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***Optical Fiber Communications***

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http://en.wikipedia.org/

To Open source community

B tech Community



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**1.0 Introduction of Optical Fiber:-**

Our current “age of technology” is the result of many brilliant inventions

and discoveries, but it is our ability to transmit information, and the

media we use to do it, that is perhaps most responsible for its evolution.

Progressing from the copper wire of a century ago to today’s **fiber optic**

**cable**, our increasing ability to transmit more information, more quickly

and over longer distances has expanded the boundaries of our

technological development in all areas.

An **optical fiber** (or **fiber**) is a glass or plastic fiber

that carries light along its length. **Fiber optics** is the

overlap

of

applied

science

and

engineering

concerned with the design and application of optical

fibers. Optical fibers are widely used in fiber optic

communications, which permits transmission over

longer distances and at **higher bandwidths** (data rates) because light has

high frequency than any other form of radio signal than other forms of

communications. Light is kept in the core of the optical fiber by total

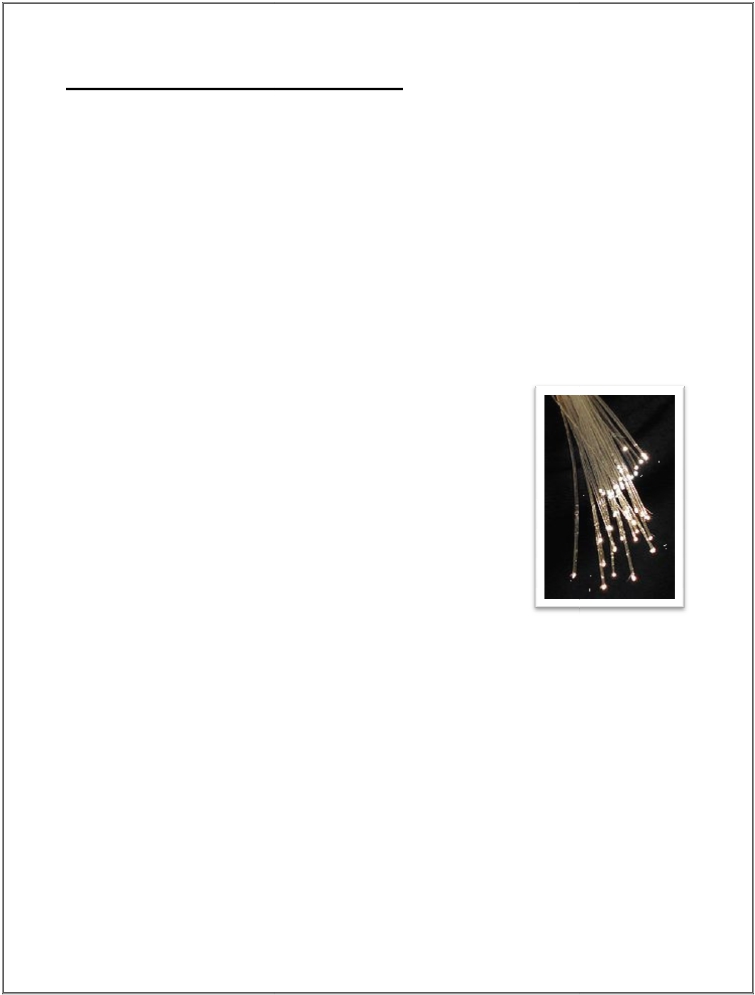
internal reflection.. This causes the fiber to act as a waveguide. Fibers are

used instead of metal wires because signals travel along them with less

loss, and they are also immune to electromagnetic interference, which is

caused by thunderstorm. Fibers are also used for illumination, and are

wrapped in bundles so they can be used to carry images, thus allowing



viewing in tight spaces. Specially designed fibers are used for a variety

of other applications, including sensors and fiber lasers.

**2.0 History of Fiber Optic Technology:-**

In 1870**, John Tyndall,** using a jet of water that flowed from one

container to another and a beam of light, demonstrated that light used

internal reflection to follow a specific

path. As water poured out through the

spout of the first container, Tyndall

directed a beam of sunlight at the path of

the water. The light, as seen by the

audience, followed a zigzag path inside

the curved path of the water. This simple

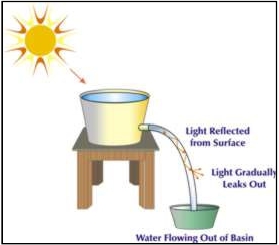
experiment, illustrated in Figure, marked the first research into guided

transmission of light.

In the same year, **Alexander Graham Bell** developed an optical voice

transmission system he called the **photo phone**. The photo phone used

free-space light to carry the human voice 200 meters. Specially placed



mirrors reflected sunlight onto a diaphragm attached within the

mouthpiece of the photo phone.

At the other end, mounted within a

parabolic reflector, was a light

sensitive selenium resistor. This

resistor was connected to a battery

that was, in turn, wired to a telephone receiver. As one spoke into the

photo phone, the illuminated diaphragm vibrated, casting various

intensities of light onto the selenium resistor. The changing intensity of

light altered the current that passed through the telephone receiver which

then converted the light back into speech. Bell believed this invention

was superior to the telephone because it did not need wires to connect

the transmitter and receiver. Today, free-space optical links find

extensive use in metropolitan applications.

The first practical all-glass fiber was devised by **Brian O'Brien** at the

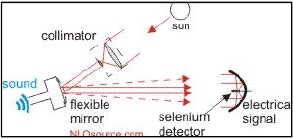
American Optical Company and **Narinder Kapany** (who first coined

the term 'fiber optics'in 1956) and colleagues at the Imperial College of

Science and Technology in London. Early all-glass fibers experienced

excessive optical loss, the loss of the light signal as it traveled the fiber,

limiting transmission distances.



In 1969, several scientists

concluded that impurities in the

fiber material caused the signal

loss in optical fibers. The basic

fiber material did not prevent the light signal from reaching the end of

the fiber. These researchers believed it was possible to reduce the losses

in optical fibers by removing the impurities.

**Jun-ichi Nishizawa**, a Japanese scientist at Tohoku University, was the

first to propose the use of optical fibers for communications in 1963.

Nishizawa invented other technologies that contributed to the

development of optical fiber communications as well. Nishizawa

invented the graded-index optical fiber in 1964 as a channel for

transmitting light from semiconductor lasers over long distances with

low loss.

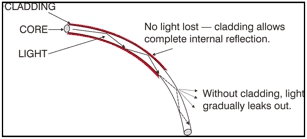
Fiber optics developed over the years in a series of generations that can

be closely tied to wavelength. Below Figure shows three curves. The

top, dashed, curve corresponds to early 1980's fiber, the middle, dotted,

curve corresponds to late 1980's fiber, and the bottom, solid, and curve

corresponds to modern optical fiber.



The earliest fiber optic systems were developed at an operating

wavelength of about 850 nm. This wavelength corresponds to the so-

called 'first window'in a silica-based optical fiber. This window refers to

a wavelength region that offers low optical loss. As technology

progressed; the first window became less attractive because of its

relatively high loss. Then companies jumped to the 'second window'at

1310 nm with lower attenuation of about 0.5 dB/km. In late 1977 the

'third window'was developed at 1550 nm. It offered the theoretical

minimum optical loss for silica-based

fibers. A 'fourth window,'near 1625

nm, is being developed. While it is

not lower loss than the 1550 nm

window, the loss is comparable, and

it might simplify some of the

complexities

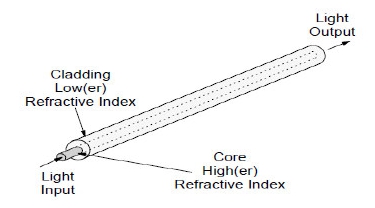
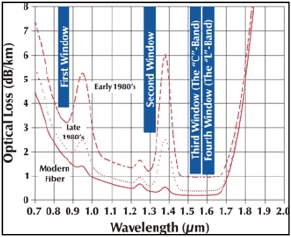
of

long-length,

multiple-wavelength.

