (b)

- In this case transmission of information will be in the form of signals and pulses for a SMSIOF a single light ray from a signal enters into the fibre and travels a single path and forms the output signal. In this case two signals match each other as shown in the above diagram(a).
- In a MMSIOF due to large bandwidth of the core which allows number of light rays from input signals enters into the core and takes multiple internal reflections as shown in the above diagram (b).
- The light ray ① which makes greater angle with the fibre axis suffers more reflections through the fibre and takes more times to travel in the optical fibre. Whereas the light ray ② makes less angle with the fibre axis suffers less number of reflections as a result of that it travels in the optical fibre.
- At the output end the light ray ② reaches first and light ray ① reaches later. Due to the path difference between the two light rays when they superimpose to form the output signal, this signals are overlapped. This overlapping is named as "intermodel dispersion". Due to this problem it is difficult to retrieve the information carried out by output signal.

2. Graded Index Optical Fibre

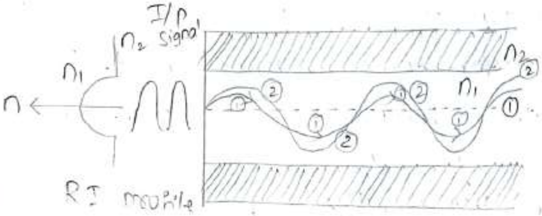
- In graded index optical fibres the refractive index of the core is maximum in the middle of the core and decreases from the fibre axis interface in a parabolic manner and it matches with refractive index of cladding as shown in the below diagram(a).



RI profile for MMGIOF

diagram(a)

Signal propogation in MMGIOF



Signal Propogation in MMGIOF
diagram(b)

- As shown in the above diagram (b) in this case the light rays are moving in the core medium whose refractive index is varying in a parobolic manner. Near fibre axis refractive index is more. As we move away from the core axis towards core cladding boundary the refractive index is decreases.
- The light rays which are moving away from the axis moves fast and the light rays which are moving near the fibre axis moves slow in reaching the other end of the optical fibre.
- So all these light rays are adjusts their velocity in such a way that they will reach simultaneously at the receiving end.
- In this case there is no overlapping of the output signals i.e., no intermodel dispersion and the output signals match with in the input signals.

- In this fibre we get a focusing effect of light rays.
- The number of possible modes through graded index optical fibre is $\frac{\nu^2}{4}$

Therefore, $\nu = \frac{2\pi}{\lambda} a \cdot NA$

where λ is the wavelength of the light ray

a is the radius of the core

NA is the numerical aperature of the given optical fibre

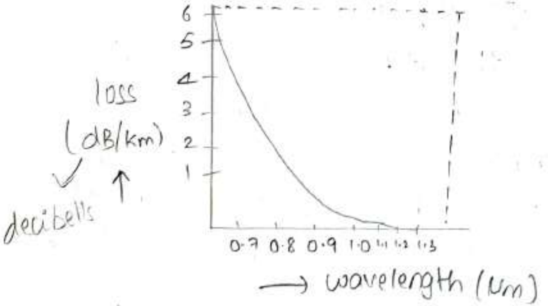
2/8/23

Losses in Optical Fibre

- The power of the light at the output end is found to be always less than intense, the power launched at the input end. The attenuation is found to be a function of fibre material, wavelength of lights and length of the fibres.
- The attenuation loss of optical fibre is divided as below
  1. Scattering loss
  2. Absorption loss
  3. Bending loss

1. Scattering loss :

- Actually the glass which is used to make a optical fibre is a amorphous solid. During its manufacturing sub microscopic variations in the density of the glass are frozen into the glass.
- Dopends added to vary the refractive indices also cause fluctuations in refractive index profile. These optical fibres acts as reflecting and refracting index to scatter a small portion of light passing through the glass contributing further losses



