Fiber Optics

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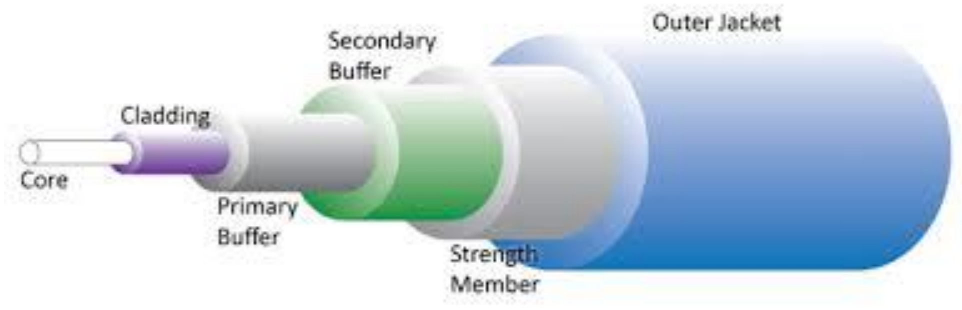
Fiber Optics

- Optical fiber is a wave guide, It guides light waves to travel over long distances without much loss of energy.
- Optical fiber consists of an inner cylinder made of glass or plastic called core. This core has a very high refractive index. The core is surrounded by a cylindrical shell of of lower refractive index called cladding. While electrical cable is a cooper wire carrying current by means of flow of electrons, optical fiber is glass wire carrying light by means of flow of photons.

Optical Fibers



Fiber optics are often long strands of very pure glass. They are very thin, about the size of a human hair. Hundreds to thousands of them are arranged in bundles (optical cables) that can transmit light great distances. There are three main parts to an optical fiber:

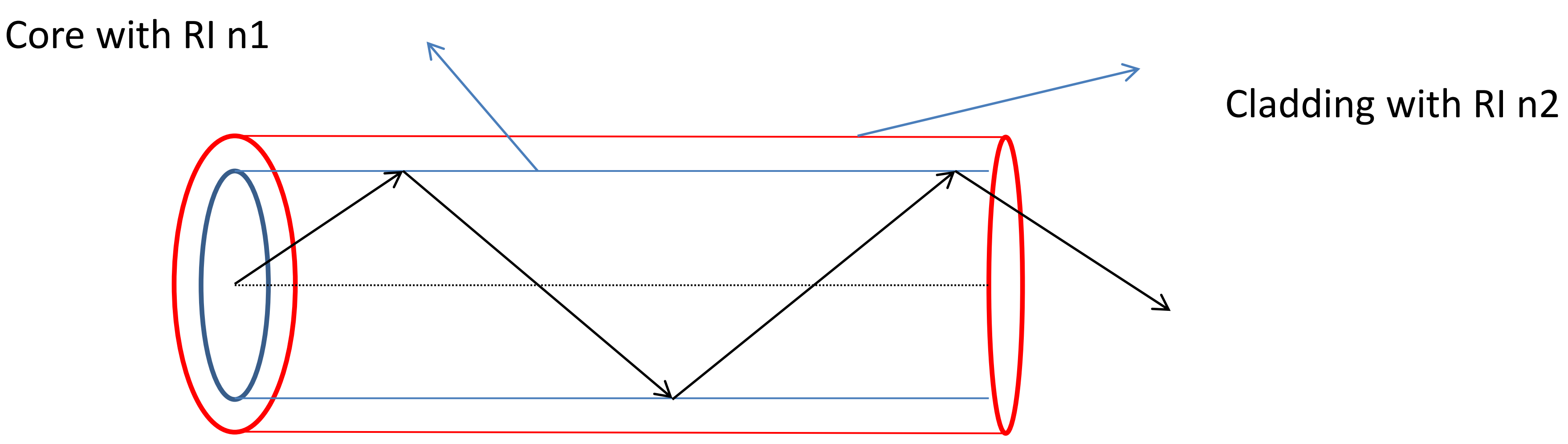
- **Core**- the thin glass center where light travels.
- **Cladding**- optical material (with a lower index of refraction than the core) that surrounds the core that reflects light back into the core.
- **Buffer Coating**- plastic coating on the outside of an optical fiber to protect it from damage.

Basic Principle of Fiber Optics

- The transmission of light in an optical fibre is based on the phenomenon of total internal reflection.
- Optical fibre consists of inner most layer known as core, a denser medium and next layer is known as cladding a rarer medium.

