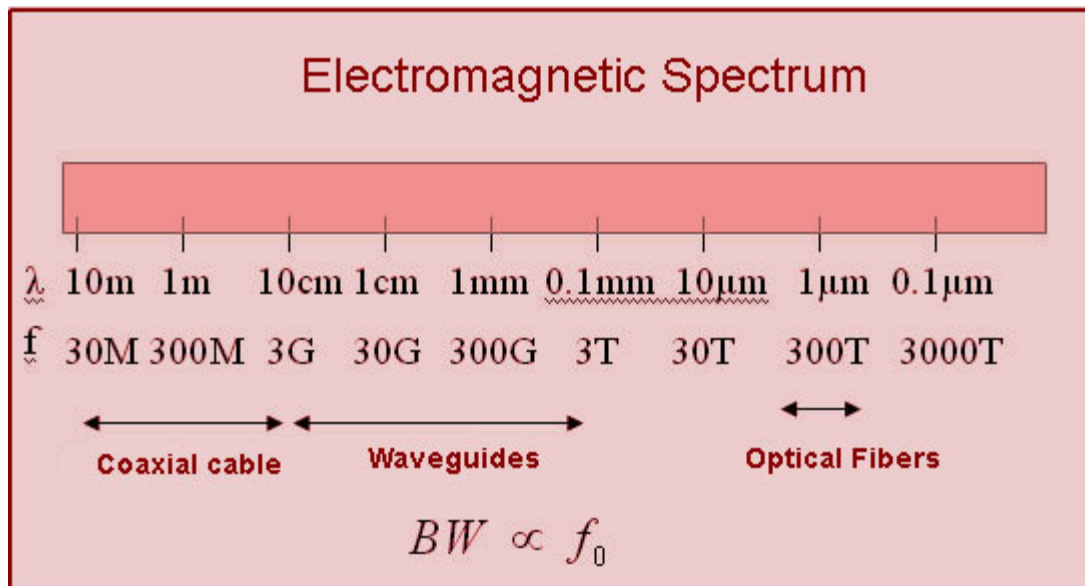


Module 1 : Introduction

Lecture 1 : Introduction

- Optical Communication is the most modern mode of wired communication.
- Optical communication is also the youngest mode of communication. However its capabilities supersede all other modes of communication.
- Before optical communication the most of the communication was in radio and microwave domain which has frequency range orders of magnitude lower than the optical see Fig for the electromagnetic spectrum.



- For good communication a system needs to have following things.
 - (1) **Bandwidth (BW)**
 - (2) **Good signal to noise ratio (SNR) i.e. low loss**
- Since the bandwidth of a system is more or less proportional to the frequency of operation, use of higher frequency facilitates larger BW.
- The BW at optical frequencies is expected to be 3 to 4 orders of magnitude higher than that at the microwave f frequencies (1GHz to 100GHz).

Transmission media Alternative to the Optical Communication

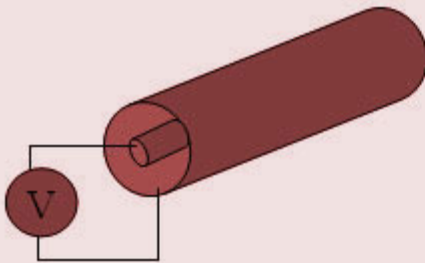
- There are various wired and wireless media used for long and short distance communication. Their broad characteristics are summarized in the following.

Twisted Pair: (point-to-point)



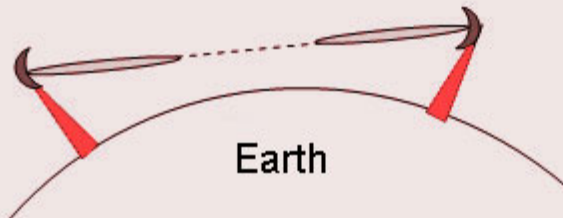
Telephone Lines
Low data rate
High EMI
Lossy at RF

Co-axial Cable (point-to-point)



