Modern Communication Trends (EC0422)

Unit-3
Optical communication

B.Tech (Electronics and Communication)
Semester-IV

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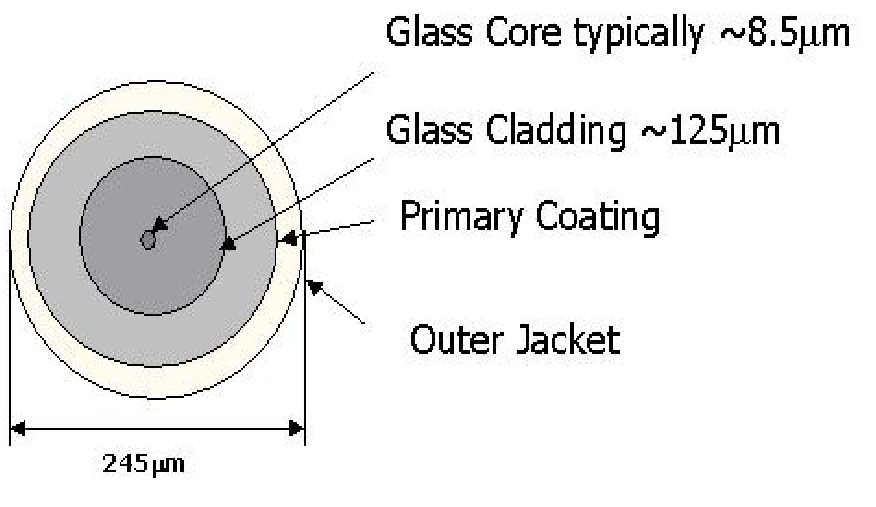
Optical Communications

- Optical communications means the use of cables to carry light. These cables are known as Fibre Optic cables.
- The definition of a Fibre Optic cable is ‘A flexible optically transparent fibre, usually made of glass or plastic, through which light can be transmitted’.



Optical Communications

- The distance that signals can be carried through the Fibre Optic cable are dependant on the quality of the cable, which in turn depends on the price that you pay for it.
- The long haul/distance, expensive, fantastically clear, under-ocean cable can run for about 100km before the signal needs a boost/Amplify.
- A 'standard' glass fibre can easily run for 2km before needing a boost.
- Compare these to a copper cable which needs to be boosted more rapidly. Repeaters are expensive.

Why fiber?

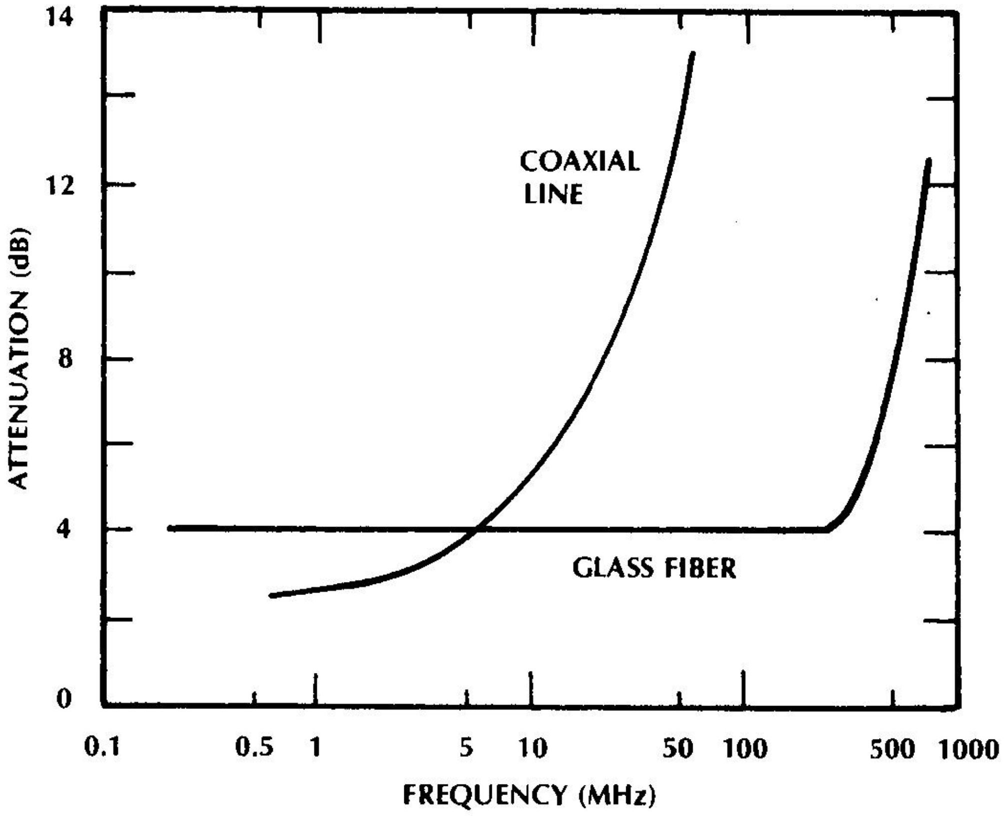


Figure 1-18 Effective attenuation of a 1-km length of coaxial line and glass fiber. The 3-dB bandwidth of the fiber is 500 MHz. (Coaxial line data from manufacturer's literature, Alpha Wire Corporation, Elizabeth, N.J.)

- A single fibre optic cable is as thin as a single human hair. Many cables can be bundled together to form one cable and thus increase the amount of data that can be transmitted dramatically.

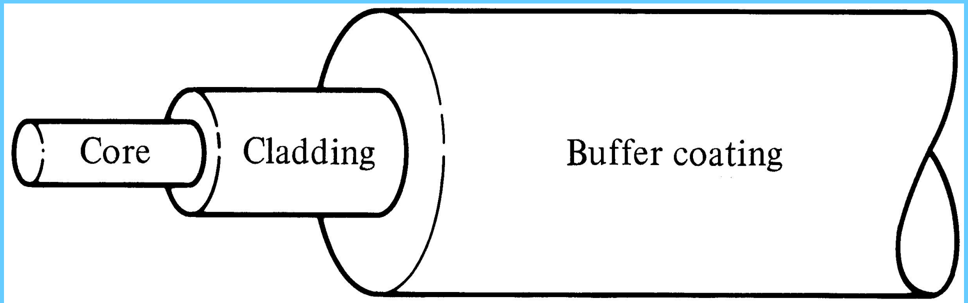
- Each fibre optic cable is capable of transmitting trillions of bits per second.

- Any one of these copper bundles can be replaced with one fibre strand

OPTICAL FIBER

- An optical fiber is a long cylindrical dielectric waveguide, usually of circular cross-section, transparent to light over the operating wavelength.

Fiber Structure



- A single solid dielectric of two concentric layers. The inner layer known as **Core** is of radius ‘a’ and refractive index ‘n_1’. The outer layer called **Cladding** has refractive index ‘n_2’.

$n_2 < n_1$ ⟹ condition necessary for TIR

Advantages of fiber cladding

The cladding provides mechanical strength to the fiber core

The cladding protects the core from absorbing surface.

The cladding reduces the scattering losses.

The cladding improves the fiber resistance to cracking during increased temperature, reduces water absorption, increases resistance to sunlight and provides resistance to air and chemical pollution.

Cladding also offers protection against rain, strong winds and modes.

Fiber optics using without cladding

Power launching capability decreases

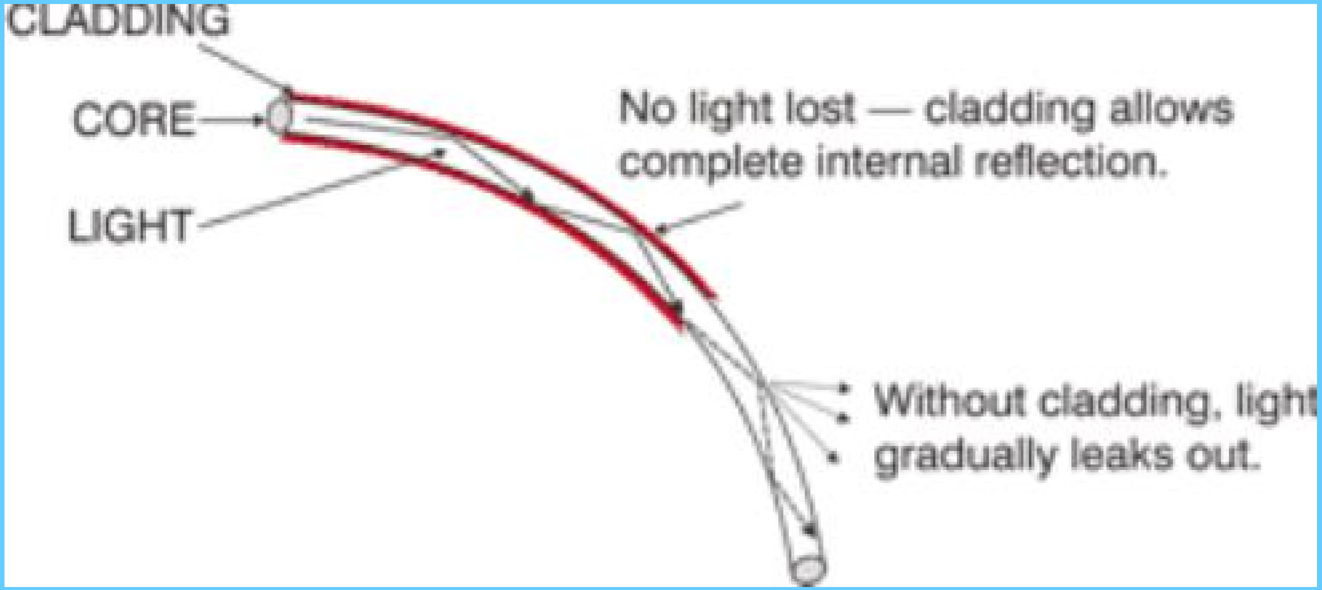
Numerical aperture Reduces

Signal becomes week/poor due to the external environment

Information loss

Data rate low

Light Propagation through Optical Fiber



- **For light propagation through the fiber, the conditions for total internal reflection (TIR) should be met at the core-cladding interface**

Advantages of Optical fibers

- Long distance Transmission
- Large Information Capacity
- Small Size
- Low Weight
  Immunity to electrical Interference: Dielectric material, does not conduct the electricity, electromagnetic interference
- Enhanced safety
  They do not have any problem of ground loops, sparks, and potentially high voltages
  Precautions wrt laser light
- Increased signal Security

Advantages of OFC over SATC

- A good communication is: BW & SNR(Low loss)

Bandwidth is more

Speed is high

Low Losses

Long life

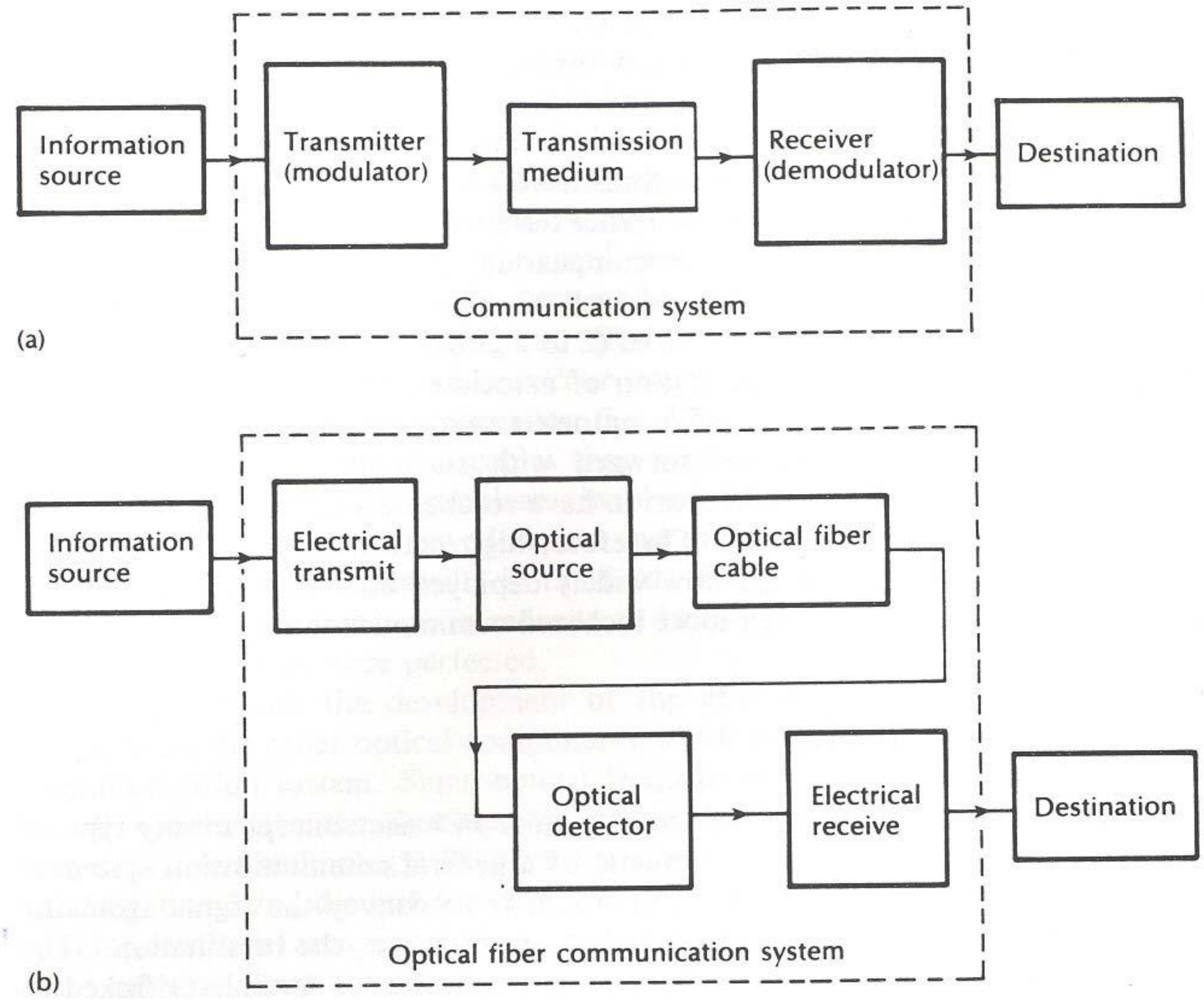
Upgradable

Low EMI

Point to point communication

Maintenance

General and Optical Communication systems



Fiber Optics Transmission

Low Attenuation
Very High Bandwidth (THz)
Small Size and Low Weight
No Electromagnetic Interference
Low Security Risk

Elements of Optical Transmission

- Electrical-to-optical Transducers
- Optical Media
- Optical-to-electrical Transducers
- Digital Signal Processing, repeaters and clock recovery.

Types of transducers used in OC

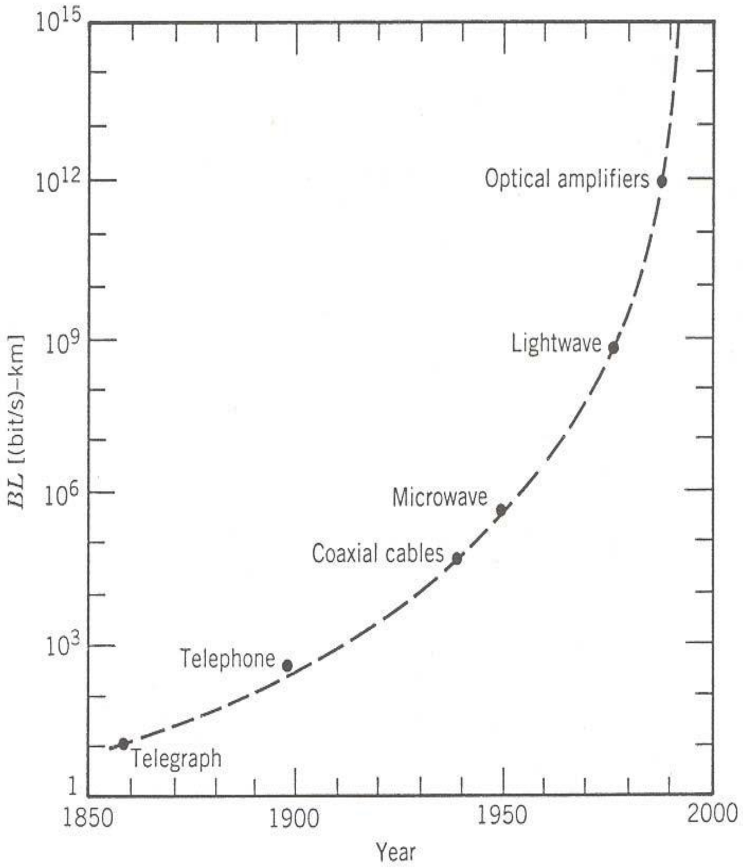
Electrical-to-Optical Transducers

- LED - Light Emitting Diode is inexpensive, reliable but can support only lower bandwidth.
- LD – Laser Diode provides high bandwidth and narrow spectrum.

Optical-to-Electrical Transducers

- PIN Diode - Silicone or InGaAs based p-i-n Diode operates well at the low bandwidth
- Avalanche Diode – Silicone or InGaAs Diode with internal gain can work with high data rate.