**3.0 Construction of Optical Fiber Cable:-**

**Figure:-Construction of Fiber**



An optical fiber is a very thin strand of silica glass in geometry quite like

a human hair. In reality it is a very narrow, very long glass cylinder with

special characteristics. When light enters one end of the fiber it travels

(confined within the fiber) until it leaves the fiber at the other end.

An optical fiber consists of two parts: the **core** and the **cladding**. The

core is a narrow cylindrical strand of glass and the cladding is a tubular

**jacket** surrounding it. The core has a (slightly) higher refractive index

than the cladding. Light travelling along the core is confined by the

mirror to stay within it even when the fiber bends around a corner.

A fiber optic cable has an additional coating around the cladding called

the **jacket**. The **jacket** usually consists of one or more layers of

polymer. Its role is to protect the core and cladding from shocks that

might affect their optical or physical properties. It acts as a shock

absorber. The jacket also provides protection from abrasions, solvents

and other contaminants. The jacket does not have any optical properties

that might affect the propagation of light within the fiber optic cable.

**4.0 Guiding Mechanism in optical fiber:-**

Light ray is injected into the fiber optic cable on the right. If the light

ray is injected and strikes the core-to-cladding interface at an angle

greater than an entity called the critical angle then it is reflected back

into the core. Since the angle of incidence is always equal to the angle of

reflection the reflected light will again be reflected. The light ray will

then continue this bouncing path down the length of the fiber optic

cable. If the light ray strikes the core-to-cladding interface at an angle

less than the critical angle then it passes into the cladding where it is

attenuated

very

rapidly

with

propagation

distance.

Light can be guided down the fiber optic cable if it enters at less than the

critical angle. This angle is fixed by the indices of refraction of the core

and cladding and is given by the formula:

The critical angle is measured from the cylindrical axis of the core. By

way of example, if n1 = 1.446 and n2= 1.430 then a quick computation

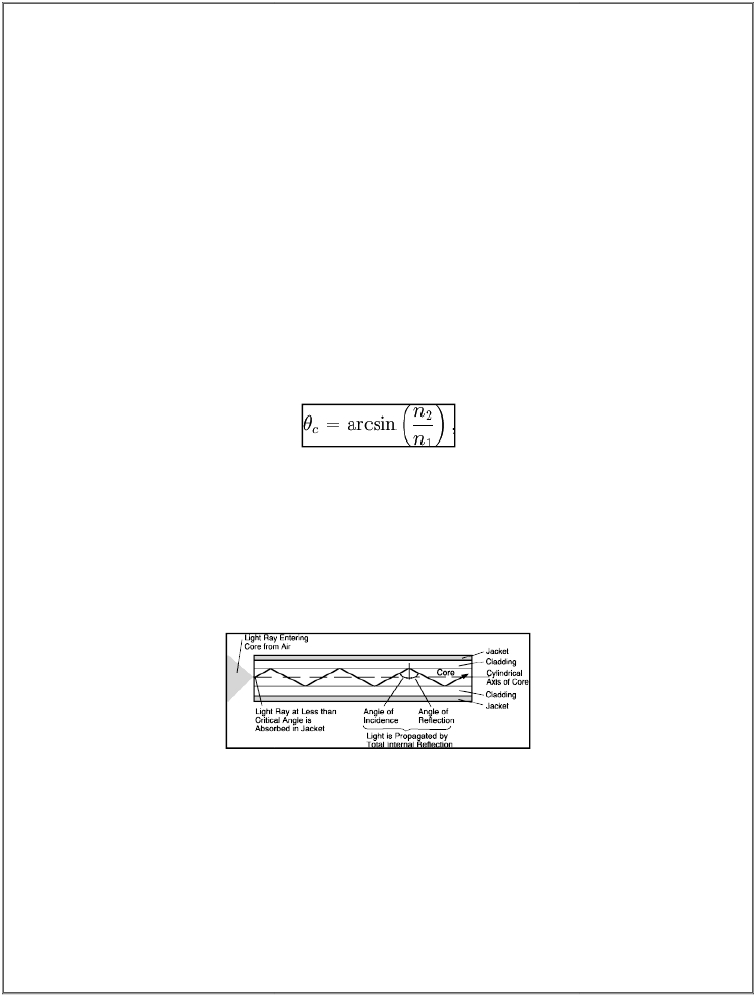
will show that the critical angle is 8.53 degrees, a fairly small angle.

**Figure:-Mechanism of Light wave guide in Fiber**

Of course, it be noted that a light ray enters the core from the air outside,

to the left of Figure. The refractive index of the air must be taken into

account in order to assure that a light ray in the core will be at an angle



less than the critical angle. This can be done fairly simply. Suppose a

light ray enters the core from the air at an angle less than an entity called

the external acceptance angle It will be guided down the core.

**5.0 Basic Component of Optical Fiber Communication:-**

**5.1 Transmitters: -**

Fiber optic transmitters are devices that include an LED or laser source,

and signal conditioning electronics, to inject a signal into fiber. The

modulated light may be turned on or off, or may be linearly varied in

intensity between two predetermined levels.

**Figure:-The basic components of an optical fiber communication**

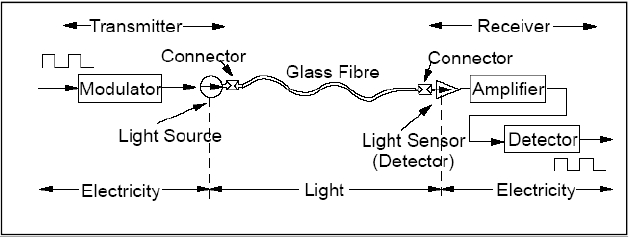
**5.2 Fiber:-**

It is the medium to guide the light form the transmitter to the receiver.

**5.3 Receivers**:-Fiber optic receivers are instruments that convert light into

electrical signals. They contain a photodiode semiconductor, signal

conditioning circuitry, and an amplifier at the receiver end.



**5.4 Process of Optical Fiber Communication:-**

A serial bit stream in electrical form is presented to a modulator, which

encodes the data appropriately for fiber transmission.

A light source (laser or Light Emitting Diode - LED) is driven by

the modulator and the light focused into the fiber.

The light travels down the fiber (during which time it may

experience dispersion and loss of strength).

At the receiver end the light is fed to a detector and converted to

electrical form.

The signal is then amplified and fed to another detector, which

isolates the individual state changes and their timing. It then

decodes the sequence of state changes and reconstructs the original

bit stream.

The timed bit stream so received may then be fed to a using device

**6.0 Principle of optical transmission**

**6.1 Index of refraction:-**

This is the measuring speed of light in respective medium. it is

calculated by dividing speed of light in vacuum to the speed of light in

material. The RI for vacuum is 1, for the cladding material of optical

fiber it is 1.46, the core value of RI is 1.48(core RI must be more than

cladding material RI for transmission. it means signal will travel around

200 million meters per second. it will 12000 km in only 60 seconds.

other delay in communication will be due to communication equipment

switching and decoding, encoding the voice of the fiber.