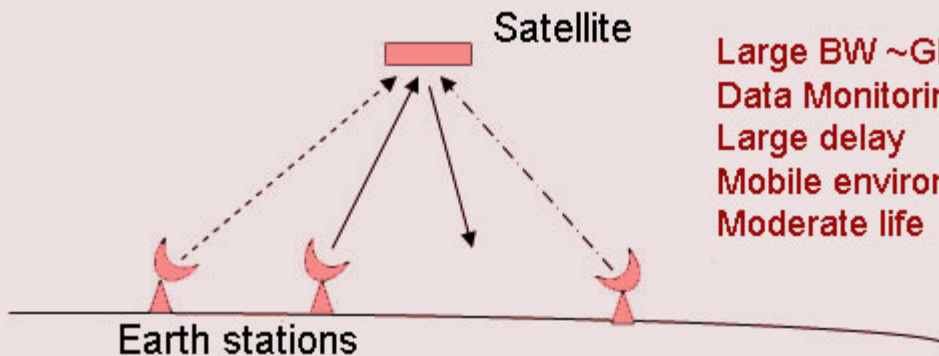
LAN
Data rates few Mbps
Low EMI
Moderate loss

Microwave Link (point-to-point)



Long distance
Large BW
Line-of-sight
High free-space loss

Satellite Communication (point-to-multi-point)



Large BW ~GHz
Data Monitoring
Large delay
Mobile environment
Moderate life

- The first two media have a very limited bandwidth.
- Microwave links and Satellite communication has comparable bandwidths as in principle their mode of operation is same but the spatial reach of satellite is far greater.
- Before Fiber optic communication became viable, satellite communication was the only choice for long distance communication.

Comparison of Satellite and Optical communication

Satellite vs Fiber Optics

Satellite	Fiber Optics
Point to Multi-point	Point to point
BW ~ GHz	BW ~ THz
Maintenance free	Needs Maintenance
Short life ~7-8 Yr	Long life
No upgradeability	Upgradeable
Mobile, air, sea	On ground only

- The two modes of transmission have their own merits and limitations. The two can infact
- play a complementary role. We therefore conclude that

Satellite and Optical communication will co-exist due their complementary nature

Advantages of Optical Communication

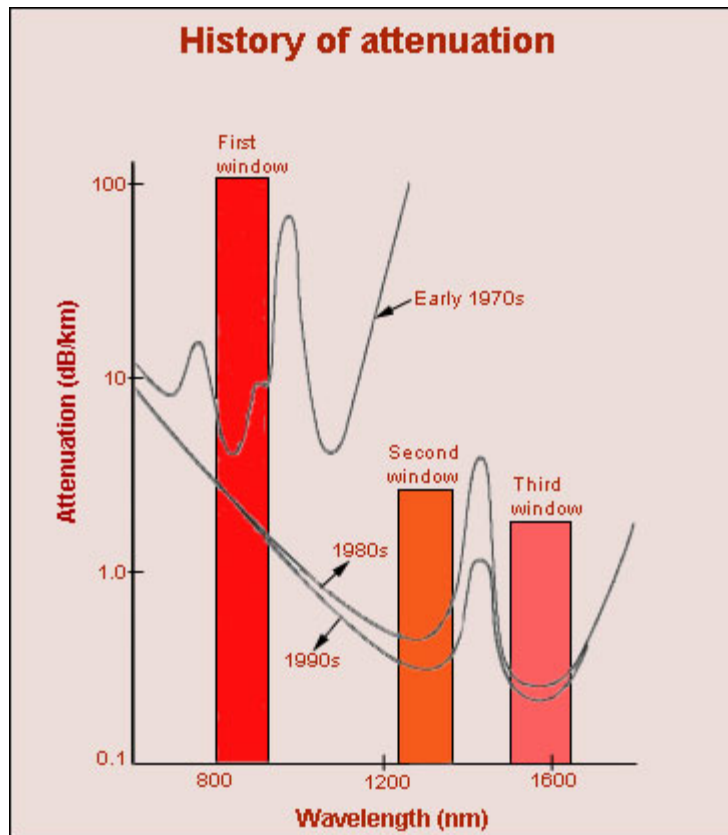
- Ultra high bandwidth (THz)
- Low loss (0.2 dB/Km)
- Low EMI

- Security of transmission
- Low manufacturing cost
- Low weight, low volume
- Point to Point Communication
- The optical transmission medium is the best in a sense that it has ultra wide bandwidth and very low attenuation.
- The attenuation history is given in the following Figure.

Initially in early 1970s due to technology limitation, the optical fiber had a low loss window around 800nm. Also the semiconductor optical sources were made of GaAs which emitted light at 800nm. Due to compatibility of the medium properties and the sources, the optical communication started in **800nm band** so called the '**First window**' .

