OPTICAL FIBER COMMUNICATIONS SYSTEMS

Lecture One

Optical Fiber Communications

Syllebus

1. **Basic concepts:** includes parameters of light wave, index of refraction, Snells law, polarization of light and electromagnetic spectrum
2. **Optical communication system:** block diagram of an optical communication system and advantages of optical communication system.
3. **Optical fiber:** optical fiber structure, propagation of light in Optical fiber, some parameters of an optical fiber, types of optical fiber, signal degradation in Optical fiber (**attenuation**: sources, calculations and methods of reduction and **dispersion** : types, calculations and methods of reduction) and advanced types of optical fiber
4. **Light sources:**light emitter and its performance characteristics, laser operation and theory, laser diode (principles of operation, characteristics and efficiency calculations), Light emitting diode (LED) (principles of operation, characteristics, coupling efficiency and optical and electrical bandwidth.
5. **Photodetectors:** photodetector characteristics, photodetector types and comparisons, noise sources and SNR calculations,
6. **Optical power and rise time budgets.**
7. **Analog systems and coherent detection.**
8. **Optical fiber applications.**
9. **Optical amplifiers**: device physics, types, performance and applications.
10. **WDM, DWDM systems.**

references

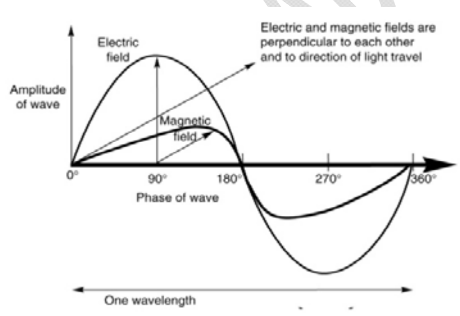
1. Senior John M., Optical Fiber Communications Principles and Practice, second edition, Prentice Hall, 2009.
2. Gerd Keiser., Optical Fiber Communication, third edition, Mc Grow Hill, 2008.
3. Gower John, Optical Communication System, second edition, Prentice Hall, 2002.

Quizes Table

What is light?

Light is an electromagnetic (EM) wave propagating through space.

Light is a transverse wave.



Electric and magnetic fields are at right angles to each other and to the direction of travel. This is called a transverse electromagnetic (TEM) wave

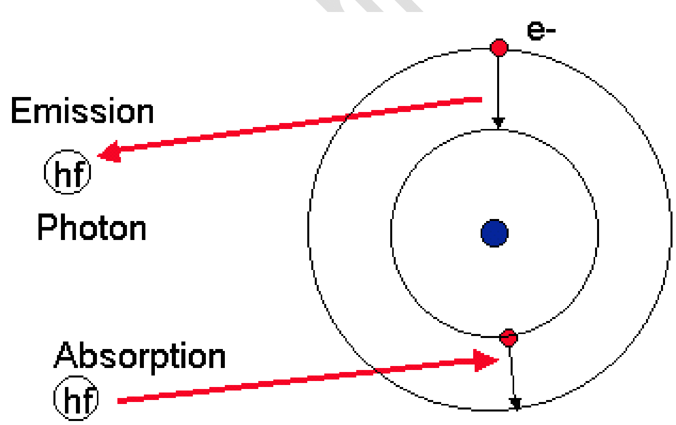
Dual Nature of Light

- **Waves**
  - **Electromagnetic radiation consisting of propagating electric and magnetic fields**
- **Photons**
  - **Quanta of energy**
- **The two views are related: the energy in a photon is proportional to the frequency of the wave.**

From where Does Light Comes?

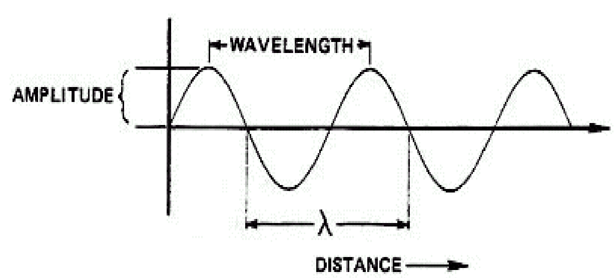
The following had been known during the 19th century:

- accelerated charges produce light
- and hence emit energy



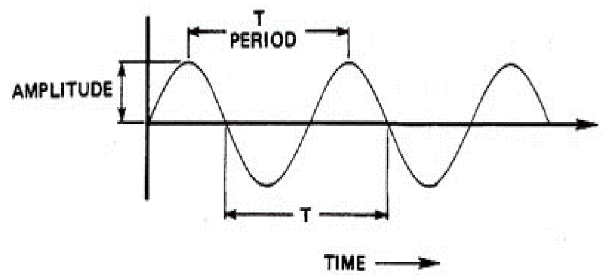
Amplitude (A) is the maximum displacement of the wave.