**6.2 Snell's Law:-**

In order to understand ray propagation in a fiber. We need one more

law from high school physics. This is Snell'slaw.

n1 sin .01 = n2 sin .02

Where n denotes the refractive index of the material.01/02 are angles in

respective medium. Higher Refractive Index means denser medium.

1) When light enters in lighter medium from denser it inclines

towards normal.

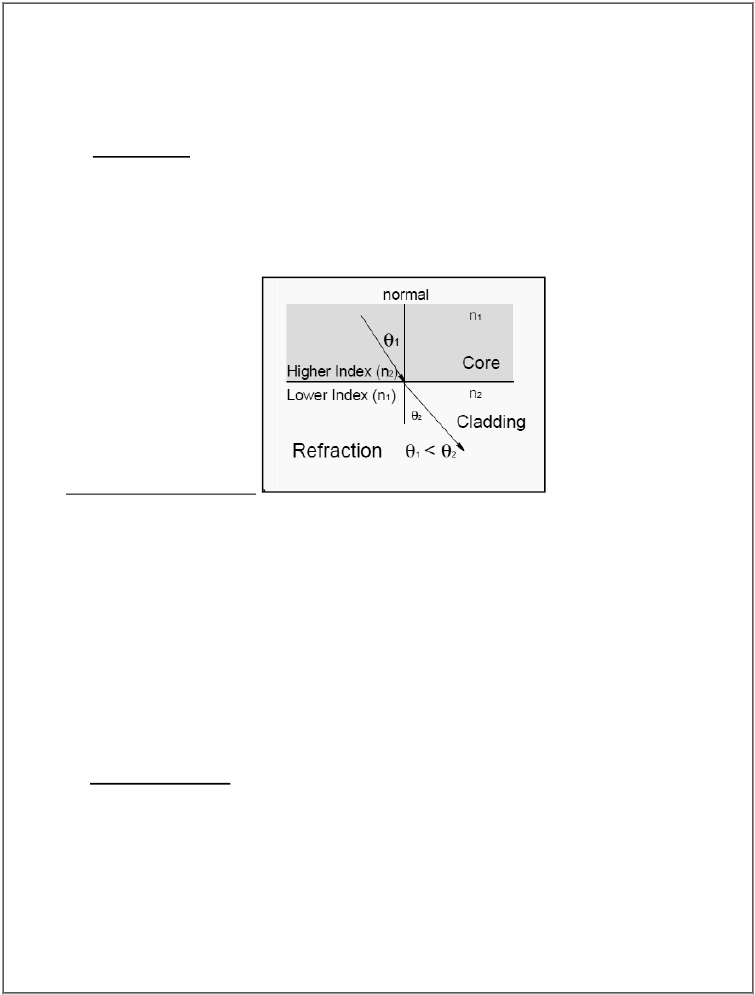
2) When light enters in denser medium from lighter it inclines away

to normal

**6.3 Critical Angle:-**

If we consider we notice above that as the angle 01 becomes larger and

larger so does the angle 02. Because of the refraction effect 02.



becomes larger more quickly than 01 .At

some point 02 will reach 90° while 01 is

still well less than that. This is called the

**“critical angle”.** When 01is increased

further then refraction ceases and the

light starts to be reflected rather than refracted. Thus light is perfectly

reflected at an interface between two materials of different refractive

index if:

1. The light is incident on the interface from the side of higher refractive

index.

2. The angle is greater than a specific value called the “critical angle”.

Glass refractive index is 1.50 (critical angle is 41.8), Diamond critical

angle is 24.4 degree.

**6.4Total Internal reflection (TIR):-**

When light traveling in a dense medium hits a boundary at a steep angle

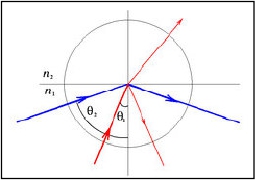
(larger than the "critical angle “for the boundary), the light will be

completely reflected. This phenomenon is called **total internal**

**reflection**. This effect is used in optical fibers to confine light in the

core. Light travels along the fiber bouncing back and forth off of the

boundary; because the light must strike the boundary with an angle



greater than the critical angle, only light that enters the fiber within a

certain range of angles can travel down the

fiber without leaking out.. Total internal

reflection occurs when light enters from

higher refractive index to lower refractive

index material, i.e from glass to air total

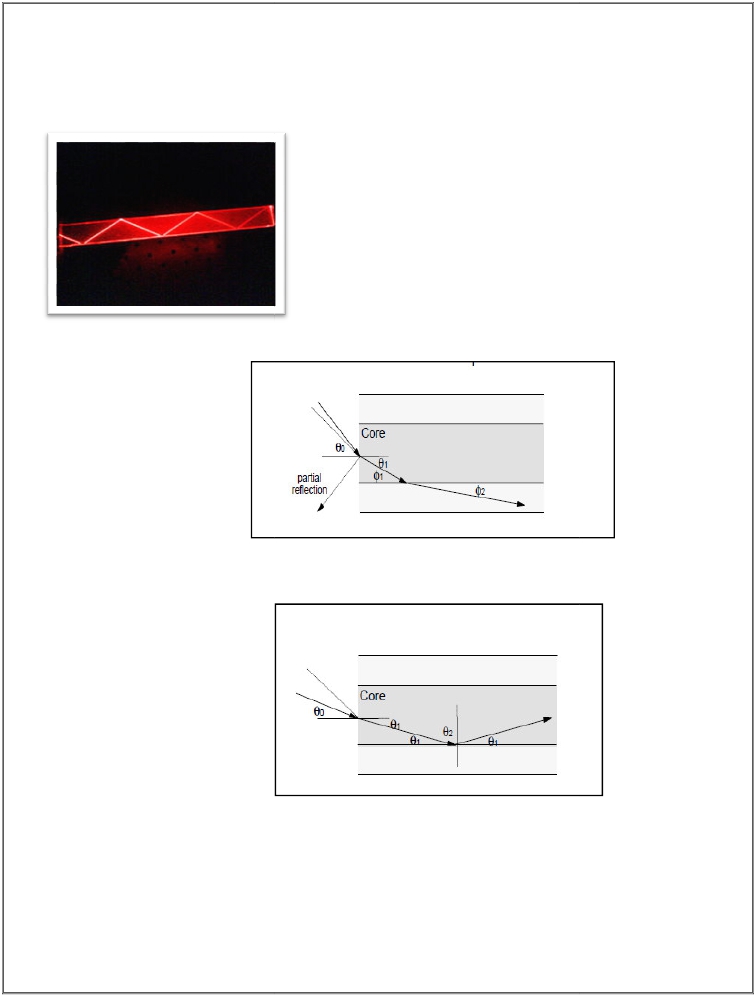
internal reflection is possible but it is not

possible in air to glass.

Figure-1(optical rays leaks out from core i.e. is loss)

Fig-2 (Optical rays reflected back due to TIR)

If we now consider above Figures we can see the effect of the critical



angle within the fiber. In Figure 2 we see that for rays where angle01 is

less than a Critical value then the ray will propagate along the fiber and

will be “bound” within the fiber. In Figure 1 we see that where the angle

01 is greater than the critical value the ray is refracted into the cladding

and will ultimately be lost outside the fiber. This is loss.