As the glass purification technology improved, the true silica loss profile emerged in 1980s. The loss profile shows two low loss windows, one around 1300nm and other around 1550nm. In 1980s the optical communication shifted to **1300nm band** , so called the '**Second Window**' . This window is attractive as it can support the highest data rate due to lowest dispersion.

In 1990s the communication was shifted to **1550nm** window, so called '**Third Window**' due to invention of the Erbium Doped Fiber Amplifier (EDFA). The EDFA can amplify light only in a narrow band around 1550nm. Also this window has intrinsically lowest loss of about **0.2 dB/Km** . This band has higher dispersion, meaning lower bandwidth. However, this problem has been solved by use of so called 'dispersion shifted fibers'.



- Both 1300nm and 1550nm band have approximately 100nm bandwidth each.
- The frequency bandwidth is related to the wavelength bandwidth as

$$\Delta f = \frac{c}{n \lambda^2} \Delta \lambda$$

- Where c is the velocity of light in vacuum, n is the refractive index of the medium, λ is the central wavelength of the band, and $\Delta \lambda$ is the wavelength bandwidth (also called **spectral width**).
- For 1550nm window, $\lambda = 1550nm$, and $\Delta \lambda \approx 100nm$. For silica optical fibers $n \approx 1.5$. We therefore get

$$\Delta f = \frac{3 \times 10^8}{1.5 \times (1550 \times 10^{-9})^2} \times 100 \times 10^{-9} = 8.3 \times 10^{12} \text{ Hz}$$

So we have Approximately.

1 nm spectral width = 120 GHz at 1300nm

1 nm spectral width = 80 GHz at 1550nm

- So , as **a rule of thumb** we can take for optical communication,

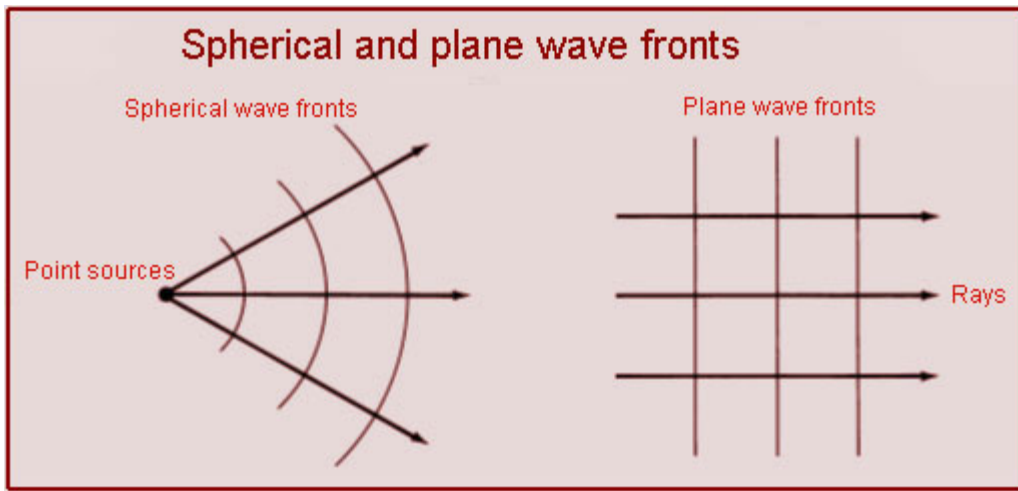
$$1 \text{ nm spectral width} \approx 100 \text{ GHz}$$

Basics of Light

Characteristics of light

- Intensity (Power per unit solid angle)
 - Wavelength (Color)
 - Spectral width (purity of color)
 - Polarization
 - Linear
 - Circular
 - Elliptical
 - The characteristics of light are summarized in the following. The first three parameters scalar characteristics of light whereas the last parameter, polarization, describes the vector nature of light.
 - The choice of wavelength depends upon the loss profile of the medium. For optical fiber the wavelength has to be 1300nm or 1550nm for low loss.
 - The spectral width has direct bearing on the data rate which the medium can support. Larger the spectral width, smaller is the data rate. A semiconductor laser typically has spectral width about 20 to 100 times less compared to LED. Consequently, laser based communication can support much higher data rates.
- Polarization is an intrinsic property of an electromagnetic wave.
-

Spherical and plane wave fronts



- Light is an Electromagnetic wave.
- It consists wave fronts. The lines normal to the wave fronts are called the light rays.
- If the phase fronts are concentric spheres, the light is called a spherical wave, and if the phase fronts are parallel planes, the light is called a plane wave.
- For a plane waves the rays are parallel whereas for the spherical wave, the emerge from the center of the spheres.