Need for Fiber Optical Communication



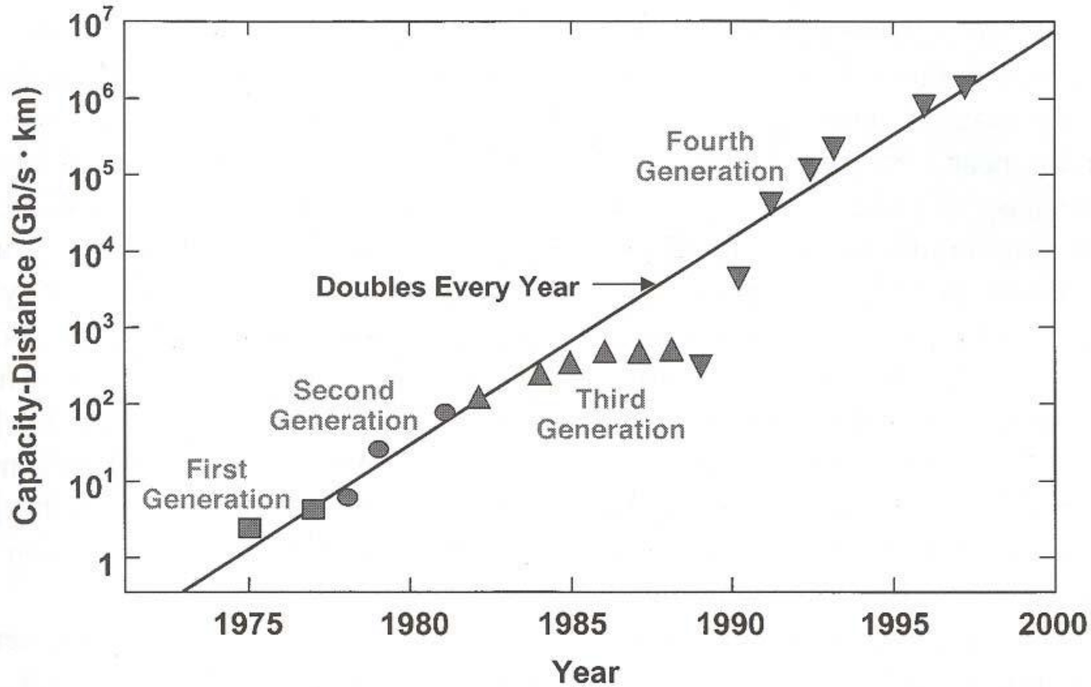
Increase of the bit rate distance product BL for different communication Technologies over time.

(Ref.: G.P. Agrawal, Fiber- Optic Comm. Systems)

Bandwidth-Distance Product is used to define the inherent operational limit of an optical fiber transmission system. The effect of dispersion in fiber increases with the increase in the length of the fiber.

The value of bandwidth-distance product is expressed in terms of MHz-Km and is derived as a product of bandwidth and distance. The bandwidth of the signal and the distance it can be carried by the fiber optic system are related to each other.

Need for Fiber Optical Communication



Bit-rate distance product (BL) for different generations of optical communication systems.

The increase of the capacity-distance product can be explained by the four major innovations.

(Ref.: G.P. Agrawal,Fiber-optic Communication systems)

The bandwidth–distance product is typically limited by the fact that the bit error rate rises sharply for too high data rates.

- For a transcontinental channel – latency/Delay = 50 milliseconds & Bandwidth = 45 Mbps.

Bandwidth delay product =

$$50 \times 10^{-3} \times 45 \times 10^{6}$$

$$= 2.25 \text{ Mbits}$$

We can transmit 2.25 M bits before the first bit reaches the other end of the channel !

CLASSIFICATION OF OPTICAL FIBERS

Classified on basis of :

- Core and Cladding materials
- Refractive index profile
- Modes of propagation

Three Varieties:

a. Glass core and cladding (SCS: silca-clad silica)

- Low attenuation & best propagation characteristics
- Least rugged – delicate to handle

b. Glass core with plastic cladding (PCS: plastic clad silica)

- More rugged than glass; attractive to military applications
- Medium attenuation and propagation characteristics

c. Plastic core and cladding

- More flexible and more rugged
- Easy to install, better withstand stress, less expensive, weigh 60% less than glass
- High attenuation- limited to short runs.

Refractive Index Profile: Two types

- **Step Index :** Refractive index makes abrupt change
- **Graded Index** : Refractive index is made to vary as a function of the radial distance from the centre of the fiber

Mode of propagations : Two types

- **Single mode :** Single path of light
- **Multimode :** Multiple paths

Evolution of fiber optic system

Fiber optics deals with study of propagation of light through transparent dielectric wav guides,.

The fiber optics are used for transmission of data from point to point location.

First Generation:

The first generation of light wave systems uses GaAs semiconductor laser and operation region was 0.8 micrometer.

Bit rate: 45 Mb/s

Repeater spacing : 10 Km

Second Generation:

Bit rate: 100 Mb/s to 1.7 Gb/s

Repeater spacing : 50 Km

Operating Wavelength: 1.3. micro meter

Semiconductor: In GaAsP (Indium gallium arsenide phosphide)

Third Generation:

Bit rate: 10 Gb/s

Repeater spacing : 100 Km

Operating Wavelength: 1.55 micro meter

Fourth Generation:

Bit rate: 10 Tb/s

Repeater spacing : Greater than 10000 Km

Operating Wavelength: 1.45 to 1.52 micro meter

Fifth Generation:

Bit rate: 40 t0o 160 Tb/s

Repeater spacing : 24000 Km-35000 Km

Operating Wavelength: 1.53 to 1.57 Micro meter

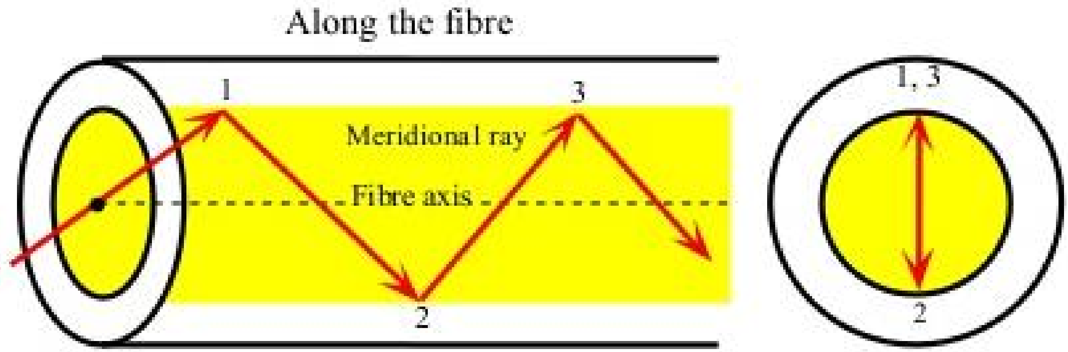
Types of Rays

- If the rays are launched within core of acceptance can be successfully propagated along the fiber. But the exact path of the ray is determined by the position and angle of ray at which it strikes the core.

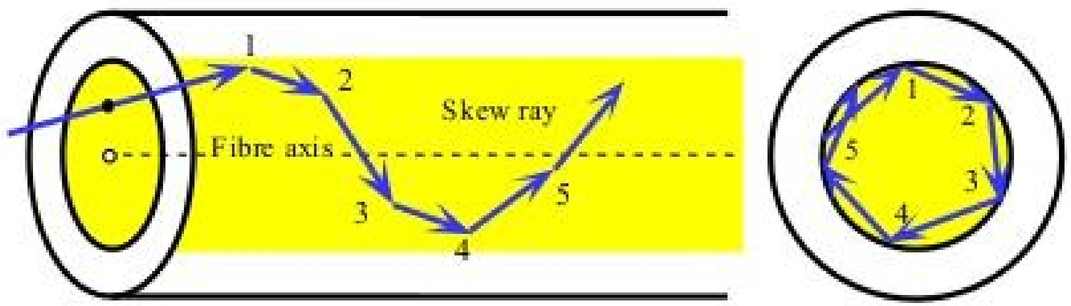
There are three different types of the rays

- Skew rays: does not passing through the center and follows a three dimensional path (helical path).
- Meridional ray: passing through the center and follows zig-zag path.

Axial ray: The axial ray travels along the axis of the fiber and stays at the axis all the time.



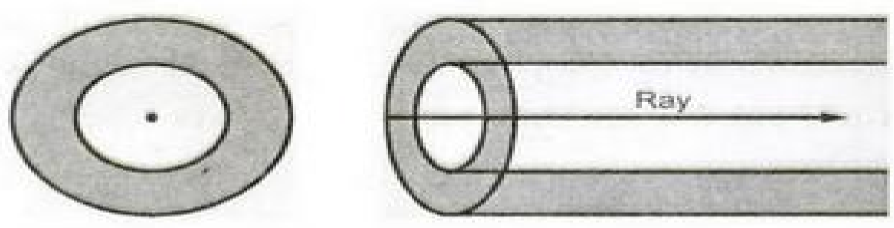
(a) A meridional ray always crosses the fiber axis.



(b) A skew ray does not have to cross the fiber axis. It zigzags around the fiber axis.

Ray path along the fiber

Ray path projected on to a plane normal to fiber axis



Basic optical laws

Refractive index, Reflection, refraction

In optics the **refractive index** or **index of refraction** *n* of an optical medium is a dimensionless number that describes how light, or any other radiation, propagates through that medium. It is defined as

$$n=c/v$$

where *c* is the speed of light in vacuum and *v* is the speed of light in the substance.

For example, the refractive index of water is 1.33, meaning that light travels 1.33 times faster in a vacuum than it does in water.

$$\text{Refractive Index} = \frac{\text{Speed of light in air}}{\text{Speed of light in medium}}$$

Reflection & Refraction

Reflection occurs when- A light ray is incident upon a reflective surface at some incident angle $\succ_1$ from imaginary perpendicular normal, the ray will be reflected from the surface at some angle $\succ_2$ from normal which is equal to the incident angle , where $\succ_2$ called as reflection angle.

Angle of incident $\succ_1$ = Angle of reflection $\succ_2$.

Refraction occurs when- A light ray passes from one medium to another (i.e. light ray changes its direction at interface) or Refraction occurs whenever density of medium changes. (refraction occurs at air and water medium).

When a wave passes through less dense medium to more dense medium, the wave is refracted towards the normal.

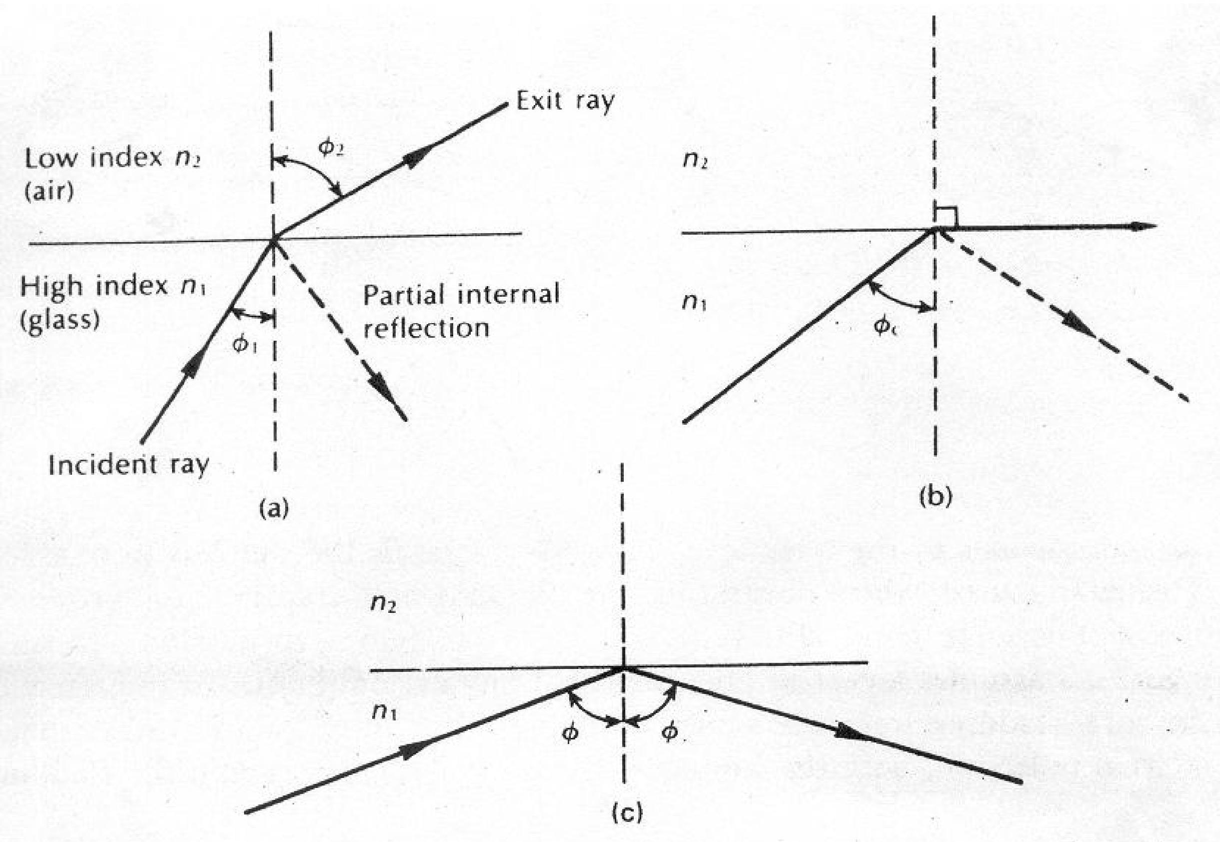
The refraction takes place because light travels at different speed in difference medium. (the speed in air is more than the speed in water/glass).

The amount of refraction is called index of refraction.

The index of refraction for vacuum and air is 1.0 for water it is 1.33 and for glass it is 1.50.

Total Internal Reflection

- Light entering from glass-air interface ($n_1 > n_2$) - **Refraction**



Snell's Law:

$n_1 \sin \phi_1 = n_2 \sin \phi_2$

or $$\frac{\sin \phi_1}{\sin \phi_2} = \frac{n_2}{n_1}$$

$\phi_2 > \phi_1$

At $\phi_2 = 90^o$, refracted ray moves parallel to interface between dielectrics and $\phi_1 < 90^o$ - **Limiting case of refraction**

Angle of incidence, $\phi_1 \equiv \phi_C$; **critical angle**

Critical Angle

When the angle of incident $\succ_1$ is progressively increased , there will be progressive increase of refractive angle $\succ_2$. At some condition the refractive angle $\succ_2$ becomes 90 to the normal. When this happens the refracted wave travels along the interface.

The angle of incident at the point at which the refractive angle becomes 90 is called critical angle $\succ_c$

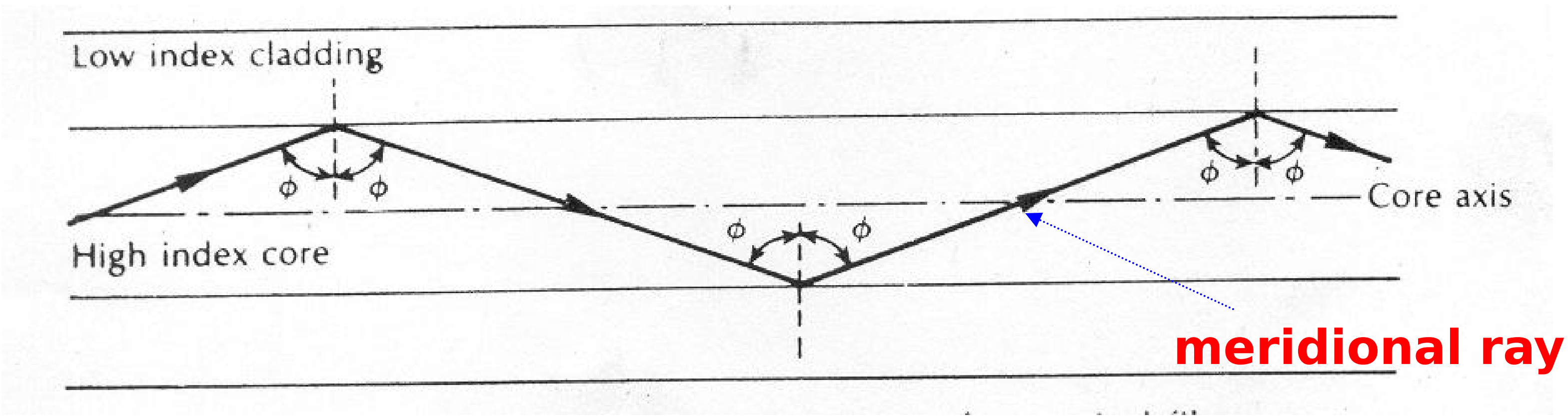
It is defines as the minimum angle of incidence $\succ_1$ at which the ray strikes the interface of two media and causes an angle of refraction $\succ_2$ equal to 90.