**6.5 Acceptance Cone:-**

Figure 3: Acceptance cone

When we consider rays entering the fiber from the outside (into the end

face of the Fiber) we see that there is a further complication. The

refractive index difference between the fiber core and the air will cause

any arriving ray to be refracted. This means that there is a maximum

angle for a ray arriving at the fiber end face at which the ray will

propagate. Rays arriving at an angle less than this angle will propagate

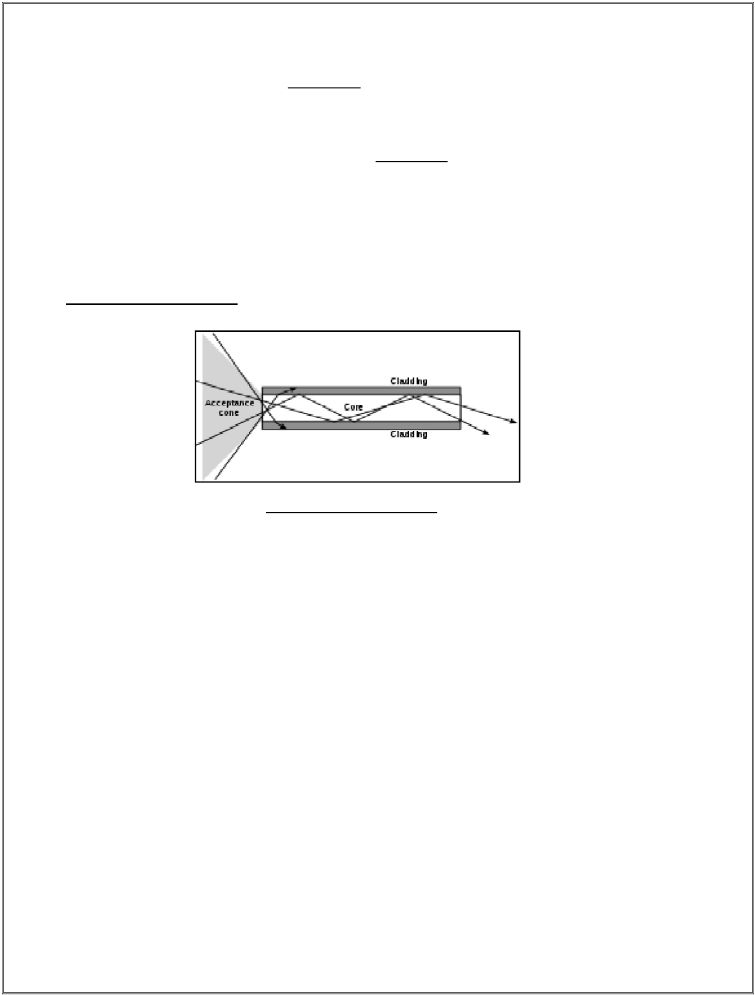
but rays arriving at a greater angle will not. This angle is not a “critical

angle” as that term is reserved for the case where light arrives from a

material of higher RI to one of lower RI. (In this case, the critical angle

is the angle within the fiber.) Thus there is a “**cone of acceptance**” at the

end face of a fiber. Rays arriving within the cone will propagate and



ones arriving outside of it will not. The size of acceptance cone is

function of difference of RI of core and cladding.

**6.6 Numerical aperture (NA):-**

Figure: - 4 (Numerical aperture)

One of the most often quoted characteristics of an optical fiber is its

“**Numerical Aperture**”. The NA is intended as a measure of the light

capturing ability of the fiber. However, it is used for many other

purposes. For example it may be used as a measure of the amount of loss

that we might expect on a bend of a particular radius etc.

Figure 2 on shows a ray entering the fiber at an angle close to its axis.

This ray will be refracted and will later encounter the core-cladding

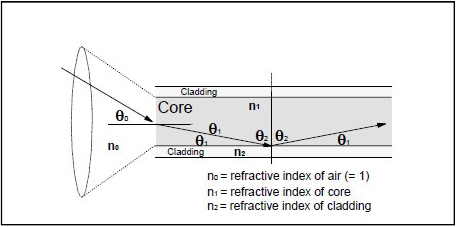
interface at an angle such that it will be reflected. This is because the

angle 02 will be greater than the critical angle. The angle is greater

because we are measuring angles from a normal to the core-cladding

boundary not a tangent to it.

Figure 1 on shows a ray entering at a wider angle to the fiber axis. This



One will reach the core-cladding interface at an angle smaller than the

critical angle and it will pass into the cladding. This ray will eventually

be lost. It is clear that there is a “cone” of acceptance (illustrated in

Figure 3 ). If a ray enters the fiber at an angle within the cone then it will

be captured and propagate as a bound mode. If a ray enters the fiber at

an angle outside the cone then it will leave the core and eventually leave

the fiber itself.

*The* ***Numerical Aperture*** *is the sine of the largest angle contained within*

*the cone of acceptance. In figure 4 it is SINE 0O*

We know that sin 02 =n2/n1

Because 02 is the critical angle

And n0 sin 00 = n1 sin 01 from Snell's Law

Now, cos 01 = sin 02 =n2/n1

We know that sin x = (1 − cos2x )1/2(Rule)

Therefore sin 01 = (1 –n22/n12)1/2

Since n0 = 1 then sin 00 = n1 (1 –n22/n12)1/2

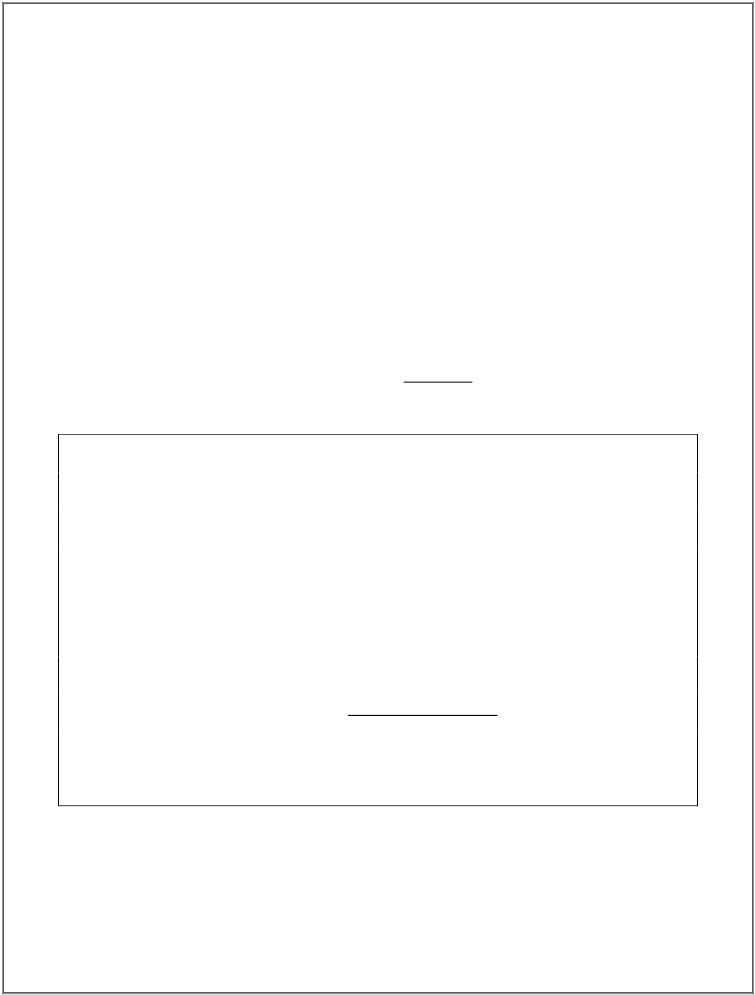
Therefore NA = (n12-n22)1/2

Where n1 = refractive index of the core

n2 = refractive index of the cladding

Typical NA for single-mode fiber is 0.1. For multimode, NA is between

0.2 and 0.3(usually closer to 0.2)



**6.6.1 Significance of NA with fiber characteristics:-**

It is a measure of the ability of the fiber to gather light at the input

end.