Total Internal Reflection

- ***When the light ray travels from denser medium to rarer medium the refracted ray bends away from the normal. When the angle of incidence is greater than the critical angle, the refracted ray again reflects into the same medium. This phenomenon is called total internal reflection.***

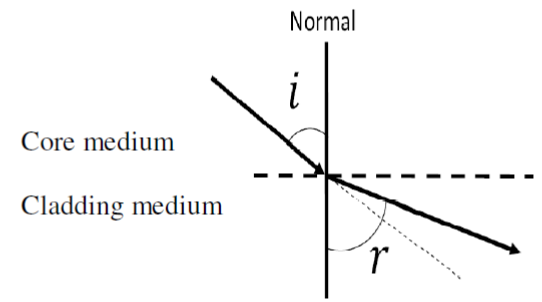


Let us consider *n1* and *n2* are refractive indices of core and cladding mediums. Let, a light ray traveling from core medium to cladding medium, then the refracted ray bends away from the normal with is the angle of incidence and is the angle of refraction.

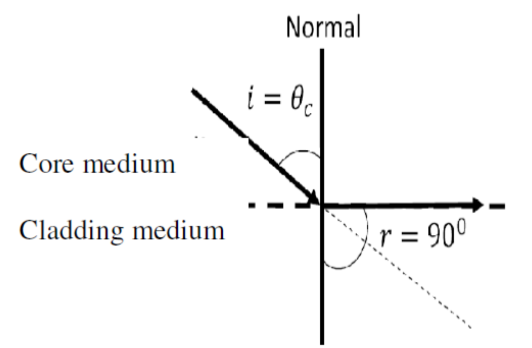
In this we can consider three cases

Case I:

When , $\theta_c > i$ the light ray refracts into cladding medium.



Case II: when $\theta_c = i$, the light ray travels along the interface of core and cladding, *C* q is known as critical angle.



When the angle of incidence is increased angle of reflection also increases and for a particular angle of incidence $i = \theta_c$ the refracted ray travels along the interface of two mediums. This angle of incidence is known as ***critical angle*** θ_c

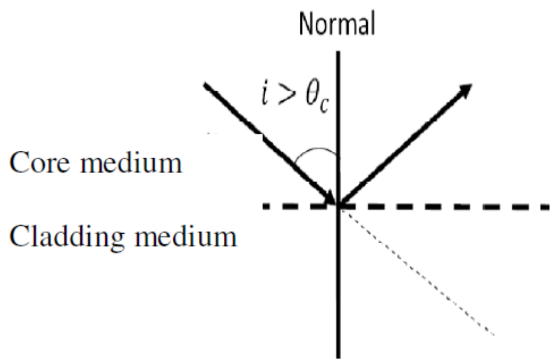
$$n1 Sin\,\theta_c = n2 sin 90$$

$$Sin\,\theta_c = \frac{n2}{n1}$$

$$\boxed{\theta_c = sin^{-1}\frac{n2}{n1}}$$

Case III:

When , $\theta_c < i$, then the light ray will be reflected back into the core medium and undergoes total internal reflection.



When the angle of incidence is greater than the critical angle , the refracted ray again reflects into the same medium. This phenomenon is called total internal reflection

Classification of fibres

Based on the refractive index of core medium, optical fibres are classified into two categories.

i. Step index fibre

ii. Graded index fibre

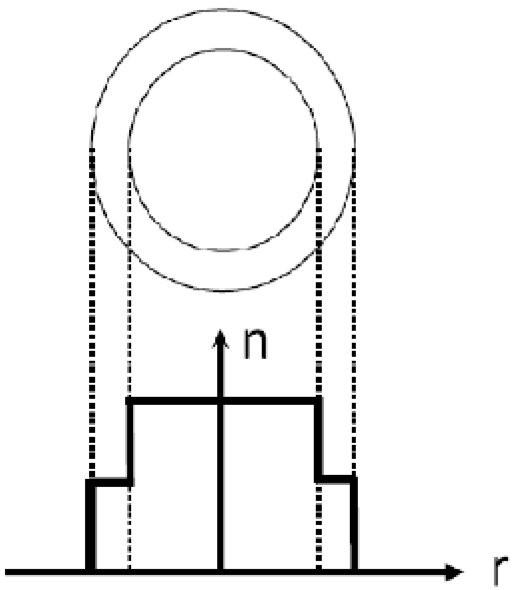
Based on the number of modes of transmission, optical fibres are classified into two categories

