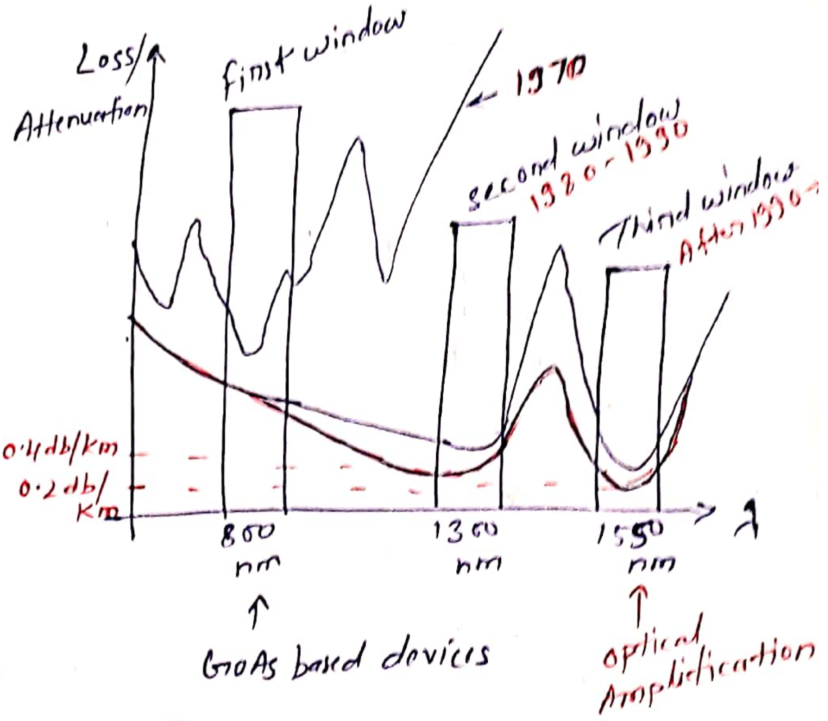
Basics of Light

centre frequency of operation for communication ↑ over last few decades starting from Hz → GHz.
Now communication system designers are exploring optical window which increases the centre frequency further in the range of THz.

↳ To meet the ever increasing demand of higher and higher bandwidth

Satellite Communication $\xleftrightarrow{\text{complimentary}}$ Optical Communication

Loss profile of Glass



Advantages of Optical Comm.

1. Ultra High Bandwidth –
2. low Loss (0.2 db/km) –
3. Low EMI — At uw freq. wavelength ≃ cms ≃ seperation b/w components. Therefore there would be coupling and EMI
   At optical freq. wavelength ≃ μm (10^{-6} m) seperation b/w components is larger than it therefore no coupling & No EMI
4. Security
5. low cost – material is free (silica). Cost is in technology to manufacture the fibers.
   Cost per channel on fiber is very less because of BW ↑

6. Low weight
7. Point to point communication – Disadvantage

Light → Ray model – light is energy source
→ Wave model – light of E & H fields
→ Quantum model – light is photons

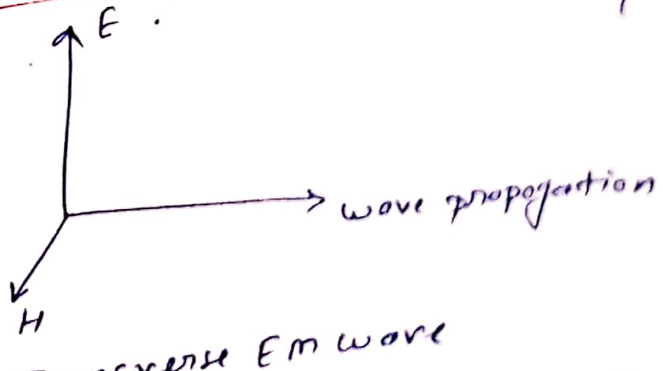
Characteristics of light –

1. Intensity – Power per unit solid angle.
   Tube light – appears less bright – wide solid angle
   Laser – appears brighter – narrow angle
2. wavelength – λ (also called color)
   loss performance is dependent on λ
   SNR is dependent ~~at~~ on choice of λ
3. Spectral width (Δλ) – purity of color
   Δλ ↓ Data rate ↑ BW ↑

→ Ray model → Treats light as a scalar quantity

4. Polarisation
   - linear
   - circular
   - Elliptical
   - Random

Wave model → Treats light as a vector quantity



Transverse EM wave

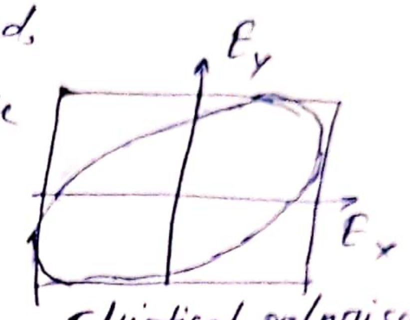
If medium of propogation has dimensions larger than the wavelength of light, light can be treated as a transverse EM wave.

$$\frac{|E|}{|H|} = \eta = \text{Intrinsic Impedance} = \sqrt{\frac{\mu}{\epsilon}}$$

Polarisation → The way electric field E behaves as a function of time (t) is called polarisation of light.

