

UNIT - I

Communication Satellite

History of Satellite Communication : —

* The origins of Satellite communications can be traced to an article written by C. Clarke in the British radio magazine "Wireless world" in 1945.

* Clarke suggested that a radio relay satellite in an Equatorial orbit with a period of 24h would remain Stationary with respect to the Earth's Surface and make possible long distance radio links.

* In 1957 Russian Geostationary Satellite "Sputnik" was launched.

* In 1965 the first geostationary Satellite "Early Bird" began to provide telephone service across the Atlantic Ocean, fulfilling Clarke's vision of 20 years earlier.

* Satellite Communication Systems were originally developed to provide long-distance telephone service.

* Satellite Communications began in 1957 with the launch by the USSR of a small satellite called Sputnik I. This was the first artificial Earth satellite.

* The first Satellite successfully launched by the United States was Explorer I,

* Aryabhata → ^{1st} Indian Satellite launched on April 19, 1975.

* Bhaskara-I → In 1979 remote sensing experiments were conducted using Bhaskara-I.

* The first voice heard from space was that of President, who recorded a brief Christmas message that was transmitted back to Earth from the Project "Score" Satellite.

* A tape recorder on Score had a storage capacity that allowed a 4 min message received from an Earth station to be retransmitted. The batteries on "Score" failed after 35 days in orbit.

* The first true communications Satellites, Telstar I and Telstar II were launched in July 1962 & May 1963. The Telstar Satellites were built by Bell Telephone Laboratories.

* In 1965, the first commercial geostationary Satellite INTELSAT I (or Early Bird) is launched.

These Satellites provided video (television) and Voice (telephone) Communications for their audiences.

* INTELSAT → International Telecommunications Satellite Organization.

Satellite	Country	Launch Date	Status
SCORE	USA	18/12/1958	Active for <u>13</u> days
ECHO A-10	USA	13/5/1960	Failure
ECHO 1	USA	12/8/1960	100 ft balloon
COURIER 1A	USA	18/8/1960	Launch failure
COURIER 1B	USA	4/10/1960	Lost Command Capability after 17 days
ECHO (AVT-1)	USA	14/1/1962	Failure, balloon ruptured
TELSTAR-1	USA	10/7/1962	Operating until 21/2/1963
ECHO (AVT-2)	USA	18/7/1962	

INSAT India (Indian National Satellite) → Multipurpose Satellite.

Satellite	Country	Launch Date	Status
RELAY-1	USA	12/12/1962	1 Transponder, OK until Feb 1965
SYNCOM 1	USA	14/2/1963	Comms lost at orbit injection
TELSTAR 2	USA	7/5/1963	Operating until May 1965
SYNCOM 2	USA	26/7/1963	Used until 1966, turned off 1969
RELAY 2	USA	21/1/1964	Used until September 1965
ECHO 2	USA	25/1/1964	Used with USSR, decayed 1969
MOLNIYA	USSR	19/2/1964	Failure
SYNCOM 3	USA	19/8/1964	Used until 1966, turned off Apr 1969
INTELSAT-1 (Early Bird)	USA	6/4/1965	Used until Jan 1969
MOLNIYA	USSR	23/4/1965	Decayed 16/8/1979.
APPLE	India	18/06/1981	(Arian Passenger Payload Experiment) ↓ 1 st Geosynchronous Satellite.

Communication Satellite :-

* A Communication Satellite is basically an Electronic Communication package placed in orbit around the Earth.

* The prime objective of the Satellite is to aid Communication Such as Voice (telephone), Video (television) and digital data (teletype).

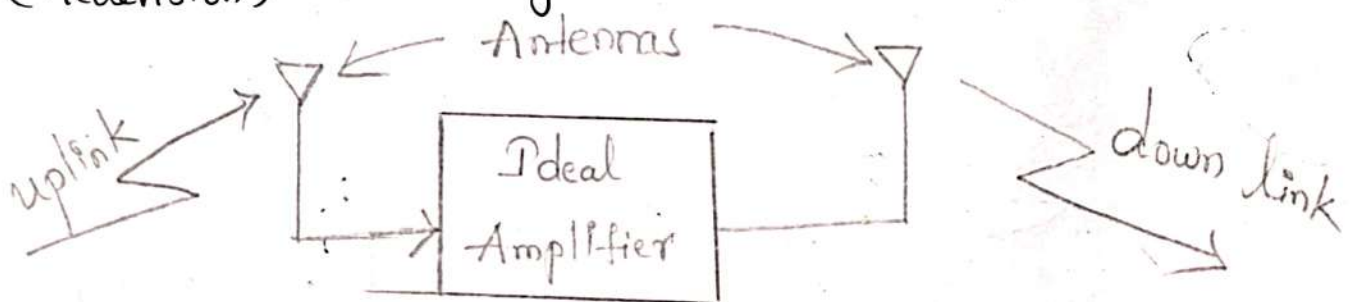


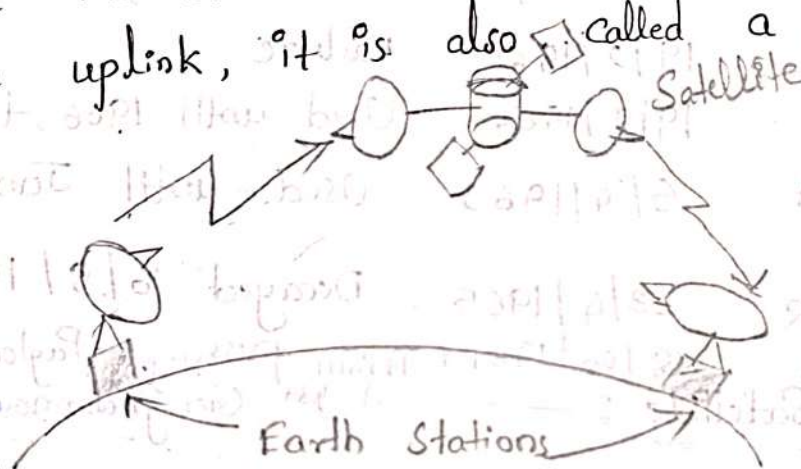
fig: Ideal block diagram of Satellite

* Ideally, Satellite would receive the uplink carrier, amplify to the desired power level and retransmit in the downlink.

Communication Satellite Systems:-

* A Satellite that relays the uplink carrier as a downlink is referred to as a relay Satellite or repeater Satellite.

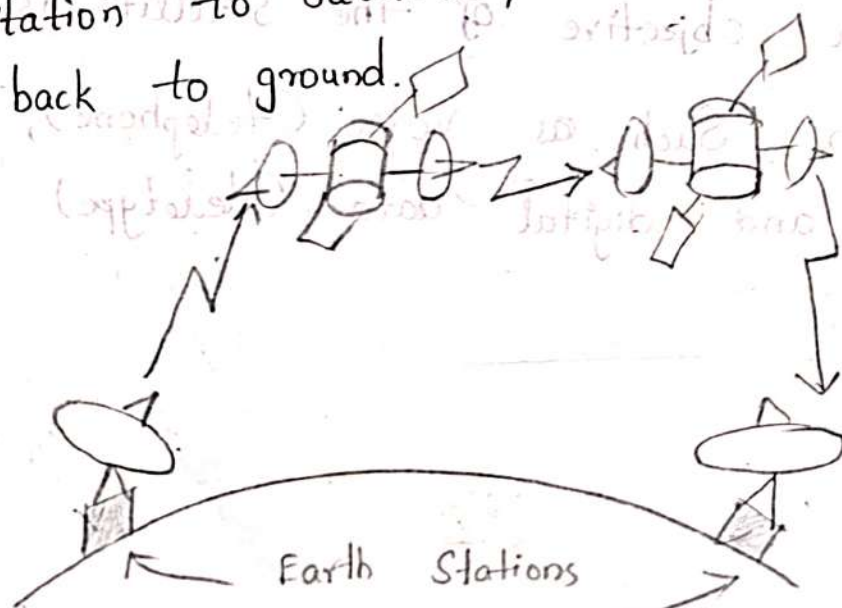
* Since the Satellite transmits the downlink by responding to the uplink, it is also called a "transponder".



I

Fig: Ground - Ground Satellite System

* System I shows an uplink from a ground-based Earth station to Satellite, and a downlink from Satellite back to ground.



II

Ground-to-Satellite-to-Ground Satellite System

* System II shows a Satellite Crosslink between two Satellites prior to downlink transmission. Such Systems allow Communication between Earth Stations not visible to the same Satellite.

* By Spacing multiple Satellites in proper orbits around the Earth, worldwide Comm's between Earth Stations in different hemispheres can be performed via such crosslinks.

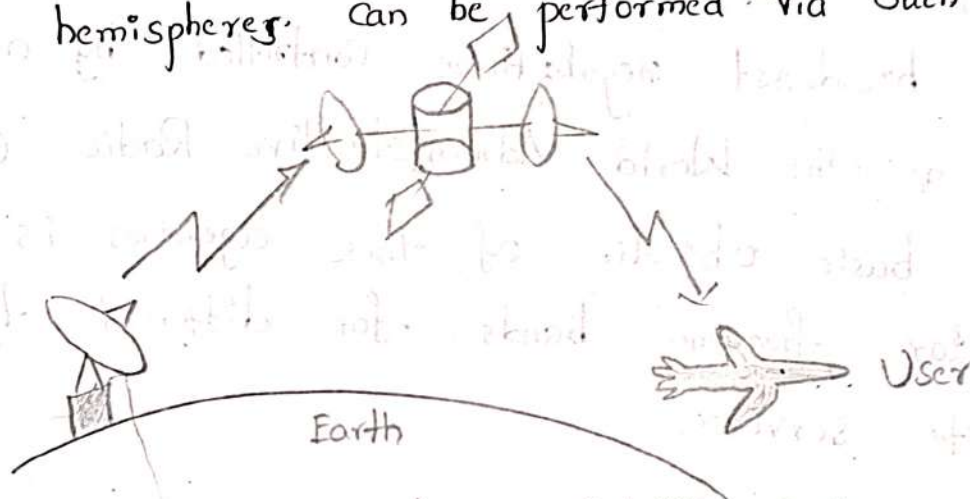


Fig: Ground - User relay Satellite System.

* System III shows a Satellite relay System involving Earth Stations, near Earth users, (aircraft, ships etc) and Satellites.

* The user responds by retransmitting back through the Satellite to the Earth Station.

* The link from Earth Station to relay to user is called the forward link, while the link from user to Satellite back to Earth is called the return link.

Satellite Frequency Bands :-

* The frequencies used for Satellite Comm's should be selected from bands that are most favorable in terms

of power efficiencies, minimal propagation distortions and reduced noise and interference effects. These conditions tend to force operation into particular frequency regions that provide the best trade-off of these factors.

* Frequencies to be used by satellites are established by the International Telecommunications Union (ITU), with broadcast regulations controlled by a subgroup known as the World Administrative Radio Conference (WARC).

* The basic objective of these agencies is to allocate particular frequency bands for different types of satellite services.

