Principles of Communication

Unit 5 Satellite and Optical Communication

Unit - V

Satellite and Optical Communication

I. Optical communication

Optical Fiber Communication System

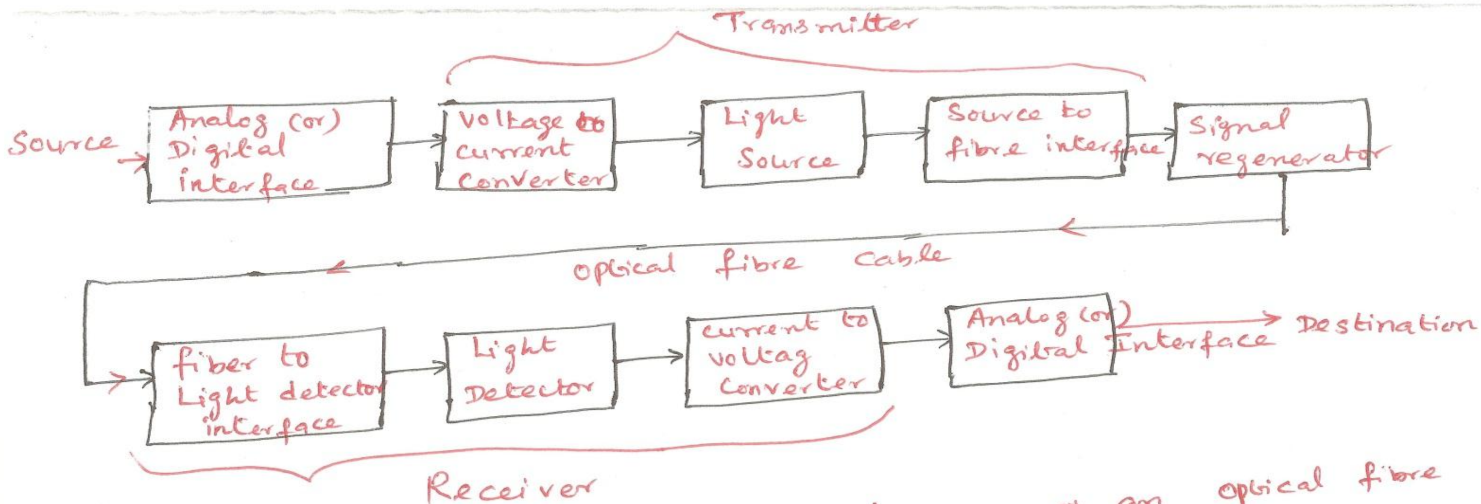


Fig. 1. Figure shows block diagram of an optical fibre communication systems.

Fig. shows a simplified block diagram of a simplex optical fiber communication link. The three primary blocks are: [1]. The transmitter [2]. Receiver and [3]. The optical fiber communication.

Transmitter

(*). The light source can be modulated by a digital (or) an analog signal. The voltage to electrical current converter serves as an interface between the input circuit and the light source.

(*). The light source is either an infrared light emitting diode (LED) (or) an Injection Laser diode (ILD). The output light emitted by the light source is proportional to the magnitude of the input voltage.

(*). The source to fiber coupler (such as an optical lens) is an mechanical interface. It's function is to couple the light emitted by the light source into the optical fiber cable.

Signal Regenerator and fiber cable

It is a transmission medium and the fiber cable may be glass (or) plastic cables. Depending on the distance between the transmitter and receiver, one (or) more regenerators are added.

The signal regenerator performs light amplification (i.e) used to restore the original transmitted signal.

Receiver

* The fiber to light detector coupling device is also a mechanical coupler, it's function is to couple as much light as possible from the fiber cable into the light detector.
* The light detector is a PIN diode, (or) APD (Avalanche Photo Diode) (or) a Photo transistor.
* Current to voltage converter transforms the changes in detector current to changes in photo detector voltage.
* Analog (or) digital interface are electrical interfaces that match impedance and signal levels between the information present in the input source and destination and output circuitry.

Optical Fiber Types →

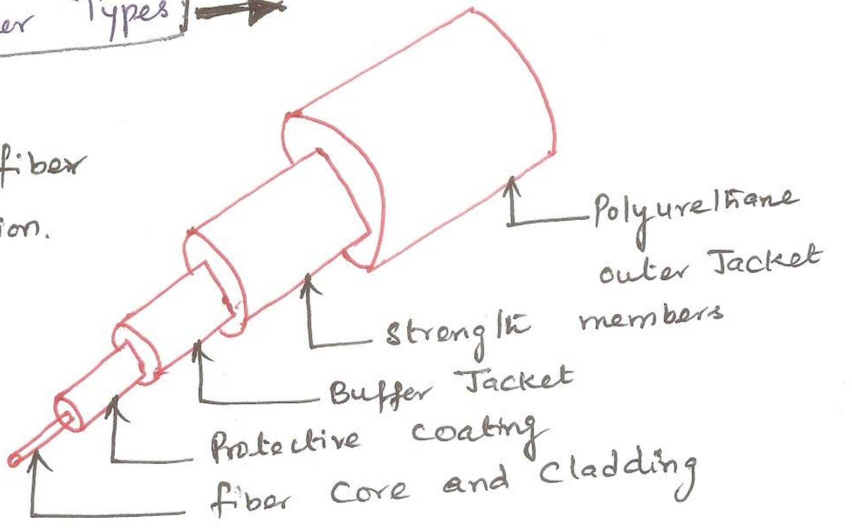


Fig 2. Optical fiber construction.

Optical fiber Construction:

(*). The actual fiber portion of a optical cable consists of both the fiber core and cladding.

(*). A special silicone coating is applied to the outside of the cladding to seal and preserve the fiber strength.

(*). The protective coating is surrounded by the buffer jacket which provides the cable additional protection against corrosion and shock.

(*). Buffer jacket is encapsulated in a strength members which increases the tensile strength of the overall cable assembly.

(*). Finally the entire cable assembly is contained in an outer polyurethane jacket.

Types of optical fibers:

Three types of optical fiber generally used:

1. Plastic core and cladding.
2. Glass core with plastic cladding [PCS - Plastic Cladd silica].
3. Glass core and glass cladding [SCS - silica Cladd silica].

(1). Plastic core and Cladding:

Advantages of plastic fiber

- (*). Plastic fibers are more flexible and rugged.
- (*). The plastic cables are easier to install.
- (*). can better with stand stress
- (*). less expensive.
- (*). weightless approximately 60% less than glass.

Disadvantage of plastic fiber

- (*). Plastic fiber have higher attenuation and donot propagate light as efficiently as glass.
- (*). Plastic fiber is limited to relatively Short distance such as within a single building.

(2). Glass core with plastic cladding. (PCS)

Advantages

- (*). Fibers with glass core provides less attenuation than plastic fibers.
- (*). PCS fibers are less affected by radiation.
- (*). They Are more immune to external interference.

(3). Glass core & Glass Cladding

Advantages

(*). SCS fibers have the best propogation and are easier to terminate than PCS fibers.

Disadvantages

(*). SCS fibers are more susceptible to increase in attenuation when exposed to radiation.

Main Disadvantage of optical fibers

One main disadvantage of optical fiber is lack of tensile strength. For this reason the fiber must be reinforced with the strengthening material, so that it can withstand mechanical stresses.

Note: The following materials commonly used to strength and protect fibers from abrasion and environmental stress are:

(1) steel
(2). fiber glass
(3). plastic, PVC.
(4). kevlar yarn
(5). paper.

---x---x---

Losses in Optical Fiber Cables:

Power loss (or) attenuation results in a reduction in the power of the light wave as it travels down the cable.

formula to calculate power loss in a optical fiber cable is

$$A_{(dB)} = 10 \log_{10} \left(\frac{P_{out}}{P_{in}} \right) \rightarrow (1)$$

$A_{(dB)}$ → Total reduction in power level (i.e) attenuation in dB.

P_{out} → Cable output power (watts)

P_{in} → cable input power (watts)

The optical power in watts at a given distance from a power source,

$$P = P_t \times 10^{-\frac{Al}{10}} \longrightarrow (2)$$

P → Measured Power level in watts.

P_t → transmitted power levels in watts.

A → Cable power loss (dB/km).

l → cable length (km).

The optical power in decibel unit is

$$P_{(dBm)} = P_{in\,(dBm)} - A\,l\,(dB) \longrightarrow (3)$$

The following are the predominate loss in OFC's are:

(i). Absorption loss

(ii). Material (or) Rayleigh Scattering loss

(iii). Chromatic (or) wavelength dispersion loss.

(iv). Radiation losses.

(v). Modal dispersion (or) pulse spreading

(vi). Coupling losses

(i). Absorption loss:

Absorption losses in optical fiber is due to the impurities in fiber absorb the light and convert it in to heat. There are three factors that contribute to the absorption losses in optical fiber:

(i) UV absorption (Ultra violet)

(ii) IR absorption (Infra red)

(iii) Resonance absorption.