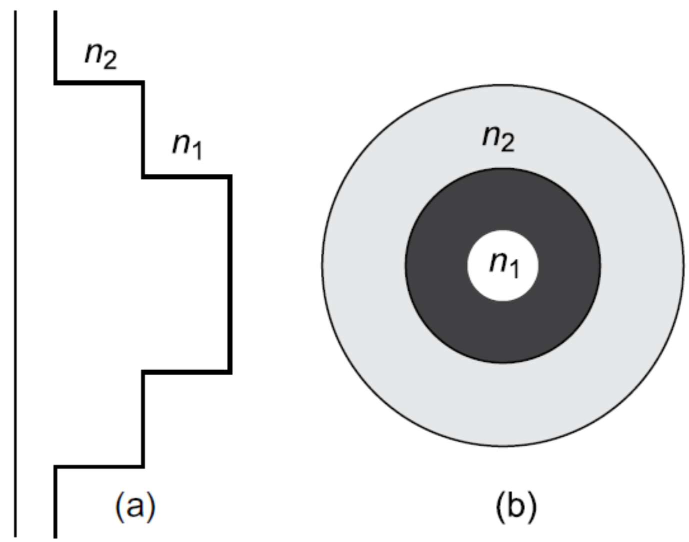
i. Single mode fibre

ii. Multi mode fibre

Step index fibre

In step index fibre the refractive index of the core medium is uniform and undergoes an abrupt change at the interface of core and cladding as shown in figure.

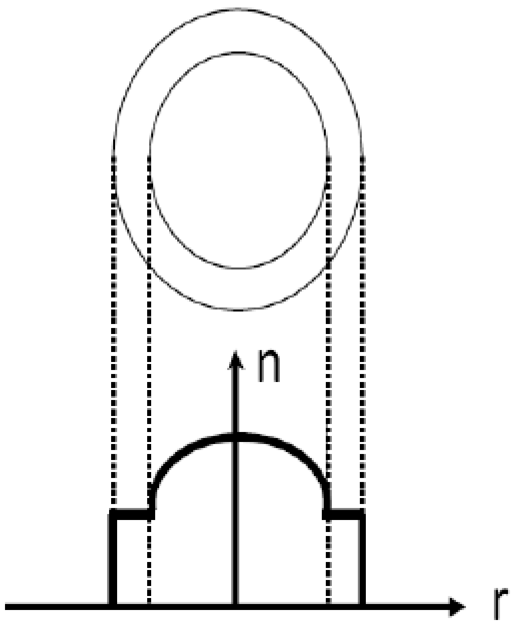




The diameter of core is about 10 micrometers in single mode and in case of multi mode fibre 50 to 200 micrometers

Graded index fibre

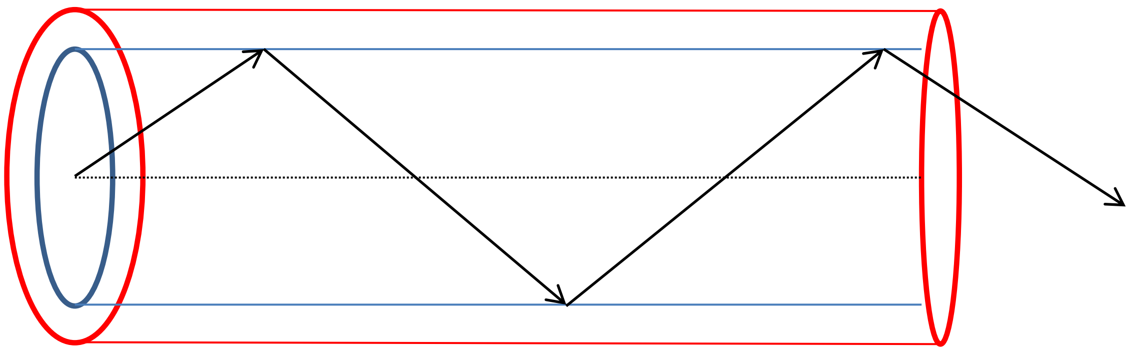
In graded index fibres, the refractive index of the core medium is varying in the parabolic manner such that the maximum refractive index is present at the centre of the core.