If the source is a a finite distance, the appropriate model is the spherical wave model, and if the source is assumed to be at infinite distance, the plane wave model is appropriate.

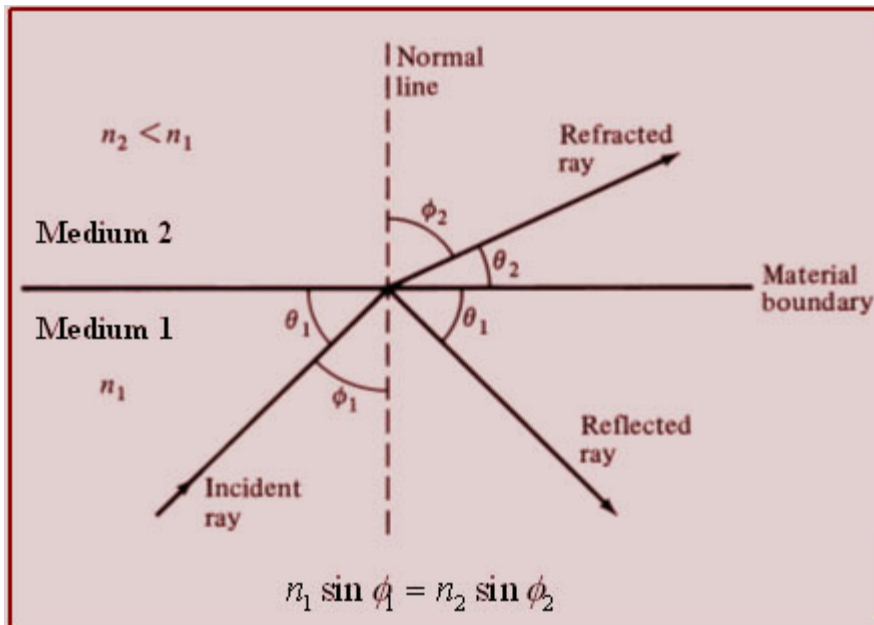
- A plane wave can be represented by a wave function which is a composite function of space and time

- Wave Function $\psi(x, t) = A \exp(\omega t - \beta x)$

A : Amplitude of the wave
 ω : Angular frequency of the wave (rad/s)
 β : Phase constant (rad/m)
 x : Distance
 t : Time

Snell's Law

- When light travels from one medium to other, it gets refracted. The relation between the angle of incidence and the angle of refraction is given by the Snell's law. The Snell's law is described in the following figure.



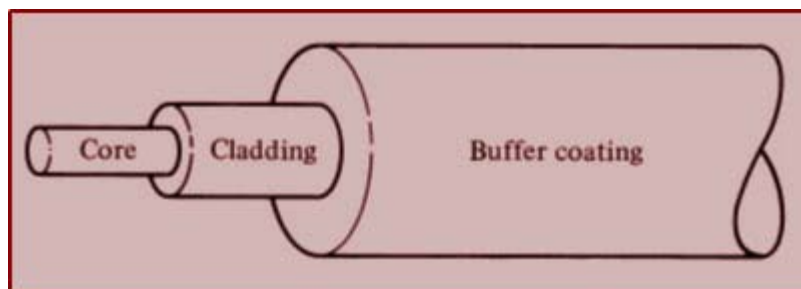
- If the angle of incidence, ϕ_1 is greater than the critical angle, ϕ_c given by

$$\phi_c = \sin^{-1}(n_2/n_1)$$

where n_1 and n_2 are the refractive indices of the two media as shown in Fig., then the light is **Total Internally reflected** in medium 1. There is no refracted ray in that case.

Basic Fiber Structure

- An optical fiber basically is a solid glass rod surrounded by concentric glass shell as shown in Fig



- The rod is called the **core** and is made of highly purified glass. Most of the light energy is confined to the core.
- The glass shell called **cladding**. The cladding shields optical fields so as not to get interfered by the outer layers of the fiber. The cladding is an essential part of an optical fiber.

- The cladding is surrounded by the buffer layers. These layers have no role in propagation of light. They are essentially there to provide the mechanical support to the glass fiber and to protect the fiber from external damage.