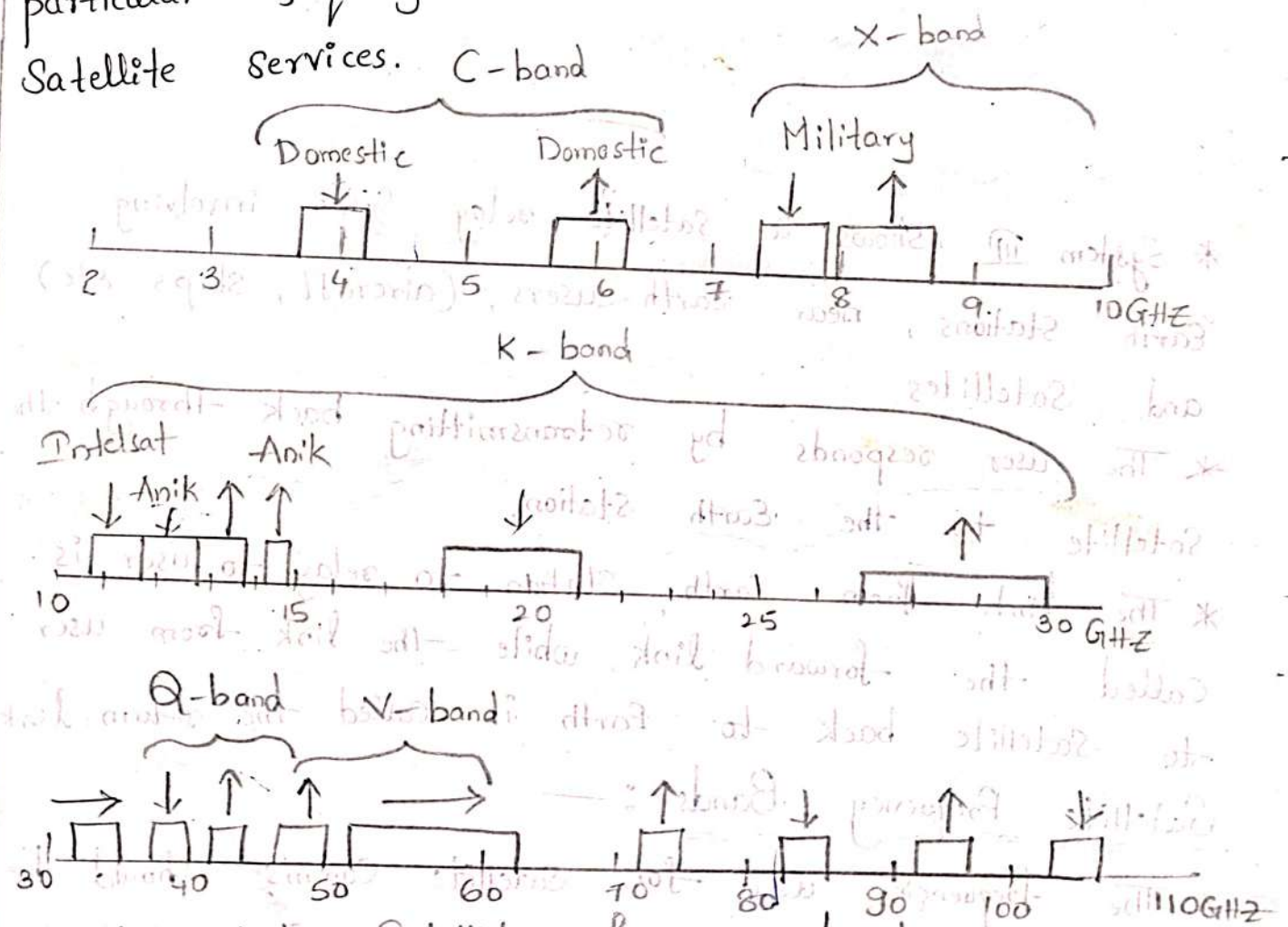


Fig: Allocated Satellite frequency bands WARC.
 ↑ = uplink, ↓ = downlink, → = Crosslink

Important Definitions : —

Orbit : —

* When a body 'A' revolves around another body 'B', body 'A' is said to be orbiting around body 'B'.

Orbit Path : —

* The path followed by an orbiting body is called "orbit path".

Elliptical orbit : —

* Every satellite revolves with a certain angular velocity ' ω ' around the primary body. If ' ω ' varies the path tends to become "Elliptical".

Circular orbit : —

* When angular velocity ' ω ' remains constant the path of orbit is circular. For comm's satellites, circular orbit is preferred, as power requirement remains constant.

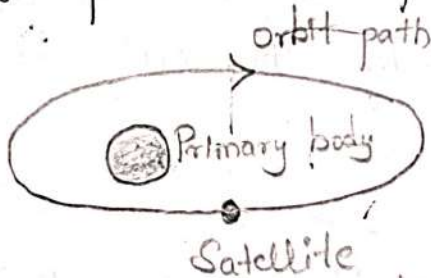


fig: Elliptical orbit

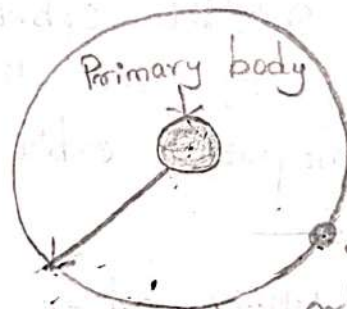


fig: Circular orbit

Radius of orbit : —

* In a circular orbit the primary body lies at the centre of the circular path and the satellite on the circumference of the circle. Hence the radius of the circle is called "radius of orbit".

Orbit Plane : —

* The plane in which the satellite orbits is called the "plane of orbit".

Polar Plane : —

* It is the plane assumed to be cut along the poles of the Earth.

Equatorial plane : —

* It is the plane assumed to be cut along the Equator. A satellite revolving in this plane is called "Equatorial Satellite". A special case of a satellite orbiting in this plane is the geostationary satellite.

Inclined plane : —

* The plane of orbit, which is at an angle to both polar plane and Equatorial plane, is called "inclined plane".

Prograde : —

* When a satellite orbits in the same direction as the direction of revolution of Earth, the orbit is called "prograde orbit".

Retrograde : —

* When a satellite orbits in the opposite direction than that of the direction of revolution of Earth, the orbit is called "retrograde orbit".

Geosynchronous orbit : —

* A satellite which moves with the same angular velocity as that of revolution of Earth around its axis of rotation is called "Geosynchronous".

Geostationary orbit : —

* A Satellite which is geosynchronous in the Equatorial plane and has prograde circular orbit, is said to be "geostationary".

Altitude : —

* Altitude is defined as the height of the Satellite from the Surface of the Earth.

* Satellites can be categorized depending on their altitude above the Earth's Surface, these are

1. Low Earth Orbit (LEO)
2. Medium Earth orbit (MEO)
3. Geostationary Earth Orbit (GEO).

1. Low Earth Orbit (LEO) : —

* In LEO the Satellites are located at an altitude of approximately 1000 km.

* The LEO Satellites are Confined b/w 500 to 1500 km.

* The advantage of using a non-GEO (LEO) Satellite network is that the range to the user is shorter, hence less radiated power is required & the propagation delay is reduced as well.

* Satellite orbit period is b/w 1.6 and 1.8 hours.

Advantages of LEO : —

1. LEO Satellite System offers lowest path loss compared to MEO and GEO
2. Propagation delay is lowest i.e. 5 to 10 msec & is comparable to fiber optic system time delay.

3. LEO Satellite can provide true global coverage.
4. LEO Satellite uses frequency spectrum effectively.

Disadvantages of LEO: —

1. To cover entire globe large number of satellites are required.
2. Doppler effects are highest.
3. Architecture and space segment is most complex.
4. Since the satellite replacement rate is more than GEO & MEO orbital maintenance is high.

Applications of LEO: —

1. In mobile satellite comm.
2. Surveillance of Earth surface
3. Earth resource applications.
4. Geological surveys.

2. Medium Earth Orbit (MEO): —

* The altitude of MEO system is around, 1500 km to 36000 km.

* Satellite orbit period is about 6 hours, a much larger longer period than LEO system.

* Propagation delay is greater than for LEO but still significantly less than GEO.

Advantages of MEO: —

1. MEO Satellite can provide true global coverage.
2. MEO Satellite system offers lower path loss than GEO.
3. Propagation delay is moderate i.e. 30msec to 100msec depending on the height.
4. Lower path loss makes it possible to use hand held terminals.

Disadvantages of MEO: —

1. To cover entire globe, large number of satellites are required typically 10 to 12.
2. Received signal strength is variable because of range and elevation angle.
3. Doppler effects can be observed significantly.
4. Initial deployment of such systems requires large time, several months to years.

Applications of MEO: —

1. Surveillance of Earth Surface
2. Global Positioning System (GPS) Constellation.
3. Data gathering for military.

3. Geostationary Earth Orbit (GEO): —

* GEO has 23h, 56 min, 4.091 Sec or 24 hours period of revolution

* GEO Satellite has the ability to provide coverage of an entire hemisphere at one time.

* The GEO Satellite altitude is of around 36,000 km & above.

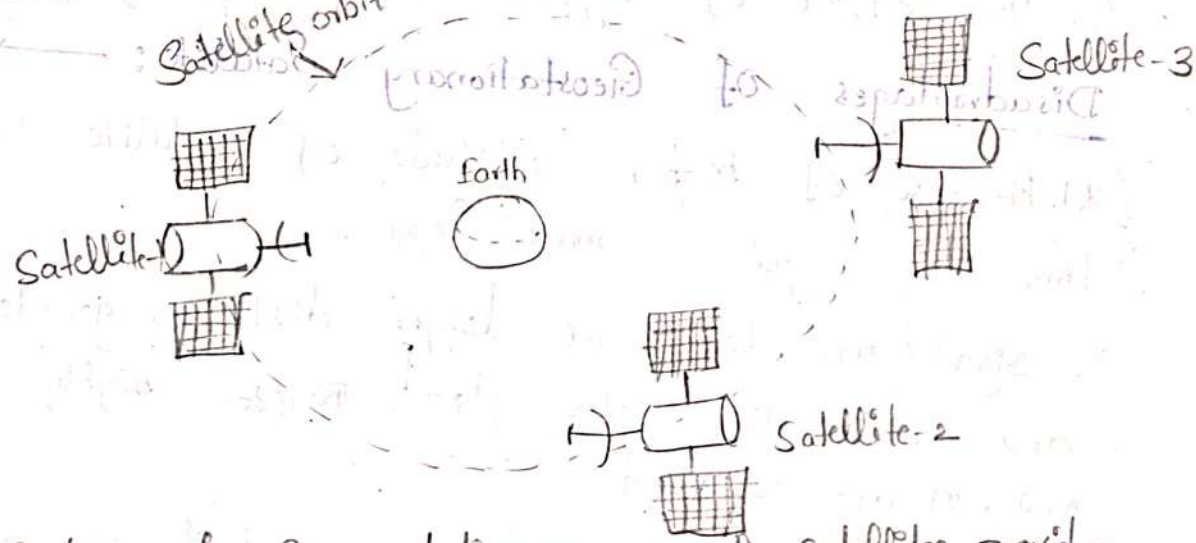


fig: A System of 3 geostationary Comm Satellites provides nearly world wide Coverage.

* A System of three Satellites in GEO Each separated by 120 degrees of longitude, can receive & send radio signals over almost all the parts of Earth.

* The Effect of Doppler Shift of frequency is negligible.

* The orbital period of the GEO Satellite is equal to the orbital period of the Earth. Hence the GEO Satellite seems to be stationary to an observer on the Earth hence the name as "Geostationary".

Advantages of Geostationary Satellite: —

1. Keeping track of geostationary Satellite is easy, as the Satellite remains almost stationary in respect to a given Earth station.
2. The relative positions of Satellite and Earth station are fixed hence continuous "Comm" is possible by one Satellite only. i.e. no need to switch from one Satellite to another.
3. The Coverage area on the Earth is very large because the height of Satellite is more.
4. The Effect of Doppler shift frequency is negligible.

Disadvantages of Geostationary Satellite: —

* 1. Because of higher altitude of Satellite the propagation time for signal is much longer.

2. Signal has to travel longer distance, greater path loss and attenuation takes place. Therefore highly sensitive receivers are required.

3. Satellite launching mechanism must be powerful & most accurate.

Applications Of Geostationary Satellite :-

* Most Commⁿ Satellites today are geostationary Satellites.

1. Television broadcasting
2. Regional, national and international global commⁿs
3. Telephone and data circuits.
4. Mobile telephone Services.
5. Private n/w for Corporations, government agencies.
6. Military applications.

Orbital Period (T) and Velocity (V) :-

* Newton's laws of motion can be encapsulated into 4 Eqⁿs:

$$S = ut + \frac{1}{2}at^2$$

$$v^2 = u^2 + 2at$$

$$v = u + at$$

$$F = P = ma.$$

where $S \rightarrow$ distance travelled from time $t=0$

$u \rightarrow$ initial velocity of the object at time $t=0$

$v \rightarrow$ final velocity of the object at time t'

$a \rightarrow$ acceleration of the object

$F \rightarrow$ force acting on the object.

$m \rightarrow$ mass of the object.

* To understand the motion of Satellite in a Stable orbit, we have to use $F=ma$ Eqⁿ.

* When in a stable orbit, there are two main forces acting on a Satellite: a Centrifugal force due to the kinetic Energy of the Satellite, which attempts to fling the Satellite into a higher orbit, and a Centripetal force due to gravitational attraction of the planet about which the

Satellite is orbiting, which attempts to pull the Satellite down toward the planet. If these two forces are equal, the Satellite will remain in a stable orbit.