Hence, at critical angle $\succ_1 = \succ_c$ & $\succ_2 = 90$

Using Snell's law : $\succ_c = \sin^{-1} (n_2/n_1)$

Total Internal Reflection

- Value of critical angle (X_C); $\sin X_C = n_2/n_1$
- At angle of incidence greater than critical angle, the light is reflected back into the originating dielectric medium (TIR) with high efficiency (® 99.9%)

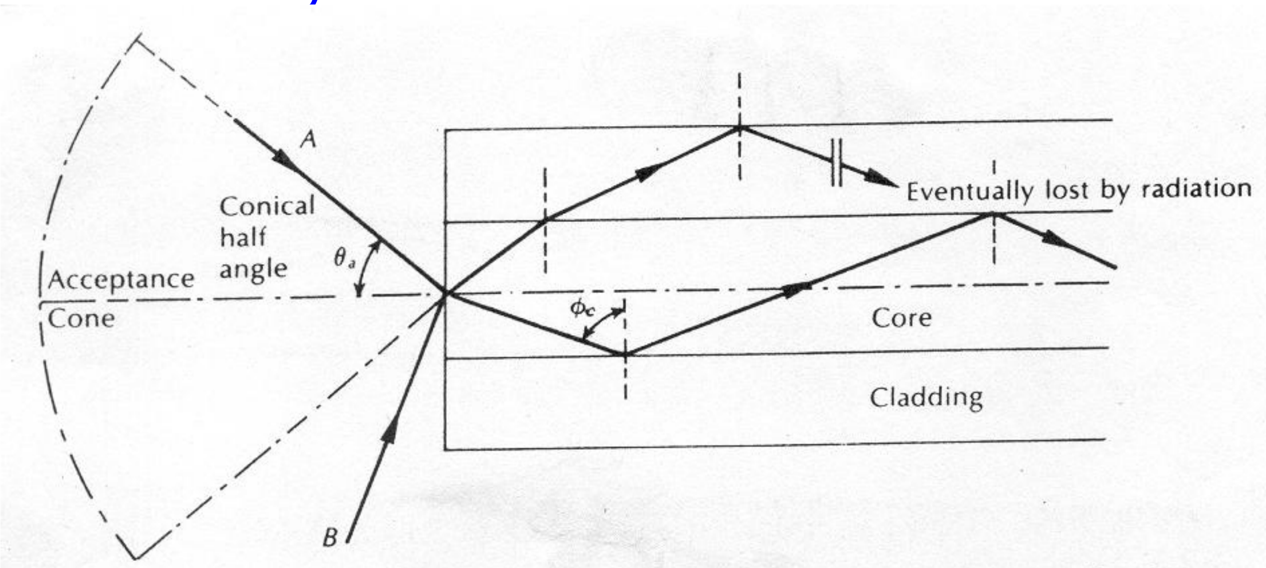


Transmission of light ray in a perfect optical fiber

ACCEPTANCE ANGLE

- Not all rays entering the fiber core will continue to be propagated down its length

- Only rays with sufficiently shallow grazing angle (i.e. angle to the normal > ϕ_C) at the core-cladding interface are transmitted by TIR.



- Any ray incident into fiber core at angle > θ_a will be transmitted to core-cladding interface at an angle < ϕ_C and will not follow TIR Lost (case B)

- The ability of fiber to capture the amount of light called N.A

For a good light launching efficiency acceptance angle should be as large as possible..

- Diameter
- Acceptance angle: Between which all lights coupled into the fiber.

Numerical Aperture

The numerical aperture (NA) of a fiber is a figure of merit which represents its light gathering capability.
Larger the numerical aperture, the greater the amount of light accepted by fiber.
The acceptance angle also determines how much light is able to be enter the fiber and hence there is relation between the numerical aperture and the cone of acceptance.
Numerical aperture (NA) = sin Φ0(max)

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

For air $n_0 = 1$

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

$$\boxed{NA = \sqrt{n_{core}^2 - n_{cladding}^2}} \quad \ldots (4)$$

$$\Delta = \frac{(n_1 - n_2)}{n_1} \qquad (5\,(a))$$

$$\boxed{\Delta = \frac{NA^2}{2 n_1^2}} \qquad \dots (5\,(b))$$

also

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

$$NA = (n_1^2 - n_2^2)^{1/2}$$

$$\boxed{NA = n_1 (2\Delta)^{1/2}}$$

Example 1 : *Calculate the numerical aperture and acceptance angle for a fiber cable of which $n_{core} = 1.5$ and $n_{cladding} = 1.48$. The launching takes place from air.*

Solution :

$$\boxed{NA = \sqrt{n_{core}^2 - n_{cladding}^2}}$$

$$NA = \sqrt{1.5^2 - 1.48^2}$$

$$NA = \mathbf{0.244} \qquad \dots \text{Ans.}$$

$$\boxed{\text{Acceptance angle} = \sin^{-1}\sqrt{n_{core}^2 - n_{cladding}^2} = \sin^{-1} NA}$$

$$\text{Acceptance angle} = \sin^{-1} 0.244$$

$$\phi_0 = \mathbf{14.12^\circ} \qquad \dots \text{Ans.}$$

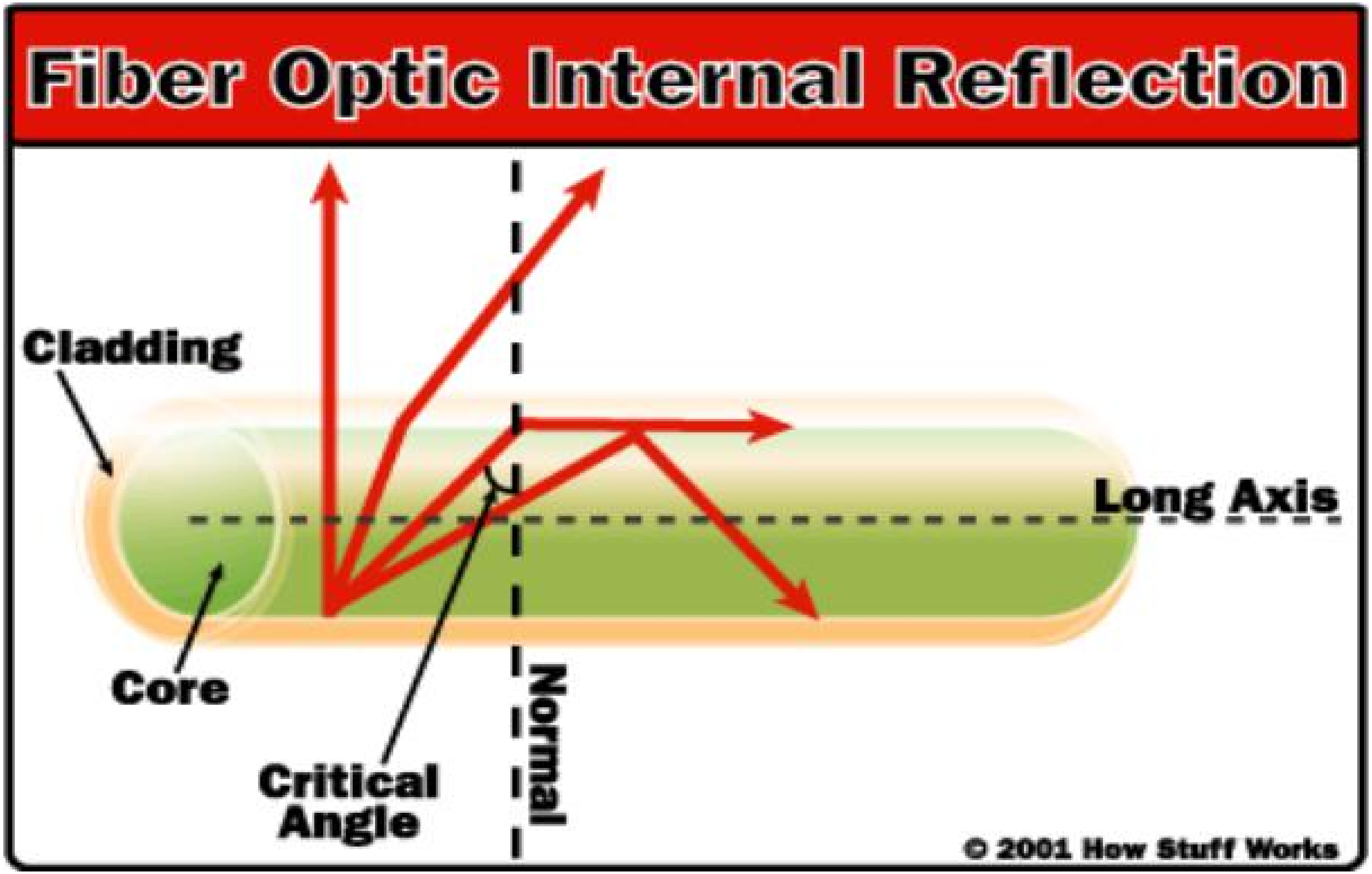
PRINCIPLE

- Light pulses move easily in fiber optic cable because of the principle known as total internal reflection(**T.I.R**).

Condition for T.I.R

- Light should travel from denser medium to rarer medium.
- Angle of incidence is greater than the critical angle.
- Transparent glass or plastic fiber which allow light to be transmitted from transmitted to receiver with minimal loss.

TOTAL INTERNAL REFLECTION



Total Internal Reflection

- There is a critical angle at which no light can be refracted at all, so 100% of the light is reflected
  - Light is trapped in the water and cannot escape into the air
  - This works with any dense medium, such as plastic or glass, the same way it works with water

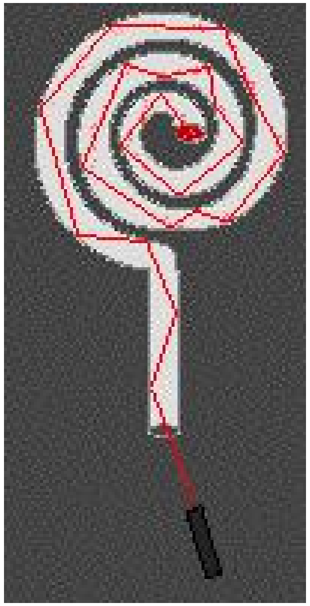
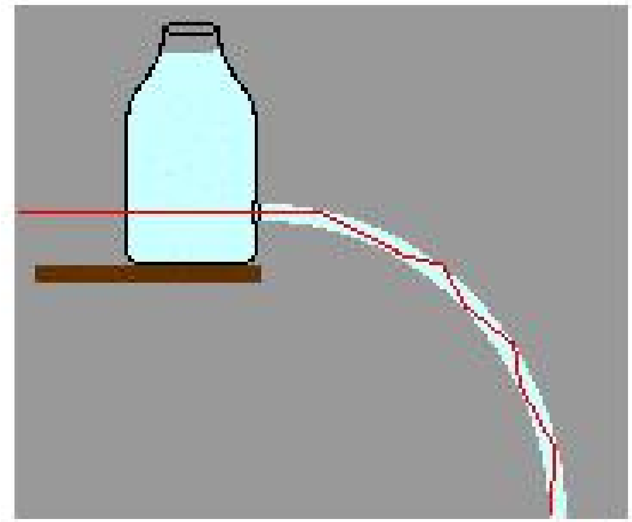


Image from **glenbrook.k12.il.us**

Guiding Light With Water

- Light in a stream of water stays inside the water and bends with it
- This was first demonstrated in the 1840s



The laser beam stays internal to the water, continuously reflecting at each boundary.

Image from glenbrook.k12.il.us/gbssci

Refraction (Bending) of Light

- Ray A comes from straight up and does not bend much
- Ray B comes at a shallow angle and bends a lot more

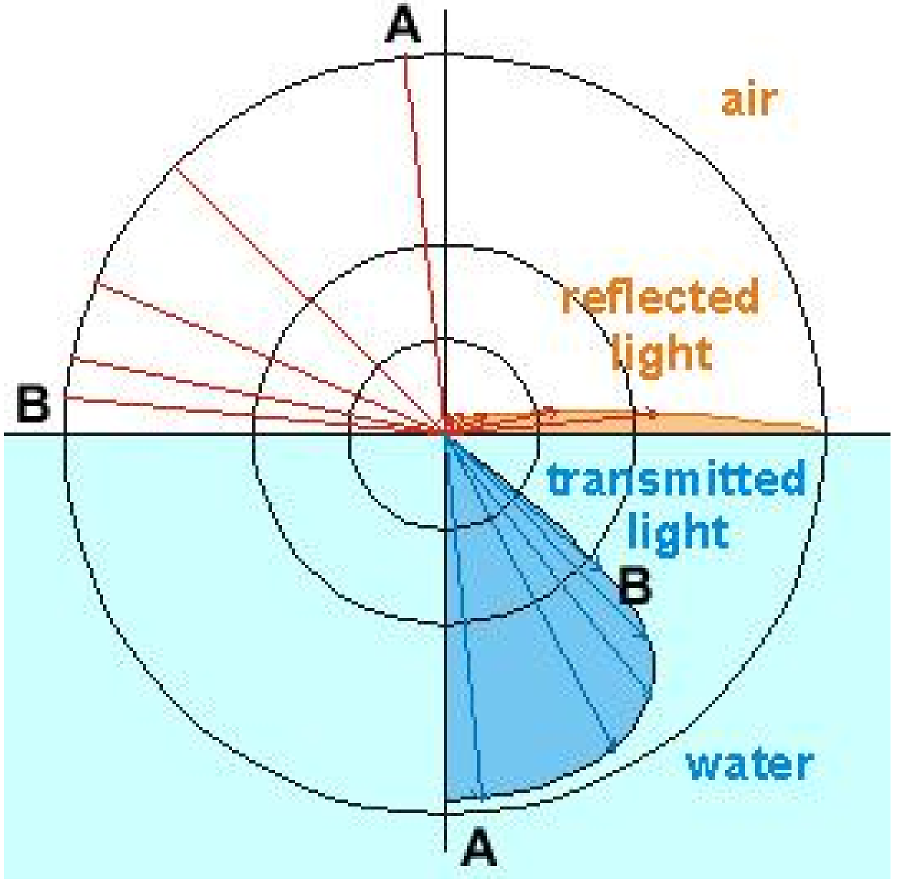


Image from seafriends.org.nz

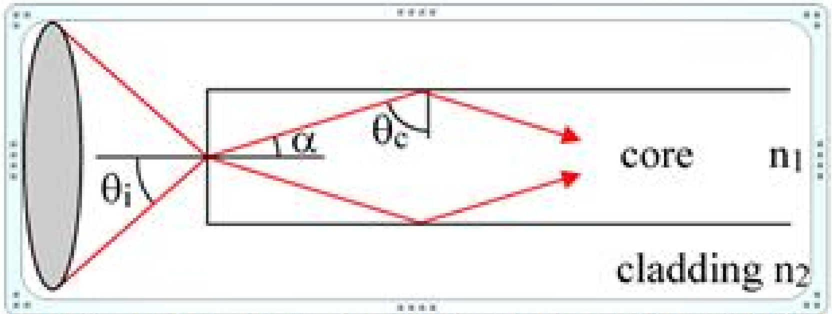
A Light ray is incident from air to glass. Calculate the critical angle.

A light ray is incident from glass medium to air medium. With incident
angle of 32 degree. Will TIR take place?

When a light ray is passed from one water medium to glass medium.
Determine angle of refraction . Incident angle is 30.