(ii). Scattering Loss:

During the glass manufacturing the tension applied to the glass causes the cooling glass to develop permanent sub-microscopic irregularities. When light rays propagate through this, they are diffracted. Some of the diffracted light travels through the fibre and some of it escapses through the cladding. This is called Rayleigh scattering loss.

(iii). Wavelength Dispersion:

The light rays emitted by LED containing many wavelength and donot arrive at the farend of the fibre at the same time resulting in the impairment called wavelength dispersion (or) Chromatic dispersion.

(iv). Radiation loss:

They are caused mainly by small bends in the fiber. There are two ~~methods~~ types of bends:

(1). Micro bends

(2). Constant radius bends (or) macro bends

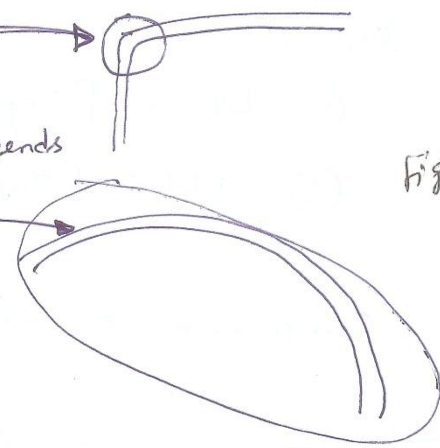


Fig (3).

They are also called as bending losses.

(v). Modal dispersion

It is sometimes called pulse spreading and it is caused by the difference in the propagation time of light rays, that take different paths.

Modal dispersion can cause a pulse of light energy to spread out in time as it propagates down a fiber.

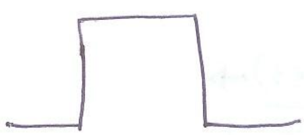


Fig (4) Actual pulse

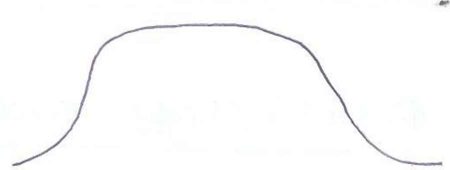


Fig (5). pulse spreading due to Modal dispersion.

(vi). Coupling loss:

It is caused by imperfect physical connections. It occur at three types of junctions:

(1). Light source to fibre connection.

(2). Fiber-to-Fiber connection.

(3). Fiber-to-photo detector connection.

—— x —— x —— x ——

Optical Sources: ⇒

Two types of practical light sources are used to generate light for optical fiber communication system:

1. LED's [Light Emitting Diode's]
2. ILD's [Injection type LASER Diode's]

Comparison of LED & ILD's

LED	ILD
1. They have spectral width's of 30nm to 50nm.	They have spectral widths of 1nm to 3nm.
2. LED's are low cost and lower performance.	High cost & higher application
3. They are reliable	They are not reliable
4. Emit light by spontaneous emission	Emit light by stimulated emission.

1. LED's (Light Emitting Diodes) →

An LED is a Light Emitting PN junction diode actually made from a semiconductor material such as aluminium-gallium-Arsenide (AlGaAs) (or) Gallium-Arsenide-Phosphide (GaAsP).

Operation of LED's

When forward bias is applied across the LED junction, carriers are generated. Minority carriers recombined with majority carriers and give up energy in the form of light.

In conventional semiconductor diode (Ge, Si) the recombination process is non-radiative and no photons are produced.

Whereas in LEDs it is radiative and photons are produced.

The energy gab of the material used to construct the LED determines the colour of light it emits and whether the light emitted by it is visible to human eye.

Table 1: Semiconductor material used and their Corresponding wavelength.

Material	Wavelength (nm)
InGaAs	980
InGaAsP	1100 – 1650
GaAlAs	620 – 895
GaAs	904

①, Homo junction LED's

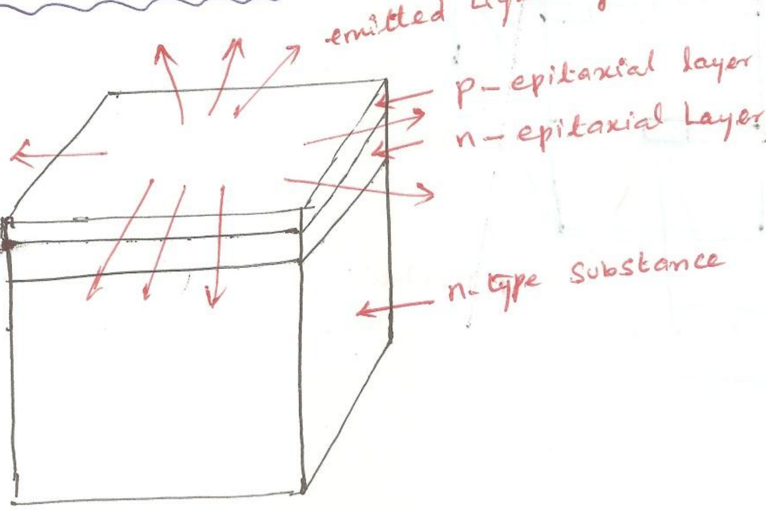


Fig. ⑥.

2. Heterojunction LED's

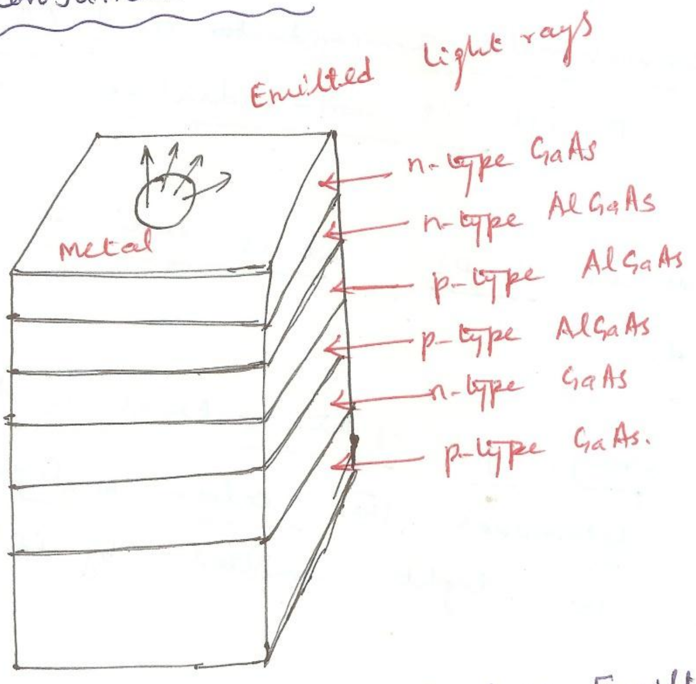


Fig. 7.

3. Burrus Etched-well Surface Emitted LED

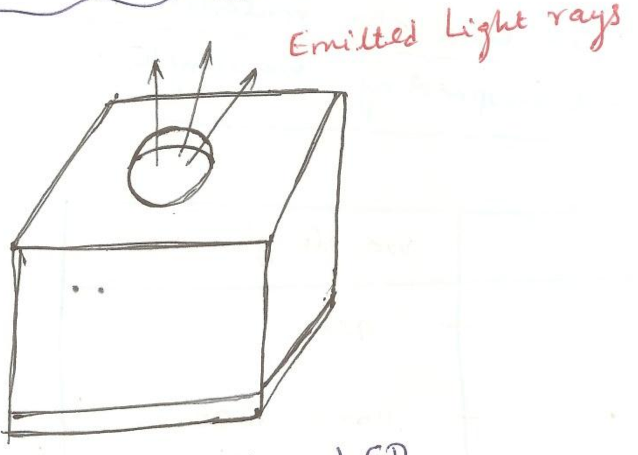


Fig. 8.

4. Edge-Emitting LED

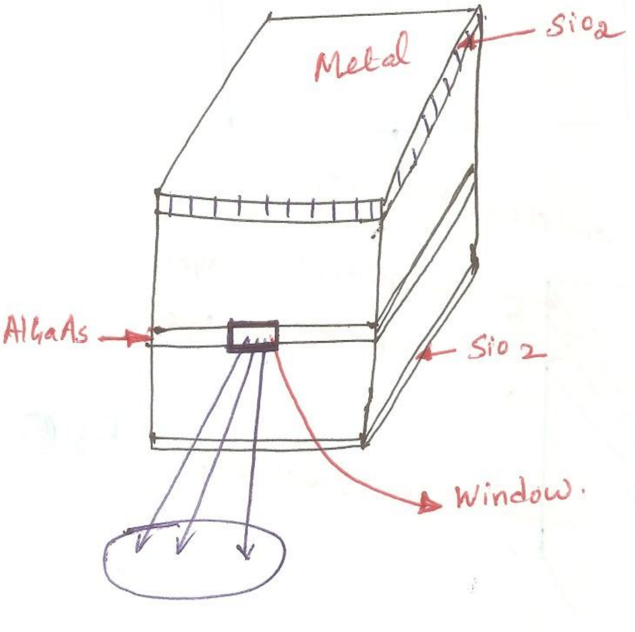


Fig. 9.