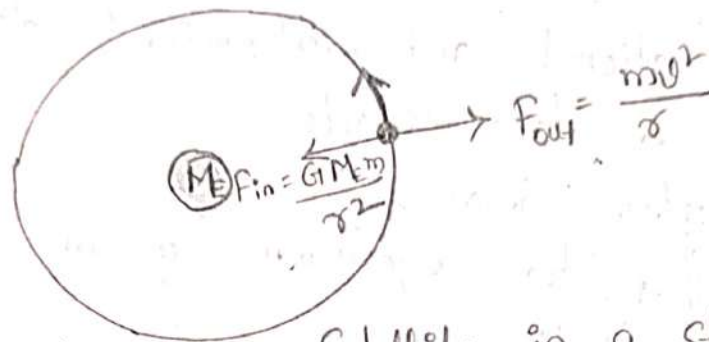


Fig: Forces acting on a Satellite in a stable orbit around Earth.

* Force = mass $\times$ acceleration.

* The acceleration, a , due to gravity at a distance ' r ' from the center of the Earth is

$$a = \frac{\mu}{r^2} \text{ km/s}^2$$

where $\mu \rightarrow$ Constant $\rightarrow$ Kepler's Constant.

μ is the product of the universal gravitational Constant ' G ' and the mass of the Earth M_E .

* $\mu = 3.986004418 \times 10^5 \text{ km}^3/\text{s}^2$

$$G = 6.672 \times 10^{-11} \text{ N m}^2/\text{kg}^2 = 6.672 \times 10^{-20} \text{ km}^3/\text{kg s}^2$$

mean Earth radius $\rightarrow 6378.137 \text{ km}$.

* The centripetal force acting on the Satellite, F_{IN} , is

given by $F_{IN} = m \times \left(\frac{\mu}{r^2} \right)$

$$= m \times \left(\frac{GM_E}{r^2} \right)$$

* The centrifugal acceleration is given by ' a ' $= \frac{v^2}{r}$

Centrifugal force $F_{OUT} = m \times \left(\frac{v^2}{r} \right)$

* For the stable orbit, the two forces must be equal

$$\text{i.e. } F_{IN} = F_{OUT}$$

$$m \times \frac{u}{r^2} = m \times \frac{v^2}{r}$$

$$v^2 = \frac{u}{r}$$

$$v = \left(\frac{u}{r} \right)^{1/2}$$

* If the orbit is circular, the distance traveled by a satellite in one orbit around a planet is " $2\pi r$ ", where ' r ' is the radius of the orbit. from the satellite to the center of the planet.

* $\text{Time} = \frac{\text{Distance}}{\text{Velocity}}$

$$T = \frac{2\pi r}{\left(\frac{u}{r} \right)^{1/2}}$$

$$T = (2\pi r^{3/2}) / (u)^{1/2}$$

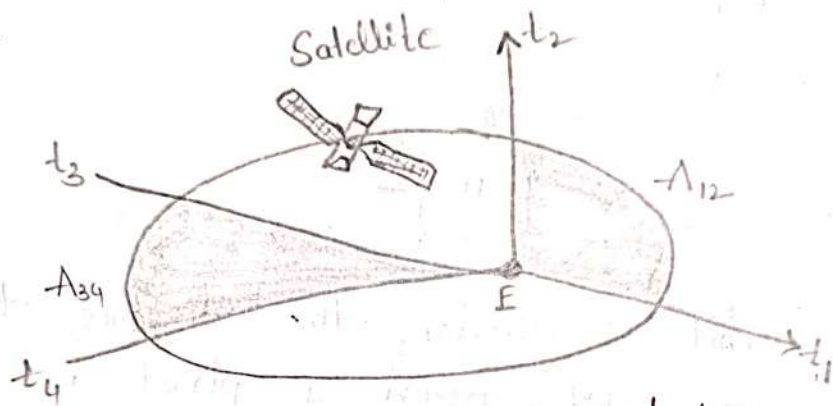
$T \rightarrow$ orbital period of the satellite.

Kepler's Three Laws of Planetary Motion: —

* Johannes Kepler was a German Scientist who developed his three laws of planetary motion by careful observations of the behavior of the planets in the solar system.

* Kepler's three laws are

1. The orbit of any smaller body about a larger body is always an ellipse, with the center of mass of the larger body as one of the two foci.
2. The orbit of the smaller body sweeps out equal areas in equal time.



* The Satellite moves in the orbit between times t_1 and t_2 and sweeps out an area denoted by A_{12} . while, the satellite moves in the orbit b/w times t_3 and t_4 and sweeps out an area denoted by A_{34} .

* If $t_2 - t_1 = t_4 - t_3$ then $A_{12} = A_{34}$

3. The Square of the period of revolution of the smaller body about the larger body equals a constant multiplied by the third power of the semimajor axis of the orbital ellipse.

$$T^2 = \frac{4\pi^2 a^3}{\mu}$$

where $T \rightarrow$ Orbital period.

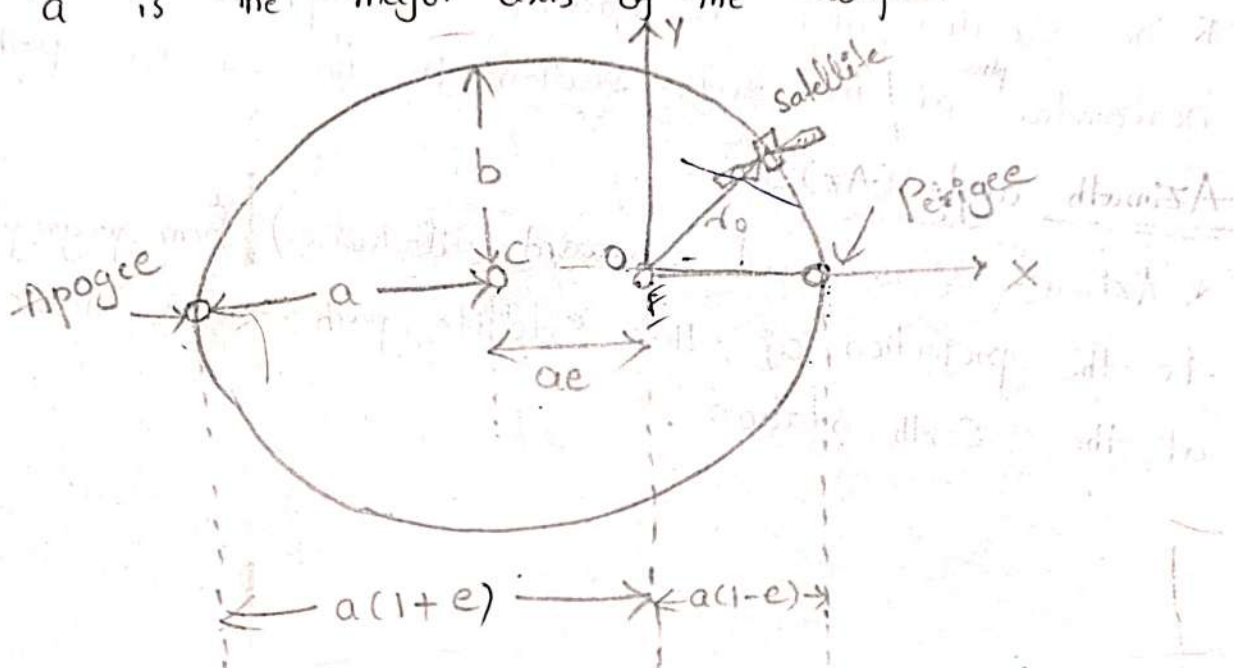
$a \rightarrow$ Semimajor axis of the orbital ellipse.

$\mu \rightarrow$ Kepler's Constant.

* If the orbit is circular, then 'a' becomes distance 'r'.

Perigee : —

- * It is a point in the Elliptical orbit when satellite is nearest to the Earth is called perigee.
- * The perigee depends on the eccentricity, and is equal to $a(1-e)$ where 'a' is the major axis of the ellipse.



- * The point 'O' is the center of the Earth and the point 'C' is the center of the Ellipse.
- * The two centers do not coincide unless the Eccentricity 'e' of the Ellipse is zero (i.e. the Ellipse becomes a circle and $a=b$).

$a \rightarrow$ Semimajor axis

$b \rightarrow$ Semiminor axis.

Apogee : —

- * It is a point in orbit when the satellite is farthest from the Earth.
- * Apogee is Equal to $a(1+e)$.

Inclination : —

* The angle between orbital plane and Earth's Equatorial plane is called "angle of inclination".

Elevation angle (EL) : —

* The elevation angle is measured from upward from the local horizontal ^{plane} at the Earth station to the Satellite path. Projection of path on

Azimuth angle (AZ) : —

* Azimuth is measured Eastward (clockwise) from geographic north to the projection of the Satellite path on a horizontal plane at the Earth station.

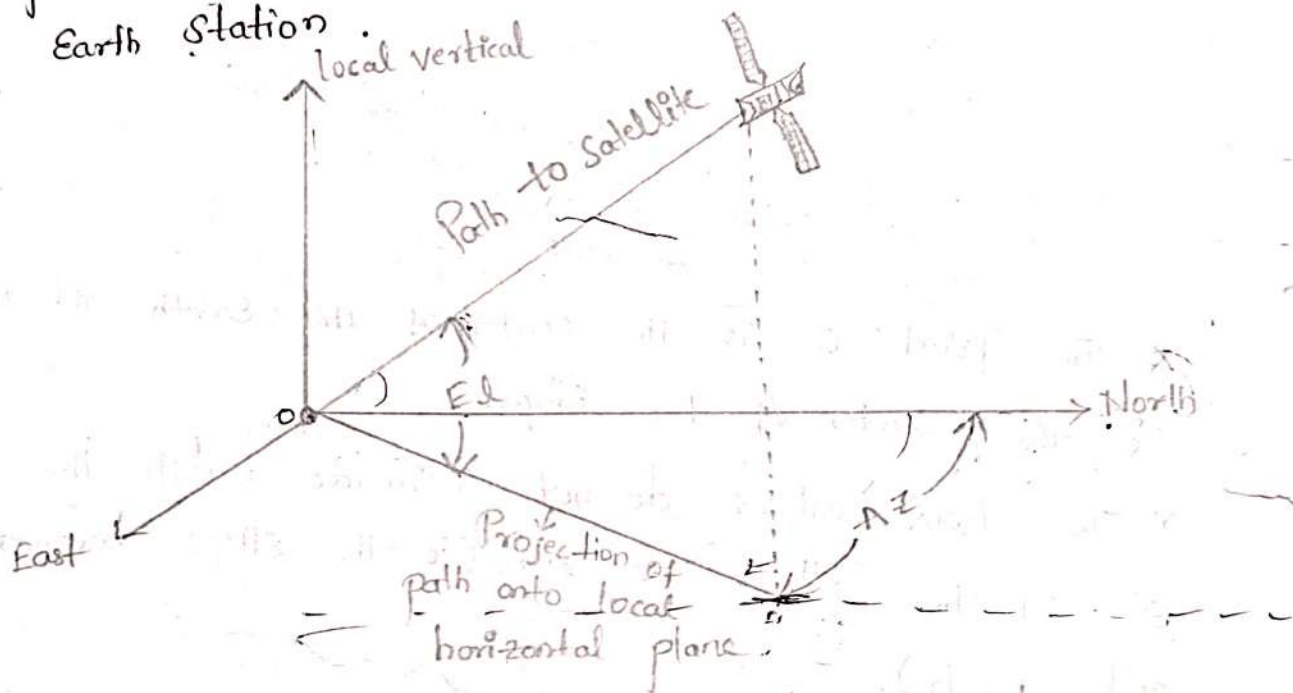


Fig: Definition of Elevation & Azimuth angles

Subsatellite Point : —

* Subsatellite point is the location on the surface of the Earth that lies directly between the Satellite and the center of the Earth.