Spatial period (λ) **or** **wavelength** : is the distance between two similar points in the wave, e.g. the valleys or peaks measured in angstrom, nanometers or micrometers.



Spatial frequency(x): is how many a spatial period or wavelength in a unit length and measured in angstrom^{-1}, nanometers^{-1} micrometers^{-1} or centimeter^{-1}.

Temporal Period(T): is the time over which the wave repeats it self- the time required for one complete cycle of the wave measured in seconds.



Temporal frequency (υ): is the number of temporal periods of the wave in one second and is measured in Hz.

The light wave can be expressed as in below:

$$E(x,t) = A\cos(\omega t - kx + \phi)$$

Where E(x,t) is the value of electric field at point x at time t, A is the amplitude of the wave, ω is the is the angular frequency (ω = 2π ν), k is the wavenumber (k=2πλ) and ϕ is the phase constant. The term (ωt – kx – ϕ) is the phase of the wave.

C = υλ

C is the speed of light in space and = $3*10^8$ m/s

Electromagnetic spectrum

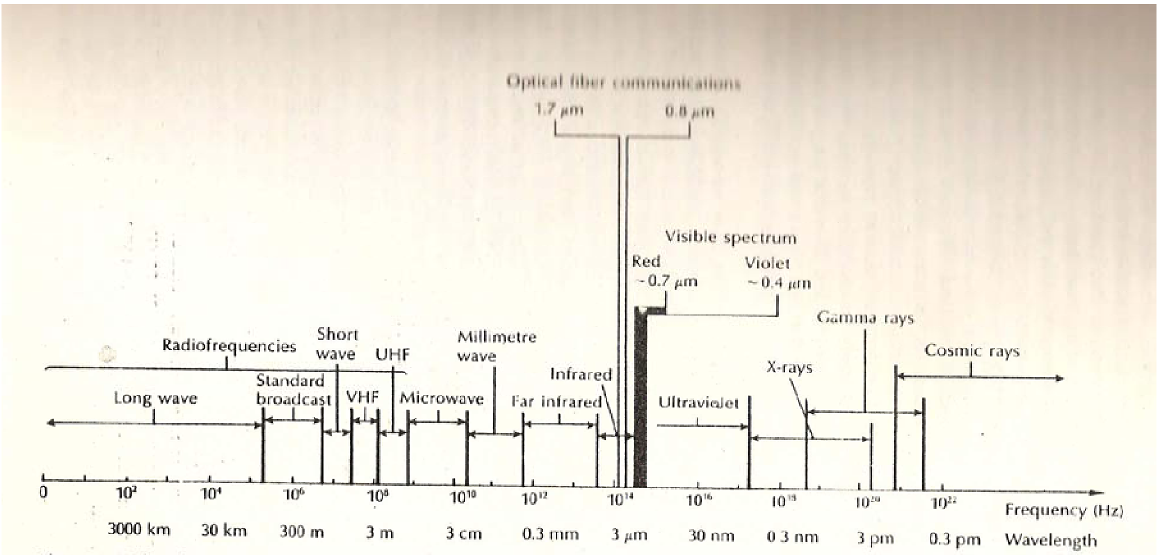


Figure 1.1 The electromagnetic spectrum showing the region used for optical fiber communications.

Energy units

In Joule:

h = Planck's constant = 6.624×10^{-34} joule-seconds = $4.14*10^{-15}$ eV-second.

e = $1.6*10^{-19}$ C

Homwork

1. Given: A HeNe laser photon has a wavelength of 632.8 nm Find photon energy in joules.
2. Given: a Nd:YAG laser photon of energy $1.87*10^{-19}$ joules Find: Photon energy in electron volts (eV)