Because it is a measure of the contrast in RI between the core and

the cladding. It is a good measure of the light guiding properties of

the fiber. The higher the NA the tighter (smaller radius) we can

have bends in the fiber before loss of light becomes a problem.

The higher the NA the more modes we have rays can bounce at

greater angles and therefore there are more of them. This means

that the higher the NA the greater will be the dispersion of this

fiber (in the case of Multi Mode fiber).

In Single Mode(SM) fiber a high RI contrast usually implies a high

level of dopant in the cladding. Since a significant proportion of

optical power in SM travels in the cladding we get a significantly

increased amount of attenuation due to the higher level of dopant.

Thus (as a rule of thumb) the higher the NA of SM fiber the higher

will be the attenuation of the fiber.

**7.0 Advantage of Optical fiber:-**

Fiber optic transmission systems a fiber optic transmitter and receiver,

Connected by fiber optic cable offer a wide range of benefits not offered

by traditional copper wire or coaxial cable. These include:

*Less Expensive***.** First, fiber optics are less expensive than copper

wire. This is because many miles of optical cable are easier and

less expensive to install than the same amount of copper wire or

cable.

*Thinner***.** Fiber optics is thinner than copper wire cables, so they

will fit in smaller, more crowded places. This is important for

underground cable systems, like in cities, where space needs to be

shared with sewer pipes, power wires, and subway systems.

*Higher Carrying Capacity***.** More information can also be carried

over fiber optic systems. This can be especially important for

computers, since a computer has to send so much information at

one time. Also, more phone lines can be in one optical fiber. Many

people use the same optical cable for phone conversations at the

same time.

*Less signal degradation .* Information gets lost over distances an

any kind of wire. But, fiber optic cables don’t lose as much signal

(information) as other kinds of wires and cables.

*Use Light Signals .* Because fiber optics use light signals instead of

electricity, the signals don’t interfere with each other. This makes

the signals clearer and easier to understand.

*Low Power***.** Optical fiber signals are created using low-power

transmitters because the signal degrades less (instead of high-

power electric transmitters used for copper wires). Lower power

use saves money for users and providers.

*Digital Signals .* Computer networks need digital information, since

fiber optic cables send information digitally; they are the best thing

to use for computer networks.

*Non-flammable***.** Since fiber optics send light instead of electricity,

fiber optics are non-flammable. This means there is not a fire

hazard. Fiber optics also does not cause electric shocks, because

they do not carry electricity.

*Light weight***.** Fiber optics is easier to install and transport than

copper wires. That is good news for technicians

*Flexible.* Since fiber optics is more flexible, they can go around

corners and into tighter places than traditional cable. This is

important in computer and very big office networks.

Other benefits are:-

The fiber is totally immune to virtually all kinds of

interference, including lightning, and will not conduct

electricity. It can there- fore come in direct contact with high

voltage electrical equipment and power lines. It will also not

create ground loops of any kind.

As the basic fiber is made of glass, it will not corrode and is

unaffected by most chemicals. It can be buried directly in

most kinds of soil or exposed to most corrosive atmospheres

in chemical plants without significant concern.

Fiber optic cables are virtually unaffected by outdoor

atmospheric conditions, allowing them to be lashed directly

to telephone poles or existing electrical cables without

concern for extraneous signal pickup.

Fiber optic cable is ideal for secure communications systems

because it is very difficult to tap but very easy to monitor. In

addition, there is absolutely no electrical radiation from a

fiber.

**7.1 Advantage of optical fiber communication:-**

*Wider bandwidth*: The information carrying capacity of a

transmission system is directly proportional to the carrier

frequency of the transmitted signals. The optical carrier frequency

is in the range 1013 to 1015 Hz while the radio wave frequency is

about 106 Hz and the microwave frequency is about 1010 Hz. Thus

the optical fiber yields greater transmission bandwidth than the

conventional communication systems and the data rate or number

of bits per second is increased to a greater extent in the optical

fiber communication system. Further the wavelength

division

multiplexing operation by the data rate or information carrying

capacity of optical fibers is enhanced to many orders of magnitude.

*Low transmission loss*: Due to the usage of the ultra low loss fibers

and the erbium doped silica fibers as optical amplifiers, one can

achieve almost lossless transmission. In the modern optical fiber

telecommunication systems, the fibers having a transmission loss

Of 0.002 dB/km are used. Further, using erbium doped silica fibers

over a short length in the transmission path at selective points;

appropriate optical amplification can be achieved. Thus the

repeater spacing is more than 100 km. Since the amplification is

done in the optical domain itself, the distortion produced during

the strengthening of the signal is almost negligible.

*Dielectric waveguide*: Optical fibers are made from silica which is

an electrical insulator. Therefore they do not pickup any

electromagnetic wave or any high current lightning. It is also

suitable in explosive environments. Further the optical fibers are

not affected by any interference originating from power cables,

railway power lines and radio waves. There is no cross talk

between the fibers even though there are so many fibers in a cable

because of the absence of optical interference between the fibers.

*Signal security*: The transmitted signal through the fibers does not

radiate. Further the signal cannot be tapped from a fiber in an easy

manner. Therefore optical fiber communication provides hundred

per cent signal security.

*Small size and weight*: Fiber optic cables are developed with small

radii, and they are flexible, compact and lightweight. The fiber

cables can be bent or twisted without damage. Further, the optical

fiber cables are superior to the copper cables in terms of storage,

handling, installation and transportation, maintaining comparable

strength and durability.

**8.0 Dispersion:-**

Figure:-5 Effect of Dispersion

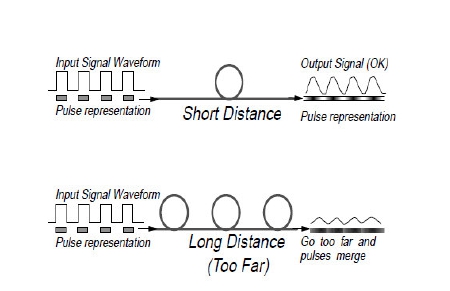
Dispersion occurs when a pulse of light is spread out during

transmission on the fiber. A short pulse becomes longer and ultimately

joins with the pulse behind, making recovery of a reliable bit stream

impossible. (In most communications systems bits of information are

sent as pulses of light. 1 = light, 0 = dark. But even in analogue



transmission systems where information is sent as a continuous series of

changes in the signal, dispersion causes distortion.)

There are many kinds of dispersion, each of which works in a different

way, but the most important three are discussed below:

**8.1Material dispersion (chromatic dispersion**):-

Both lasers and LEDs produce a range of optical wavelengths (a band

Of light) rather than a single narrow wavelength. The fiber has different

refractive index characteristics at different wavelengths and therefore

each wavelength will travel at a different speed in the fiber. Thus, some

wavelengths arrive before others and a signal pulse disperses (or smears

out).

**8.2 Intermodal dispersion (Mode Dispersion):-**

When using multimode fiber, the light is able to take many different

paths or “modes” as it travels within the fiber. The distance traveled by

light in each mode is different from the distance travelled in other

modes. When a pulse is sent, parts of that pulse (rays or quanta) take

many different modes (usually all available modes). Therefore, some

components of the pulse will arrive before others. The difference

between the arrival times of light taking the fastest mode versus the

slowest obviously gets greater as the distance gets greater.