1. Homojunction LED's

A PN junction made from two different mixture of a same type of atoms is called Homojunction structure. That will produce a light of wavelength of 940nm and an output power of 2milliwatts.

Disadvantage

It emits light in all directions. Due to this, only a small amount of light produced is coupled into the fiber which makes them a poor choice as a light source for optical fiber system.

Note: In homojunction LED light is emitted from the surface of the LED's. Therefore they are called as surface emitters.

2. Heterojunction LED's

It is made from a p-type semiconductor material of one set of atoms and n-type semiconductor material from another set of atoms.

Advantages :-

(i) Increased current density results in light of high Intensity.

(ii). The smaller emitting area makes it easier to coupled it's emitted lights into a fiber.

(iii). The small ~~affecting~~ effective area has a smaller capacitance which allows heterojunction LED to be used at higher speeds.

Note:

With heterojunction LED's light is emitted from edge of the material and therefore they are called as edge emitters. The output power emitted around 3 mW.

(3). Burrus - Etched - Well Surface Emitting LED

For telecommunication applications data rate of 100 Mbps are required for this application. Etched - well surface emitting LED was developed.

Advantage

These devices are more efficient than a standard surface emitters and they allow more power to be coupled into the optical fiber.

Disadvantage

They are more difficult to manufacture and expensive.

(4). Edge- Emitting LED

These LED's emit more directional light pattern than surface emitting LED's. The light emitted from the active region is in the form of elliptical beam.

Injection LASER Diodes (ILD)

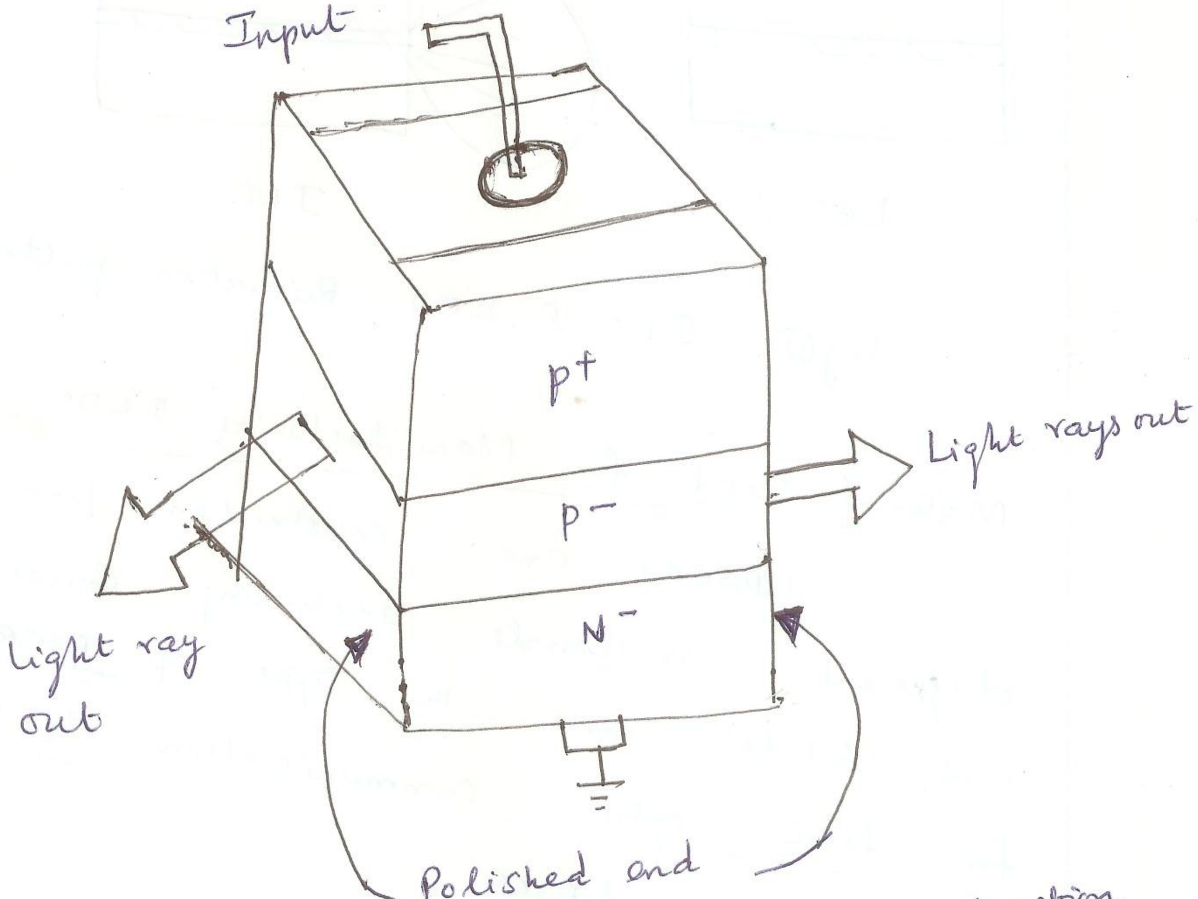


Fig (10). Injection LASER Diode Construction

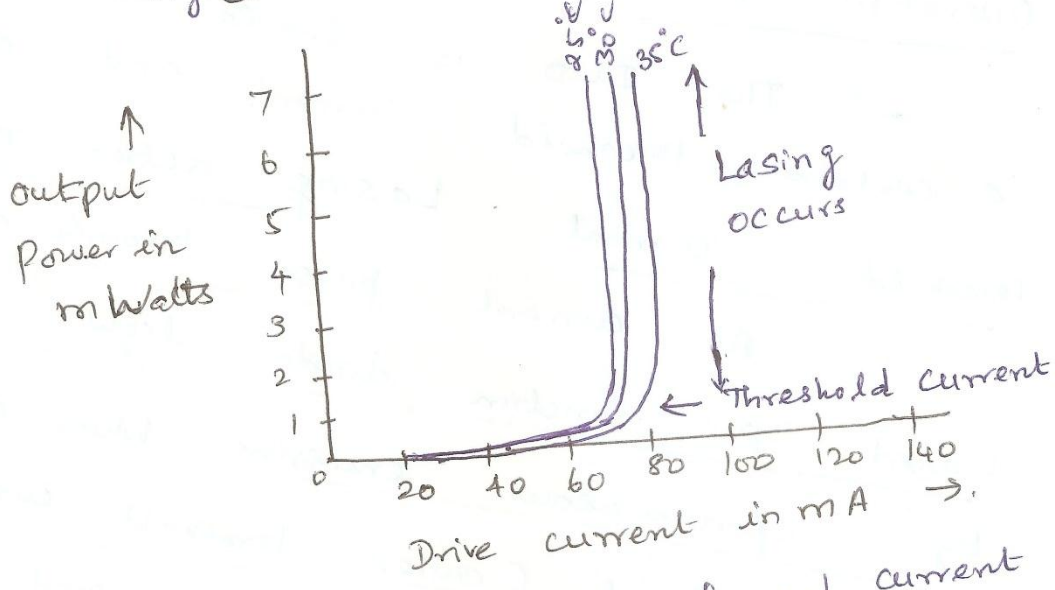


Fig (11). Output power Vs forward current for different temperatur for an ILD.

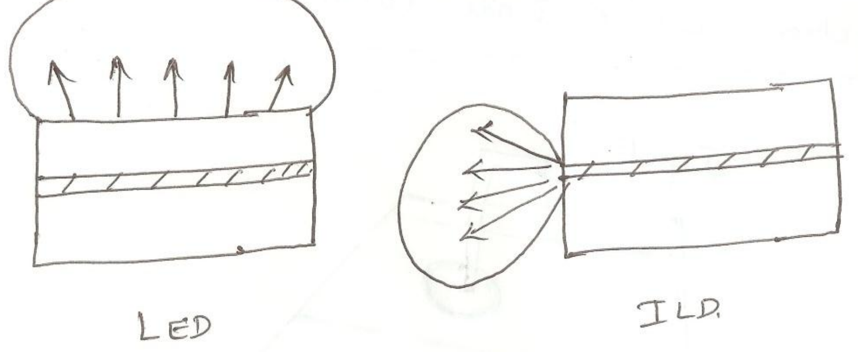


Fig (12). ILD & LED Radiation patterns

Material used for Manufacturing ILD:

LASERS are constructed from many different materials including Gases, Liquids and Solids and the type of LASER used for fiber optic communication is the Semiconductor LASER.

Operation of ILD:

The ILD is similar to LED below a certain threshold current and above the threshold current Lasing action occurs.

As current passes through a forward biased PN junction diode light is emitted by Spontaneous emission. When a particular current level (called threshold current) is reached the minority carrier and photons produced ~~[struck]~~ begin to collide with already excited minority carriers. This results in stimulated emission of light energy.

Construction of ILD:

ILD is similar to that of an LED except that the ends are highly polished. The mirror like ends trap the photons in the active region and they reflected back and forth results in stimullated free electrons to recombine with holes at a higher energy level. This process is called LASING.