Numerical Aperture

- The acceptance angle for a fiber defines its numerical aperture (NA)



- The NA is related to the critical angle of the waveguide and is defined as:

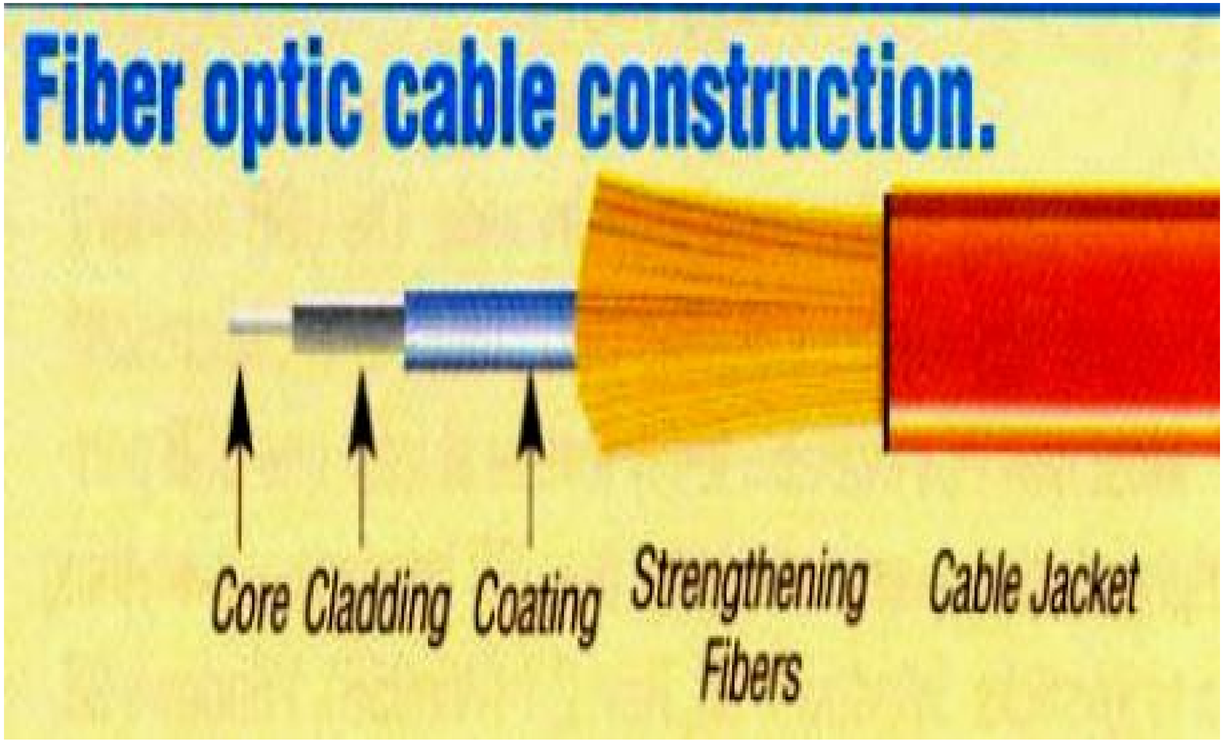
$$NA = \sin(\theta_i) = \sqrt{n_1^2 - n_2^2}$$

- Telecommunications optical fiber $n_1 \sim n_2$,

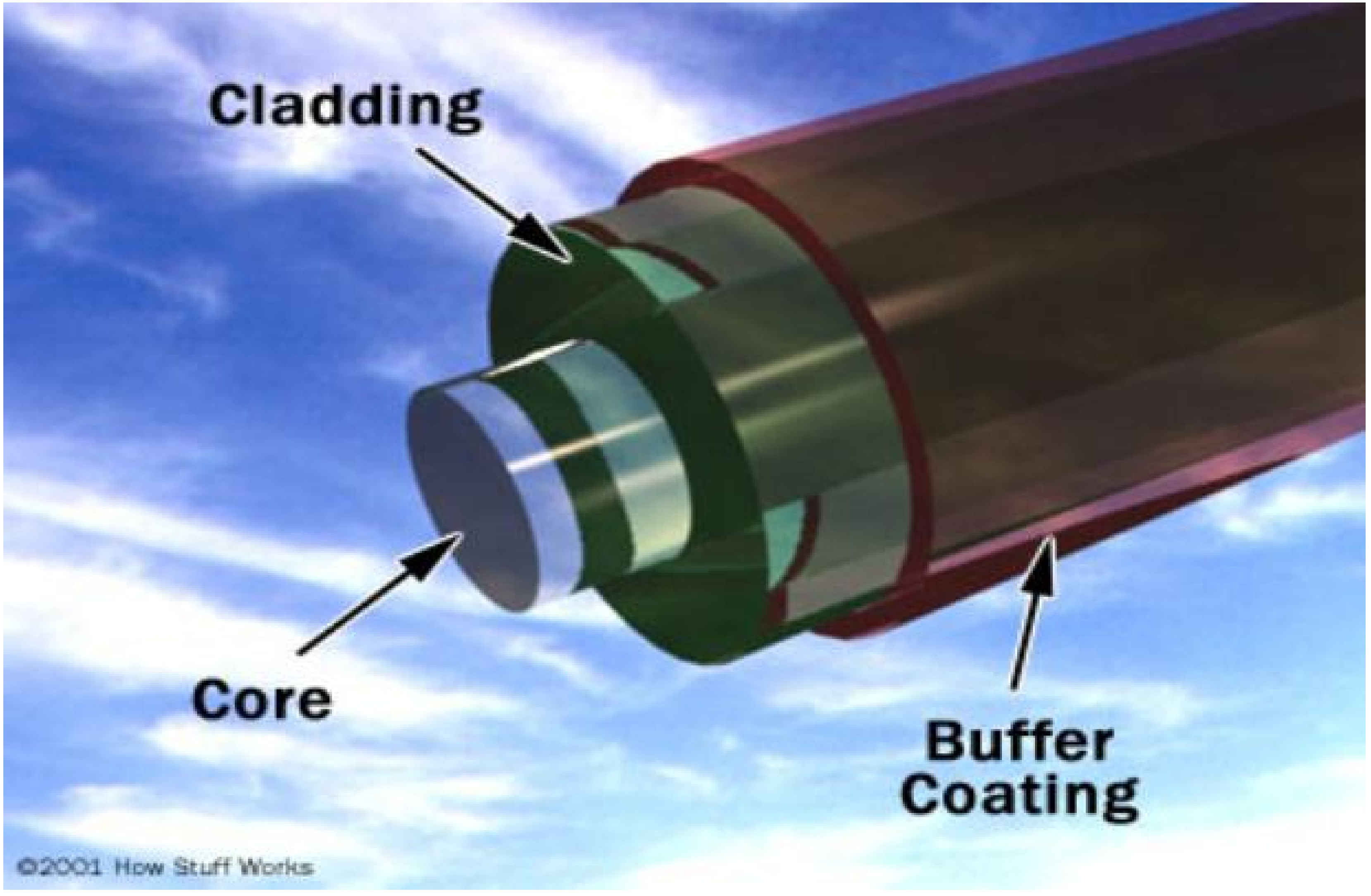
$$NA = \sqrt{n_1^2 - n_2^2} = \sqrt{(n_1 - n_2)(n_1 + n_2)} \cong \sqrt{2 n_1^2 \frac{n_1 - n_2}{n_1}}$$

$$NA \cong n_1 \sqrt{2\,\Delta} \qquad \Delta = \frac{n_1 - n_2}{n_1}$$

CONSTRUCTION



CONSTRUCTION…



TYPES

- **STEP INDEX FIBRE** → **SINGLE MODE**, **MULTI MODE**

- **GRADED INDEX FIBRE**

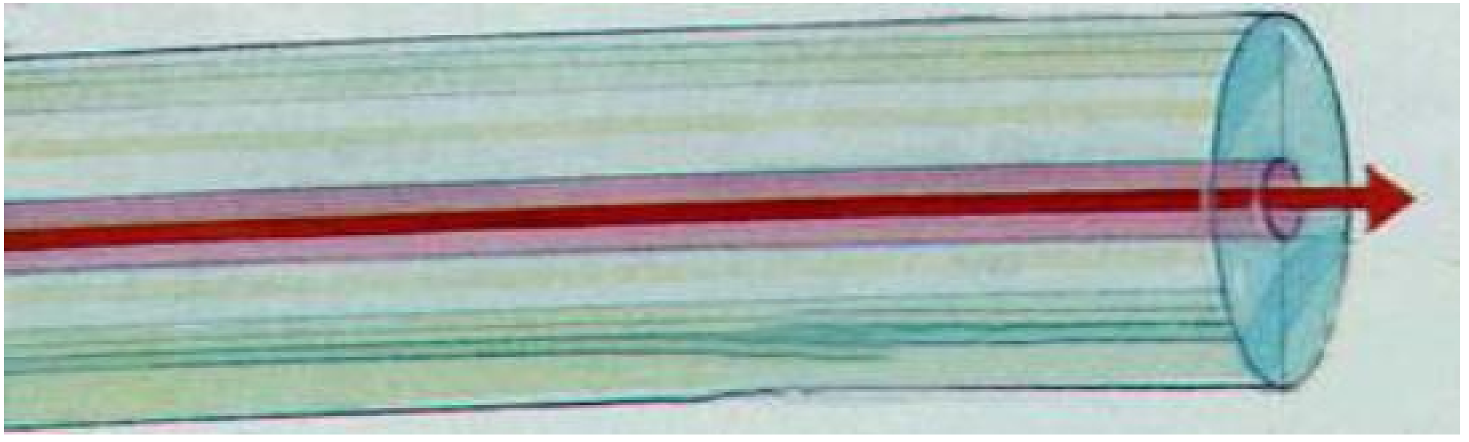
DESCRIPTION

STEP INDEX FIBRE

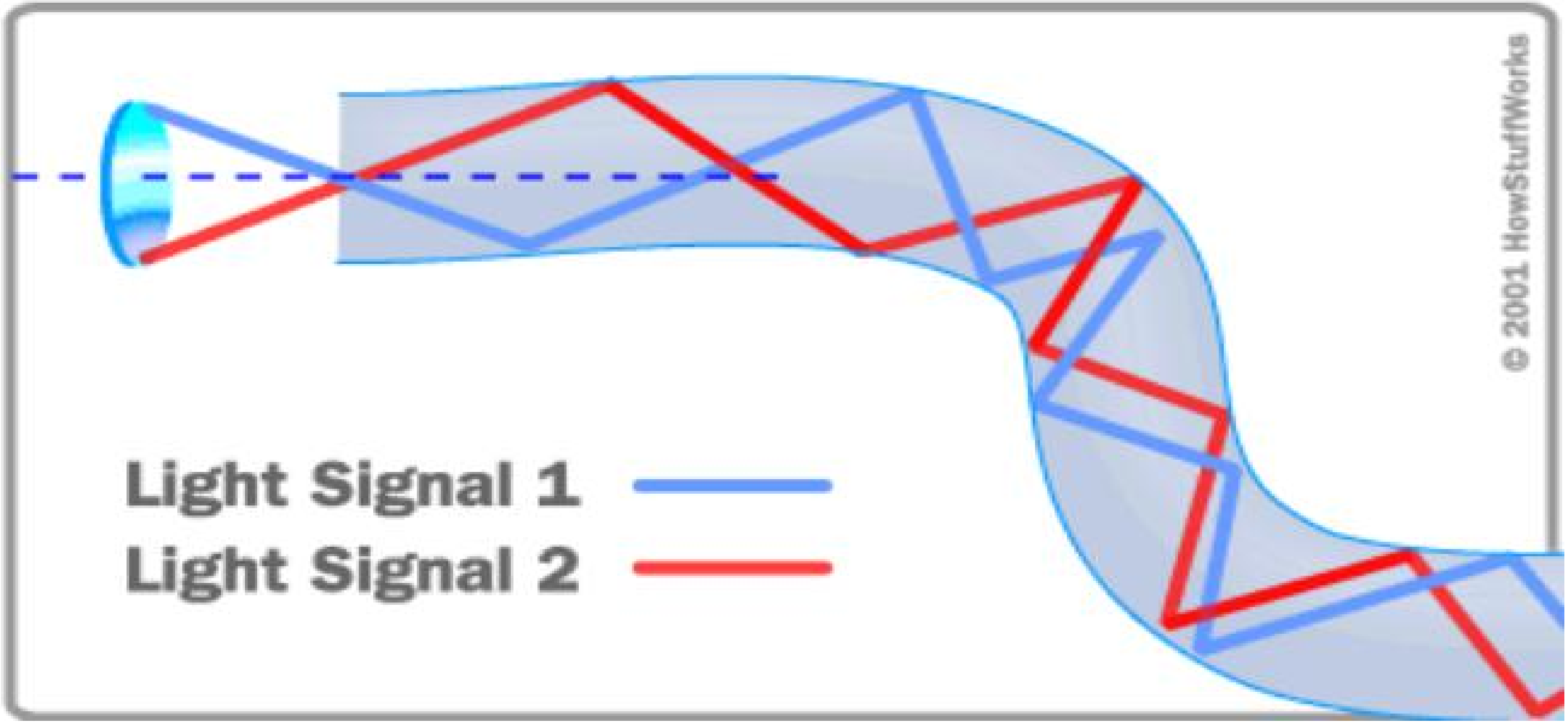
- It is an optical fibre whose core has a refractive index which is slightly greater than that of cladding.
- Because of refractive index of this type the fibre makes a step change a core cladding interface.

SINGLE MODE STEP INDEX

- DIAMETER VARIES FROM 8.3 - 10 MICRON.
- BANDWIDTH IS HIGHER THAN MULTIMODE.
- IT GIVES HIGHER TRANSMISSION RATE.
- NO OVERLAPPING,DISTORTION OF LIGHT PULSES OCCUR WITH LEASTY ATTENUATION.

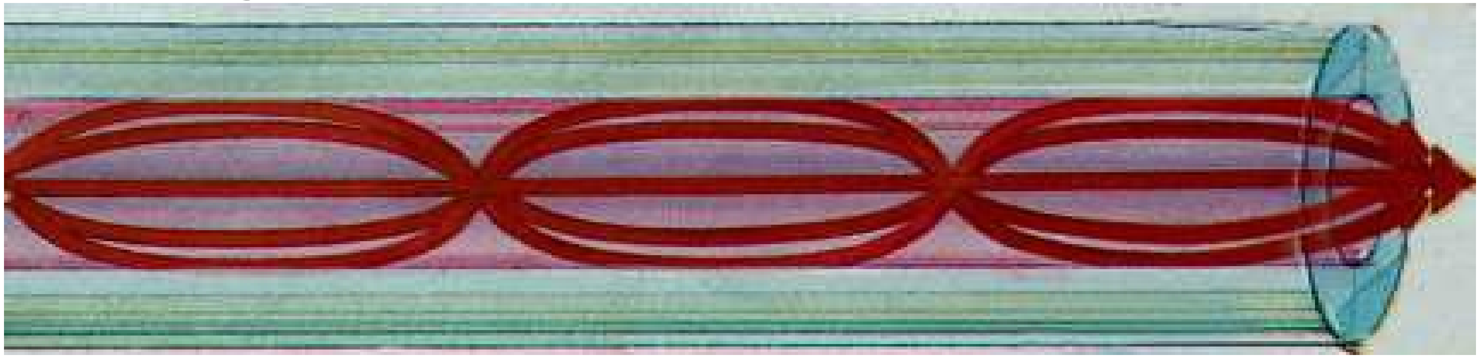


MULTI MODE

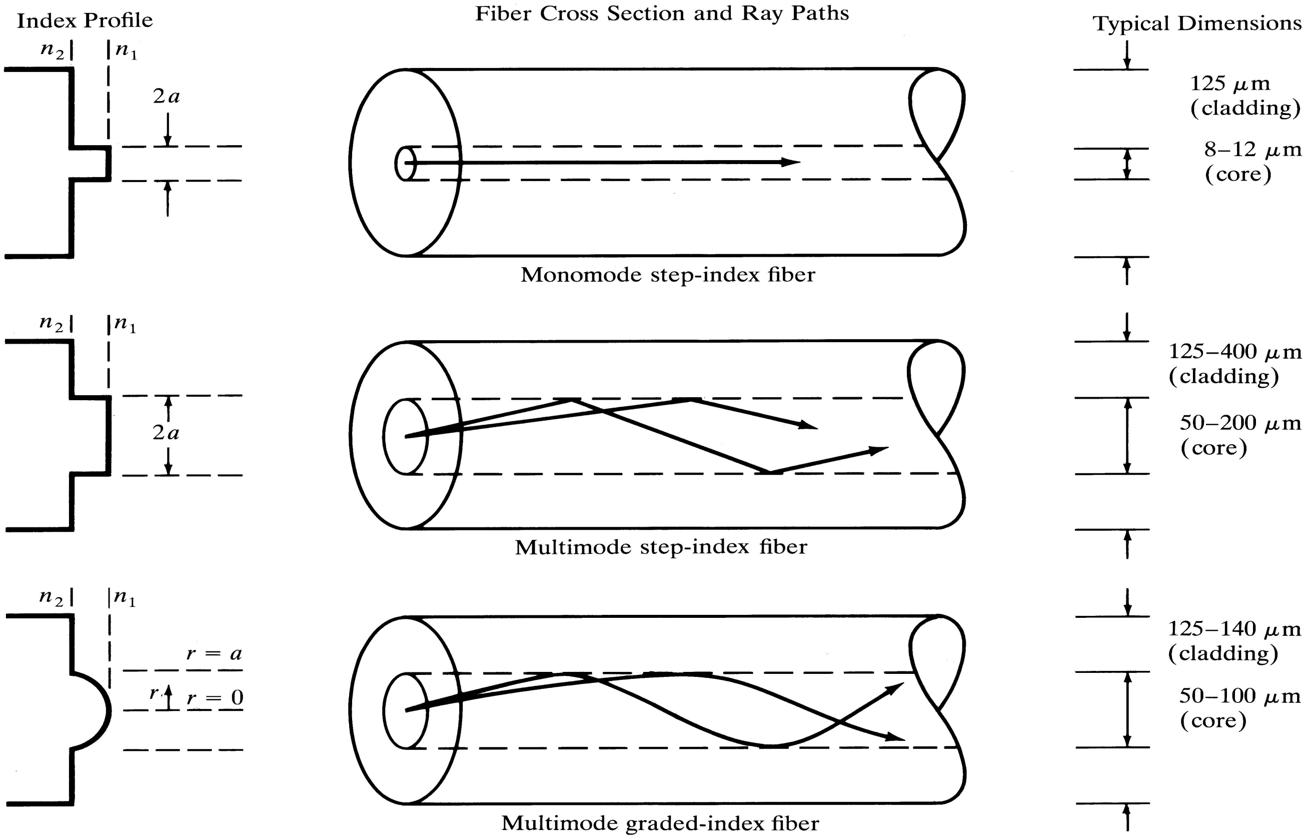


GRADED INDEX

- Contains a core in which r.I gradually decreases from core to cladding.
- The higher r.I at the core makes the light ray moving down the axis advance more slowly than those near cladding.
- Here light rays move in helical path instead of zigzagging due to graded index , hence reducing travelling time.