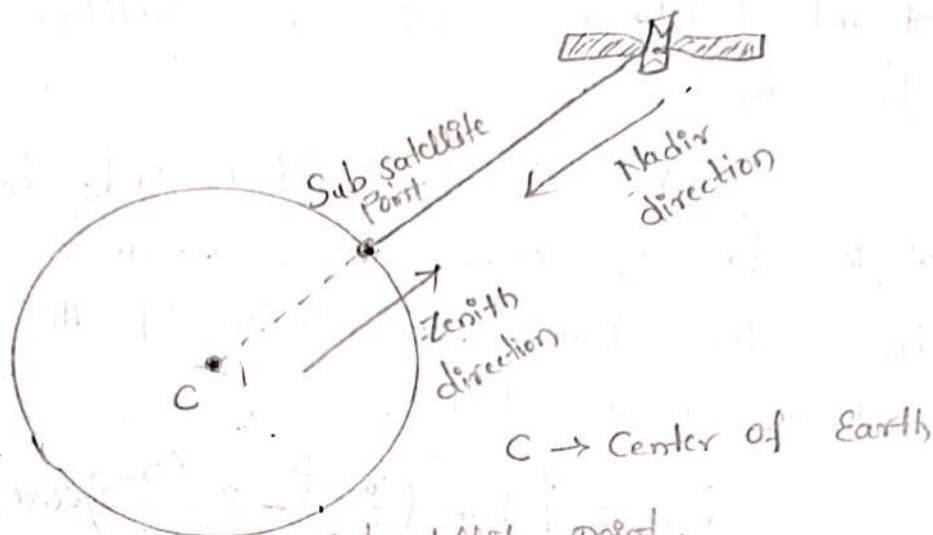


Fig: Definition of Subsatellite point.

Elevation Angle Calculation:

r_s → Vector from the Center of the Earth to the Satellite.

r_e → Vector from the Center of the Earth to the Earth Station.

d → Vector from the Earth Station to the Satellite.

* These three vectors lie in the same plane and form a triangle.

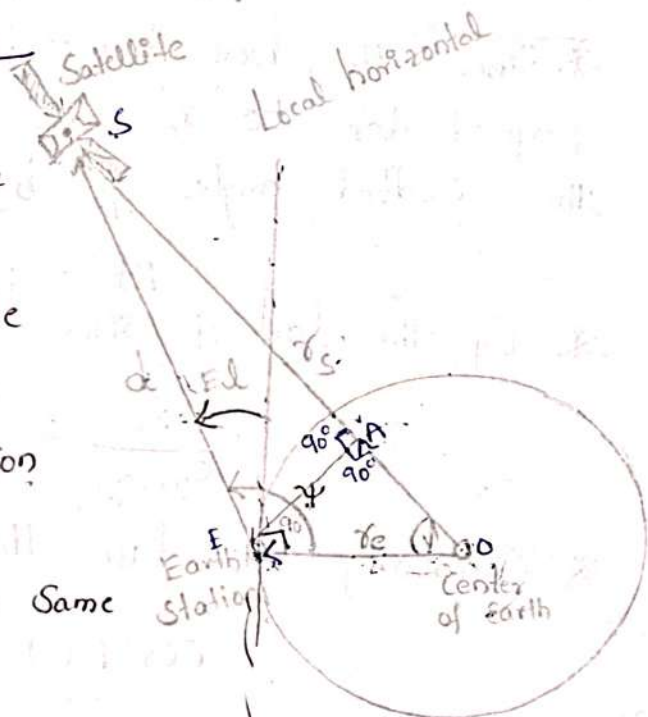
* The central angle ' ψ ' measured between ' r_e ' and ' r_s ' is the angle b/w the Earth station and the Satellite.

ψ → angle measured from ' r_e ' to ' d '.

ψ → related to the Earth station north latitude L_e and west longitude λ_e

L_e → no. of degrees in latitude that the Earth station is north from the Greenwich meridian.

λ_e → no. of degrees in longitude that the Earth station is west from the Greenwich meridian.



* Subsatellite point at north latitude ' L_s ' and west longitude ' λ_s ' by

$$\cos(\psi) = \cos(L_e) \cdot \cos(L_s) \cdot \cos(\lambda_s - \lambda_e) + \sin(L_e) \sin(L_s)$$

* The law of cosines allows us to relate the magnitudes of the vectors joining the center of the Earth, the Satellite, and the Earth Station.

$$d = r_s \left[1 + \left(\frac{r_e}{r_s} \right)^2 - 2 \left(\frac{r_e}{r_s} \right) \cos(\psi) \right]^{1/2}$$

* Since the local horizontal plane at the Earth Station is perpendicular to ' r_e ', the Elevation angle ' El ' is related to the Central angle ' ψ ' by

$$El = \psi - 90^\circ$$

* By the law of Sines we have

$$\frac{r_s}{\sin(\psi)} = \frac{d}{\sin(El)}$$

* Combining the last three Equations

$$\cos(El) = \frac{r_s \sin(\psi)}{d}$$

$$\cos(El) = \frac{\sin(\psi)}{\left[1 + \left(\frac{r_e}{r_s} \right)^2 - 2 \left(\frac{r_e}{r_s} \right) \cos(\psi) \right]^{1/2}}$$

$r_e \rightarrow$ Earth radius.

* Average Earth radius is 6378.137 km ($\because \sin(90^\circ + \theta) = \cos \theta$)

$$El = \cos^{-1} \left[\frac{\sin \psi}{\left[1 + \left(\frac{r_e}{r_s} \right)^2 - 2 \left(\frac{r_e}{r_s} \right) \cos \psi \right]^{1/2}} \right]$$

$El \rightarrow$ Elevation angle.

$\because \Delta EAS \Rightarrow ES^2 = EA^2 + AS^2$
Pythagoras theorem

From ΔOAE

$$OE^2 = EA^2 + OA^2$$

$$\Rightarrow EA^2 = OE^2 - OA^2$$

And $OS = OA + AS = r_s$

$$\Rightarrow AS = OS - OA$$

$$\textcircled{1} \Rightarrow ES^2 = OE^2 - OA^2 + (OS - OA)^2$$

From ΔOAE , $\cos \psi = \frac{OA}{OE}$

$$OE = r_e, \textcircled{1} \Rightarrow d^2 = r_e^2 - r_e^2 \cos^2 \psi + r_s^2 \cos^2 \psi - 2 r_s r_e \cos \psi$$

$$\therefore d^2 = r_s^2 + r_e^2 - 2 r_s r_e \cos \psi$$

Azimuth Angle Calculation :-

* Because the Earth Station, the center of the Earth, the Satellite, and the Subsatellite point all lie in the same plane, the azimuth angle AZ from the Earth Station to the Satellite is the same as the azimuth from the Earth Station to the Subsatellite point.

* This is more difficult to compute than the Elevation angle because the exact geometry involved depends on whether the Subsatellite point is East or West of the Earth Station, and in which of the hemispheres the Earth Station and the Subsatellite point are located.

* To find the azimuth angle, an intermediate angle ' α ' must first be found.

* The intermediate angle ' α ' permits the correct 90° quadrant to be found for the azimuth since the azimuthal angle can lie anywhere b/w 0° (true north) and clockwise through 360° (back to true north again).

* The intermediate angle is given by

$$\alpha = \tan^{-1} \left[\frac{\tan |(\phi_s - \phi_e)|}{\sin(L_e)} \right]$$

* Having found the intermediate angle ' α ', the azimuth angle AZ can be found from:

Case 1: Earth Station in the Northern Hemisphere with

(a) Satellite to the SE of the Earth Station: $AZ = 180^\circ - \alpha$

(b) Satellite to the SW of the Earth Station: $AZ = 180^\circ + \alpha$

Case 2: Earth Station in the Southern Hemisphere with

(c) Satellite to the NE of the Earth Station : $AZ = \alpha$

(d) Satellite to the NW of the Earth Station : $AZ = 360^\circ - \alpha$

Visibility Test: —



* The Satellite is said to be Visible from the Earth Station if the Elevation angle 'El' is positive.

* This requires that the orbital radius ' r_s ' be greater than the ratio ' $\frac{r_e}{\cos \psi}$ ' where ' r_e ' is the radius of the Earth and ' ψ ' is the Central angle.

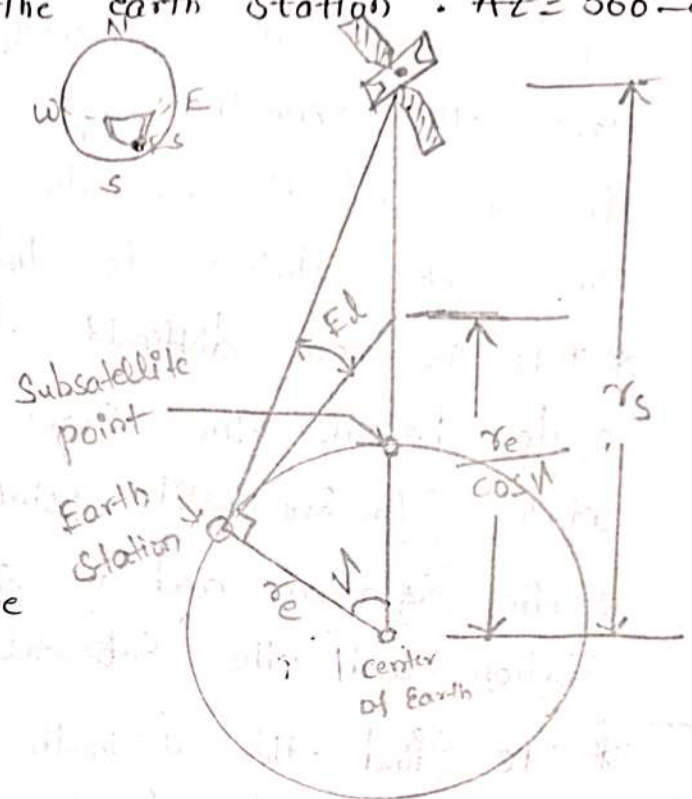


fig: Geometry of the visibility calculation.

i.e.
$$r_s \geq \frac{r_e}{\cos(\psi)}$$

* This means that the maximum central angular separation b/w the Earth Station and Subsatellite point is

$$\psi \leq \cos^{-1}\left(\frac{r_e}{r_s}\right)$$

* $\psi \leq 81.3^\circ$ for the Satellite to be visible.

Slant range: —

* The line of sight distance from a particular point on the Earth to Satellite is called "Slant range".

Orbital Perturbations : —

- * Under ideal conditions, a "keplerian" orbit results, which is an ellipse whose properties are constant with time.
- * In practice, the satellite and the Earth respond to many other influences including asymmetry of the Earth's gravitational field, the gravitational fields of the Sun & moon, solar radiation pressure.
- * For low Earth orbit satellites, atmospheric drag can also be important.
- * All of these interfering forces cause the true orbit to be different from a simple keplerian ellipse.
- * The perturbations are assumed to cause the orbital elements to vary with time and orbit & satellite location at any instant.
- * The orbital elements are $a, e, t_p, \Omega, i, \omega$.
- * Orbital perturbations are mainly two types:
 1. Longitudinal changes.
 2. Inclination changes.

Longitudinal Changes : —

Effects of the Earth's Oblateness : —

- * The Earth is neither a perfect sphere nor a perfect ellipse.
- * The equatorial radius is not constant.
- * In addition to these nonregular features of the Earth, there are regions where the average density of the Earth

appears to be higher. These are referred to as regions of mass concentration or "Mascons".

* The nonsphericity of the Earth, the noncircularity of the equatorial radius and the Mascons lead to a nonuniform gravitational field around the Earth.

* The force on an orbiting satellite will therefore vary with position. This will lead to longitudinal changes in the location of the satellite.

Inclination changes: —

Effects of the Sun and the Moon: —

* The plane of the Earth's orbit around the Sun is the ecliptic — is at an inclination of 7.3° to the equatorial plane of the Sun.

* The Earth is tilted about 23° away from the normal to the ecliptic.

* The moon circles the Earth with an inclination of around 5° to the equatorial plane of the Earth.