1. The diameter of the core is about 50 micro meters.
2. Attenuation is very less in graded index fibres
3. Numerical aperture is less in graded index fibres
4. This fibre is called reflective type fibre.

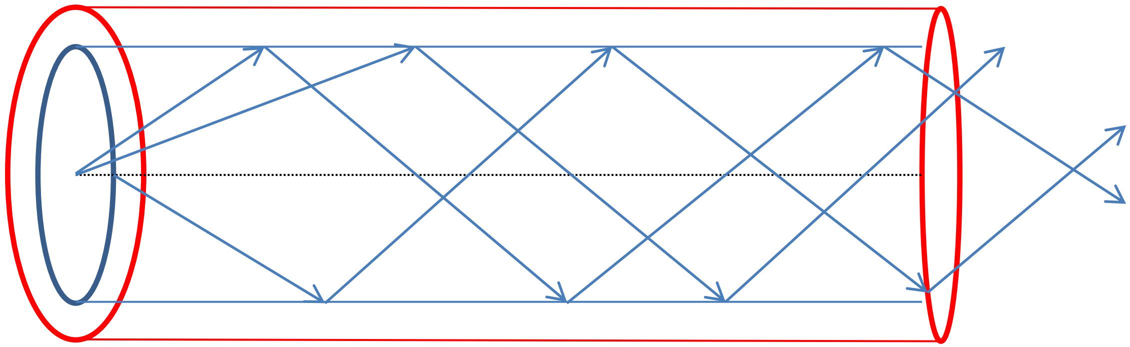
$\boxed{NA = n \sin\theta}$

Single mode fiber



1. In single mode optical fibres only one mode of propagation is possible.
2. Core diameter is 5 to 10 micrometer
3. These fibres have small core diameter and the difference between the refractive indices of core and cladding is very small.
4. In single mode fibres there is no dispersion, so these are more suitable for communication.
5. The single mode optical fibres are costly, because the fabrication is difficult.

Multimode Fibers



1. In multi mode optical fibres many mummer of modes of propagation are possible.
2. Core diameter is 50 to 150 micrometer
3. These fibres have large core diameter and the difference between the refractive indices of core and cladding is also large compared to the single mode fibres.
4. Due to multi mode transmission, the dispersion is large, so these fibres are not used for communication purposes.
5. The multi mode optical fibres are cheap than single mode fibres, because the fabrication is ~~difficult~~. easier
6. The process of launching of light into single mode fibres is very easy.
7. Fabrication is very easy and the fibre is cheaper.

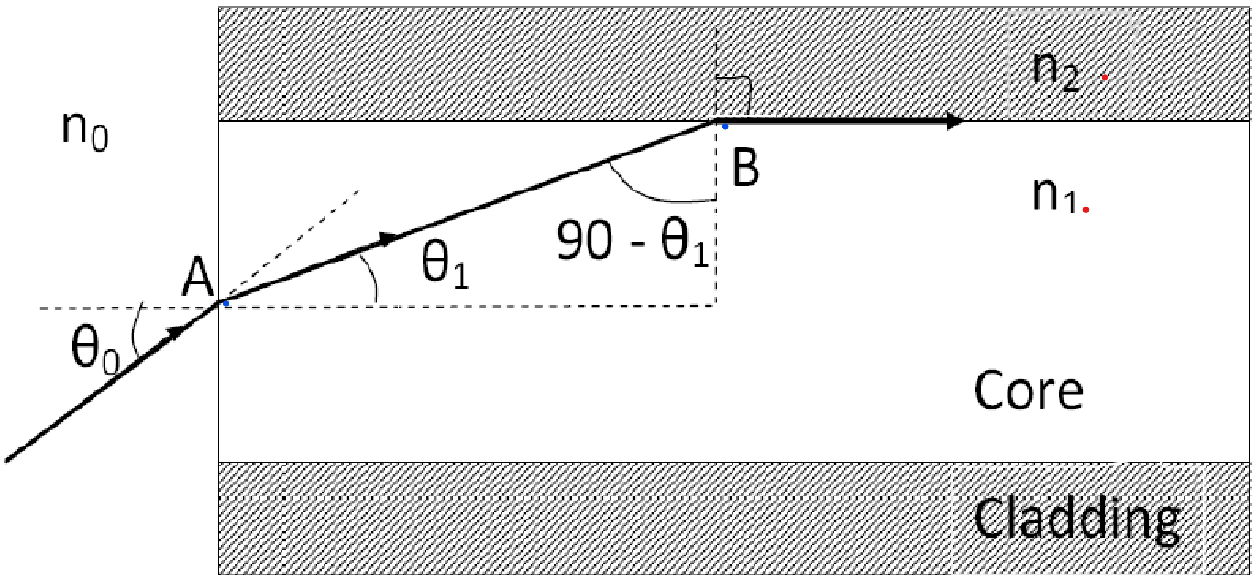
Comparison between Single Mode and Multimode Fibres