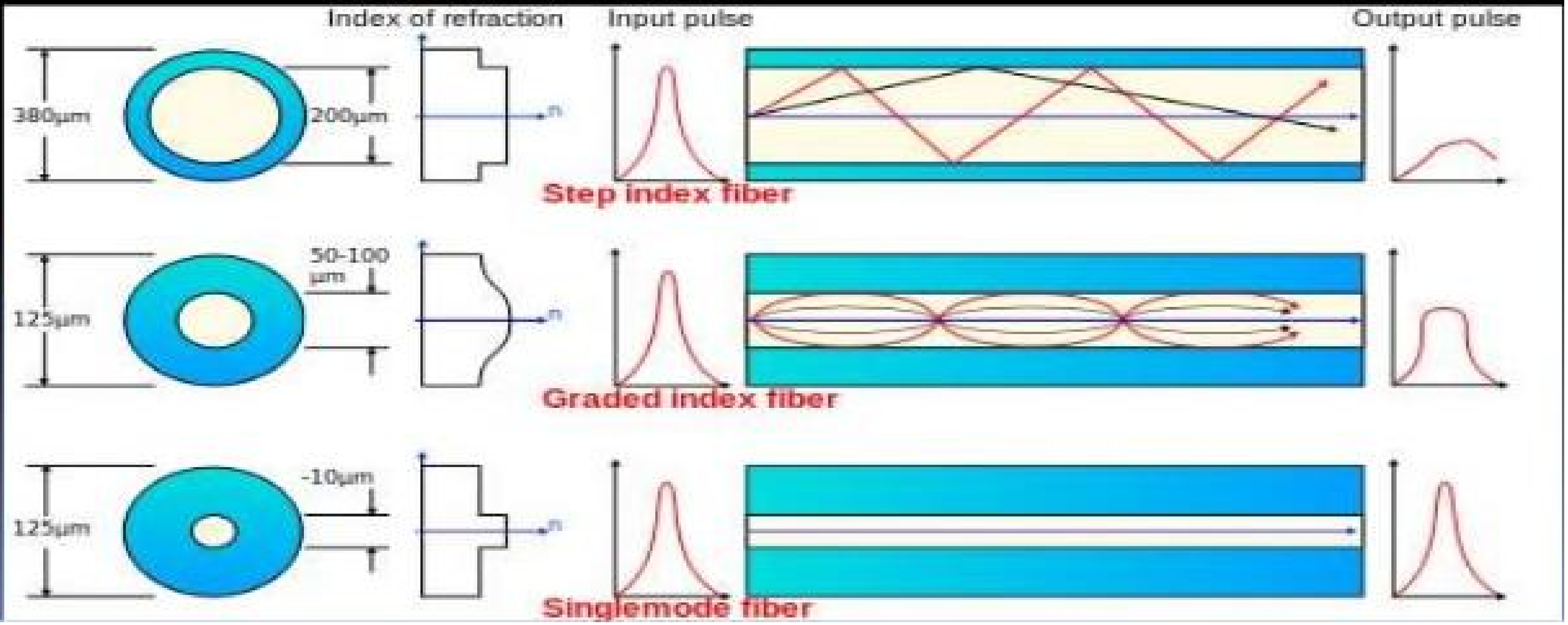


Comparision

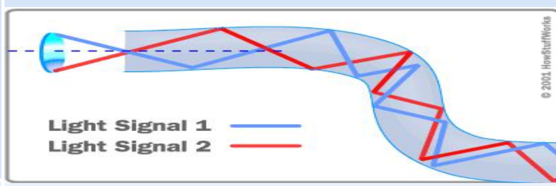
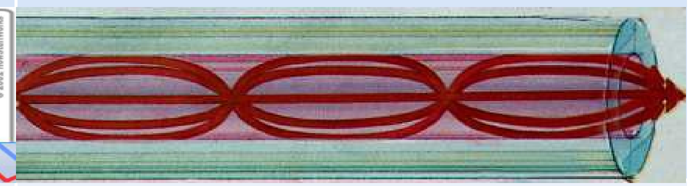


Types of Fiber

- Both types of fiber described earlier are known as **step-index** fibers because the index of refraction changes radically between the core and the cladding
- **Graded-index** fiber is a compromise multimode fiber, but the index of refraction gradually decreases away from the center of the core
- Graded-index fiber has less dispersion than a multimode step-index fiber



Comparision of S.I & G.I Fibers

Sr. No.	Parameter	Step index	Graded index
1	Data Rate	Slow	Higher
2	Coupling efficiency	Coupling efficiency is higher	Lower Coupling efficiency
3	Ray Path	By total internal reflection 	Light ray travels in oscillatory fashion 
4	Index variation	$- = \frac{n_1 - n_2}{n_1}$	$- = \frac{n_1^2 - n_2^2}{2n_1}$
5	N.A	Remains same	Changes continuously with distance from fiber axis
6	Material used	Normally plastic or glass is preferred	Only glass is preferred

Comparision of S.I & G.I Fibers

Sr. No.	Parameter	Step index	Graded index
7.	Bandwidth efficiency	10-20 MHz/km	1 GHz/km
8.	Pulse spreading	Pulse spreading by fiber length is more	Pulse spreading is less
9.	Attenuation	Less typically 0.34 dB/km at 1300 nm	More 0.6 to 1 dB/km at 1300 nm
10.	Light source	LED	LED, LASER
11.	Core diameter	50-80 Micro-meter (Multimode)	50-100 micrometer (Multimode)
12.	Cladding diameter	125 micro-meter	125-140 micrometer
13.	Refractive Index	Drastic change in R.I. as compared to G.I	Decreases slowly

- The velocity of light in the core of step index fiber is $2.01X10^8$ m/s. critical angle is 80, find the acceptance angle.

- A light bulb is set in the bottom of 3 meter deep swimming pool. What is the diameter of the ring of light see on the pool’s surface?

Comparison of SM & MM

Sr. No.	Parameter	Single mode	Multimode
1	modes	Only one mode is carried through the waveguide	Number of modes (light ray)are carried simultaneously through the waveguide
2	Core diameter	Smaller as compare to multimode	Core diameter is larger (which allows large number of modes)
3	Loss	Less	More
4	Bandwidth	Higher as compare to multimode	Lower
5	efficiency	More information transmitted per unit time	Less information transmitted per unit time

Sr. No.	Parameter	Single mode	Multimode
6.	**Advantage**	**For Long distance transmission is better as dispersion is absent**	**More chances of dispersion**
7.	Disadvantage	Smaller core diameter makes coupling light into the core more difficult	Smaller core diameter makes coupling light into the core less difficult
7.	NA	NA is small	Na is higher
8	Connection	Interconnection of cables and interfacing of source is difficult	Interconnection of cables and interfacing of source is easier
9	Bandwidth of step index fiber	Large	Small (because of that it is used for distances of less than 1 km)

Standard Fibers

Sr. No.	Fiber type	Core diameter	Cladding diameter	Δ	Application
1	Single mode	8	125	0.1 % to 0.2 %	Long distance, high data rate
2	Multimode	50	125	1 to 2 %	Short distance, low data rate
3	Multimode	62.5	125	1 to 2%	LAN
4	Multimode	100	140	1 to 2%	LAN

Fiber modes

- Optical modes: an optical mode is a specific solution of the wave equation that satisfies boundary conditions. There are three types of fiber modes.

- Guided modes
- Leaky modes
- Radiation modes

Normalized frequency

- Normalized frequency is dimensionless parameter and sometimes it is also called as V number.
- It gives relation among three design variables of the fiber core radius(a), refractive index difference (Δ) and operating Wavelength(λ).

Normalized frequency is given as,

$$V = \frac{2\pi a (n_1^2 - n_2^2)^{1/2}}{\lambda}$$

$$V = \frac{2\pi a NA}{\lambda}$$

- Calculate the number of modes of an optical fiber having diameter of 50 micro meter, core refractive index is 1.48 and cladding refractive index is 1.46, wavelength is 0.82 micrometer.

Ans: 1083 .

A fiber has normalized frequency V=26. and the operating wavelength is 1300 nm. If the radius of the fiber core is 25 micro meter. Compute the NA.

Ans: 0.220

- A multimode step index fiber with a core diameter of 80 micrometer and a relative index difference of 1.5% is operating at a wavelength of 0.85 micro meter. If the core refractive index is 1.48, estimate the normalized frequency for the fiber and number of guided modes?
- Ans : V=75.78, M=2872

- A step index multimode fiber with a NA of a 0.20 supports approximately 1000 modes at 850 nm wavelength. How many modes does the fiber support at 1320 nm & 1550 nm ?

Ans: (207,300)

- A step index optical fiber has a NA 0f 0.2 and cladding refractive index of 1.59. determine

(1) the acceptance angle of the fiber in water (9.40)

(2) critical angle (92.20)

(3) number of modes transmitted at a 1300 nm wavelength and 25 micrometer core radius. (292)

- A typical relative index difference for an optical fiber designed for long distance transmission is 1%. Estimate the NA and the solid acceptance angle in air for the fiber when the core index is 1.48. further calculate the critical angle at the core cladding interface within the fiber.

Ans: (90.9)

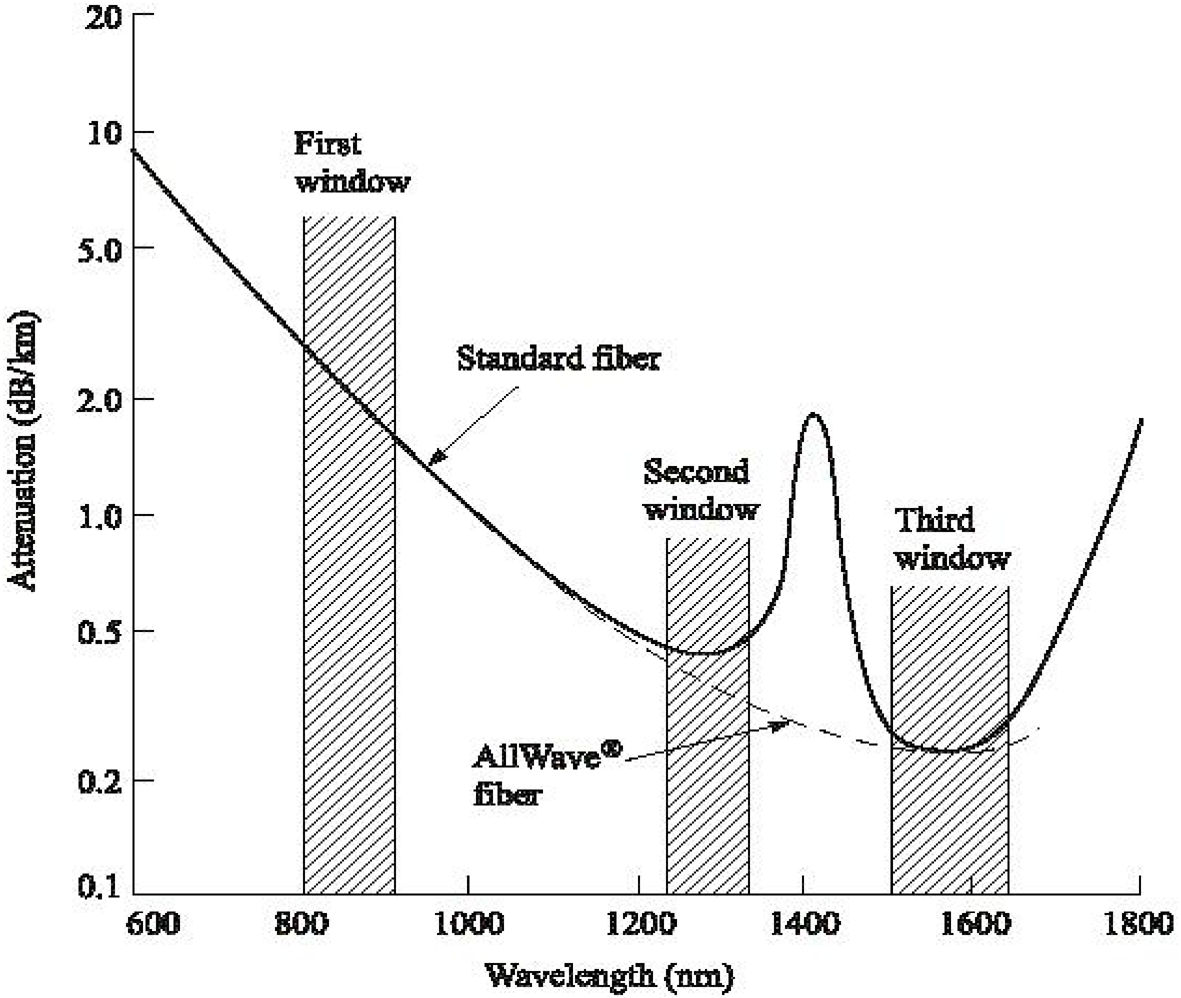
- A step index fiber has normalized frequency of 26.6 at 1300nm wavelengths. If the core radius is 25 micrometer. Find the NA, solid acceptance angle and number of modes supported by it. (354)

- For a single mode fiber with n1=1.49 and n2=1.47. find the cutoff wavelength of fiber if core radius is 2 micro meter and maximum core diameter for single mode operation for 1310 nm wavelength.

- Determine the wavelength of a SI fiber to exhibit single mode operation when the core refractive index is 1.48 and radius is 4.5 micro meter respectively, refractive index difference being 0.25 %.

- A multimode step index fiber with relative refractive index difference is 1.5% and core refractive index 1.48 is to be used for single mode operation. If the operating wavelength is 0.85 micro meter . Calculate the maximum core diameter. (2.6 micro meter)

Optical fiber attenuation vs. wavelength



Optical Fiber communications, 3rd ed.,G.Keiser,McGrawHill, 2000

Optical Sources

LED (Light Emitting Diode)

LASER (Light Amplification by Stimulated Emission of Radiation)

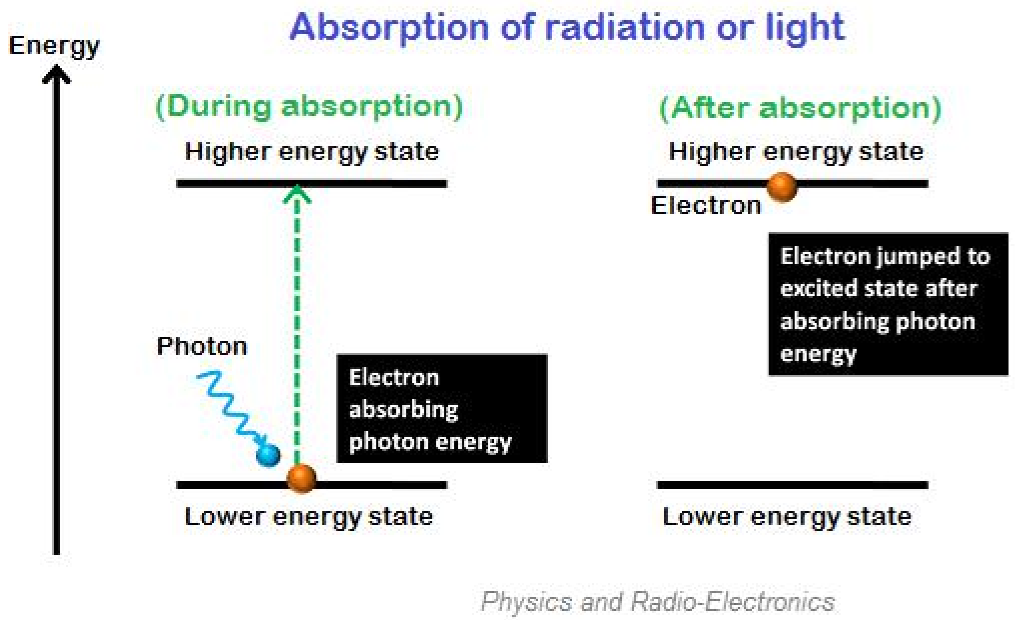
LASER

In lasers, photons are interacted in three ways with the atoms:

Absorption of radiation
Spontaneous emission
Stimulated emission

Absorption of radiation

Absorption of radiation is the process by which electrons in the ground state absorbs energy from photons to jump into the higher energy level.