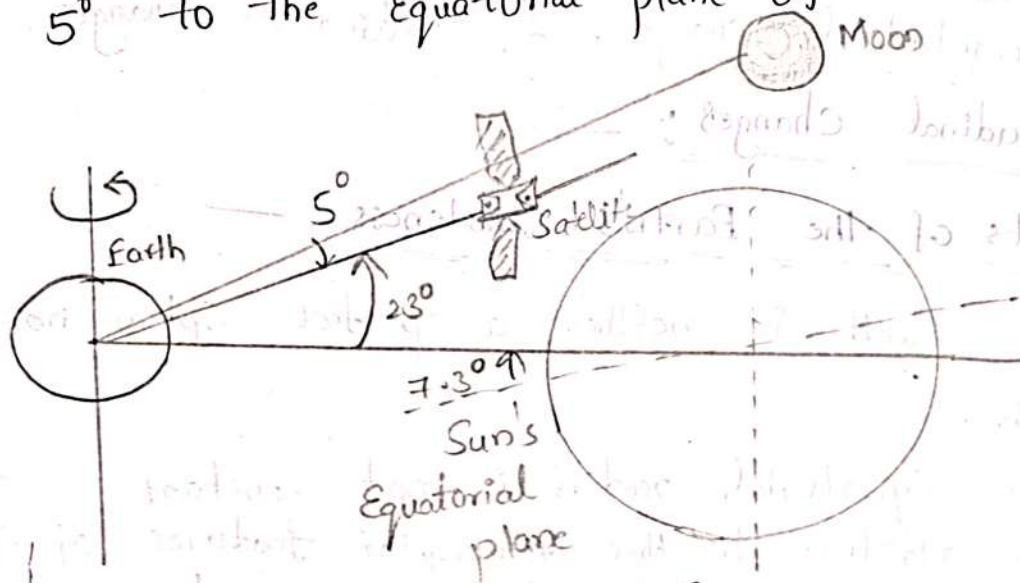


Fig: Relationship b/w the orbital planes of Sun, moon & Earth

* A Satellite in orbit around the Earth will be subjected to a variety of out-of-plane forces. ^(due to gravitational forces of Sun & Moon) There will be a net acceleration force that is not in the plane of Satellite's orbit and this will tend to try to change the inclination of the Satellite's orbit from its initial inclination.

* The mass of the Sun is significantly larger than that of the Moon but the Moon is considerably closer to the Earth than the Sun. For this reason, the acceleration force induced by the Moon on a geostationary satellite is about twice as large as that of the Sun.

* The net effect of the acceleration forces induced by the Moon and the Sun on a geostationary satellite is to change the plane of the orbit at an initial average rate of change of $0.85^\circ/\text{year}$ from the Equatorial plane.

* Ground controllers command spacecraft maneuvers ^{are used} to correct for both the in-plane changes (longitudinal) & out-of-plane changes (inclination) of a satellite so that it remains in the correct orbit.

Placing Satellites into Geostationary orbit: —

* There are three methods to place the satellite into Geostationary orbit. They are

- ① Geostationary Transfer Orbit & AKM
- ② Geostationary Transfer orbit with slow orbit raising.
- ③ Direct Insertion to GEO.

1) Geostationary Transfer Orbit & AKM : —

* The initial approach to launching geostationary satellites was to place the spacecraft, with the final rocket stage still attached into low Earth orbit.

* After a couple of orbits, during which the orbital elements are measured, the final stage is reignited & the spacecraft is launched into a geostationary transfer orbit (GTO).

* The GTO has a perigee that is the original LEO orbit altitude and an apogee that is the GEO altitude.

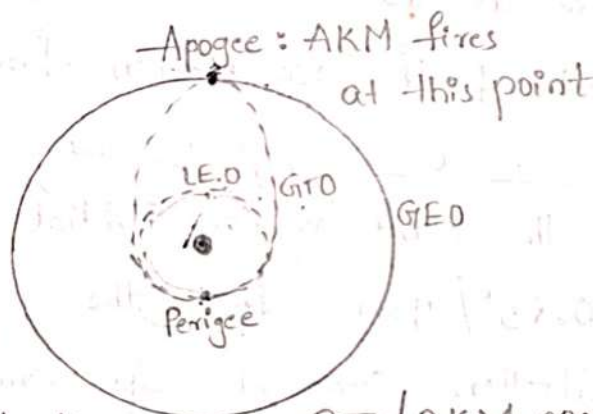


Fig: Illustration of the GTO/AKM approach to Geostationary orbit.

* Again, after more careful orbit determination, a rocket motor (usually contained within the satellite itself) is ignited at apogee & the GTO is raised until it is a circular, geostationary orbit.

* Since the rocket motor fires at apogee, it is commonly referred to as the apogee kick motor (AKM).

* The AKM is used both to circularize the orbit at GEO and remove any inclination error, so that final orbit of the satellite is very close to geostationary.

2. Geostationary Transfer Orbit with Slow orbit Raising:

* In this procedure, rather than employ an apogee kick motor, the spacecraft thrusters are used to raise the orbit from GTO to GEO over a number of burns.

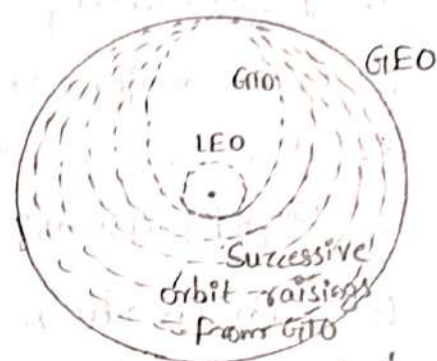


fig: Illustration of Slow orbit raising to geostationary orbit

* The thruster firings occur symmetrically about the apogee.

* The burns are typically 60 to 80 min long on successive orbits and up to six orbits can be used.

* These thruster firings will also reduce the inclination to close to zero.

Note: For Geostationary Earth Orbit satellite, the inclination must be equal to zero.

3. Direct Insertion to GEO:

* In this method, the final stages of the rocket are used to place the satellite directly into GEO rather than the satellite using its own propulsion system to go from GTO to GEO.

Orbital Elements:

* Orbital elements are defined as set of parameters which are needed to specify the location of an orbiting satellite.

* The minimum no. of parameters required is six.

* They are

1. Eccentricity of orbit = e ($e=0$ for circular orbit)
2. Semi-major axis of orbit ellipse = a ; ($a=r$ for circular orbit)
3. Time of Perigee = t_p
4. Right ascension of ascending node (RAAN)
5. Inclination of orbit = i
6. Argument of Perigee = Ω .
↓ the angle from ascending node to perigee, measured in the orbital plane.

RAAN : —

* The angle measured Eastward, in the Equatorial plane, from the line to the first point of aries (γ) to the ascending node.

Eccentricity : — (e) : —

* It is determined from $e = \frac{r_a - r_p}{r_a + r_p}$, for ellipse $e < 1$, for circle $e = 0$.

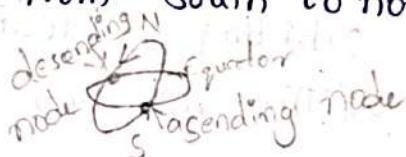
r_a → The distance from the center of the Earth to the apogee point.

r_p → The distance from the center of the Earth to the perigee point.

Look angles : — (Elevation angle & Azimuth angle) :

* The angle at which the Satellite is visible from the Earth Station.

Ascending node : — The point of intersection of orbit path with the Equatorial plane while travelling from South to north is called ascending node.



Orbital Effects in Communication System Performance:

(i) Doppler Shift:

The Doppler Effect in Satellite Communications is the change in frequency of an electromagnetic signal that results from the relative speed of the satellite and the Earth terminal. When the orbital parameters of a satellite are known, Doppler shift can be used to determine the position of the Earth terminal. When a Earth terminal's position is known, Doppler shift can be used to estimate the orbital parameters of a satellite.

When the satellite (or the Earth station) is moving quickly, the Doppler effect is an important consideration in satellite communications.

Doppler shift can be expressed mathematically as:

$$\frac{(f_R - f_T)}{f_T} = \frac{\Delta f}{f_T} = \frac{V_T}{V_p}$$

$$\Delta f = V_T \cdot \frac{f_T}{c} = \frac{V_T}{\lambda}$$

f_T = Transmitter frequency

f_R = Received frequency

V_T = Component of transmitter frequency directed towards the receiver.

V_p = c , phase velocity (3×10^8 m/sec)

λ = Wavelength of transmitted signal.

(ii) Range Variation : —

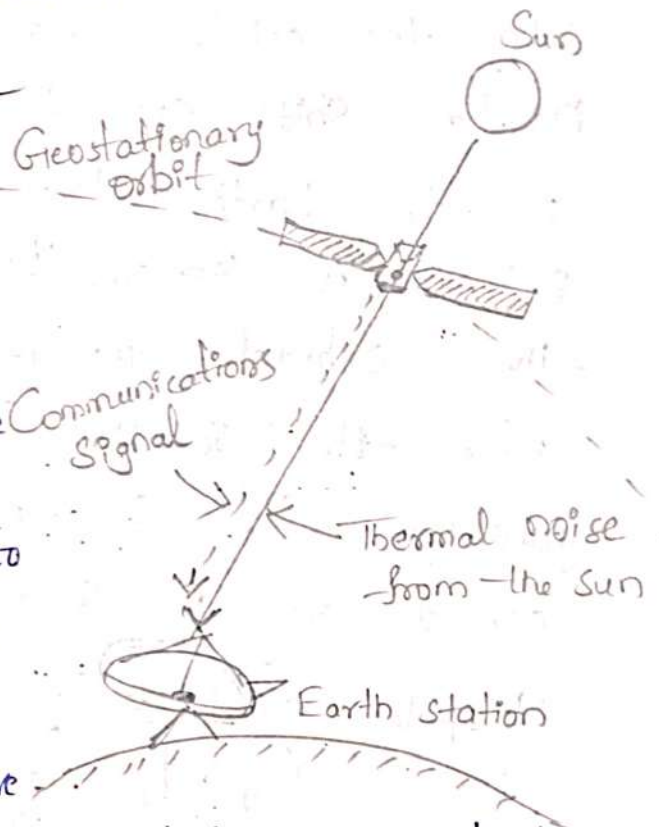
The position of a Satellite with respect to the Earth shows cyclic variation. This variation in position causes variation in range between Satellite and user terminals. The range variations are more significant in Low Earth orbit (LEO) Satellites.

(iii) Sun Transit Outage : —

The orbit of Satellite will also pass directly in front of the Sun.

The Sun is a 'hot' microwave source with an equivalent temperature of about 6000 to 10,000 K, depending on the time. The Earth Station antenna will therefore receive

not only the signal from the Satellite but also the noise temperature by the Sun. The added noise temperature will cause the fade required quality of service margin of the receiver to be exceeded and is not achievable. an outage will occur.



(iv) Solar Eclipse : —

* A Satellite is said to be in 'Eclipse' when the Earth prevents Sunlight from reaching it, that is, when the Satellite is in the shadow of the Earth.

* For geostationary Satellites, Eclipses occur during two periods that begin 23 days before the Equinoxes (about March 21 and about September 23) and end 23 days after the Equinox periods.