Advantages of ILD over LED:

(i). ILD emits coherent light, whereas LED emits non-coherent light.

(ii). ILD have a more direct radiation pattern making it easier to couple light emitted by ILD into an optical fiber cable. This reduces the coupling loss and allows smaller fibers to be used.

Disadvantages of ILD over LED:

(i). ILD's are 10 times more expensive than LED's.

(ii). ILD's operate at high powers. Therefore they have much shorter life time than LED's.

(iii). ILD's are more temperature dependent than LED's.

Light Detector (or) Photo Detector :→

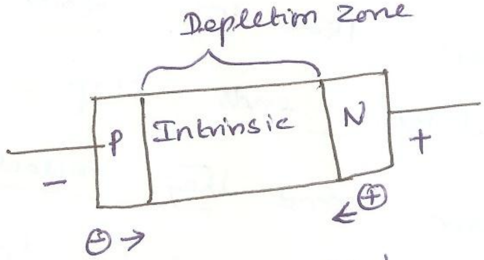


Fig (13). ~~Avalanche~~ PIN Photo diode

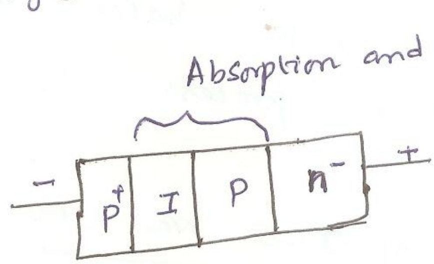


Fig (14). Avalanche Photo Diode (APD)

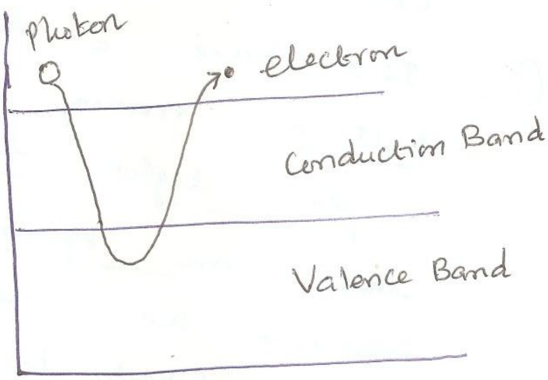


Fig (15). Photons adds sufficient energy to allow more ~~Electrons~~ from VB (Valence Band) to CB (Conduction band)

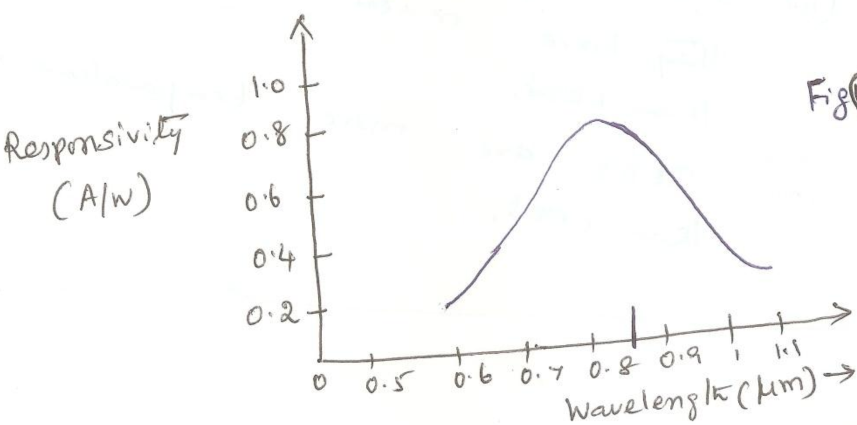


Fig (16). Spectral response curve

For silicon,

Energy gap $(E_g) = 1.12\,ev$

$1\,ev = 1.6 \times 10^{-19}\,J$

$E_g = (1.12\,ev)(1.6 \times 10^{-19}\,J/ev)$

$$E_g = 1.792 \times 10^{-19}\ \text{Joules}$$

For $E = hf$ = Energy of a photon

$h \rightarrow$ plank's constant $\rightarrow 6.625 \times 10^{-34}\,J/Hz$

$f \rightarrow$ frequency (Hz)

$f = E/h$

$$f = \frac{1.792 \times 10^{-19}}{6.6256 \times 10^{-34}\,J/Hz}$$

$$f = 2.705 \times 10^{14}\,Hz$$

$$\lambda = \text{wavelength} = \frac{c\ (\text{velocity})}{f\ (\text{frequency})}$$

$$= \frac{3 \times 10^{8}\,m/sec}{2.705 \times 10^{14}\,Hz}$$

$$\lambda = 1109\,nm/cycle$$

① PIN Diodes:

A very lightly doped intrinsic layer of n-type semiconductor material is sandwitched between the junction of the two heavily doped n & p - type materials.

Operation of PIN Diode

Light enters the device through the very small window and falls on the intrinsic material. The intrinsic material is made thick enough so that most of the photons that enter the device are observed by this layer. When the photons are observed, they add sufficient energy to generate carrier in the depletion region and allow current flow through the device.

(2) APD : Avalanche Photo Diode :

Construction of APD:

An APD is an PNPN structure. Light enters the diode and is observed by the thin intrinsic layer & heavily doped n- Layer.

Operation of APD:

A high electric field intensity developed across the I-p-n junction by reverse bias causes impact ionization to occurs. During impact ionization, the carrier can gain sufficient energy to ionize other bound electrons. These ionized carrier inturn cause more ionization to occurs. The process continuous as in an avalanche manner.

Advantage of APD over PIN Diode

APD's are more sensitive than PIN diode and requires less additional amplification.

Disadvantage of APD over PIN Diode

Generate more noise due to avalanche multiplication of carrier.

Characteristics of Photo Detection:

(i). Responsitivity:

It is the ratio of the output current of an photo diode to the input optical power and is measured in an unit of ampere/volt.

(ii). Dark Current:

The leakage current that flow through the photo diode with no light input.

(iii). Transit Time:

The time taken by a carrier travel across the depletion region of a semiconductor

(iv). Light Sensitivity:

The minimum optical power ~~a~~ a light detector can receive and produce a useful electrical output signal.

II. Satellite communication →

Satellite ↦

A satellite is a celestial body that orbits around a planet (e.g. the moon is a satellite of Earth).

In aerospace terms, however, a satellite is a space vehicle launched by humans and orbits Earth (or) another celestial body.

Satellite orbits:

(i). LEO – Low Earth orbits
(ii). MEO – Medium Earth orbits
(iii). GEO – Geosynchronous Earth orbits

LEO	MEO	GEO
(i). Frequency: 1GHz to 2.5GHz	1.2 GHz to 1.66 GHz	2GHz – 18GHz
(ii). Distance from Earth 480 Miles approx.	6000 Miles to 12000 Miles	22,300 Miles

Geostationary Satellites:

Satellites have orbital time of approx. 24 hours and they rotate along GEO orbit. They remains in a fixed position in respect to a given point on Earth.

Satellite orbital Patterns:

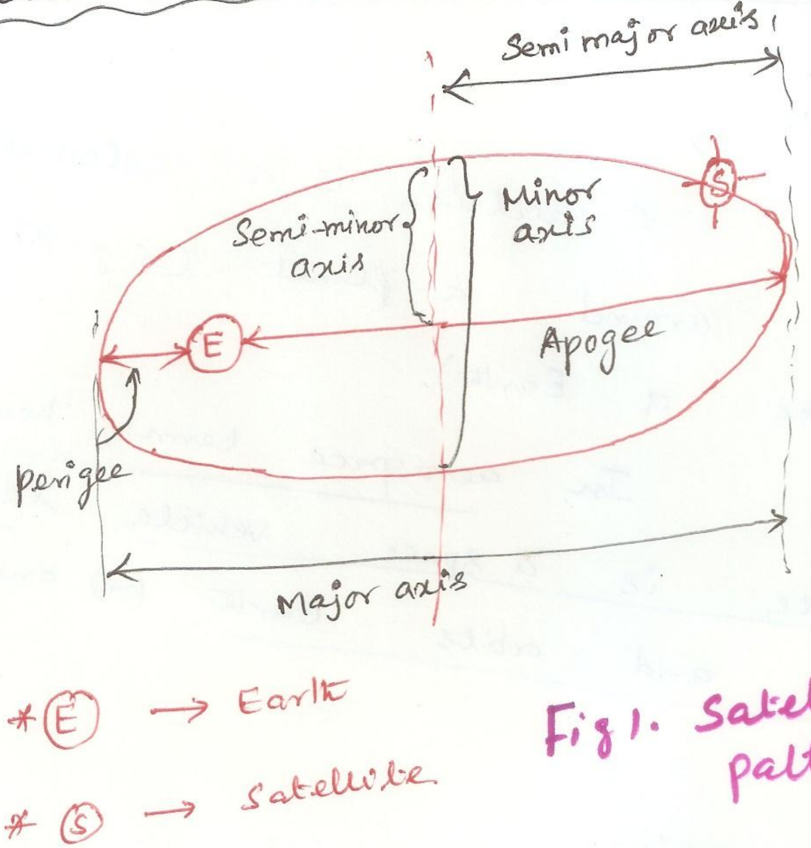


Fig 1. Satellite orbital patterns

(i). **Apogee:**

A point in an orbit that is located farthest from earth (distant point)

(ii). **Perigee:**

The point in an orbit that is located closest to earth.