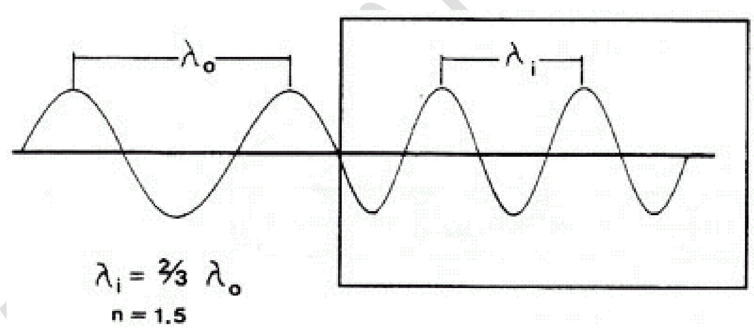
Index of refraction

The basic optical property of a material, relevant to optical fibers, is the index of refraction. **The index of refraction (n) measures the speed of light in an**

optical medium. The index of refraction of a material is the ratio of the speed of light in a vacuum (C) to the speed of light in the material (V) itself. The speed of light (C) in free space (vacuum) is 3 X 10^8 meters per second (m/s). The speed of light is the frequency (υ) of light multiplied by the wavelength of light. When light enters the fiber material (an optically dense medium), the light travels slower at a speed (v). Light will always travel slower in the fiber material than in air. The index of refraction is given by:

where: λ_0 = wavelength in vacuum.

λ_i = wavelength in the material.



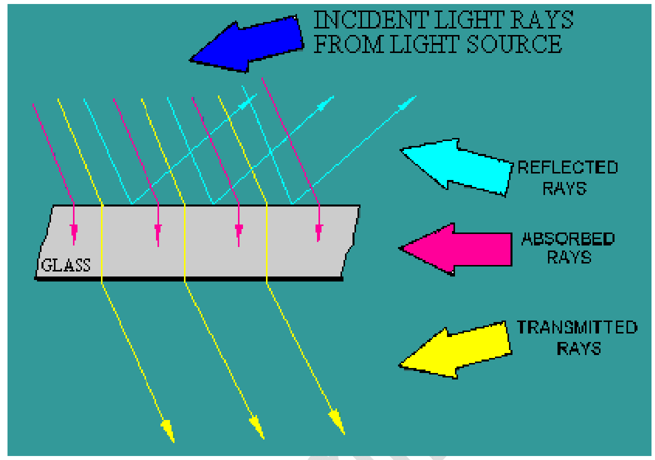
$n_{air} = 1.0003 \approx 1.0$ in most applications.

Homework

1. Given: A He-Ne laser beam (l = 633 nm) travels through a glass window with an index of refraction of 1.65. Find: Speed and wavelength inside the glass.
2. The indices of refraction of several materials situated in air are given below. Calculate the velocity of light in each.
   a. Fused quartz at 643 nm: n = 1.457.
   b. Zinc crown glass at 434 nm: n = 1.528.
   c. Fused quartz at 397 nm: n = 1.471.
3. The wavelengths given in problem 2 are in vacuum. Calculate the wave lengths inside the materials.

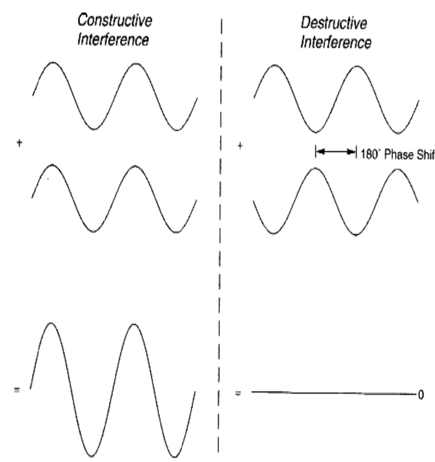
Properties of Light

LIGHT RAYS, when they encounter any substance, are either transmitted, refracted, reflected, or absorbed.



Interference

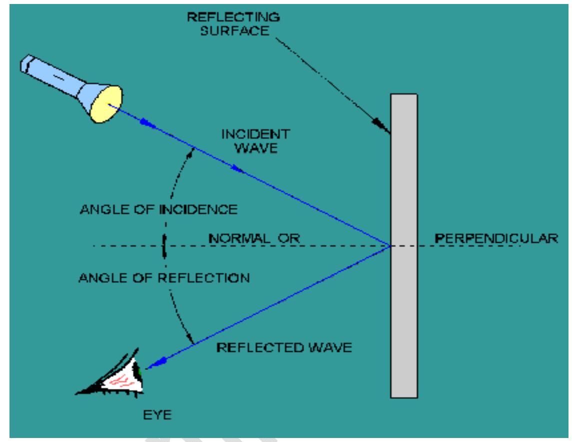
- Waves can add constructively or destructively depending on their relative phase
- This happens only with coherent light of one frequency and phase
- White light does not show interference because it has many wavelengths and all possible phase angles.