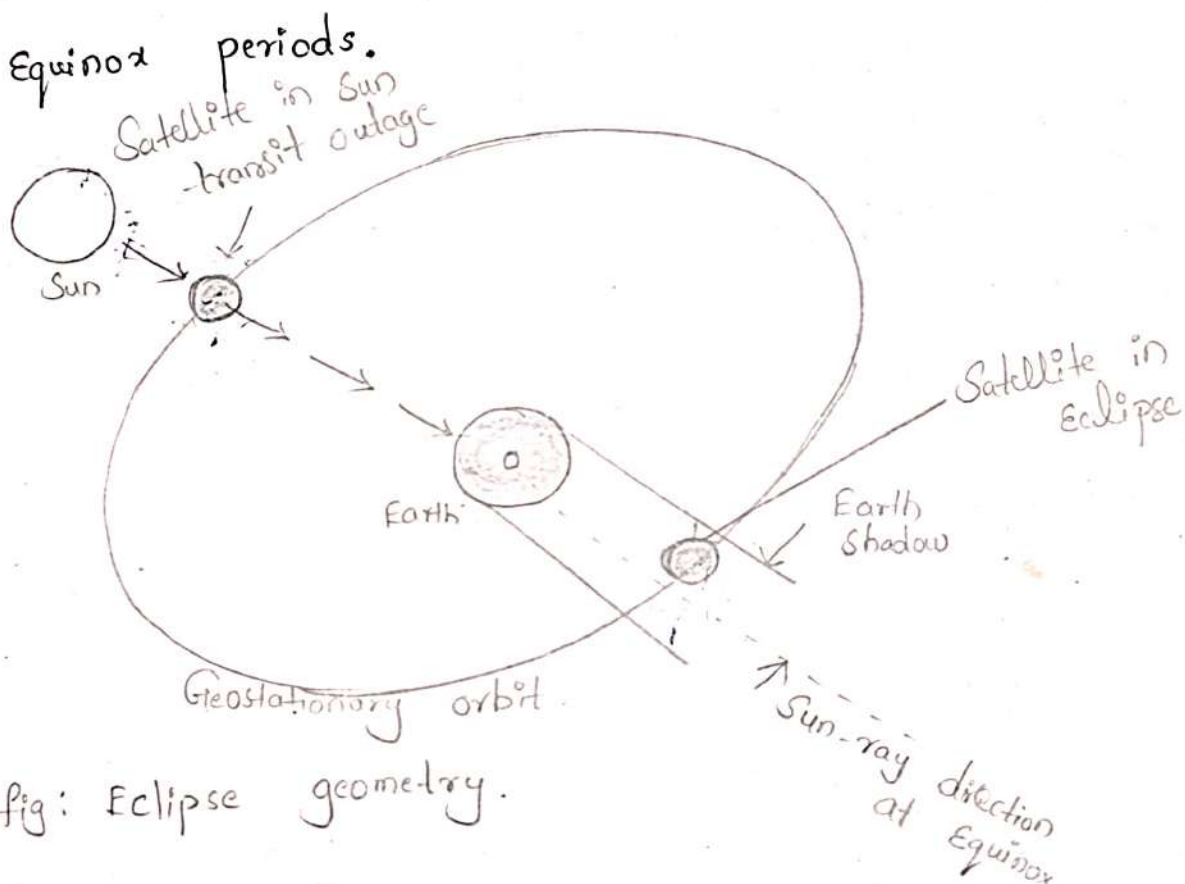


fig: Eclipse geometry.

* Eclipses occur close to the Equinoxes, as these are the times when the Sun, the Earth, and the Satellite are all nearly in the same plane.

* During full Eclipse, a Satellite receives no power from its Solar array and it must operate entirely from its batteries.

* Nickel - Hydrogen batteries, long - the mainstay of Comm's Satellites, can operate at about a 70% depth of discharge and recover fully once recharged.

* Ground Controllers perform battery - conditioning routines prior to Eclipse operations to ensure the best battery performance during the Eclipse.

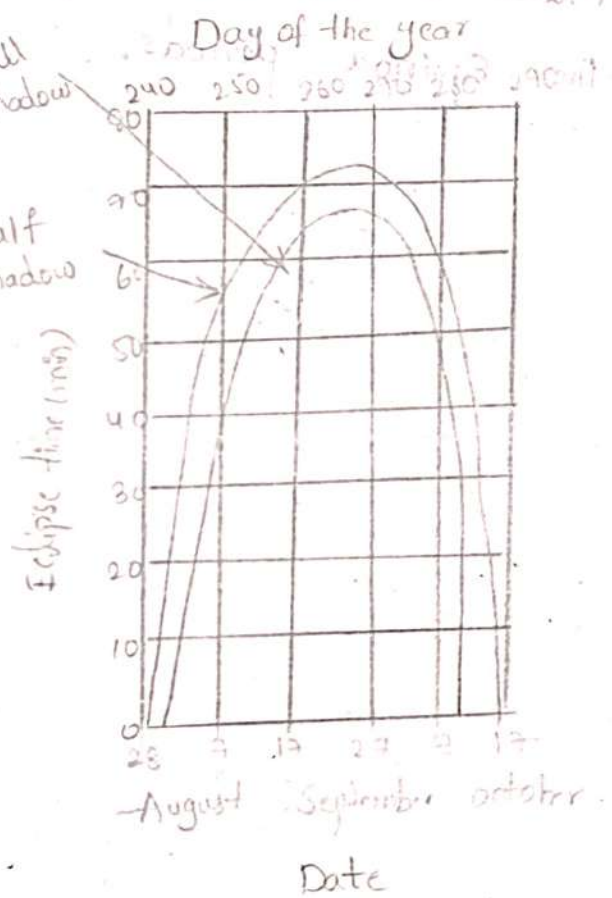
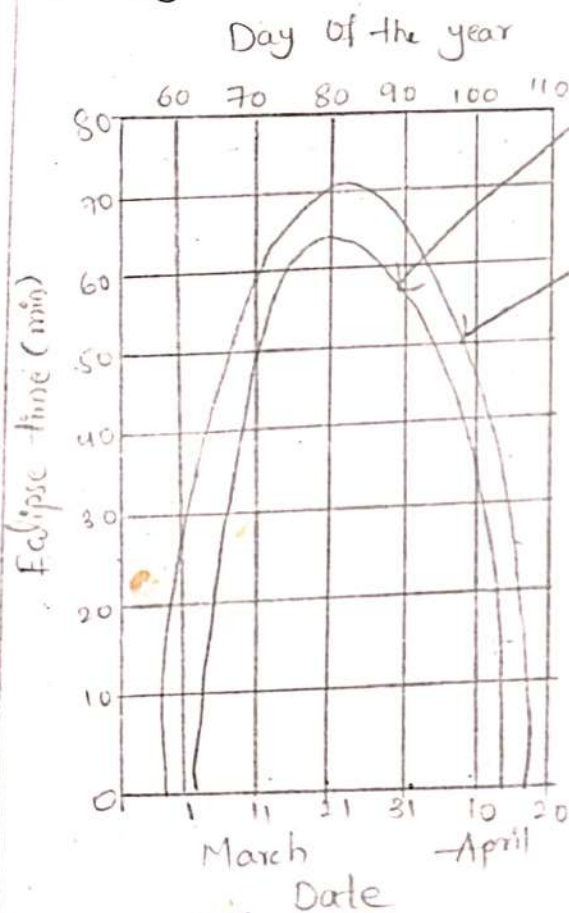


fig: Dates and duration of eclipses.

Orbit Determination: —

Orbit determination requires that sufficient measurements be made to determine uniquely the six orbital elements needed to calculate the future orbit of the satellite. Major satellite networks maintain their own TTC & M stations around the world. Smaller satellite systems generally contact for such TTC & M functions from the spacecraft manufacturer. TTC & M stations are used to measure the angular position of the satellites also carry out range measurements using telemetry stream.

Launches and Launch Vehicles : —

There are two types of Launch Vehicles.

1) Expendable Launch Vehicle (ELV)

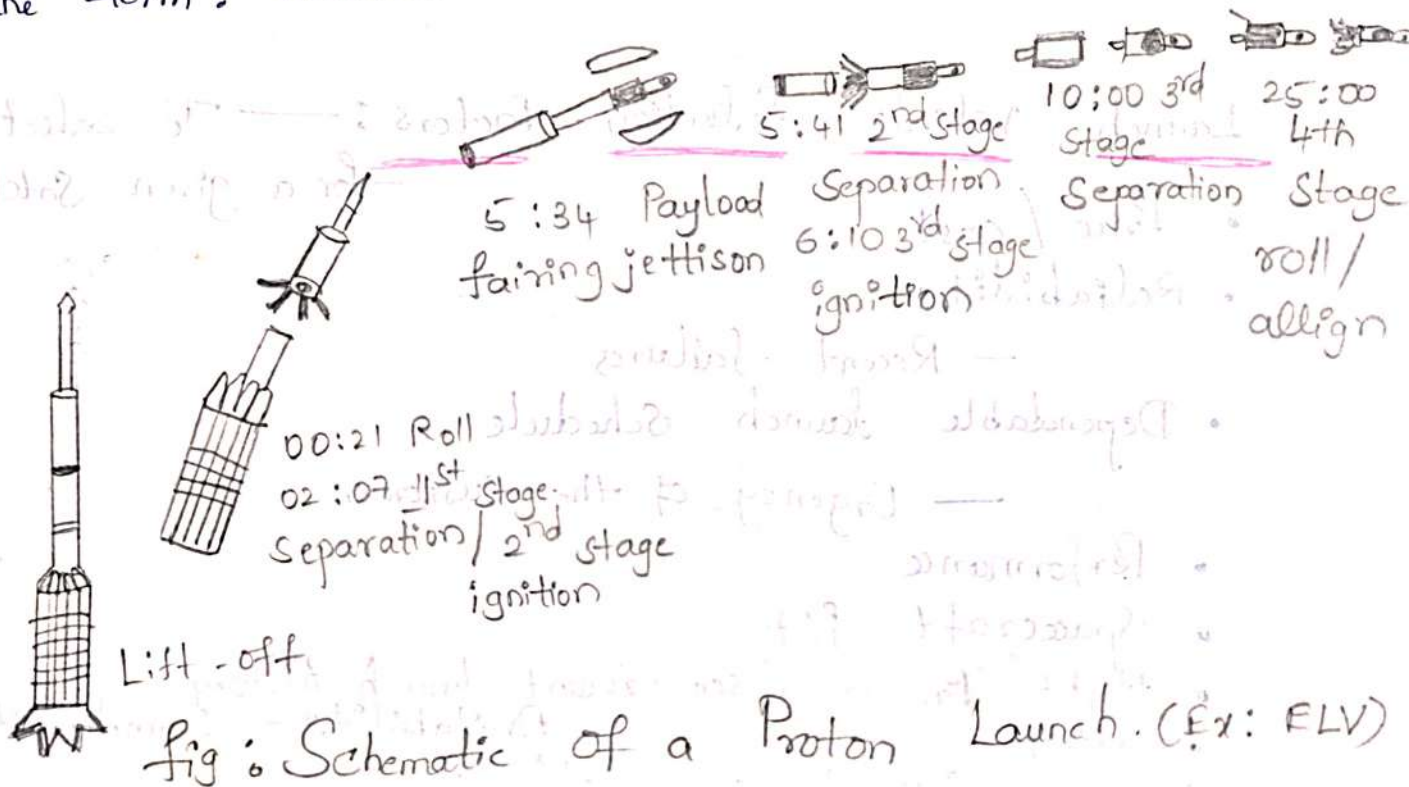
2) Reusable Launch Vehicle (RLV)

1) Expendable Launch Vehicle : —

Most launch vehicles have multiple stages and as each stage is completed, that portion of the launcher is expended until the final stage places the satellite into the desired location. Hence the term: Expendable launch vehicle.

2) Reusable Launch Vehicle : —

The solid rocket boosters are recovered for future missions and the shuttle vehicle itself is flown back to earth for refurbishment and reuse. Hence the term: Reusable launch vehicle.



Launcher	weight to orbit (kg)	Total cost (\$M)	Lead time (months)	Payload diameter (m)	Launch Latitude (°)
Ariane 44	4000	130	36	3.65	5.2
Ariane 5	6800	120	36	4.57	5.2
Atlas IIAS	3700	100	36	3.45	28.5
Atlas IIIA	4120	125	36	4.19	28.5
Atlas IIIB	4500	135	48	4.19	28.5
Atlas V	6500	150	48	5.40	28.5
Delta II	3800	130	36	4.00	28.7
Delta IV (Small)	2177	60	36	3.00	28.7
Delta IV (Med.)	4173	120	36	4.00	28.7
Delta IV (Heavy)	13200	400	48	5.00	28.7
Titan III	4500	260	36	3.65	28.6
Titan IV	5700	435	48	4.57	28.6
Proton M	4800	80	24	3.68	51.6

fig: Comparison of different Launch Vehicles

Launch Vehicle Selection Factors : — To select a rocket for a given satellite.

- Price / cost
- Reliability
 - Recent failures
- Dependable launch schedule
 - Urgency of the customer
- Performance
- Spacecraft fit
- Flight Proven (see recent launch history)
- Safety
 - Availability — Launch site
- Launch site location
 - Market Conditions — what the market

Future Trends of Satellite Communication: — 19

In the future the Satellite Communication will move towards personal communication with space switching and direct broadcast, rather than just being a repeater. Improvements in the higher-freq^y (microwave) technology will also improve the Bandwidth Capabilities.

Spacecraft Cluster in Space: —

With the crowding in the geostationary orbit (GSO), it is inevitable that a cluster of Satellites will have to be located and maintained in a given longitudinal slot.