(iii). **Major Axis:**

The line joining the perigee and apogee through the center of the earth.

(iv). **Minor Axis:**

The line perpendicular to the major axis and half-way between perigee and apogee.

Paths useful for Communication Satellites:

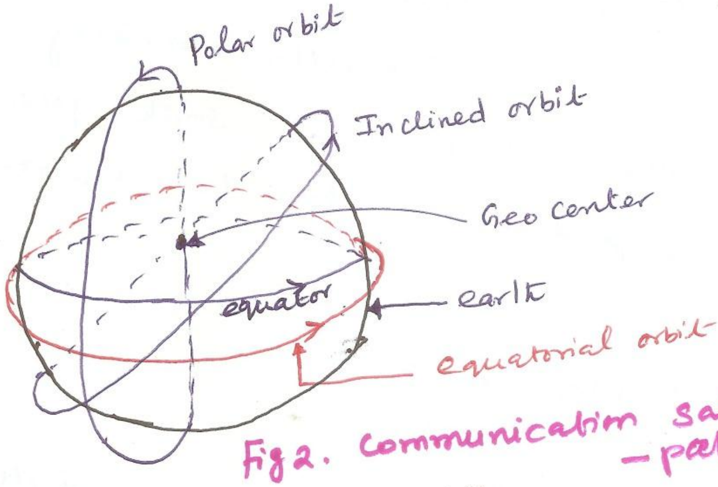


Fig 2. Communication satellites - paths

Paths
→ ①. Inclined orbits
→ ②. Equatorial orbits
→ ③. Polar orbits

①. Inclined orbits

All orbits except those path travel directly above the equator (or) North and South poles.

④. Ascending node → The point where a polar (or) inclined orbit crosses the equatorial plane travelling from south to North is called Ascending node.

Descending node → The point where a polar (or) inclined orbit crosses the equatorial plane travelling from North to South is called descending node.

②. Equatorial orbit

Satellites rotates in an orbit directly above the equator. Angle of inclination is 0° (or) 360°.

③. Polar orbits

Satellite rotating path takes it over the North and South poles in an orbit perpendicular to the equatorial plane.

Kepler's Law:

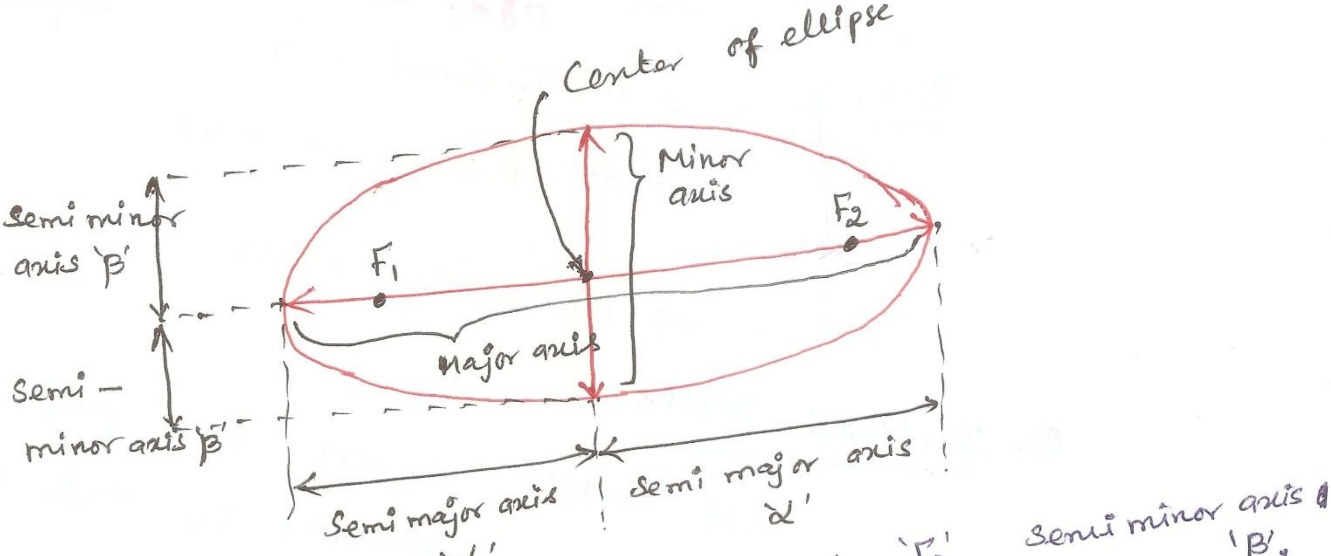


Fig. 3. Focal points 'F1' and 'F2' semi minor axis 'β', Semimajor axis 'α'. Kepler's First Law.

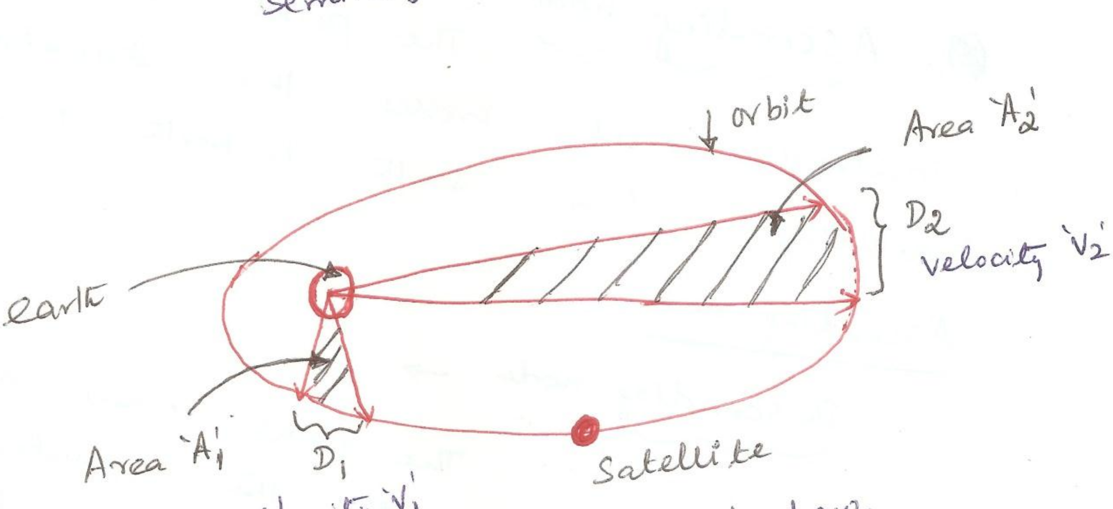


Fig. 4. Kepler's second Law.

Kepler's First Law

It states that a satellite will orbit a primary body (like Earth) following an elliptical path.

An ellipse has two focal points (foci) say 'F1' and 'F2' as shown in Fig.1. and the center of mass (called the bary center) of a two-body system is always centered on one of the focci.

Because the mass of Earth is substantially greater than that of the satellite, the center of mass will always coincide with the center of Earth.

The eccentricity of ellipse can be defined as,

$$\boxed{\varepsilon = \frac{\sqrt{\alpha^2 - \beta^2}}{\alpha}} \longrightarrow (1)$$

ε → eccentricity

α → semi-major axis

β → semi-minor axis

Kepler's Second Law (Law of Areas)

It states that for equal intervals of time a satellite will sweep out equal areas in the orbital plane, focused at the bary center.

As shown in fig 4, for a satellite traveling distances D_1 and D_2 meters in '1' second, Areas 'A_1' and 'A_2' will be equal. Because of the equal area law, distance 'D_1' must be greater than Distance 'D_2' and therefore velocity 'V_1' > velocity 'V_2'.

The velocity will be greatest at the point of closest approach to Earth (known as the perigee), and the velocity will be least at the farthest point from Earth (known as the apogee).

Kepler's Third Law (also known as Harmonic Law).

The Third Law states that the square of the periodic time of orbit is proportional to the cube of the mean distance between the primary and the satellite.

The mean distance is equal to the semimajor -axis.

$$\boxed{\alpha = A(P)^{2/3}} \rightarrow (2) \Rightarrow \boxed{\alpha = A \times (P)^{2/3}}$$

where A → constant (unitless)

α → semimajor axis (kilometers)

P → mean solar earth days

P → is the ratio of the time of one sidereal day (t_s = 23 hours and 56 minutes) to the time of one revolution of Earth on its own axis (t_e = 24 hours)

$$\boxed{P = \frac{t_s}{t_e} = \frac{1436 \text{ minutes}}{1440 \text{ minutes}}} \rightarrow (3)$$

$$\boxed{P = 0.9972}$$

for earth, sub equ (3) in (2) we get $\boxed{A = 42241.1}$ → (4).