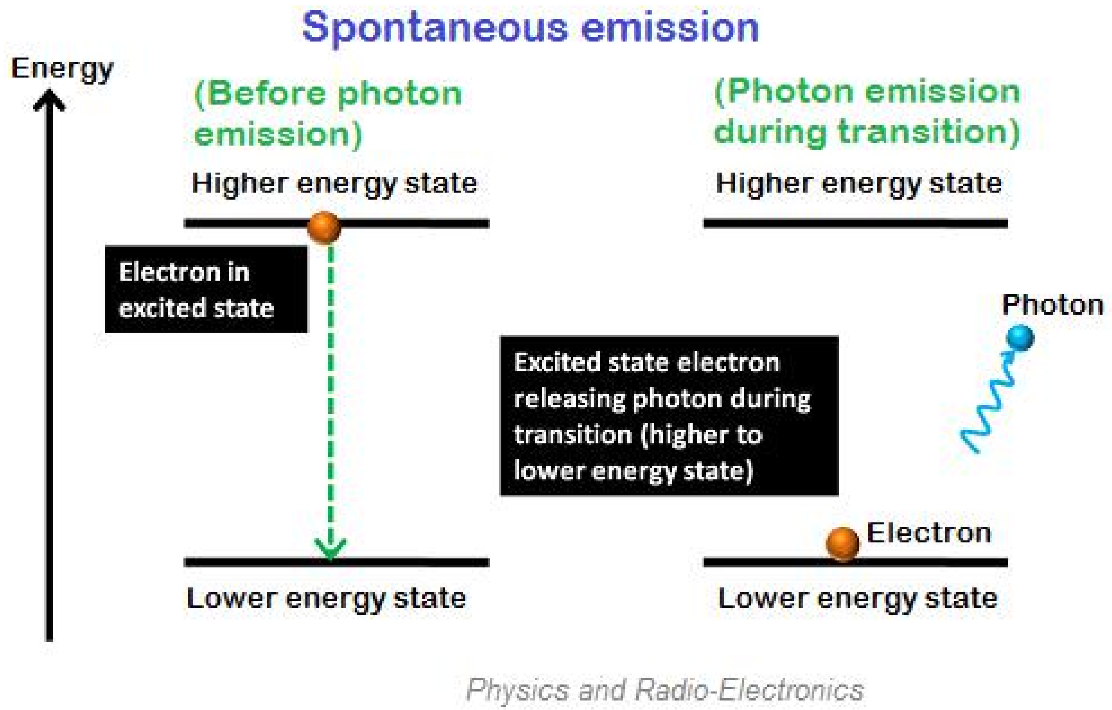


Spontaneous emission

Spontaneous emission is the process by which electrons in the excited state return to the ground state by emitting photons.
The electrons in the excited state can stay only for a short period. The time up to which an excited electron can stay at higher energy state (E2) is known as the lifetime of excited electrons. The lifetime of electrons in excited state is 10^{-8} second.
In spontaneous emission, the electrons move naturally or spontaneously from one state (higher energy state) to another state (lower energy state) so the emission of photons also occurs naturally. Therefore, we have no control over when an excited electron is going to lose energy in the form of light.

Spontaneous emission

The photons emitted in spontaneous emission process constitute ordinary incoherent light.
In other words, the photons emitted in the spontaneous emission process do not flow exactly in the same direction of incident photons.



Stimulated emission

Stimulated emission is the process by which incident photon interacts with the excited electron and forces it to return to the ground state.

In stimulated emission, the light energy is supplied directly to the excited electron instead of supplying light energy to the ground state electrons.

Unlike the spontaneous emission, the stimulated emission is not a natural process it is an artificial process.

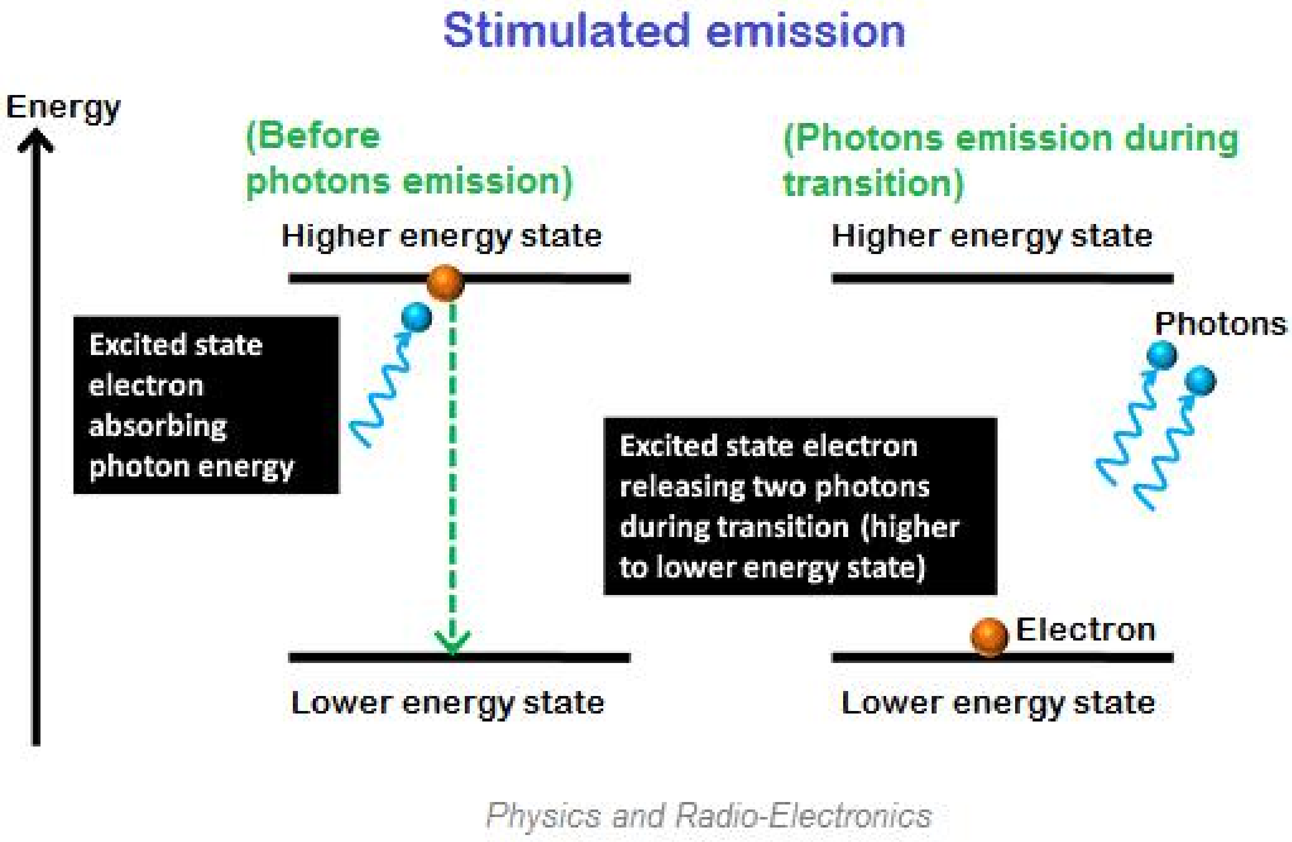
In stimulated emission, the electrons in the excited state need not wait for completion of their lifetime. An alternative technique is used to forcefully return the excited electron to ground state before completion of their lifetime. This technique is known as the stimulated emission.

Stimulated emission

In stimulated emission, two photons are emitted (one additional photon is emitted), one is due to the incident photon and another one is due to the energy release of excited electron. Thus, two photons are emitted.

All the emitted photons in stimulated emission have the same energy, same frequency and are in phase. Therefore, all photons in the stimulated emission travel in the same direction.

Stimulated emission



Population Inversion

Population inversion is the process of achieving greater population of higher energy state as compared to the lower energy state.

Population inversion technique is mainly used for light amplification. The population inversion is required for laser operation.

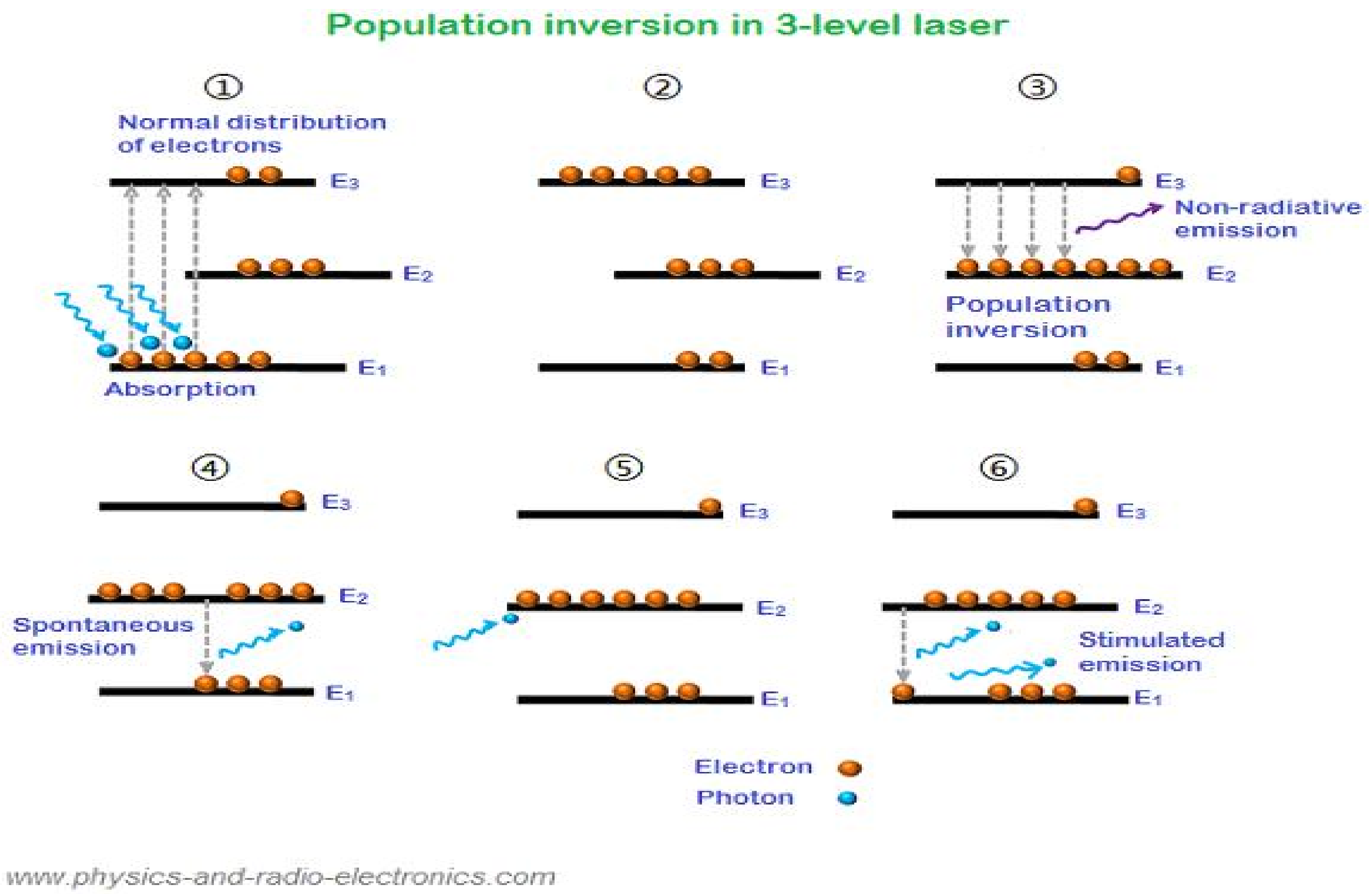
Under normal conditions, the number of electrons (N1) in the lower energy state (E1) is always greater as compared to the number of electrons (N2) in the higher energy state (E2).

$N1 > N2$

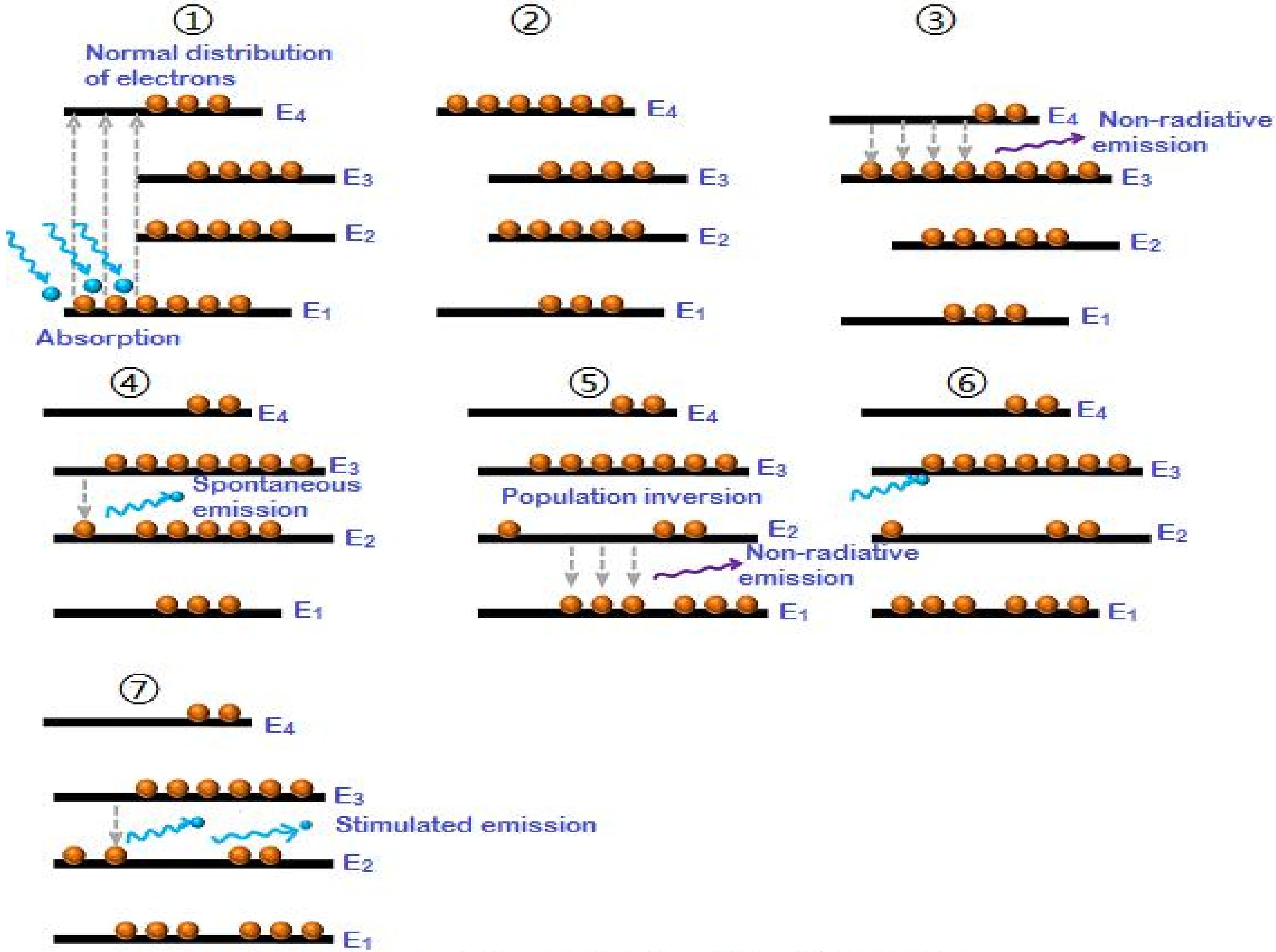
The best condition is $N1 = N2$

Therefore, we need 3 or more energy states to achieve population inversion. The greater is the number of energy states the greater is the optical gain.

3-level Laser



Population inversion in 4-level laser



Characteristics of Laser

Laser light has four unique characteristics that differentiate it from ordinary light:

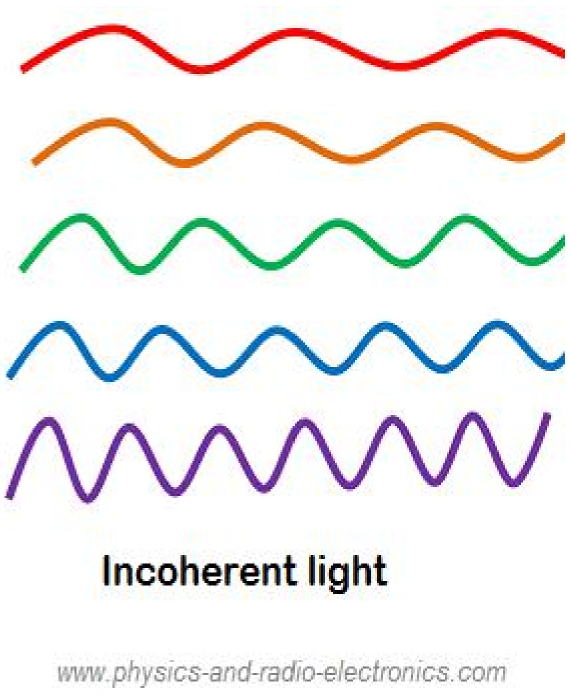
- Coherence
- Directionality
- Monochromatic
- High intensity

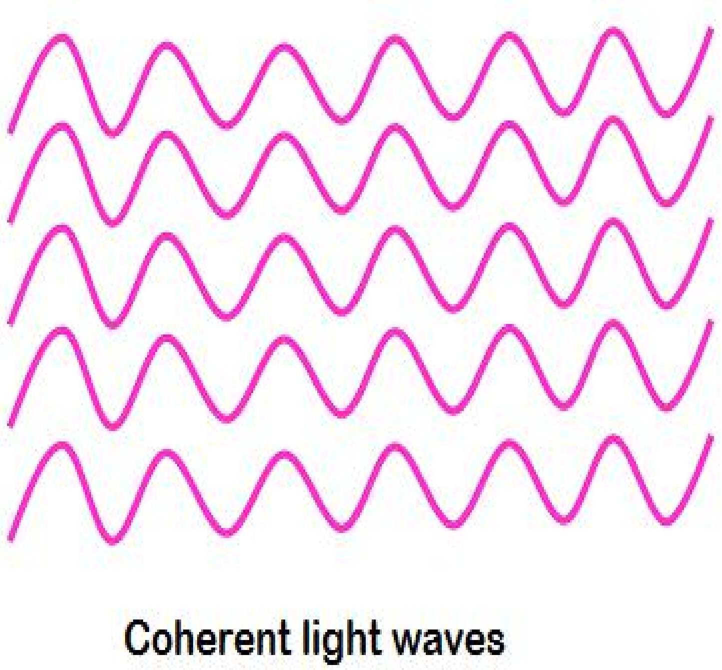
COHERENCE

In ordinary light sources (lamp, sodium lamp and torch light), the electron transition occurs naturally. The photons emitted from ordinary light sources have different energies, frequencies, wavelengths, or colors, wavelengths and out of phase.