From the mission control point of view, the station keeping of this cluster is much more difficult than that of an individual satellite. So Coordinated Station Keeping (CSK) Strategies have to be evolved using proven Computer Simulations and then adopted for operations. Inter Satellite ranging will help in preserving the required minimum Separation between the Satellites.

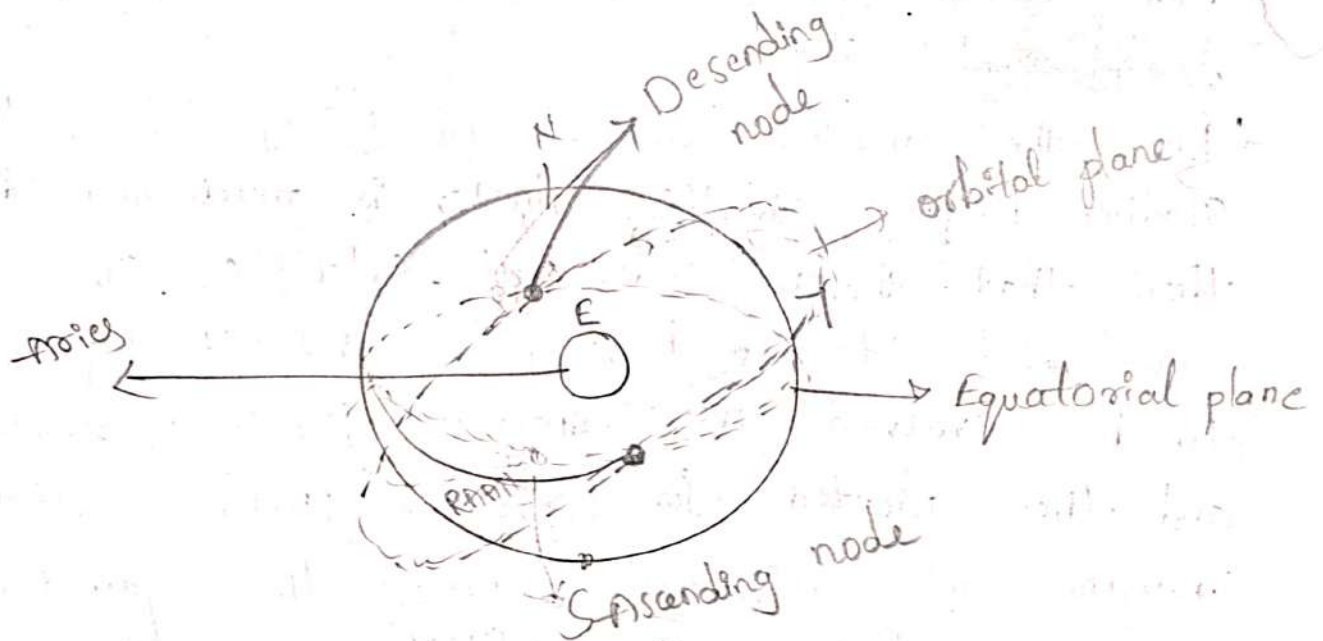
FSS → Fixed Satellite Services will develop in the future.

→ A number of mobile Satellite Systems using non geostationary orbit will offer voice and broadband personal Services.

The use of direct-to-home broadcasting is also expected to rise in many parts of the world. Several developments in technology are likely to further enhance the applicability of Satellite comm's. for applications such as VSATs or personal mobile terminals.

VSAT $\rightarrow$ Very Small Aperture Terminals.

$\rightarrow$ Other areas being investigated include reduction in the coding bit rate of speech signals, which will result in greater bandwidth utilization.



UNIT - II

Satellite Subsystems

Introduction: —

* An operating Communication Satellite System consists of several Elements or Segments.

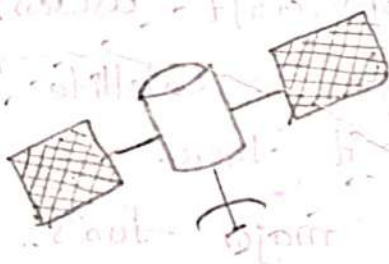
* Important Space Craft Subsystem includes

1. Attitude and Orbit Control System (AOCS)
2. Telemetry Tracking and Command (TTC) and Monitoring
3. Power System
4. Communications Subsystem
5. Satellite Antennas.

* The Space Segment Equipment carried aboard the Satellite can be classified under two functional areas:

1. The bus

2. Payload.



Payload:
Transponders,
Satellite antennas

Bus:
Physical Structure, AOCS, Power System,
Thermal control,
Telemetry, Tracking, Command & Monitoring

fig: Satellite Subsystem.

Attitude and Orbit Control System (AOCS) : —

- * Spacecraft control is usually synonymous with "Attitude Control",
- * The attitude and orbital control subsystem checks that a spacecraft is placed in its precise orbital position, and maintains, thereafter, the required attitude throughout its mission.
- * Control is achieved by employing momentum wheels, which produce gyroscopic torques, combined with an auxiliary reaction control gas thruster system.
- * Many various sensors are employed to detect attitude errors, including Sun's initial orientation purposes.
- * The AOCS performs satellite orientation and accurate orbital positioning throughout its lifetime, because loss of attitude renders a spacecraft useless.
- * AOCS is needed to get the satellite into the correct orbit and keep it there.
- * AOCS performs following major fun's.
 - * 1. Orbit insertion
 - 2. Orbit maintenance.
 - 3. Fine Pointing.
- * The objective of attitude control is to keep the antenna RF beam pointing at intended areas on the Earth, which procedure involves following steps.

1. Measuring the attitude of the satellite by sensors
2. Comparing the results of measurements with the required values.
3. Calculating the corrections to reduce eventual errors.
4. Introducing these corrections by operating the appropriate torque units.

* The major parts of AOCs are -

1. Attitude Control System
2. Orbit Control System.

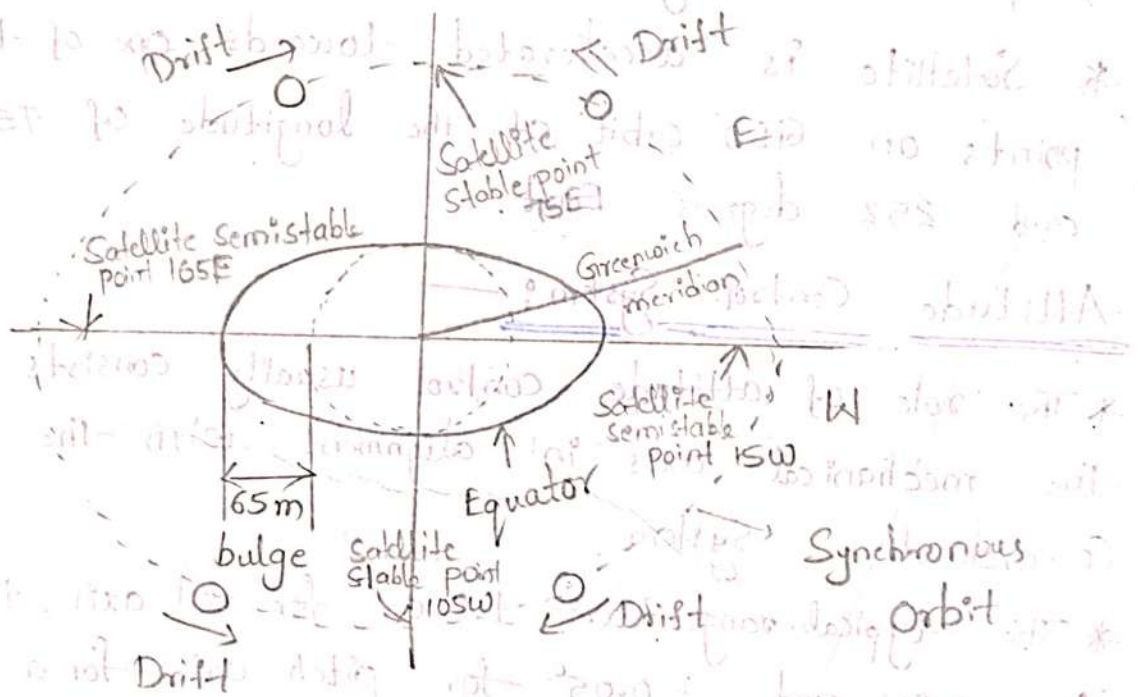


Fig: forces on a Synchronous Satellite

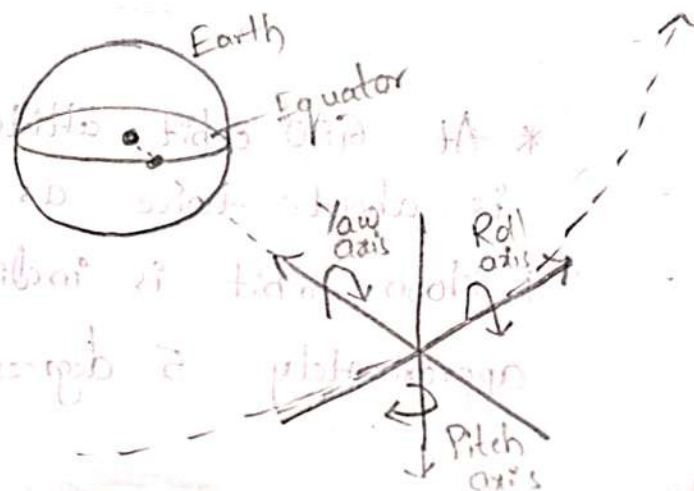
- * At GEO orbit altitude the moon's gravitational force is about twice as strong as the sun's.
- * Moon orbit is inclined to the equatorial plane by approximately 5 degrees.

- * The plane of the Earth's rotation around the Sun is inclined to 23 degrees to the Equatorial plane.
- * Net gravitational force on the satellite tends to change the inclination of the satellite.
- * Approximately 0.86 degrees per year from the Equatorial plane.
- * LEO Satellites are less affected by this gravitational pull from the Sun and moon.
- * At the Equator there are bulges of about 65m at longitudes 162 degrees East and 348 degrees East.
- * Satellite is accelerated towards one of two stable points on GEO orbit at the longitude of 75 degree East and 252 degrees East.

Attitude Control System:

- * The role of attitude control usually consists of maintaining the mechanical axes in alignment with the local Co-ordinate System.
- * The typical ranges are $\pm 0.05^\circ$ for roll axis, $\pm 0.2^\circ$ for Yaw axis and $\pm 0.05^\circ$ for pitch axis for a geostationary satellite.

- * Attitude of a satellite is represented with respect to three axes — Roll axis, Pitch axis and Yaw axis.



* Satellite must be stabilized to prevent nutation move unsteadily.

* There are two principle forms of attitude stabilization

1. Spin stabilization (Body stabilized)

2. Three-axis stabilized

* Two ways to make the satellite stable in orbit when it is weightless.

1. Satellite can be rotated at a rate b/w 30 and 100 rpm to create gyroscopic force that provides stability (Spinner Satellites).

2. Satellites can be stabilized by one or more momentum wheels, called three-axis stabilized satellites.

Orbit Control System :-

* A geostationary satellite is subjected to several forces that tend to accelerate it away from its required orbit.

* For the geostationary satellite, the most important are the gravitational forces of the moon and the sun, which cause inclination of the orbital plane and the nonspherical shape of the earth around the equator, which causes the drift of the subsatellite point.

* Satellites need in-phase (E-W) and out-of-plane (N-S) maneuvers to maintain the correct orbit.