**8.3 Waveguide dispersion:-**

Waveguide dispersion is a very complex effect and is caused by the

shape and index profile of the fiber core. However, this can be

controlled by careful design and, in fact, waveguide dispersion can be

used to counteract material dispersion.

*Dispersion in different fibers*:

Mode dispersion > .material dispersion > waveguide dispersion.

**9.0Attenuation:-**

**Figure:-6. Fiber Infrared Absorption Spectrum. The lower curve shows the characteristics of a single-mode**

**fiber made from a glass containing about 4% of germanium dioxide (GeO2) dopant in the core. The upper**

**curve is for modern graded index multimodefibre. Attenuation in multimode fiber is higher than in single-**

**mode because higher levels of dopant are used. The peak at around 1400 nm is due to the effects of traces of**

**water in the glass.**

Attenuation in fiber optics, also known as transmission loss, is the

reduction in intensity of

the light

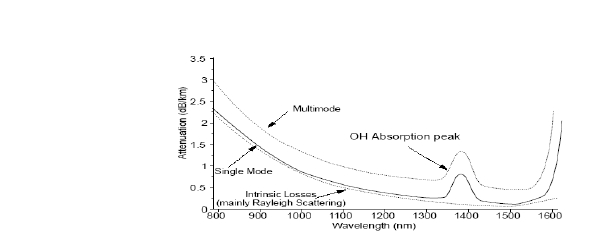
beam with respect

to

distance

travelled through a transmission medium. Attenuation coefficients in

fiber optics usually use **units of dB/km** through the medium due to the



relatively high quality of transparency of modern optical transmission

media.

Attenuation in an optical fiber is caused by absorption, scattering, and

bending losses. **Attenuation** is the loss of optical power as light travels

along the fiber. Signal attenuation is defined as the ratio of optical input

power (Pi) to the optical output power (Po). Optical input power is the

power injected into the fiber from an optical source. Optical output

power is the power received at the fiber end or optical detector.

Each mechanism of loss is influenced by fiber-material properties and

fiber structure. However, loss is also present at fiber connections i.e.

connector, splice, and coupler losses.

**9.1 Absorption loss:-**

Absorption in optical fibers is explained by three factors:

Imperfections in the atomic structure of the fiber material

The intrinsic or basic fiber-material properties

The extrinsic (presence of impurities) fiber-material properties

Imperfections in the atomic structure induce absorption by the presence

of missing molecules or oxygen defects. Absorption is also induced by

the diffusion of hydrogen molecules into the glass fiber.



**9.1.1 Intrinsic Absorption.** -

Intrinsic absorption is caused by basic fiber-

material properties. If an optical fiber were absolutely pure, with no

imperfections or impurities, then all absorption would be intrinsic.

Intrinsic absorption sets the minimal level of absorption.

**9.1.2Extrinsic Absorption.**

- Extrinsic absorption is caused by impurities

introduced into the fiber material. Trace metal impurities, such as iron,

nickel, and chromium, OH ions

are introduced into the fiber during

fabrication. Extrinsic absorption is caused by the electronic transition of

these metal ions from one energy level to another.

**9.2 Light scattering:-**

Basically, scattering losses are caused by the interaction of light with

density fluctuations within a fiber. Density changes are produced when

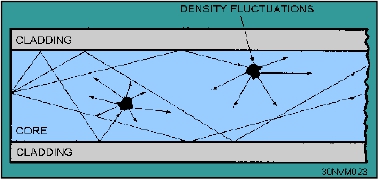
optical fibers are manufactured. During manufacturing, regions of higher

and lower molecular density areas, relative to the average density of the

fiber, are created. Light traveling through the fiber interacts with the

density areas as shown in Light is then partially scattered in all direction.

**Figure: - 7(Scattering process)**



In commercial fibers operating between 700-nm and 1600-nm

wavelength, the main source of loss is called **Rayleigh scattering**.. As

the wavelength increases, the loss caused by Rayleigh scattering

decreases. If the size of the defect is greater than one-tenth of the

wavelength of light, the scattering mechanism is called **Mie scattering**.

**9.3 Bending loss:-**

As light travels along the fiber, it is reflected from the interface between

the core and cladding whenever it strays from the path straight down the

Center. When the fiber is bent, the light only stays in the fiber because

of this reflection. But the reflection only works if the angle of incidence

is relatively low. If you bend the fiber too much the light escapes.

The amount of allowable bending is specific to particular cables because

it depends on the difference in refractive index, between core and

cladding. The bigger the difference in refractive index, the tighter the

allowable bend radius. There is a tradeoff here because there are many

other reasons that we would like to keep this difference as small as

possible. Two types of losses are there.microbend loss or macro bend

loss.

**Micro bends losses** are small microscopic bends of the fiber axis that

occur mainly when a fiber is cabled. **Micro bend losses** are caused by

small discontinuities or imperfections in the fiber. External forces are

also a source of micro bends.

**Figure:-8 Bending loss**

**10.0 Fiber:-**

Fiber is the medium to guide the light form the transmitter to the

receiver. It is classified into two types depending on the way the light is

transmitted: multimode fiber and single-mode fiber.

**10.1 Multimode Fiber:-**

Multimode fiber designed to transmit more than one light at a time.

Fiber diameter ranges from 50-to-100 micron. Multimode fibers can be

divided in to two categories Multimode Step-index Fiber and Multimode

Graded-index Fiber .

In **Multimode Step-index Fiber** the lights are sent at angles lower

than the critical angle or straight (or simply the angle is zero). Any light

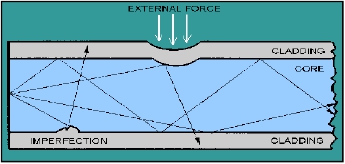
angle exceed the critical angle will cause it to penetrate through cladding

(refracted) and being lost as shown in Figure 9. Obviously light with

lower angle which has less number of reflection, reach the end faster

than those with larger angle and this will result in unstable wave light.

To avoid this problem there should be spacing between the light pulses,



but this will limit the bandwidth and because of that it is used for very

short distance.

**Figure 9 :- Multimode Step-index Fiber**

The **Multimode Graded-index** Fiber designed to reduce the

problem in Multimode Step-Index fiber by making all the beams

reaching the receiver at the same time. This can be done by slowing

down the ones with shorter distance and increasing the speed for ones

with longer distance, see Figure 10. This is done in fiber implementation

by increasing its refractive index at the center and gradually decreases it

toward the edges. In the Figure 10 we can see the light near the edges is

curved until it is reflected, this is due to the refraction caused by the

change in density.

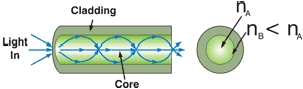
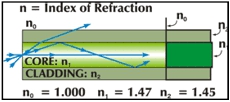
**Figure 10:- Multimode Graded-Index Fiber**

**10.2 Single-Mode Fiber:-**

In single-mode, only one light is transmitted in the fiber which

diameter ranges from 8.3 to 10 microns, see Figure 11. Since there is

only one light the problem associated with the multimode fiber does not



exist and by this we can have a higher transmission rate and also it can

be used for longer distance.

**Figure 11:- Single-Mode Fiber**

**11.0 Optical Sources:-**

There are two kinds of devices that are used as light sources: **Lasers** and

**LEDs.**

**11.1 LED: -**

LED is just a forward biased p-n junction. There is a

recombination of holes and electrons. This recombination requires

energy possessed is the unbound free electron is transferred to another

state. In all semiconductor p-n junctions some of this energy will be

given off as heat and some in the form of photons .In silicon and

germanium greater percentage is given up in the form of heat and the

emitted light is insufficient. In other material, such as gallium arsenide

phosphide (GaAsP) or gallium phosphide (GaP) , the number of photos

of light energy emitted is sufficient to create a very visible light source.