In laser, the electron transition occurs artificially. All the photons emitted in laser have the same energy, frequency, or wavelength. Hence, the light waves of laser light have single wavelength or color. Therefore, the wavelengths of the laser light are in phase in space and time. In laser, a technique called stimulated emission is used to produce light.

COHERENCE


Incoherent light
www.physics-and-radio-electronics.com

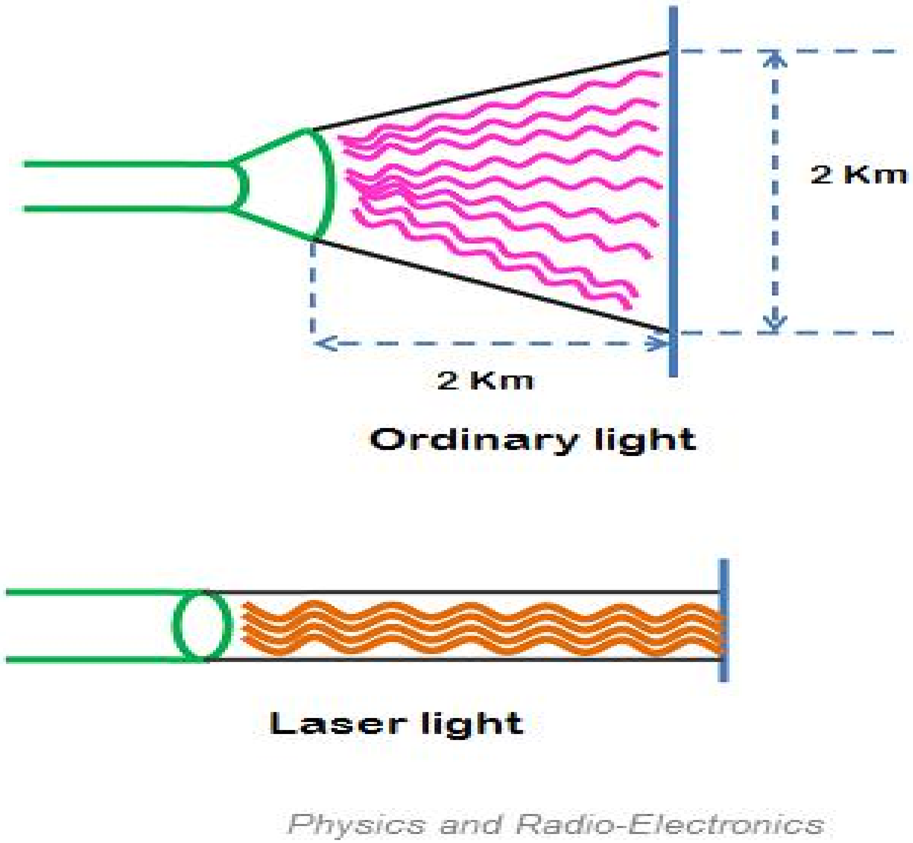

Coherent light waves

Directionality

In conventional light sources (lamp, sodium lamp and torchlight), photons will travel in random direction. Therefore, these light sources emit light in all directions.

On the other hand, in laser, all photons will travel in same direction. Therefore, laser emits light only in one direction. This is called directionality of laser light. The width of a laser beam is extremely narrow. Hence, a laser beam can travel to long distances without spreading.

Directionality



Monochromatic

Monochromatic light means a light containing a single color or wavelength. The photons emitted from ordinary light sources have different energies, frequencies, wavelengths, or colors. Hence, the light waves of ordinary light sources have many wavelengths or colors.

On the other hand, in laser, all the emitted photons have the same energy, frequency, or wavelength. Hence, the light waves of laser have single wavelength or color. Therefore, laser light covers a very narrow range of frequencies or wavelengths.

High Intensity

In laser, the light spreads in small region of space and in a small wavelength range. Hence, laser light has greater intensity when compared to the ordinary light.

If you look at a 100 Watt lamp filament from a distance of 30 cm, the power entering your eye is less than 1/1000 of a watt.

If you look directly along the beam from a laser, then all the power in the laser would enter your eye. Thus, even a 1 Watt laser would appear many thousand times more intense than 100 Watt ordinary lamp.

Applications of Lasers

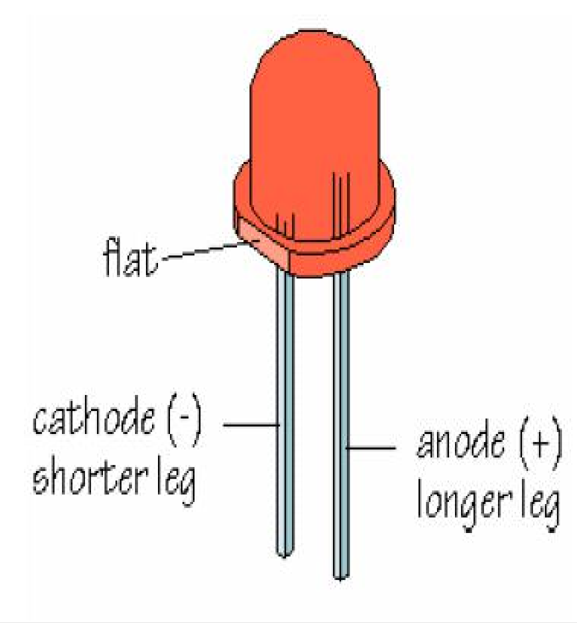
Laser light is different from an ordinary light. It has various unique properties such as coherence, monochromacity, directionality, and high intensity. Because of these unique properties, lasers are used in various applications.

The most significant applications of lasers include:

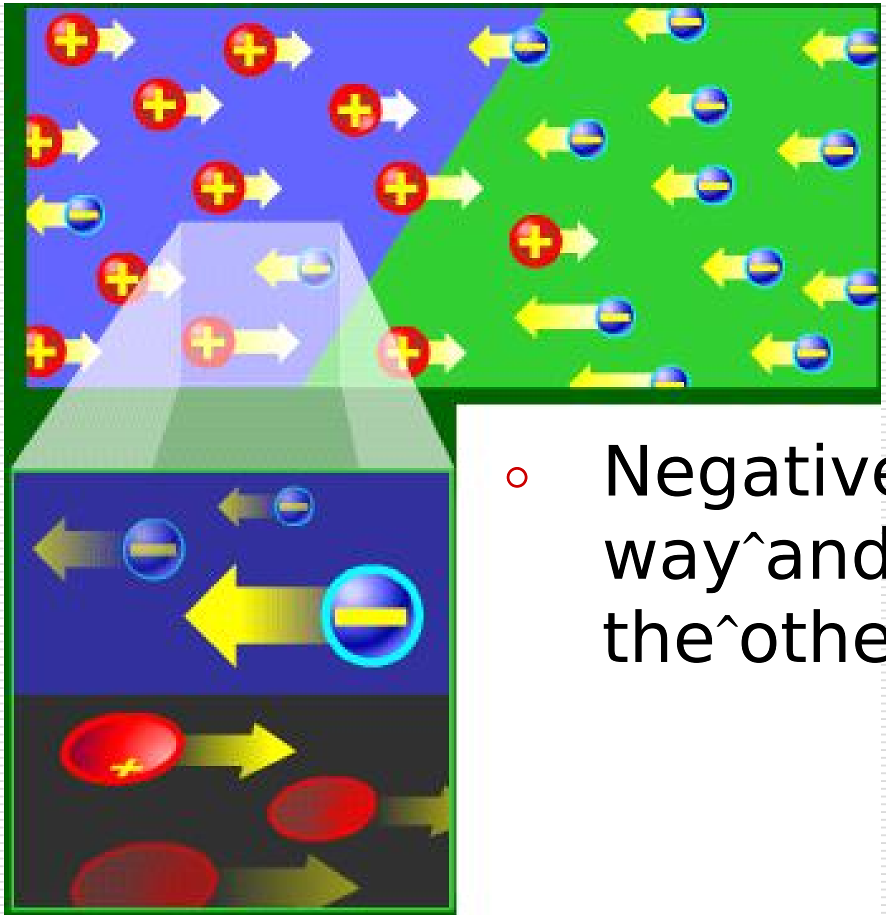
- Lasers in medicine
- Lasers in communications
- Lasers in industries
- Lasers in science and technology
- Lasers in military

What is an LED？

- Light emitting diode
- Semiconductor
- Has polarity
- Emits incoherent light through spontaneous emission.
- Used for Multimode systems with 100-200 Mb/s rates.
- 850nm region: GaAs and AlGaAs
- 1300–1550nm region: InGaAsP and InP

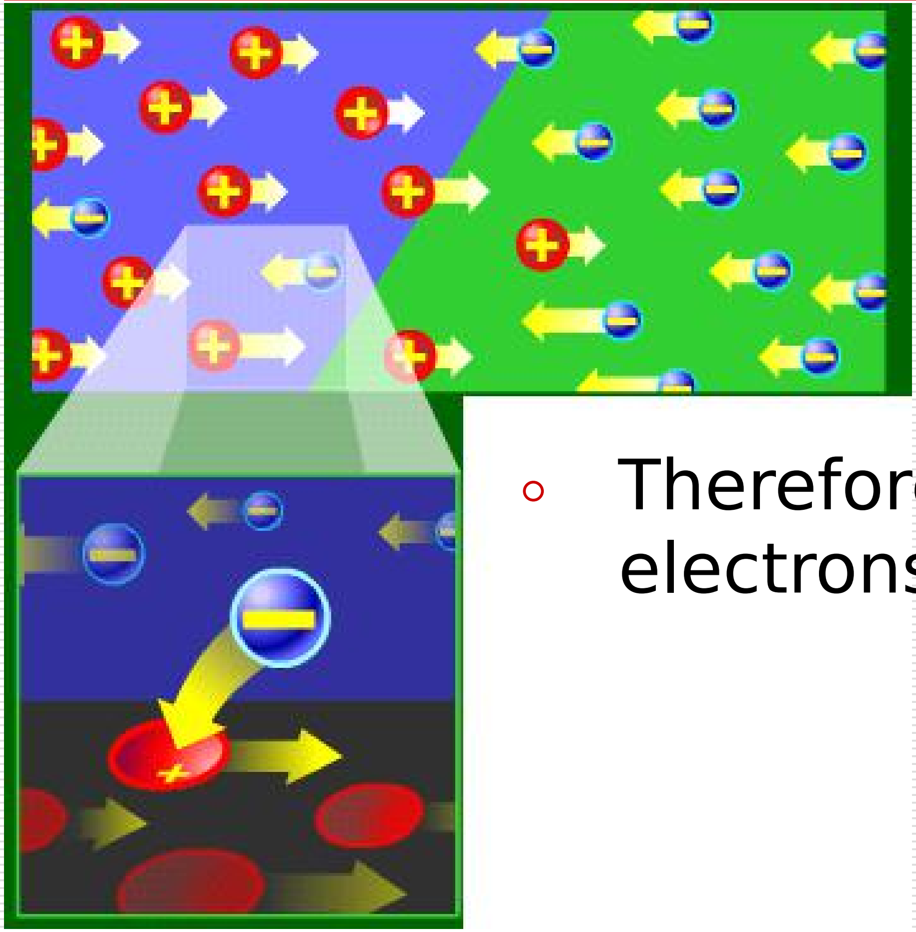


LED: How It Works



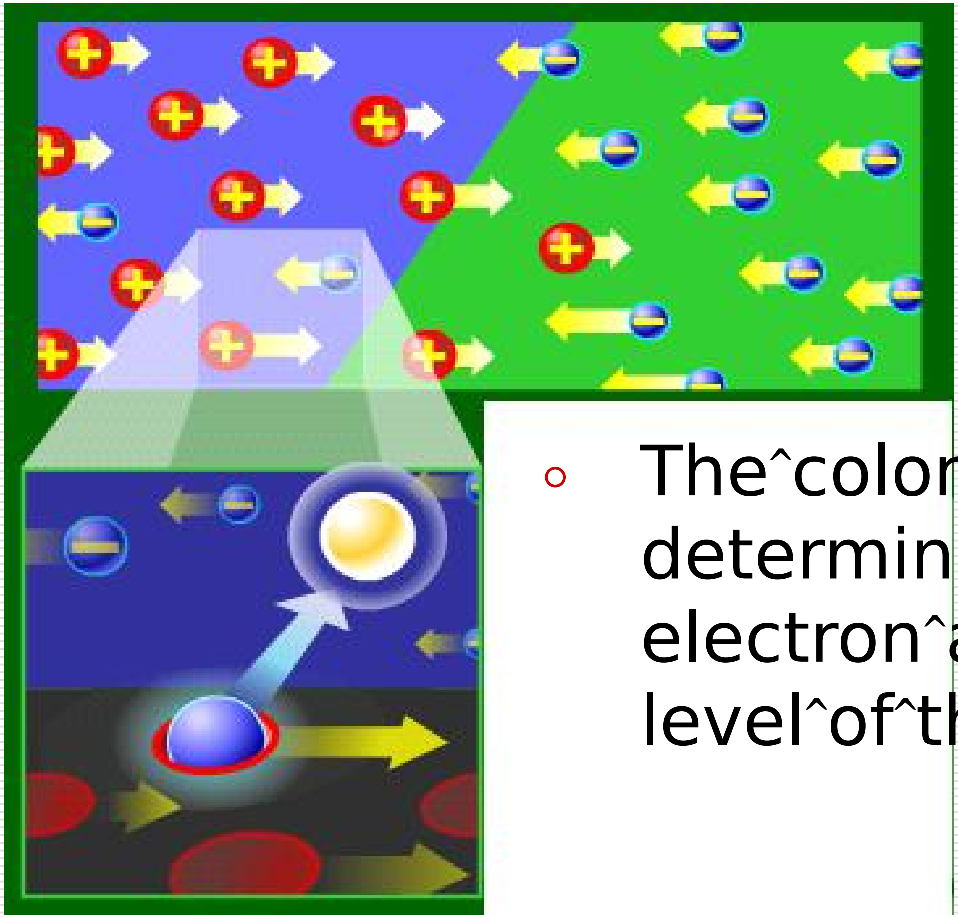
- Whenˆcurrentˆflowsˆacrossˆaˆdiode
- Negativeˆelectronsˆmoveˆoneˆwayˆandˆpositiveˆholesˆmoveˆtheˆotherˆway

LED: How It Works



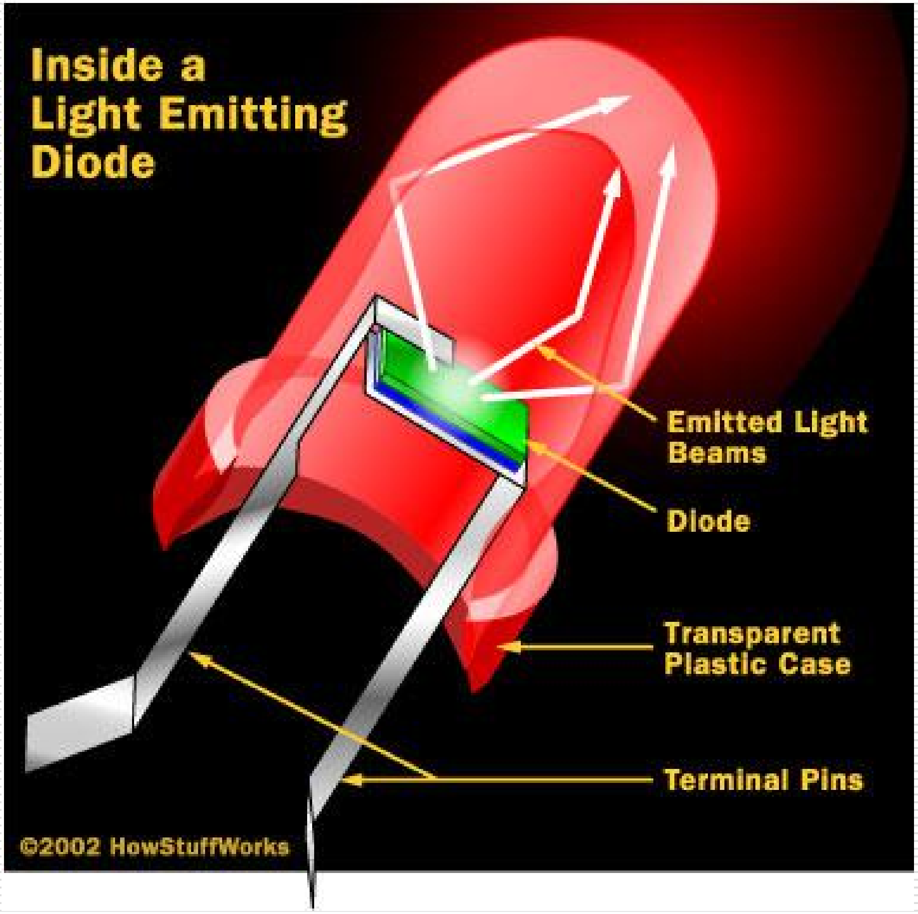
- The^holes^exist^at^ a^lower^energy^ level^than^the^ free^electrons
- Therefore^when^a^free^ electrons^falls^it^losses^energy^