Satellite Antenna Radiation Patterns: FOOTPRINTS:

footprint:

Satellite engineers select the antenna and carrier frequency for a particular spacecraft to concentrate the limited transmitted power on a specific area of Earth's surface. The geographical representation of a satellite antenna's radiation pattern is called a footprint (or) footprint map.

footprint depends on:

(1). Satellite orbital path

(2). height

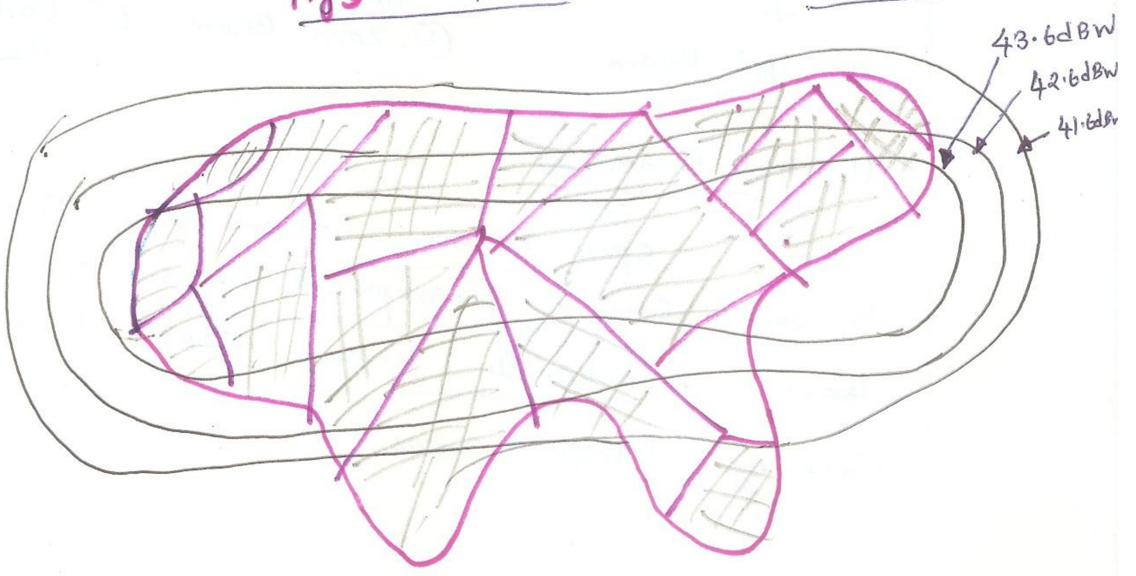
(3). Type of antenna used.

EIRP: The effective power transmitted is called effective isotropic radiated power (EIRP) and is expressed as dBm (or) dBW.

Footprint map:

A footprint map is constructed by drawing continuous lines between all points on a map with equal EIRPS.

Fig 5. A typical footprint (satellite radiation pattern)



The pattern of the contour lines and power levels of a footprint are determined by precise details of the downlink antenna design as well as by the level of microwave power generated by each onboard Channel.

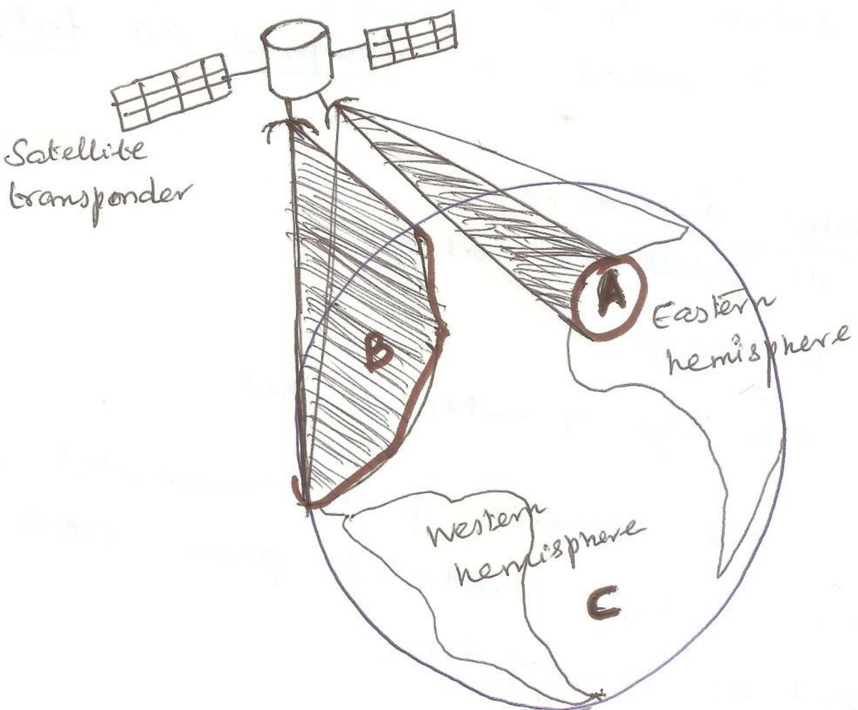


Fig6. Radiation patterns of satellite : (A). Spot Beam (B). Zonal Beam (C). Earth (Global) Beams

Satellite Radiation patterns

(1). Spot Beam
(2). Zonal Beam
(3). Earth (Global) Beams

(1). Spot Beam ⇒

Spot beams Concentrate their power to very small geographical areas and therefore have proportionally higher EIRPs than those Covering larger areas.

(2). Zonal beams.

Zonal beams larger than in size compared to spot beams and both zonal beams and spot beams cover less than 10% of the Earth's surface.

(3). Hemispherical Beams:

They cover up to 20% off the Earth's surface and therefore have EIRP's 50% less than those transmitted by spot beams.

(4). Earth (Global) Beams:

Earth coverage antenna radiation pattern have a beamwidth approximately 17° and are capable covering approximately 42% of Earth's surface.

But power levels and EIRP's < spot beam, zonal beam and hemispherical beams radiation patterns.

Satellite System Link Models →

A satellite system contains three basic sections:

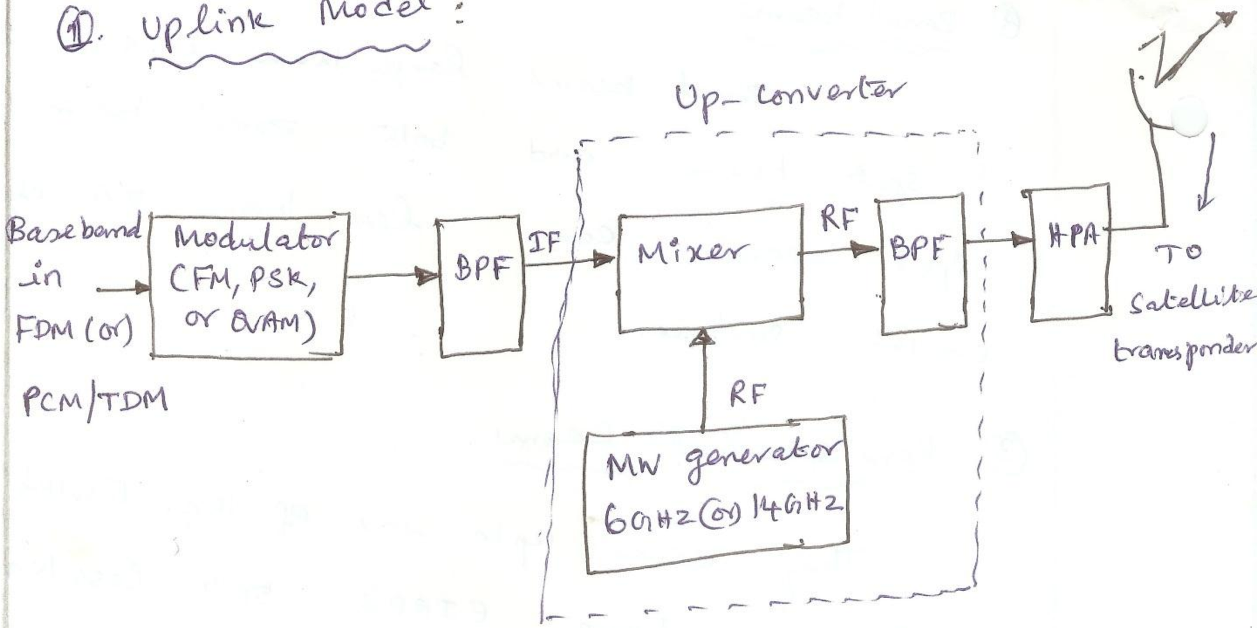
(1). An Uplink

(2). A Satellite transponder

(3). A Downlink.

(1). Uplink Model :

Up- converter



Fig(7). Satellite up-link model.

A typical earth station transmitter consists of an IF modulator, an IF-to-RF microwave up-converter, a high-power amplifier (HPA), and an output Band-pass filter.

(i). IF Modulator → converts the input baseband signals either an FM, a PSK or a QAM modulated intermediate frequency.