*The process of giving off light by applying an electrical source of energy*

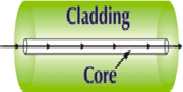
*is called* ***electroluminescence***.

**11.1.1 Operation of LEDs:-**

The wavelength of light emitted by the LED is inversely proportional to

the band gap energy. The higher the energy the shorter the wavelength.

The formula relating electron energy to wavelength is given below.



The materials of which the LED is made determine the wavelength of

light emitted. The following table shows energies and wavelengths for

commonly used materials in semiconductor LEDs and lasers.

**11.1.2 Heterojunctions (Practical LEDs):-** Heterojunction

means that a *p*-*n*

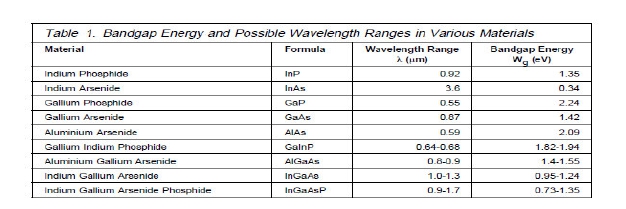
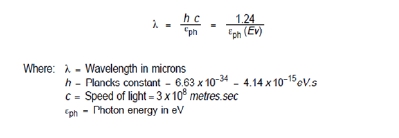
junction is formed by a single crystal such that the material on one side

of the junction differs from that on the other side of the junction. In the

modern GaAs diode lasers, a hetero junction is formed between GaAs

and GaAlAs. This type of *p*-*n* junction diode laser or LED is used at 800

m wavelength. At longer wavelengths, InP-InGaAsP heterojunction



**Figure: Hetrojunction LED**

diodes are used. Generally heterojunction LEDs have minimum

threshold current density (10 A/mm2), high output power (10 mW) even

with low operating current (<500 mA) high coherence and high

monochromaticity, high stability and longer life.

**Characteristics of LEDs:-**

Low Cost

Low Power

Relatively Wide Spectrum Produced

Incoherent Light

Digital Modulation

Analogue Modulation

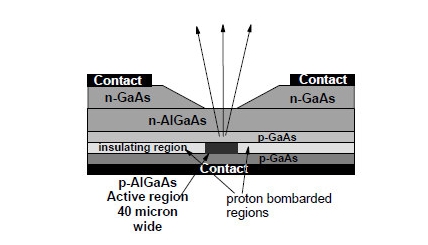
**11.2 Lasers:-**

LASER is an acronym for “*Light Amplification by the*

*Stimulated Emission of Radiation”*. Lasers produce far and away the

best kind of light for optical communication. Ideal laser light is single-

wavelength only. This is related to the molecular characteristics of the



material being used in the laser. It is formed in parallel beams and is in a

single phase. That is, it is “coherent”.

Lasers can be modulated (controlled) very precisely (the record is a

pulse length of 0.5 femto seconds.

Lasers can produce relatively high power. Indeed some types of

laser can produce kilowatts of power. In communication

applications, semiconductor lasers of power up to about 20 mill

watts are available. This is many times greater power than LEDs

can generate. Other semiconductor lasers (such as those used in

“pumps” for optical amplifiers) have outputs of up to 250 mill

watts.

Because laser light is produced in parallel beams, a high

percentage (50% to 80%) can be transferred into the fiber.

**11.2.1 Principle of the LASER**:-

1.An electron within an atom (or a molecule or an ion) starts in a low

energy stable state often called the “ground” state.

2. Energy is supplied from outside and is absorbed by the atomic

structure whereupon the electron enters an excited (higher energy) state.

3. A photon arrives with energy close to the same amount of energy as

the electron needs to give up reaching a stable state. (This is just another

way of saying that the wavelength of the arriving photon is very close to

the wavelength at which the excited electron will emit its own photon.)

**Figure:-Principle of operation of laser**

**Figure: Spontaneous Emission**

4. The arriving photon triggers a resonance with the excited atom. As a

result the excited electron leaves its excited state and transitions to a

more stable state giving up the energy difference in the form of a

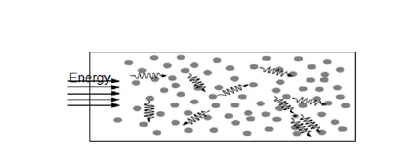
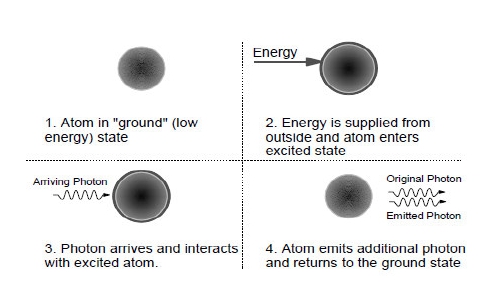
photon.

*The critical characteristic here is that when a new photon is emitted it*

*has identical wavelength, phase and direction characteristics as the*

*exciting photon.*

**Note:** The photon that triggered (stimulated) the emission itself is not



absorbed and continues along its original path accompanied by the

newly emitted photon.

**12.0 Optical Detectors:-**

The predominant types of light detector used in communications systems

rely on the principle of ionization in a semiconductor material. When

discussing photo detectors there are four important parameters:

**Detector Responsivity:-**This is the ratio of output current to input

optical power. Hence this is the efficiency of the device.

**Spectral Response Range:-**This is the range of wavelengths over which

the device will operate.

**Response Time:-**This is a measure of how quickly the detector can

respond to variations in the input light intensity.

**Noise Characteristics:-**

**12.1 Photoconductors:-**

Photoconductors are the simplest conceivable optical detector. The

device consists of a piece of (undoped) semiconductor material with

electrical contacts attached. A voltage is applied across the contacts.

When a photon arrives in the semiconductor it is absorbed and an

electron/hole pair is created. Under the influence of the electric field

between the two contacts the electron and the hole each migrate toward

one of the contacts. Wave length depends on amount of light falling .

**Figure: Photoconductor detector**

**12.2 Photodiodes**:-

Photodiodes convert light directly to electric current. An ideal (p-i-n)

diode can convert one photon to one electron of current

**12.2.1 P-N Diodes:-**

The principle involved in a PIN diode is simply the principle of the LED

in reverse. That is, light is absorbed at a p-n junction rather than emitted.

The big problem here is that the depletion zone in a p-n junction is

extremely thin. But current produced is insufficient and devices are not

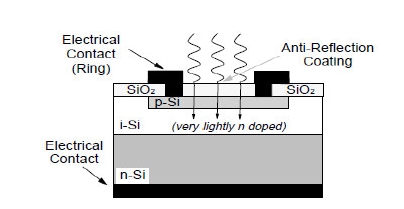
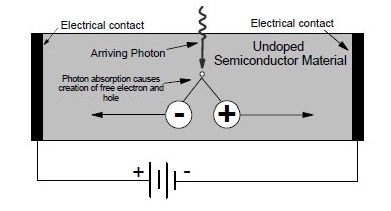
fast enough for current communications.