Single Mode	Multimode
1. It supports only one mode of of propagation.	1. It supports a large number of modes propagation
2. It has very small core diameter of the order of 5 to 10 μm.	2. It has larger core diameter of the order of 50 to 150 μm.
3. Transmission losses are very small.	3. Transmission losses are more.
4. It has higher bandwidth.	4. It has lower bandwidth.
5. It requires laser diode as source of light.	5. It can work with LED also.
6. It is used for long distance	6. It is used for short distance communication.
7. It is by default step index fibre.	7. It can be step index or graded index fibre.
8. Mostly it is made up of glass.	8. It is made preferably from plastic.

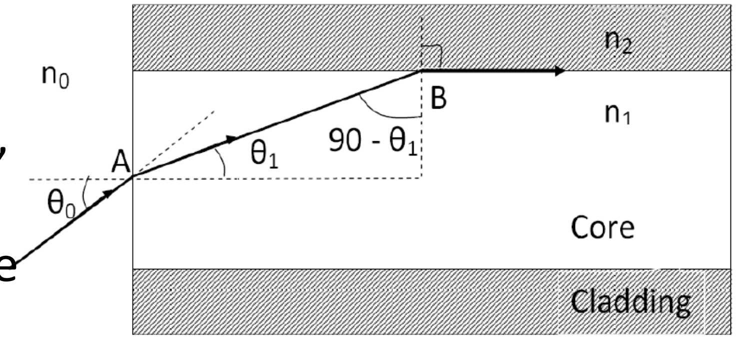
Step Index Fibre	Graded Index Fibre
1. Refractive index is uniform fort the core and suddenly charges at core cladding boundary.	1. Refractive index of core is not uniform. It is maximum along the axis of core and decreases towards core cladding boundary.
2. Pulse distortion is present.	2. Pulse distortion is minimum.
3. It can be single mode or multimode.	3. It is only multimode.
4. It can be manufactured easily.	4. Manufacturing is not easy.
5. It has high numerical aperture.	5. It has low numerical aperture.
6. Attenuation is higher.	6. Attenuation is lower.
7. It offers lower bandwidth.	7. It offers higher bandwidth.
8. Reflection losses are present.	8. Reflection losses are absent.

Acceptance angle

Acceptance angle is defined as the maximum angle of incidence at the interface of air medium and core medium for which the light ray enters into the core and travels along the interface of core and cladding.



Acceptance angle



Let n0, n1 and n3 be the refractive indices of air, core and cladding media. Let a light ray OA is incident on the interface of air medium and core medium with an angle of incidence θ_0 then the light ray refracts into the core medium with an angle of refraction θ_1 , and the refracted ray AB is again incidenting on the interface of core and cladding with an angle of incident 90- θ_1

The angle 90- θ_1 is equal to the critical angle of core and cladding media then the ray travels along the interface of core and cladding along the path BC. If the angle of incident at the interface of air and core , then will be greater than the critical angle. Therefore, the total internal reflection takes place.

According to Snell's law at point A

$$n_0 \sin\theta_0 = n_1 \sin\theta_1$$

$$\sin\theta_0 = \frac{n_1}{n_0}\sin\theta_1$$

According to Snell's law at point B

$$n_1 \sin(90 - \theta_1) = n_2 \sin 90$$

$$n_1 \cos\theta_1 = n_2$$

$$\cos\theta_1 = \frac{n_2}{n_1}$$

$$\sin\theta_1 = \sqrt{(1 - \cos^2\theta_1)}$$

$$\sin\theta_1 = \sqrt{\left(1 - \frac{{n_2}^2}{{n_1}^2}\right)} = \frac{\sqrt{({n_1}^2 - {n_2}^2)}}{n_1}$$

$$\sin\theta_0 = \frac{n_1}{n_0}\sin\theta_1 = \frac{n_1}{n_0}\frac{\sqrt{({n_1}^2 - {n_2}^2)}}{n_1} = \frac{\sqrt{({n_1}^2 - {n_2}^2)}}{n_0}$$