Constructive and destructive interference.

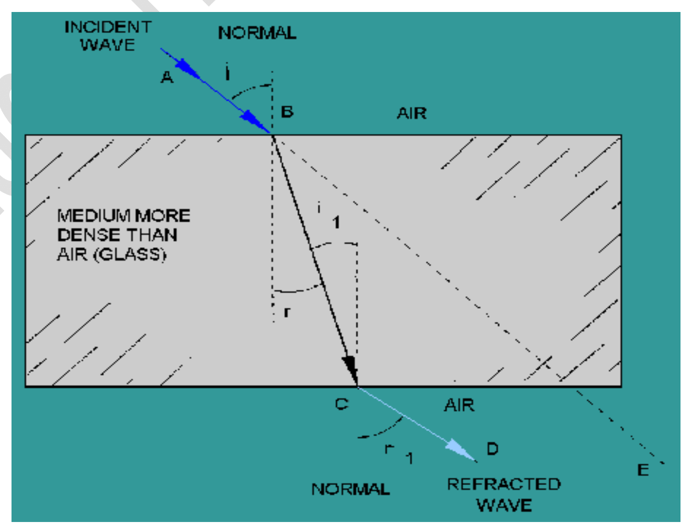
Reflection of Light

- REFLECTION occurs when a wave strikes an object and bounces back (toward the source). The wave that moves from the source to the object is called the incident wave , and the wave that moves away from the object is called the reflected wave.
- The LAW OF REFLECTION states that the angle of incidence is equal to the angle of reflection



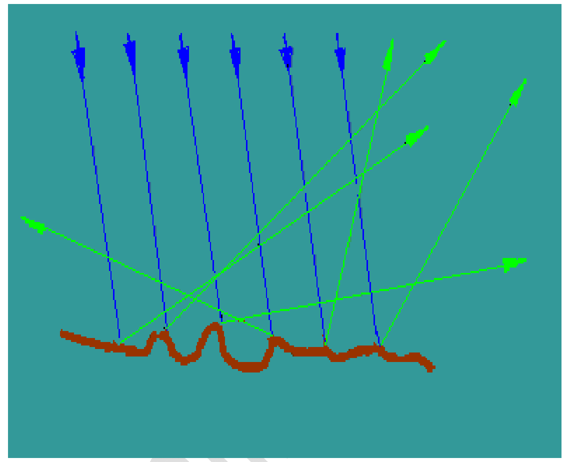
Refraction of Light

REFRACTION occurs when a wave traveling through two different mediums passes through the boundary of the mediums and bends toward or away from the normal.



Diffusion of Light

When light is reflected from a mirror, the angle of reflection equals the angle of incidence. When light is reflected from a piece of plain white paper; however, the reflected beam is scattered, or diffused. Because the surface of the paper is not smooth, the reflected light is broken up into many light beams that are reflected in all directions.



Polarization of light:

The **polarization** of light describes the orientation of the electric field in space.

- **Unpolarized light** has no specific orientation of electric field. The direction of the electric field varies randomly at approximately the frequency of light
- **An electric field vector of a polarized light**

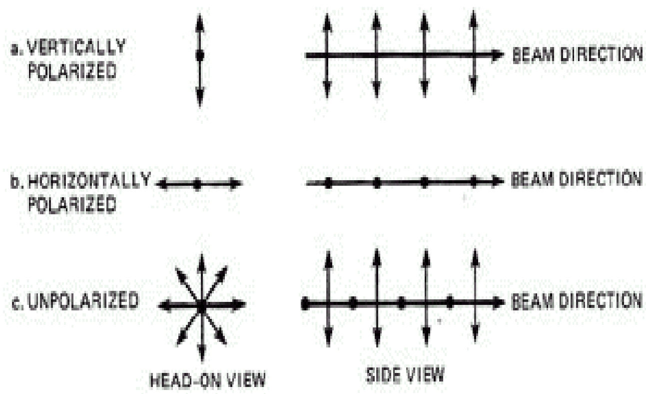
$$\mathbf{E} = \mathbf{i}E_x \sin(wt - kz) + \mathbf{j}E_y \sin(wt - kz + \theta)$$

where **i** and **j** are unit vectors.