LED: How It Works



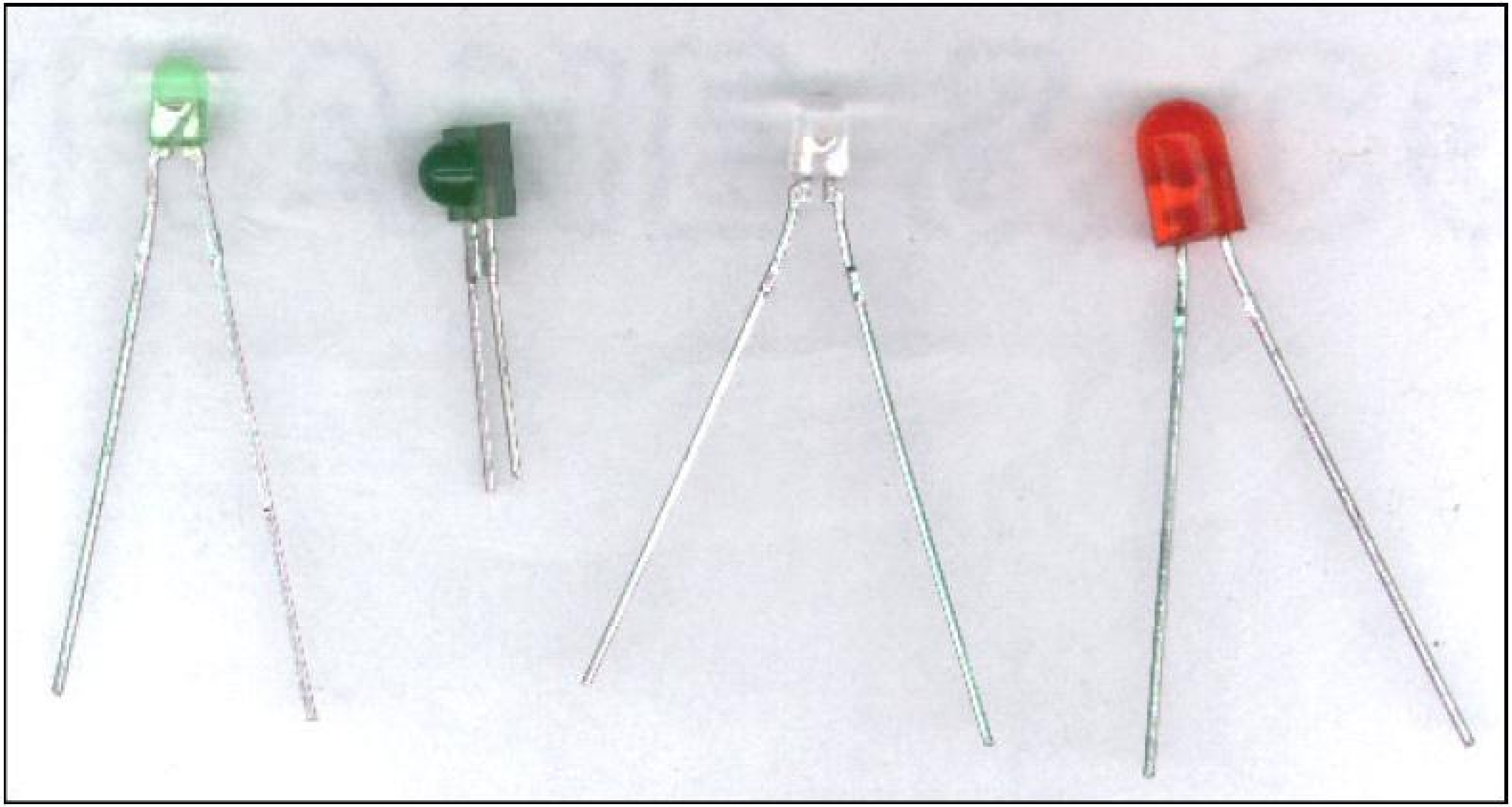
- This^energy^is^ emitted^in^a^form^ of^a^photon,^ which^causes^ light
- The^color^of^the^light^is^ determined^by^the^fall^of^the^ electron^and^hence^energy^ level^of^the^photon

Inside a Light Emitting Diode



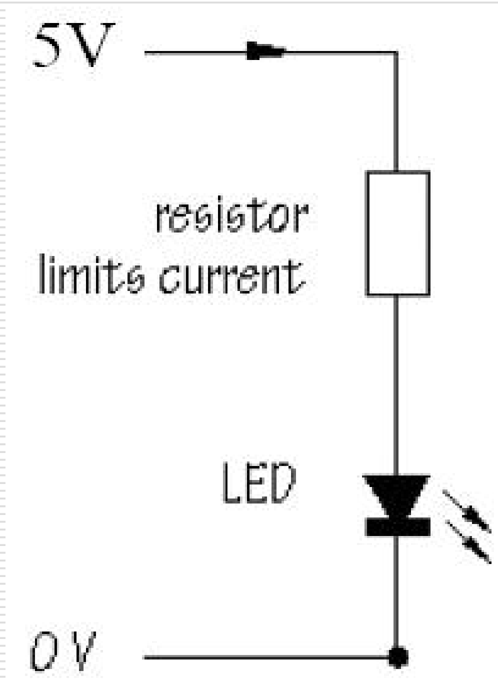
- Transparent Plastic Case
- Terminal Pins
- Diode

Kinds of LEDs



How to Connect a LED:

- Requiresˆ⊲≜~≪≜Vˆandˆ⊲≃ˆmA
- Toˆpreventˆoverloading ˆuseˆresistorˆ ≫≐≃ˆΩˆˆ



AdvantagesˆofˆLEDs

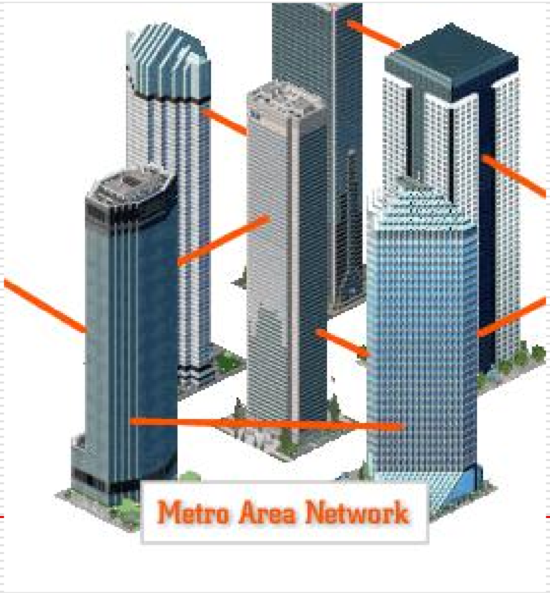
- Veryˆlowˆvoltageˆandˆcurrentˆareˆenoughˆtoˆdriveˆ theˆLED
- Totalˆpowerˆoutputˆwillˆbeˆlessˆthanˆ◁≙≃ˆmilliwatts
- Theˆresponseˆtimeˆisˆveryˆlessˆ–ˆonlyˆaboutˆ◁≃ˆ nanoseconds
- Theˆdeviceˆdoesˆnotˆneedˆanyˆheatingˆandˆwarmˆ upˆtime
- Miniatureˆinˆsizeˆandˆhenceˆlightweight
- Haveˆaˆruggedˆconstructionˆandˆhenceˆcanˆ withstandˆshockˆandˆvibrations
- AnˆLEDˆhasˆaˆlifespanˆofˆmoreˆthanˆ≪≃ˆyearsˆ

Disadvantages

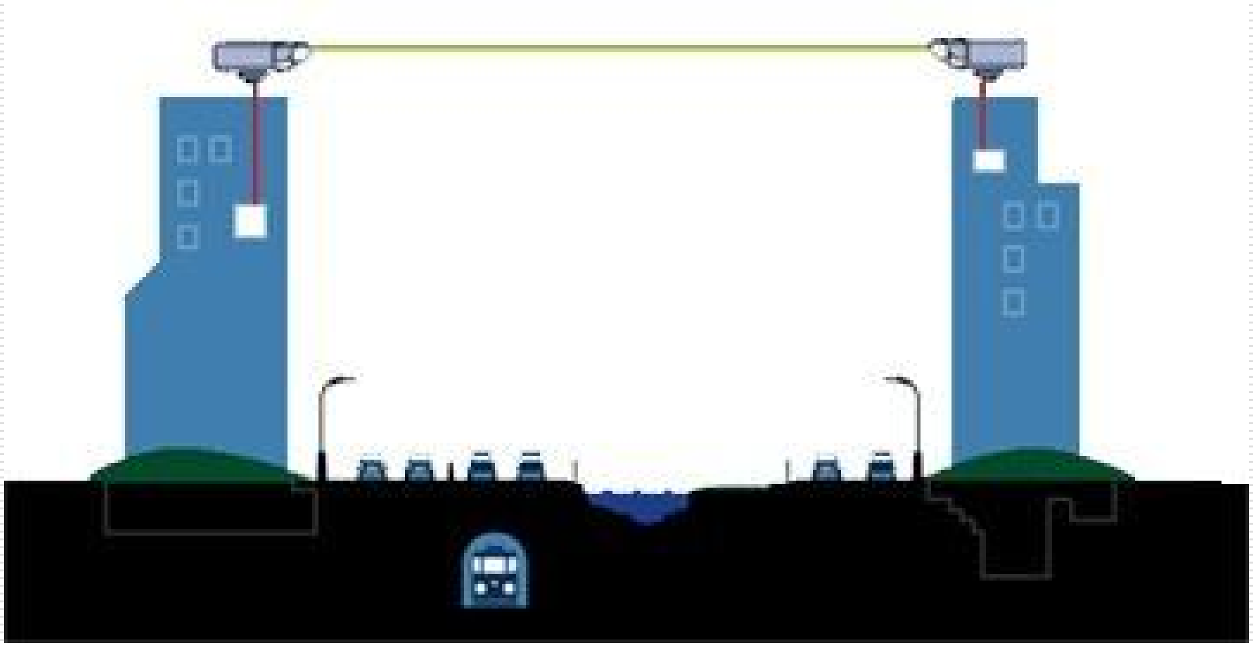
- A slight excess of voltage or current can damage the device
- The device is known to have a much wider bandwidth compared to the laser
- The temperature depends on the radiant output power and wavelength

INTRODUCTION

- Free Space Optics (FSO) communications, also called Free Space Photonics (FSP) or Optical Wireless, refers to the transmission of modulated visible or infrared (IR) beams through the atmosphere to obtain optical communications.



FREE SPACE OPTICS



FREE SPACE OPTICS

- FSO provides point to point transmission of communication information through the atmosphere using the Optical signals as the carrier frequencies.
- It has drawn attention in telecommunication industry, due to its cost effectiveness – easy installation, quick establishment of communication link especially in the disaster management scenario, high bandwidth provisioning and wide range of applications.
- The range of frequencies where it operates makes FSO communication free from licensing.
- With FSO communication, maximum data transfer rates up to ≪≜ Gbps is possible, unlike the maximum data transfer rates of ≜≪≪Mbps offered by RF communication systems.

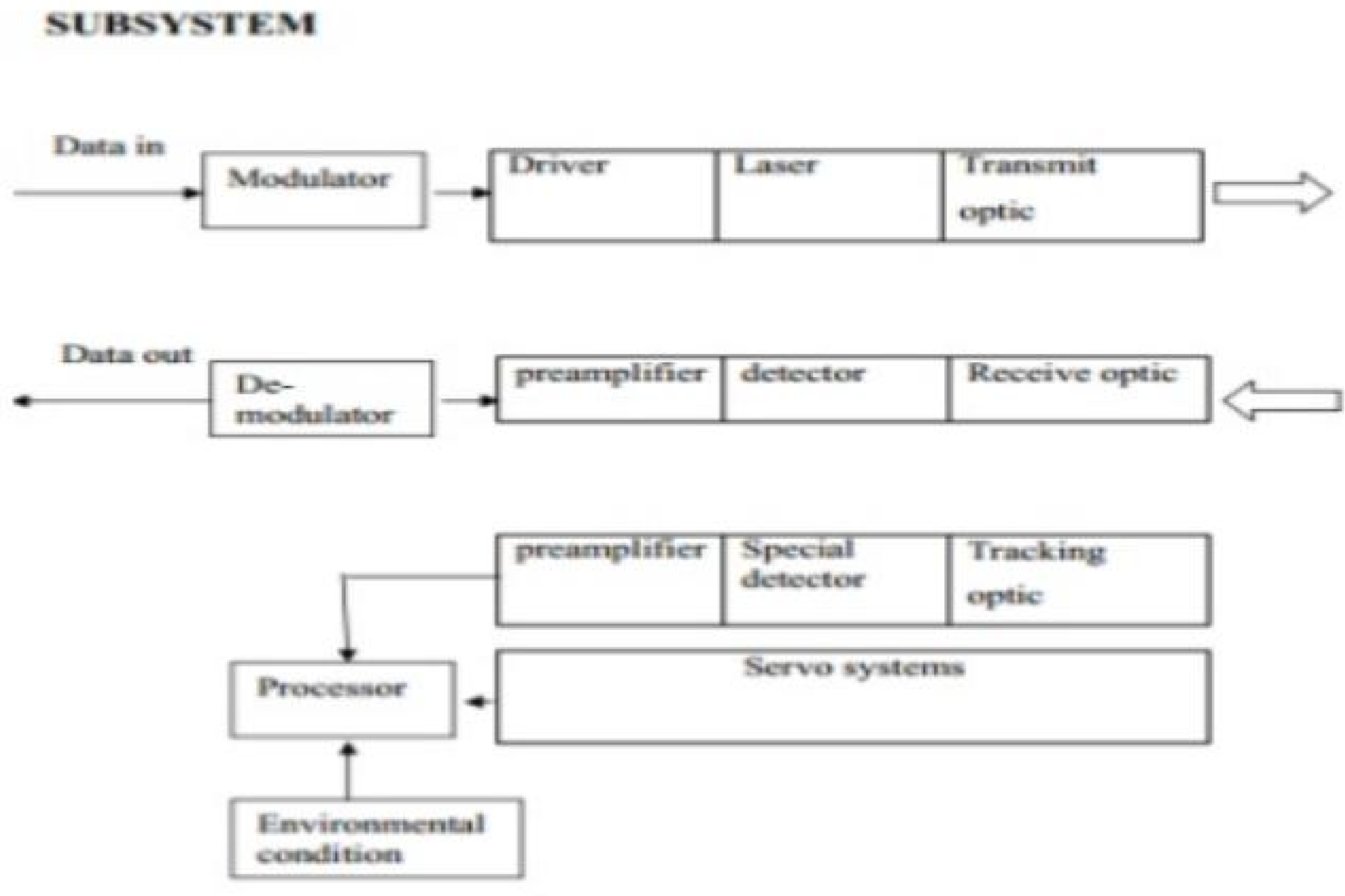
HISTORY OF FREE SPACE OPTICS (FSO)

- The engineering maturity of Free Space Optics (FSO) is often underestimated, due to a misunderstanding of how long Free Space Optics (FSO) systems have been under development.
- Historically, Free Space Optics (FSO) or optical wireless communications was first demonstrated by Alexander Graham Bell in the late nineteenth century (prior to his demonstration of the telephone!).

HOW FREE SPACE OPTICS WORKS

- Free Space Optics (FSO) transmits invisible, eye-safe light beams from one "telescope" to another using low power infrared laser in the teraHertz spectrum.
- The beams of light in Free Space Optics (FSO) systems are transmitted by laser light focused on highly sensitive photon detector receivers.
- These receivers are telescopic lenses able to collect the photon stream and transmit digital data containing a mix of Internet messages, video images, radio signals or computer files.

HOW FREE SPACE OPTICS WORKS



FREE SPACE OPTICS (FSO) SECURITY

- FSO is far more secure than RF or other wireless-based transmission technologies for several reasons:
  - Laser beams cannot be detected with spectrum analyzers or RF meters.
  - The laser beams are narrow and invisible, making them harder to find and even harder to intercept and crack.
  - Data can be transmitted over an encrypted connection adding to the degree of security available in FSO network transmissions.

Applications

- Metro Area Networks (MAN)
- Last Mile Access
- Enterprise connectivity
- Fiber backup
- Backhaul
- Service acceleration

Merits

- Flexible network solution over conventional broadband services.
- Straight forward deployment- no licenses required
- Low initial investment
- Ease of installation
- Re-deployability
- High bit rates and low error rates

Demerits

- Fog
- Physical obstructions
- Solar interference
- Scattering
- Absorption
- Building sway / Seismic activity

CONCLUSION

- Free space optics (FSO) provides a low cost, rapidly deployable method of gaining access to the fiber optic backbone.
- FSO technology not only delivers fiber-quality connections, it provides the lowest cost transmission capacity in the broadband industry.
- As a truly protocol-independent broadband conduit, FSO systems complement legacy network investments and work in harmony with any protocol, saving substantial up-front capital investments.