(ii). Up-converter → mixer and Bandpass filter converts the IF to an approximate RF carrier frequency.

(iii). HPA - High power amplifier } → adequate gain and output power to propagate the satellite signal to the transponder.

used klystrons and traveling-wave tubes.

(2). Transponder

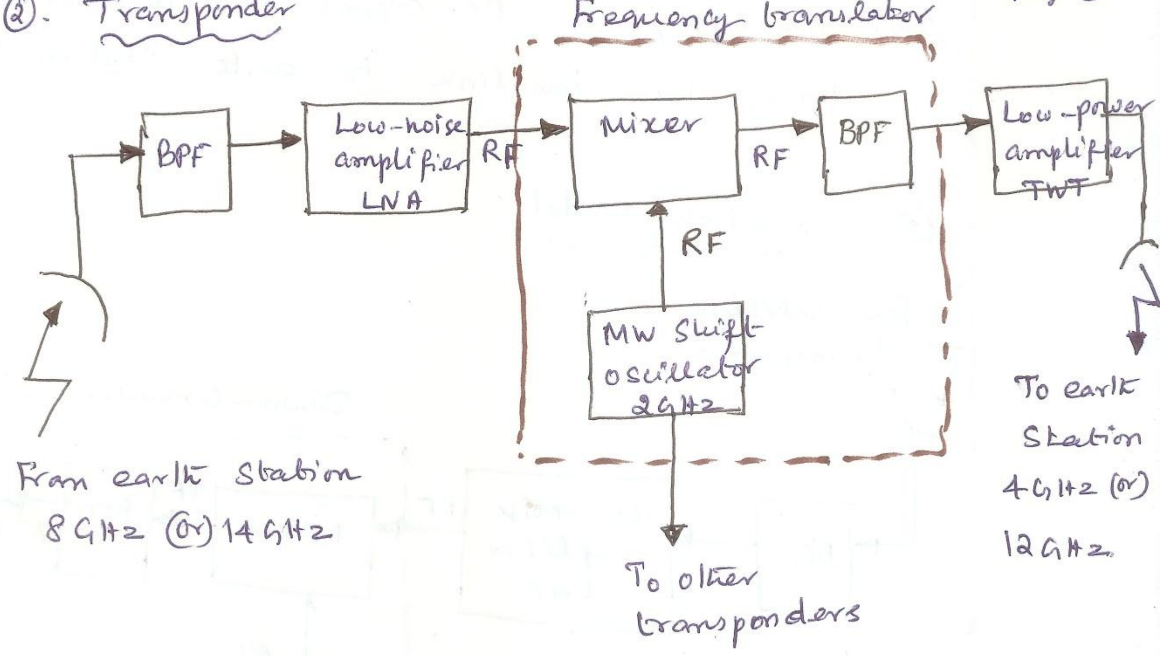


Fig (8). Satellite transponder

(*). A satellite transponder consists of:

(i). an input bandlimiting device (BPF)

(ii). an input low-noise amplifier (LNA).

(iii). A frequency translator

(iv). a low-level power amplifier

(v). an output band pass filter.

(*). A transponder is an RF-to-RF Repeater.

(*) (i). BPF → It limits the total noise applied to the input of the LNA.

(ii). ~~LNA~~ Frequency translator → It converts high-band uplink frequency to the low-band downlink frequency.

(iii). LNA → Tunnel diode used as a Low-Noise Amplifier.

(iv). Low-level power amplifier → It is a simple travelling wave tube (TWT)

TWT amplifier amplifies the RF signal for transmission through the downlink to earth station receivers.

(3). Downlink Model

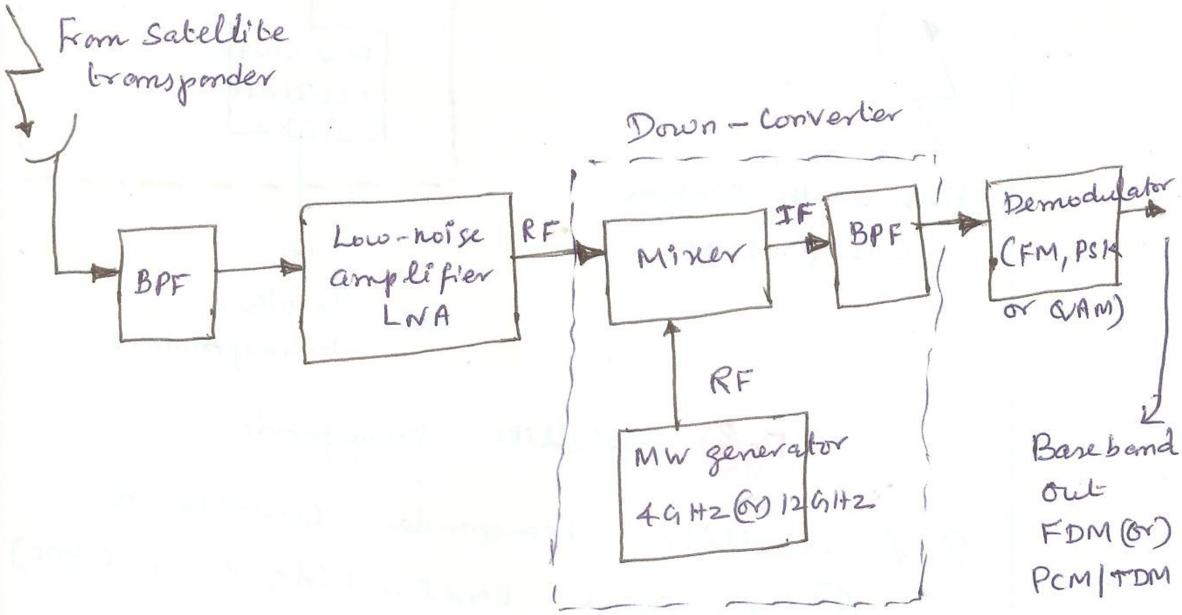


Fig (9). Satellite downlink model (earth station Receiver)

(i). BPF → It limits the input noise power to the LNA.

(ii). LNA → highly sensitive low-noise amplifier such as tunnel diode amplifiers (or) a parametric amplifier.

(iii). RF-to-IF → Down converter is a mixer/band pass filter combination that converts the received RF signal to an IF frequency.

(4). Cross-links

Communication between satellite is done using satellite cross-links (or) intersatellite links (ISLs).

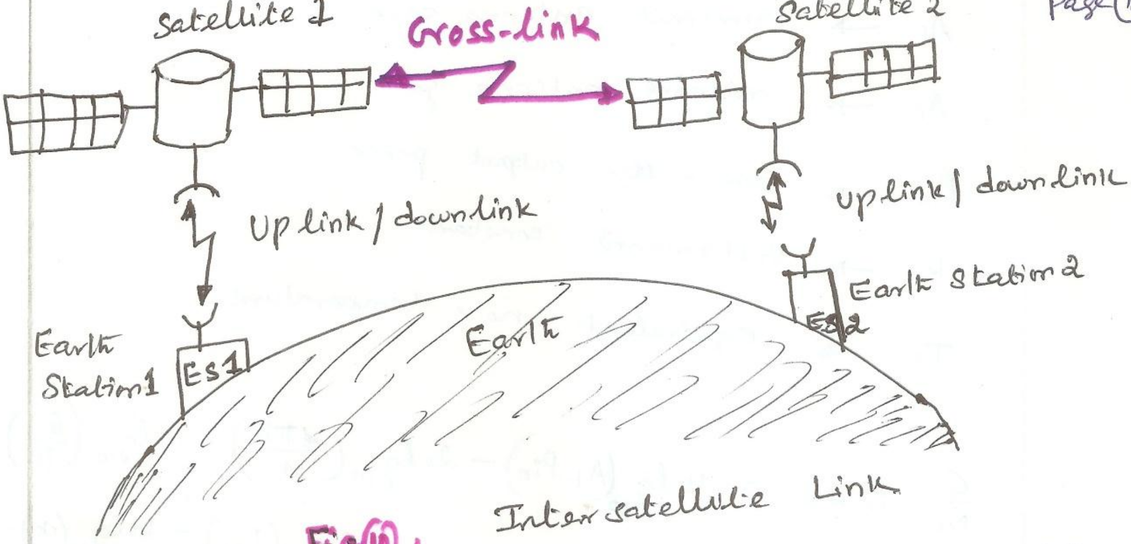


Fig (10). Intersatellite Link.

In Intersatellite Link (ISL), both the transmitted output power and the receiver's input sensitivity are limited.

Applications of communication satellites

Communication satellites are man-made satellites that orbit Earth, providing a multitude of communication functions to a wide variety of consumers, (1) including military (2) Governmental (3) private and (4) commercial subscribers. (TV & Radio users).