**12.2.2 P-I-N Diodes:-**

**Figure:- Silicon P-I-N Diode Schematic**

The answer to the problem created by the extreme thinness of a p-n

junction is to make it thicker! The junction is extended by the addition of



a very lightly doped layer called the intrinsic zone between the p and n

doped zones. Thus the device is called a p-i-n diode rather than a p-n

diode. The wide intrinsic (i) layer has only a very small amount of

dopant and acts as a very wide depletion layer. There are a number of

improvements here:

It increases the chances of an entering photon being absorbed

because the volume of absorbent material is significantly

increased.

Because it makes the junction wider it reduces the capacitance

across the junction. The lower the capacitance of the junction the

faster the device response. Increasing the width of the depletion

layer favors current carriage by the drift process which is faster

than the diffusion process. The result is that the

*Addition of the “i” layer increases the responsivity and decreases*

*the response time of the detector to around a few tens of*

*picoseconds.*

**12.3 Avalanche Photodiodes (APDs):-**

APDs amplify the signal during the detection process. They use a

similar principle to that of “photomultiplier” tubes used in nuclear

radiation detection.

**Methodology of Conduction in APDs:-**

1. A single photon acting on the device releases a single electron.

2. This electron is accelerated through an electric field until it strikes a

target material.

**Figure:- Avalanche Photodiode (APD)**

3. This collision with the target causes “impact ionization” which

releases multiple electrons.

4. These electrons are then themselves accelerated through the field until

they strike another target.

5. This releases more electrons and the process is repeated until the

electrons finally hit a collector element.

APDs develop a very high electric field in the intrinsic region as well as

to impart more energy to photoelectrons to produce new electron-hole

pairs by impact ionization. This impact ionization leads to avalanche

breakdown in the reverse biased diode. *So the APDs have high*

*sensitivity and high responsivity over p-i-n diodes due to the avalanche*

*multiplication.*



**13.0 Limitations of Optical Fiber:-**

1. The terminating equipment is still costly as compared to copper wire.

2. Delicate so has to be handled carefully.

3. Communication is not totally in optical domain, so repeated electric

to optical to electrical conversion is needed.

4. Optical amplifiers, splitters, MUX-DEMUX are still in development

stages.

5. Tapping is not possible. Specialized equipment is needed to tap a

fiber.

6. Optical fiber splicing is a specialized technique and needs expertly

trained manpower.

7. The splicing and testing equipments are very expensive as compared

to copper equipments.

8. Bending Cables

9. Gamma Radiation

10. Electrical Fields

11. Sharks Eat the Cable

12. Gophers (and Termites) Really Do Eat the Cable

**14.0 Applications of Optical Fiber:-**

Due to the advantages of fiber optic over the traditional

connectivity networks, networks are being changed to the new

technology of fiber optic. Here is some applications use fiber optics for

the communication:

Long Haul telecommunication systems on land and at sea to

carry many simultaneous telephone calls (or other signals) over

long distances. These include ocean spanning submarine cables

and national backbone networks for telephone and computer

data transmission.

Interoffice trunks that carry many telephone conversations

simultaneously between local and regional switching facilities.

Connections between the telephone N/W and antennas for

mobile telephone service.

Links among computers and high resolution video-terminals

used for such purposes as computer aided design.

Transmission of signals within ships and aircraft.

Local area Networks operating at high speeds or over large

areas, and backbone systems connecting slower local area

Networks.

High speed interconnections between computer and peripherals

devices, or between computers, or even within segments of

single large

Cable TV,CCTV ,Optical Fiber Sensors, X-ray Imaging ,Night

Vision

**Other uses of optical fibers**

Fibers are widely used in illumination applications. They are

used as light guides in medical and other applications where

bright light Some buildings, optical fibers are used to route

sunlight from the roof to other parts of the building .

Optical fiber ***illumination*** is also used for decorative

applications, including signs, art, and artificial Christmas trees.

Optical fiber is also used in imaging optics i.e. an ***endoscope***,

which is used to view objects through a small hole. Medical

endoscopes are used for minimally invasive exploratory or

surgical procedures (endoscopy). Industrial endoscopes are used

for inspecting anything hard to reach, such as jet engine

interiors.

In ***spectroscopy***, optical fiber bundles are used to transmit light

from a spectrometer to a substance which cannot be placed

inside the spectrometer itself, in order to analyze its

composition.

A ***spectrometer analyzes*** substances by bouncing light off of

and through them. By using fibers, a spectrometer can be used

to study objects that are too large to fit inside, or gasses, or

reactions which occur in pressure vessels.

**Future Applications of Optical Fiber Communication:-**

Today, however, lower costs and higher production volumes mean that

fiber optics can now make sense in areas where it didn't before,

including relatively short distances.

**Advancement in Communications: -**

Fiber technologies provide higher bandwidth, higher speed, and

increased reliability over existing DSL technology, which uses

Copper wires for communication.

In future it will be possible to have Wave length Band in Radio

compare to FM band (where synchronizing is done through

frequency).In Wavelength band Channels will have Different

wavelengths (earlier, it was once just one wavelength of light

traveling through the fiber, today it is more like 160 wavelengths

traveling at once.).So as research is going on number of

wavelength per fiber is increasing.

*In cars, fiber optics is replacing copper as a lighter*

*alternative for entertainment systems, CD players, and*

*global positioning systems.*

Research is going on to integrate semiconductor devices, including

a transistor, inside micro structured optical fibers. Then it will be

possible to manipulate signals inside optical fibers. After these

developments there will be not any need of electronic switching

devices at both ends of fiber. So signal will never leave fiber. This

results in faster cheaper and more efficient operation.

INTEL has developed new technology to connect PC USB to

Optical Fiber. So direct communication can be achieved between

users through Optical Fiber

**Advancement in Fiber Optics: -**

In the research world, fiber is enabling the creation of clocks that

are more accurate than ever before, By combining a laser with an

optical fiber, these clocks allow scientists to measure time more

accurately than they've been able to previously, enabling better,

more precise.

By using Fiber optics it is possible to prepare more reflective and

shining cloths.

Room Lighting may improve. Now you can imagine a home with

cheerful splashes of natural sunlight in every room at once.

Lighting Colour wili be changed. So, by using some almost

invisible optical fibers to an outside light source, they could bring

natural, outside light to a space that needs.

This is new way to get sunlight into a place that wouldn'totherwise

have it. Such as a dark, interior room.

Fiber-optic light bulbs have already been developed, and may be

an additional way to tap into fiber optics for household lighting.

**Conclusion:-**

The age of optical communications is a new era. In several

ways fiber optics is a pivotal breakthrough from the electric

communication we have been accustomed to.

Instead of

electrons moving back and forth over a regular copper or

metallic wire to carry signals, light waves navigate tiny fibres of

glass or plastic to accomplish the same purpose.

With a bandwidth and information capacity a thousand times

greater than that of copper circuits, fiber optics may soon

provide us with all the communication technology we could

want in a lifetime, at a cost efficient price.

At present there are many optical fiber communication links

throughout the world without using optical solutions. When we

introduce optical solutions as light pulses through the fibers, we

can achieve high quality telecommunication at a lower cost. We

can expect a great revolution in optical fiber communication

within a few years by means of solutions.

**References:-**

From paper written by *Harry J. R. Dutton for* International Technical

Support

Organization

titled

as

Understanding

Optical

Communications by IBM.

http://en.wikipedia.org/wiki/Optical\_fiber

http://www.fiber-optics.info/articles/wdm.htm

http://www.arcelect.com/fibercable.htm

From paper Optical fiber communication—An overview by M

ARUMUGAM (Department of Physics), Anna University.

An educational resource published by Communications Specialties,

Inc.paper titled Introduction to Fiber Optics