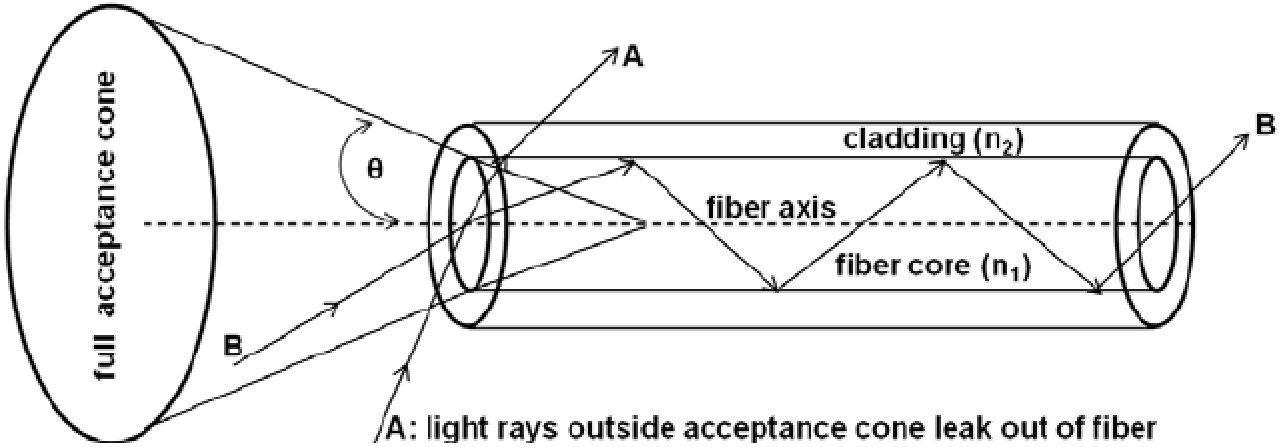
$$\sin\theta_0 = \frac{\sqrt{({n_1}^2 - {n_2}^2)}}{n_0}$$

$$\theta_0 = \sin^{-1}\left(\frac{\sqrt{({n_1}^2 - {n_2}^2)}}{n_0}\right)$$

Acceptance angle $\theta_0 = \sin^{-1}\left(\frac{\sqrt{({n_1}^2 - {n_2}^2)}}{n_0}\right)$

Acceptance Cone

A cone obtained by rotating a ray at the end face of an optical fibre, around the fibre axis with acceptance angle is known as acceptance cone.



Numerical aparture

Numerical aperture is defined as the light gathering capacity of an optical fibre and it is directly proportional to the acceptance angle.

Numerically it is equal to the sin of the acceptance angle. i.e $NA = \sin\theta_0$

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

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

If the refractive index of the air medium is equal to unity then

$$NA = \sqrt{(n_1^2 - n_2^2)}$$ $- n_0 = 1$

Fractional change in refractive index

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

$$n_1 \Delta = (n_1 - n_2)$$

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

$$NA = \sqrt{n_1 \Delta (n_1 + n_2)} \qquad \because n_1 \Delta = (n_1 - n_2)$$

$$NA = \sqrt{n_1 \Delta 2 n_1} \qquad \because n_1 \approx n_2 ; \quad n_1 + n_2 = 2n_1$$

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

The above equation gives a relationship between numerical aperture and fractional change in relative refractive index.

Attenuation

Attenuation: the decrease in magnitude of power of a signal in transmission between points; a term used for expressing the total loss of an optical system, normally measured in decibels (dB) at a specific wavelength.