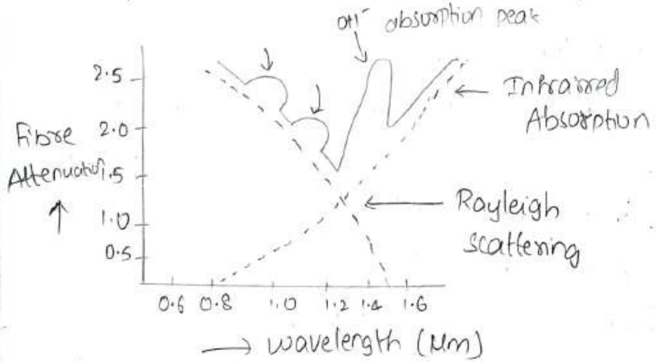
Rayleigh scattering losses in a silica fibre

- The losses induced because of scattering rayleigh inversekly with the 4th power of the light wavelength is used. Hence at 1.3um wavelength scattering losses are very less means about 0.3dB/km while at a wavelength 0.7um they are about 5dB/km as shown in the diagram.

2. Absorption loss :

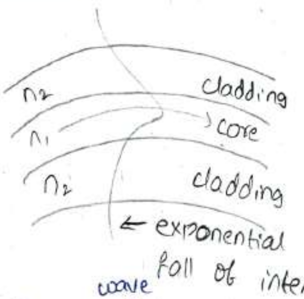
- Three different mechanisms contribute to absorption losses in optical fibres they are
  - (a) Ultravoilet absorption
  - (b) Infrarred absorption
  - (c) Ion resonance absorption
- In pure fused silica absorption of UV radiation arount 0.14um in ionization of valence electron into conduction band. Thus there is a loss of light due to ionization.
- Also during the fabrication of fibre to change the refractive index of glass to any desired value GeO_2 is doped.
- This causes shift in the UV absorption band.
- Absorption of infrarred photon by atoms with in the glass material results in the increase of random mechanical vibrations and hence heating.
- OH^- ions are present in the material due to trapping of minute quality of water molecule during manufacturing of these ions absorb energy (dB/km) at peaks of 0.815, 1.25, 1.39, and with the main peak at 1.3, 1.39um
- The presence of other impurities such as iron, copper, chromium may also create

unacceptable losses within the spectrum.



3. Bending loss:

- The distortion of optical fibre from the ideal straight line configuration may also results in fibre losses



- Consider a wave front travelling to direction of propogaton in order to maintain this, the part of the mode which is on outside of the optical fibre bend as to travel faster than that of the inside the optical fibre.
- Because of this the energy associated with this particular part of mode loss by radiation

- The loss is represented by

$$\boxed{\alpha_B = C \exp\left(-\frac{R}{R_e}\right)}$$

where C is the constant

R is the radius of curvature of optical fibre

$R_e = \frac{a}{(NA)^2}$ (where a is the radius of the optical fibre)

Loss of Bending

- Attenuation loss in optical fibre generally measured in terms of decibels (dB) which is a logarithm unit.
- The decibel ~~loss~~ loss of optical power in a fibre is measured through the formula
- Loss of optical power $= -10 \log \left[\frac{P_{out}}{P_{in}}\right]$ dB