Naturally light is elliptically polarised. Under special conditions it can degenerate into circular or linear polarisation.

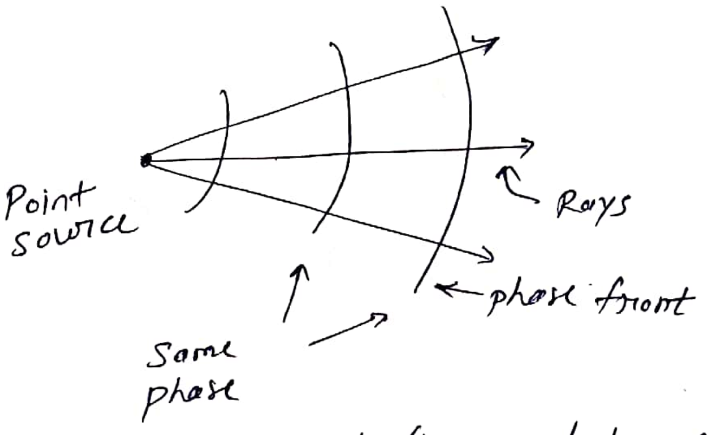
wide band sources may have random polarisation.



Eliptical polarisation

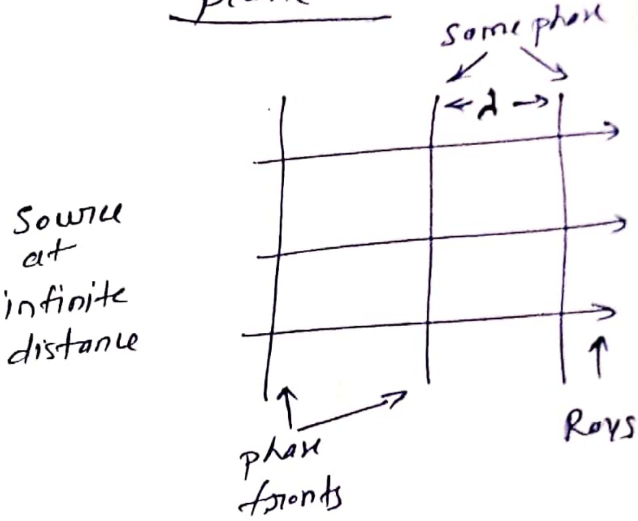
Wavefronts

Spherical



- source is at finite distance
- Phase fronts are moving radially outwards
- Phase fronts are like spheres.
- Rays are fictitious lines drawn normal to the phase fronts

plane



- source is at infinite distance
- phase fronts ~~are parallel~~ look line a plane. and are parallel to each other.

Wave Function

$$\psi(x,t) = A \exp[(\omega t - \beta x) j]$$

A - Amplitude
ω - Angular freq (rad/s)
β = phase const (rad/m)

$$\beta = \frac{2\pi}{\lambda}$$

$\lambda = \frac{v}{f}$; v = velocity of light in medium

Refractive index $\eta = \frac{c}{v}$ velocity of light in vaccum / velocity of light in medium

Air $\eta = 1$
Glass $\eta = 1.5$
Water $\eta = 1.33$

Effective Refractive index $n_{eff} = \frac{c}{v}$ v depends on material as well as structure

v may change for the same material with different dimensions

Conventionally we define light by wavelength λ

High bandwidth →

$$\lambda = \frac{v}{f}$$

$$\Delta\lambda = -\frac{v}{f^2}\Delta f$$

$$= -\frac{v}{f}\frac{\Delta f}{f}$$

$$\boxed{\frac{\Delta\lambda}{\lambda} = -\frac{\Delta f}{f}}$$

First window - 800 nm
Second window - 1300 nm
Third window - 1550 nm

$1 nm = 10^{-9} m$

let us choose $\lambda = 1000$ nm ; $\Delta\lambda = 100$ nm usually

$$\frac{100}{1000} = 0.1 = -\frac{\Delta f}{f}$$

$$0.1 = \frac{\Delta f}{\left(\frac{c}{\lambda}\right)} = \Delta f \cdot \frac{\lambda}{c} =$$

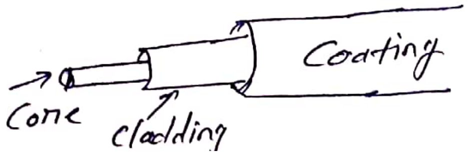
$$\Delta f = 0.1 \cdot \left(\frac{c}{\lambda}\right)$$