unit

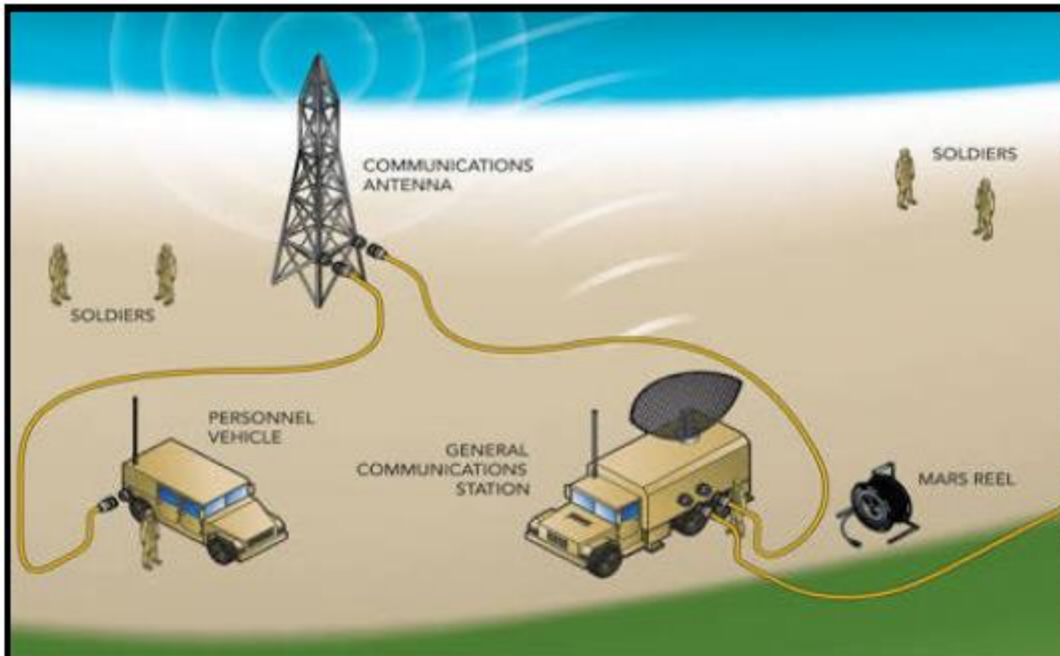
Applications

(1) Communication

- Optical fiber is mostly use in communication.
- It is use in Wi-Fi router, Landline phone and server-connector.
- A single optical fiber can carry over 3,000,000 full-duplex voice calls or 90,000 TV channels So it is use in Broad bandwidth.

(2) Military

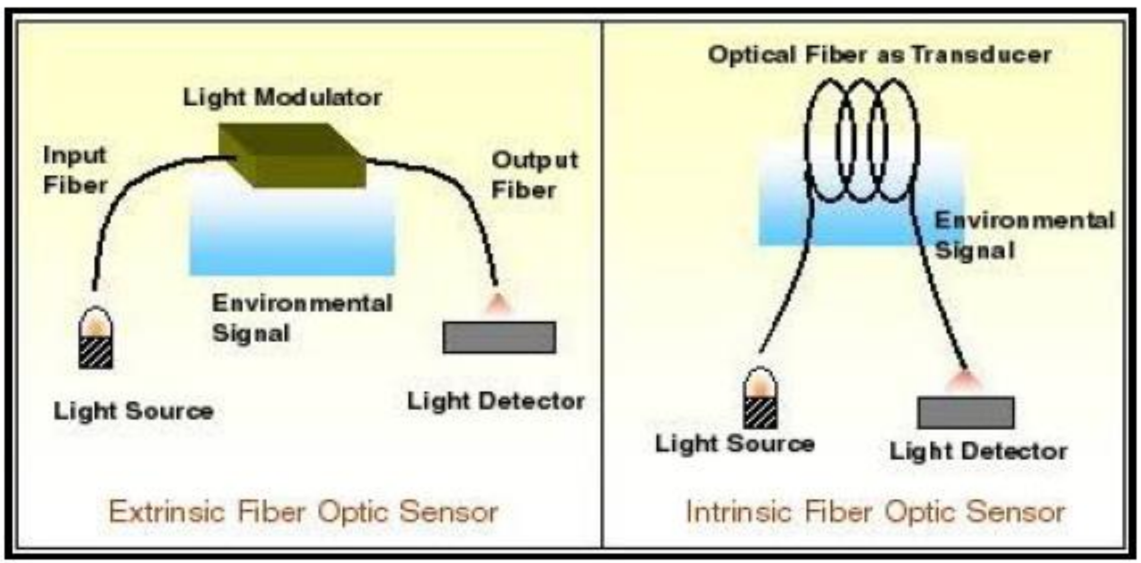
- Optical fiber is use to make military equipment, and weapons.
- It is also use to make antenna to communicate in far areas.



(3) Sensor

- Most of sensors are made from optical fiber.
- Optical is also use to make detectors

i.e. Metal detector



(4) Other application

- Optical fiber is use to make lamps, decorative application, art, toys, micro scope and outer body of devices.
- Many medical devices are made from optical fiber.