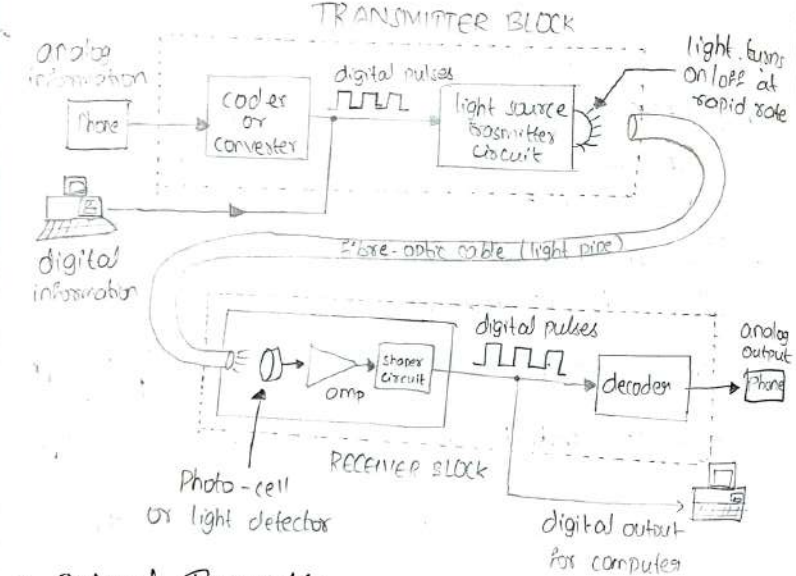
where Pout is the output power from the optical fibre

Pin is the power launched in the optical fibre

3/8/23 Optical Fibre Communication System

Fibre optic communication system consist of three important components they are

1. Optical Transmitter
2. Fibre Repeater
3. Optical Receiver



1. Optical Trasmitter

An optical transmitter converts analog to digital signal into the optical form. It consists of an encoder, light source and modulator, the input analog signal is converted into a digital signal by means of an encoder. The converted digital signal is enter into the source which can be LED (or) LASER diode - which converts digital signals into optical signals.

- These optical signals from the source is modulated either based on intensity, amplitude (or) frequency with the help of modulator. The optical signal from the modulator is coupled to the optical fibre by means of couplers. These couplers launch the optical signal into fibre without any distortion (or) loss.
- The optical signal through the fibre is properly connected to a repeaters with the help of connectors.

2. Fibre Repeaters

The optical signals while travelling through very long optical fibres through long distances can suffer transmission losses. As a result, we get weak optical signal at the output end of the optical fibre, to minimize these losses repeaters are kept at regular intervals between the fibres. The repeaters consist of an amplifier and regenerators. The amplifier amplifies the weak optical signal and it is reconstructed to original signal with the help of regenerators. At the last stage these optical signals are going to be received by the receiver.

3. Optical Receiver

The receiver unit consist of photo detectors, amplifier, demodulator and decoder. The photo detector converts optical signals into electrical signals. Then these electrical signals are going to be amplified by the amplifier and demodulated to digital signal, finally these digital signals are going to convert into analog signals with the help of decoders.

Conclusion

This is how optical fibre plays a important role in transmitting information through optical fibre communication system.

Advantages of optical fibres:

1. Extremely large bandwidth - ICC (Information Carrying Capacity) of a wave depends on its frequency. In the case of optical fibres light passes through them have very high frequency 10^{14} to 10^{15} hertz. From this we can say that optical signal carries information at a high rate.

i) Small in size - diameter and weight

Due to small size and less weight optical fibres can be handled very easier than copper cables.

ii) lack of cross talking

In ordinary cables signals are passed from one cable to another capable results in cross talking, but in optical fibre it is very negiliable.

Immune to Inductive Interference:

Fibre cables are immune to interface caused by lightning and other equipments.

Much safer than copper cable:

There is no effects (electrical or optical effects) in the case of optical fibres because they are made of insulating materials.

Long life span:

(a) High temperature resistance

(b) Easy Maintaineance

4/8/23

Applications of optical Fibres

1. Optical Fibres are used in communication system.
2. Optical Fibres are used in exchange of information between different terminals in a network of computers
3. They are used to exchange of information in Cable telvisions, space vehicles, submarines.
4. They are used in industrial automation and in industry security alarm system.
5. Optical fibres are used in electronic fields - to provide the required delays in delay lines.

6. Optical fibres are used in making sensors. pressure sensors, temperature sensors.

7. They are used in pressure sensors in biomedical and engine control applications.

8. They are used in medicine, in the fabrication of fibrescope in endoscopi for the visualization of internal portions of the human body, fibreoscopi is used for selective condensation of tissues using a LASER beam.