Satellite System Link Equations and Link Budget:

Uplink Equation

$$\frac{C}{N_0} = \frac{A_t P_{in} (L_p L_u) A_r}{K T_e} = \frac{A_t P_{in} (L_p L_u)}{K} \times \frac{G}{T_e} \rightarrow (1)$$

$\frac{C}{N_0} \rightarrow$ Carrier to Noise density ratio

$L_u \rightarrow$ Additional uplink losses due to atmosphere

$L_p \rightarrow$ path loss.

$A_t \rightarrow$ transmit antenna gain

$A_r \rightarrow$ receive antenna gain

$P_{in} \rightarrow$ transmitter output power

$k \rightarrow$ Boltzmann's constant

$T_e \rightarrow$ Equivalent noise temperature.

$$\frac{C}{N_o} \text{ in dB} = 10\log_{10}(A_t P_{in}) - 20\log_{10}\left(\frac{4\pi D}{\lambda}\right) + 10\log_{10}\left(\frac{G}{T_e}\right) - 10\log_{10}(L_u) - 10\log_{10}(k)$$

$$\left(\frac{C}{N_o}\right)_{in\, dB} = \underbrace{10\log_{10}(A_t P_{in})}_{\text{EIRP earth station}} - \underbrace{20\log_{10}\left(\frac{4\pi D}{\lambda}\right)}_{\text{free-space path loss } L_p} + \underbrace{10\log_{10}\left(\frac{G}{T_e}\right)}_{\text{Satellite } \frac{G}{T_e}} - \underbrace{10\log_{10}(L_u)}_{\text{additional atmospheric losses}} - \underbrace{10\log_{10}(k)}_{\text{Boltzmann's Constant}}$$

The above equation is called up-link budget.

$$\text{Uplink-budget} = EIRP(dBW) - L_p(dB) + \frac{G}{T_e}(dBK^{-1}) - L_u(dB) - k(dBWK)$$

Downlink Equation

$$\frac{C}{N_o} = \frac{A_t P_{in}(L_p L_d) A_r}{kT_e} = \frac{A_t P_{in}(L_p L_d)}{k} \times \frac{G}{T_e}$$

$L_d \rightarrow$ Additional downlink losses due to atmosphere.

$$\left(\frac{C}{N_o}\right)_{in\, dB} = \underbrace{10\log_{10} A_t P_{in}}_{\text{EIRP Satellite}} - \underbrace{20\log_{10}\left(\frac{4\pi D}{\lambda}\right)}_{\text{free-space path loss } L_p} + \underbrace{10\log_{10}\left(\frac{G}{T_e}\right)}_{\text{earth station } G/T_e} - \underbrace{10\log_{10}(L_d)}_{\text{additional atmospheric losses}} - \underbrace{10\log k}_{\text{Boltzmann's constant}}$$

$$\text{Downlink budget} = EIRP(dBW) - L_p(dB) + \frac{G}{T_e}(dBK^{-1}) - L_p(dB) - k(dBWK)$$

The above equation is called Down-link budget.

note: $D \rightarrow$ directivity of antenna

$\lambda \rightarrow$ wavelength of signal emitted

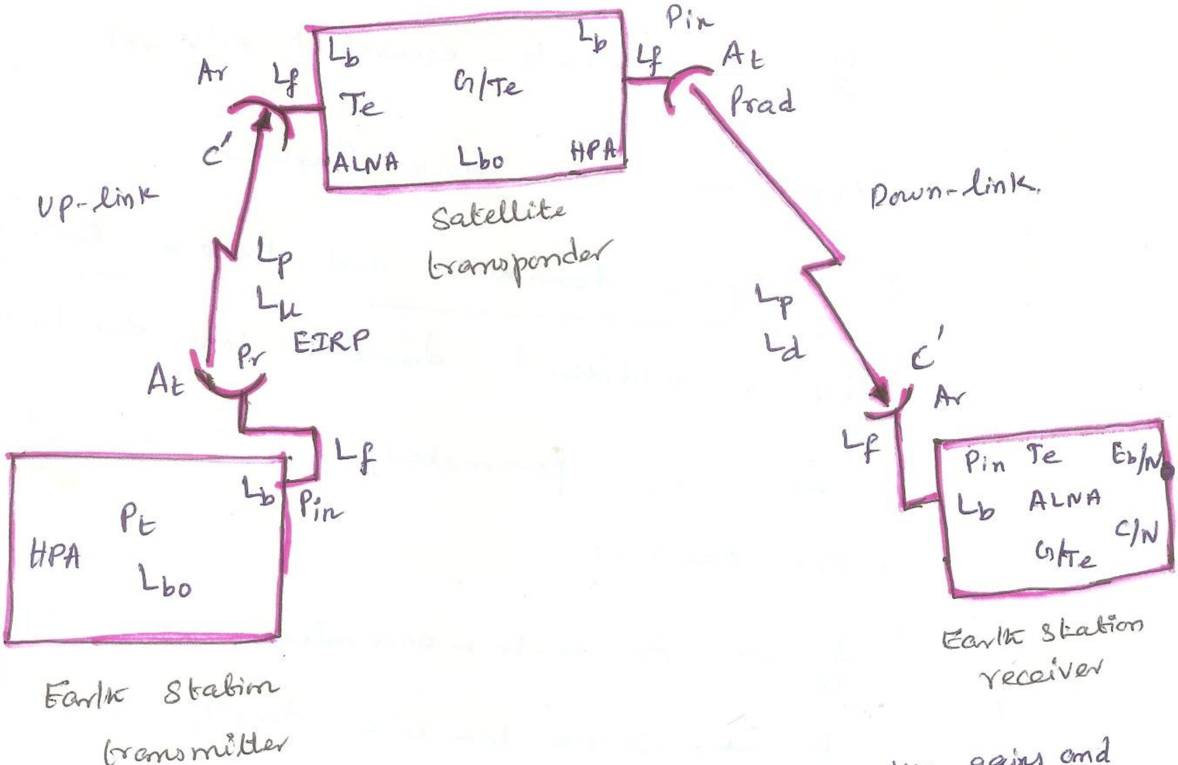


Fig 11. Overall Satellite System showing the gains and losses in curved in both the uplink and downlink sections.

from Fig Up-link section and Transmitter Earth Station

L_{bo} → back off loss

HPA → High power Amplifier

P_t → HPA output power

L_f → feeder loss

L_b → branching loss.

A_t → transmit antenna gain

P_r → total radiated power

$$P_r = P_t - L_{bo} - L_b - L_f$$

EIRP → Effective isotropic radiated power

$$EIRP = P_r \times A_t$$

L_u → additional uplink losses due to atmosphere

L_p → path loss

A_r → receive antenna gain

from Fig : Satellite transponder

$\frac{G}{Te}$ → gain-to-equivalent noise ratio.

ALNA → Low-Noise Amplifier

from Fig :- down link and Receiver Earth station

L_d → additional downlink losses due to atmosphere.

remaining parameters are same as that of up-link equations.

$\frac{C}{Te}$ → carrier-to-equivalent noise temperature ratio

$\frac{C}{N_0}$ → Carrier-to-noise density ratio

$\frac{E_b}{N_0}$ → energy of bit-to-noise density ratio.

$\frac{C}{N}$ → Carrier-to-Noise ratio.

$\frac{G}{Te}$ → gain-to-equivalent noise temperature ratio

Advantages of Optical Fiber Cables

1. Wider bandwidth and greater information capacity
   → optical fibers have greater information capacity than metallic cables because of the wider bandwidth available with optical frequencies.

2. Immunity to crosstalk
   → optical fibers cables are immune to crosstalk because glass and plastic fibers are non conductors of electrical current.

3. Immunity to static interference
   → because optical fibers cables are non-conductors of electrical current, they are immune to static noise due to electromagnetic interference (EMI) caused by lightning, electric motors, relays, fluorescent lights etc.

4. Environmental Immunity
   → optical cables also operate over a wider temperature range and are less affected by corrosive liquids and gases.

5. Safety and Convenience
   → optical fiber cables are safer and easier to install and maintain than metallic cables.

6. Low transmission loss

7. Security
   → less information loss compared to metallic cables. Suitable for secure communication.

⑧. Durability and reliability

→ optical fiber cables have a higher tolerance to changes in enviromental conditions and are immune to corrosive materials.

⑨. Economics

→ Low installation cost, fewer repeaters, improved reliability.

Numerical Aperture (NA)

Numerical Aperture (NA) is closely related to acceptance angle and is the figure of merit commonly used to measure the magnitude of the acceptance angle.

Numerical Aperture is used to describe the light-gathering (or) light-collecting ability of an optical fiber (i.e., the ability to couple light into the cable from an external source).

The larger the magnitude of the numerical aperture, the greater the amount of external light the fiber will accept.

(unitless) $NA = \text{Numerical aperture} = \sin(\theta_{in})$ → ①

θ_{in} → acceptance angle (degrees)

(or) $\theta_{in} = \sin^{-1}\sqrt{n_1^2 - n_2^2}$ → ②

(unitless) n_1 → refractive index of glass fiber core

(unitless) n_2 → refractive index of fiber cladding

sub. eqn ② in ①.

$NA = \sqrt{n_1^2 - n_2^2}$ → ③