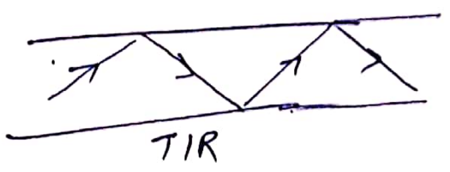
$$= 0.1 \times \frac{3\times10^8}{1000\times10^{-9}}$$

$$\boxed{\Delta f = 3\times10^{13} \text{ Hz}}$$

Bandwidth in TeraHz in optical communication

Fiber structure





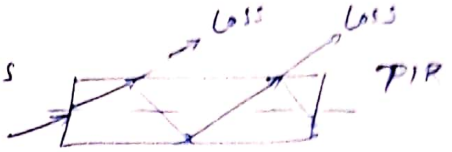
Propogation of light

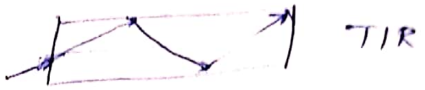
(A) From side walls of optical fibers - X

(B) From Tip of optical fiber

X ↳ Partial internal reflection — loss

✓ ↳ Total internal reflection _





Snell's law

$$\boxed{n_1 \sin\phi_1 = n_2 \sin\phi_2}$$

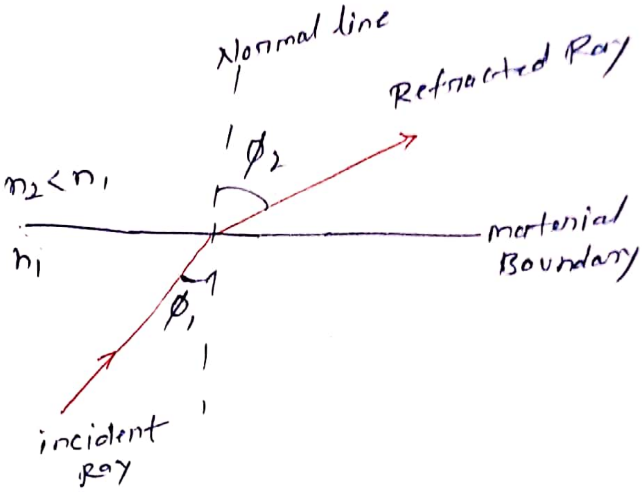
⇒ $n_1 > n_2$

⇒ $\phi_2 > \phi_1$

$$\boxed{\phi_1 \geq \phi_c \text{ for TIR}}$$

ϕ_c = critical angle

in case of TIR. $\phi_2 \geq \pi/2$

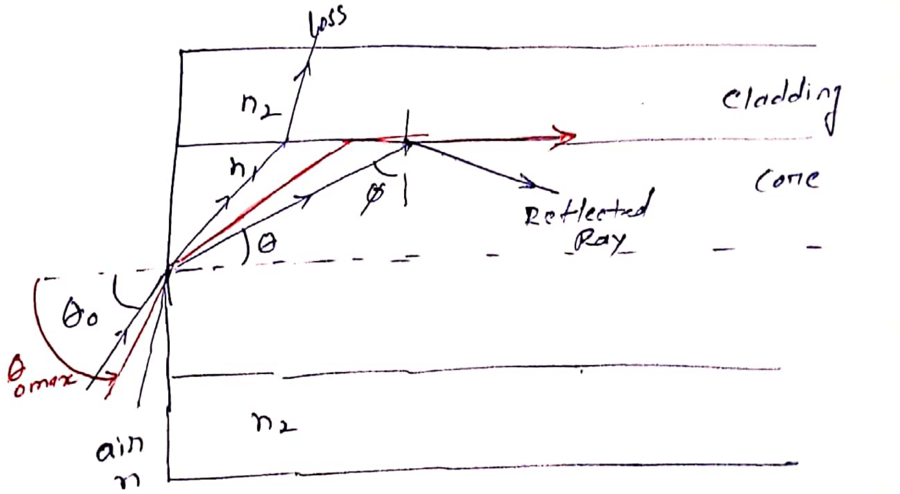


Numerical Aperture

Applying snells law.

$$n \sin\theta_0 = n_1 \sin\theta$$
$$= n_1 \sin\left(\frac{\pi}{2} - \phi\right)$$
$$= n_1 \cos\phi$$

$$\boxed{n \sin\theta_0 = n_1 \cos\phi}$$



$$n_1 \sin\phi = n_2 \sin\left(\frac{\pi}{2}\right)$$
$$= n_2$$

→ Angle of reflection = $\frac{\pi}{2}$ for TIR ⇒ $\phi = \phi_c$, $\theta_0 = \theta_{0max}$

⇒ $\sin\phi = \frac{n_2}{n_1}$ ⇒ $\cos\phi = \sqrt{1 - \frac{n_2^2}{n_1^2}}$

$$\sin\theta_{0max} = \frac{n_1 \cos\phi}{n} = \sqrt{\frac{n_1^2 - n_2^2}{n^2}}$$

$n = 1$ for air ⇒ $NA = \sin\theta_{0max} = \sqrt{n_1^2 - n_2^2}$ light launching efficiency of optical fiber