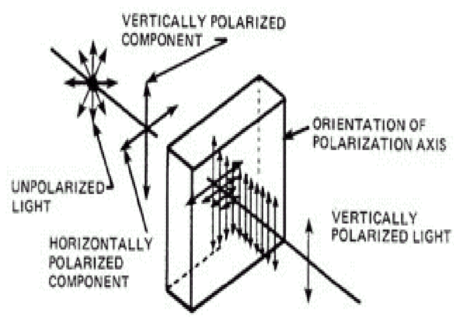
Plane-polarized light is light in which the electric field oscillates in one plane only (it always points along the same single line).

1) **Horizontally -polarized** light.
2) **Vertically -polarized** light.

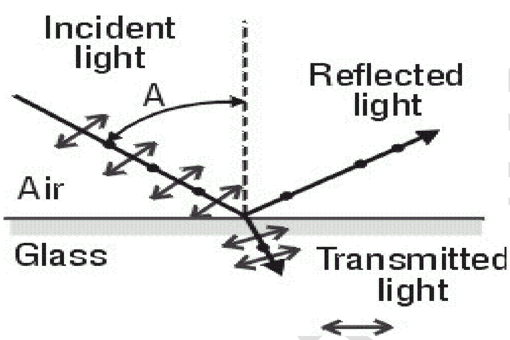
In **circularly-polarized** light: The direction of the electric field of circularly-polarized light sweeps out a circle during each period of the wave.



Linear Polarizer:



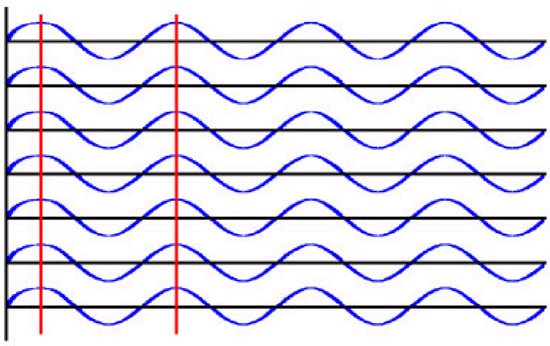
Polarization by reflection of light from a surface



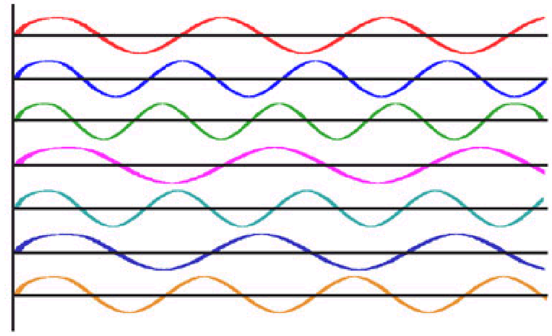
Coherence: is the condition that exists when all the light waves are 'in step,' or 'in phase.'"

Incoherent light means that the light beam has no internal order.

Coherent light in which all of individual waves are in step, or "in phase,"



Coherent light waves



Incoherent light waves

Real laser systems are neither perfectly coherent nor monochromatic.

The monchromacity of a laser beam is described by its ***wavelength linewidth*** $\Delta\lambda$ (in angstroms or nanometers) or its ***frequency linewidth*** $\Delta\upsilon$ (in Hz). The two quantities are related as:

$$\Delta\upsilon = \upsilon_1 - \upsilon_2 = \frac{c}{\lambda_1} - \frac{c}{\lambda_2} = c\left(\frac{\lambda_2 - \lambda_1}{\lambda_1 \lambda_2}\right)$$

Which assuming that λ_1 and λ_2 are much larger than $\lambda_2 - \lambda_1$ can be approximated by

$$\Delta\upsilon = \upsilon_1 - \upsilon_2 \approx c\left(\frac{\Delta\lambda}{\lambda^2}\right)$$

The fundamental linewidth for an ideal laser line is extremely small.

The monochromacity of a laser beam can also be described in terms of coherency.

Homework3:

1) consider a semiconductor laser diode with a laser linewidth of 2 Angstrom and a center operating wavelength of 870 nm. What is the frequency linewidth in Hz?

2) Consider a HeNe laser with a linewidth of 1.5 GHz and a center operating wavelength 632.8 nm. What is the laser linewidth in angstrom?

3) The uninitiated observer might confuse the center frequency of the laser line ν (in Hz) with the laser linewidth (also in Hz). However, the two numbers differ significantly in magnitude. To demonstrate this, calculate the center frequency (in Hz) and the laser linewidth (in Hz) for a semiconductor diode laser with a center operating wavelength of 760 nm and a laser linewidth of 3 angstrom?