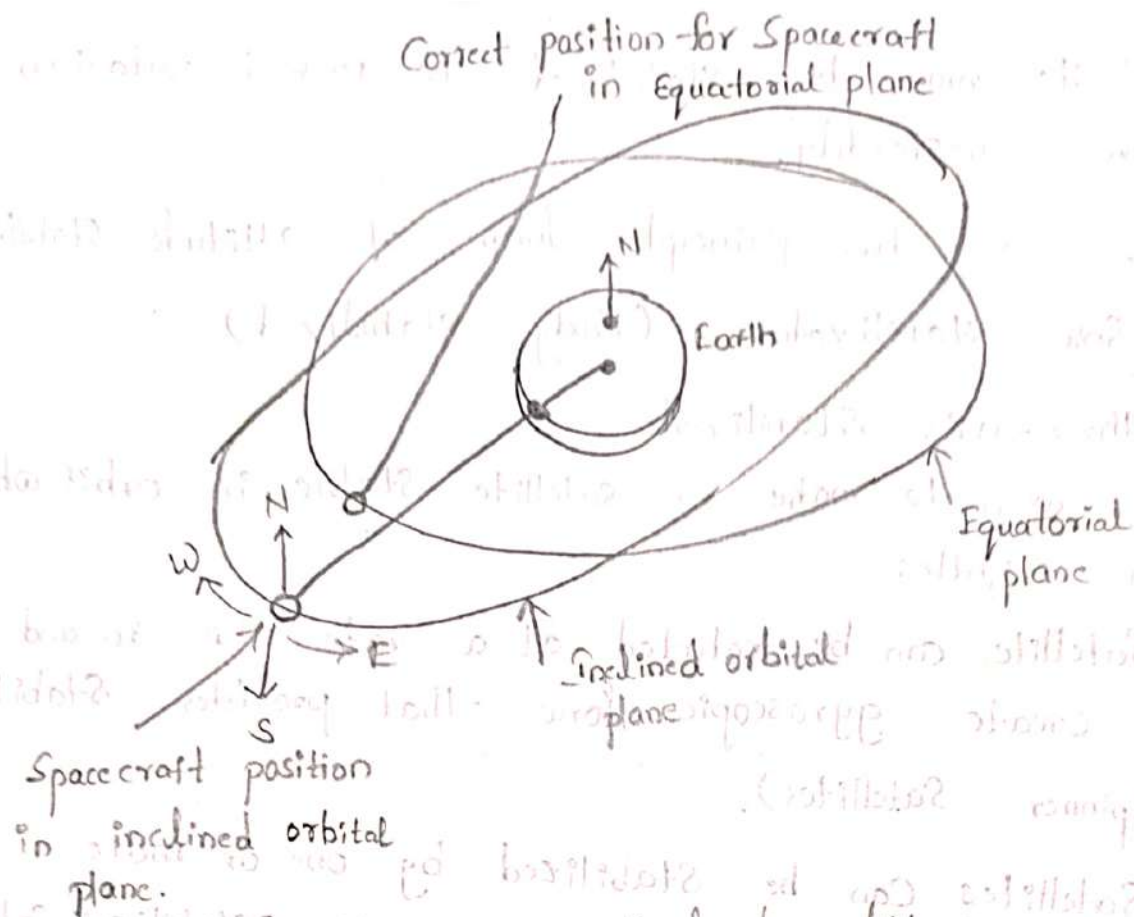


Fig: Satellite in inclined orbit.

* LEO Systems less affected by Sun and moon but may need more orbit-phasing control.

* Two types of motors used on Satellites.

1. Traditional bipropellant thruster

a. Bipropellants uses Mono-methyl hydrazine & Nitrogen tetra-oxide.

b. They are hypogolic, i.e. they ignite simultaneously on contact without any catalyst or heater.

2. Arc jets or ion thrusters.

a. High v/g is used to accelerate ions.

* Fuel stored in GEO Satellite is used for two purposes.

1. Apogee Kick Motor (AKM) that injects the satellite into its final orbit.

2. Maintain the Satellite in that orbit over its lifetime.

Telemetry, Tracking, Command and Monitoring (TTC & M):—

- * The telemetry, tracking, Command and monitoring Subsystem provides Essential Spacecraft management & Control fun's to keep the Satellite operating safely in orbit.
- * "Tracking" refers to the determination of the current Orbit, position, and movement of the Spacecraft.
- * The "telemetry" fun involves the Collection of data from Sensors on-board the Spacecraft and the relay of this information to the ground.
- * The telemetered data include Such parameters as V/g and Current Conditions in the power Subsystem, Temperature of Critical Subsystems, Status of switches and relays in the Comm's and antenna Subsystems, fuel tank pressures, and attitude Control Sensor status.
- * "Command" is the Complementary fun to telemetry. The Command system relays specific Control and operations information from the ground to the Spacecraft, often in response to telemetry information received from the Spacecraft.

Telemetry :—

Telemetry fun's :— TTC & M fun's :—

- * 1. To receive the Control signals from the Earth Station to initiate manoeuvres and also to control or change the State of operation of Equipment.

2. To transmit results of measurements, information regarding Satellite operations.
3. To facilitate the measurements of ground satellite distance, radial velocity etc.
4. On Board Data Handling (OBDH), it includes all house-keeping data processing and formatting with data traffic.
5. Reporting Spacecraft health.
6. Monitoring Command actions
7. Determining orbital Elements.
8. Launch Sequence deployment
9. Control of Thrusters.
10. Control of payload (comm's. etc).

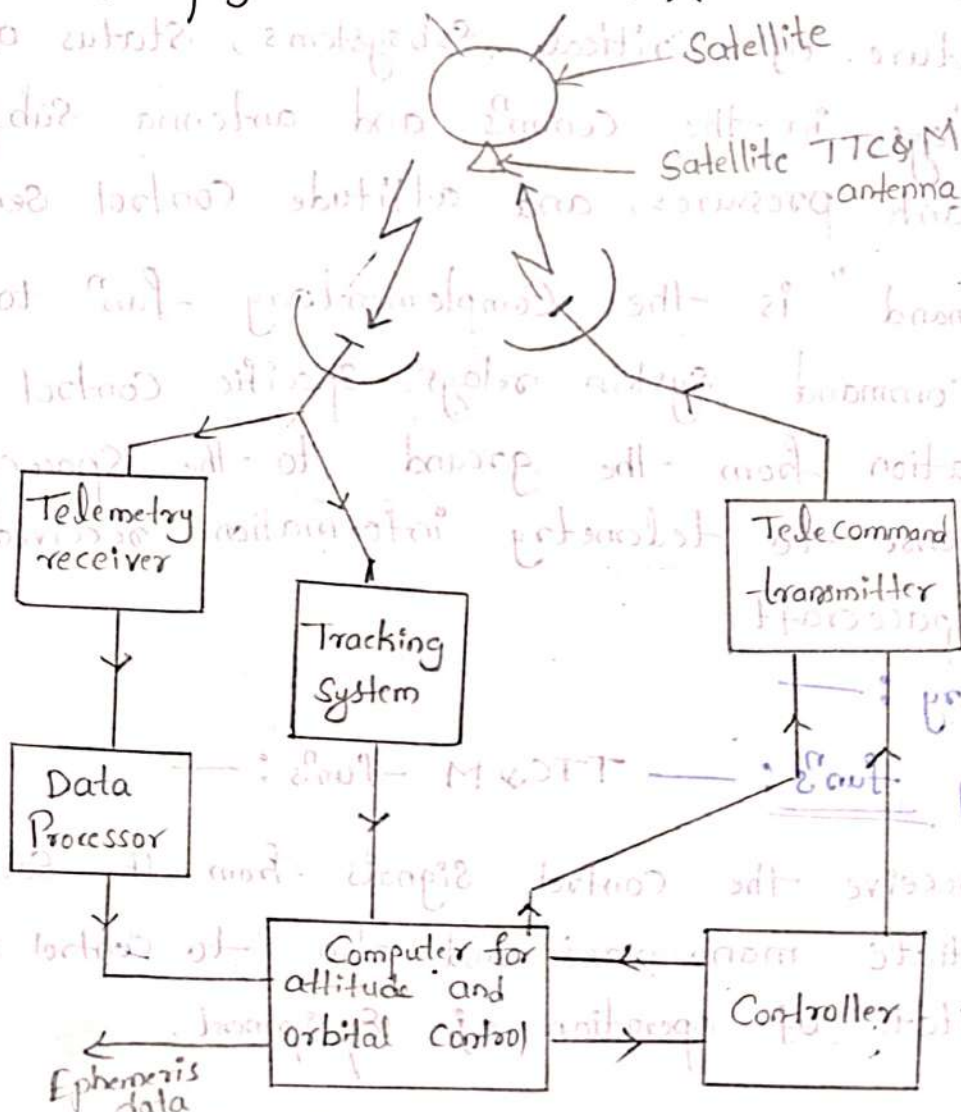


fig: Typical Telemetry, Tracking, Command & Monitoring System

* The data from various sensors of different Sub-Systems are collected by TM receiver by TM links.

* The telemetry (TM) links are carriers which are phase or frequency modulated by a sub-carrier at a 40.96 kHz.

* The data can be obtained either -

- i) Directly from Satellite Equipment.
- ii) Conditioned (ADC, formatting) in telemetry.
- iii) At the o/p of On Board Data Handling (OBDH) unit.

Tracking System :-

* Tracking involves distance (range) measurement and radial velocity measurement.

* Doppler shift of telemetry carrier gives the round trip delay and hence the distance of the satellite.

* Regular estimation of orbital parameters are necessary to maintain a satellite in its assigned orbit and to provide look angle information to the Earth station.

* The funⁿ of tracking is to provide necessary sources to Earth stations for the tracking and determination of orbital parameters.

* Tracking involves following.

1. Measuring range repeatedly.
2. Compute Orbital Elements.
3. Plan Station-keeping maneuvers.
4. Commⁿ with main control station & users.

On Board Data Handling (OBDH): —

* OBDH unit performs following fun's.

1. Command Processing : It covers decoding validation, acknowledgement and Execution of Command Signals.
2. Data Storage & processing.
3. Data traffic management.
4. Data timing and Synchronization.

Command : —

* The Command Sub-System receives Commands transmitted from the ground control centre, verifies reception & executes commands to perform various fun's of the Satellite during its operational mission, such as :

1. Satellite transponder and beacon switching
2. Antenna pointing Control,
3. Switch matrix reconfiguration.
4. Controlling direction and speed of solar arrays drive,
5. Battery reconditioning
6. Thruster firing and switching heaters of the various Systems.

* The Command System is used during launch to control the firing of the boost motor,

Power Systems : —

* The power system is meant to provide DC power to all subsystems throughout the life of a spacecraft.

* Sun is a powerful Source of Energy. Solar cells are used because Solar power is available for over 99% of Satellite lifetime.

* Silicon solar cells are widely used. The efficiency of Solar cells varies between 20% to 25% at the Beginning of life (BOL) and 7% to 10% towards End of Life (EOL).

* The Satellites are Equipped with batteries to power Subsystems during launch and during eclipses.

* A geostationary Satellite undergoes 88 eclipses per year and rechargeable batteries provide power during this period.

* Nickel - Cadmium (Ni-cad) batteries are commonly used because of their high reliability and long lifetime.

* Nickel - Hydrogen (Ni-H) cells have higher Capacity per unit mass and tolerance to higher depths of discharge and are preferred nowadays.

* Batteries are conditioned before each Eclipse.

Communication Subsystems : —

* The heart of a Commⁿ Satellite is the Commⁿ Subsystem. The Commⁿ Subsystem is a set of transponders that receive the uplink signals and retransmit them to Earth.

* The main objective of Commⁿ System is to provide a reliable Commⁿ b/w the Satellite and the ground station.

* A Comm's Satellite exists to provide a platform in the orbit for relaying of voice, video, and data.

* Example for Comm's Satellite is INTELSAT

Fun's of Comm's Subsystem: —

* The main fun's of the Comm's Subsystem (Payload):

1. To amplify the received carriers.
2. To Change the frequency of the carriers from the uplink to the down-link (Ex: 14 to 11 GHz).
3. To provide the power required for down-link transmission.
4. To radiate the carriers in the given frequency band and with the required polarization.

Elements of the Comm's Subsystem: —

* The Elements of the Comm's Subsystem:

1. Transmitting and receiving antennas.
2. Amp's, Low Noise (LNA) and High Power (HPA).
3. Filters, RF and IF band-pass
4. Oscillators.
5. Up and down Converters.
6. Multiplexers and de-multiplexers.
7. Electronic Switches.

Transponders: —

* Transponder, transmits the down link by responding to the uplink, hence it is known as transponder.

* The Component in the Satellite that receives the uplink signal, amplifies and possibly processes the signal and then re-formats and transmits the signal back to the ground, is called the transponder.

* Transponders can channel the satellite capacity both in 'freq' and in power.

* Types of transponders : —

Two major types of transponders are

1. Frequency translation transponder
2. On-board processing transponder. →

* The majority of satellite transponders are frequency translation that is, they amplify the uplink signal, shift it in frequency and transmit it as the downlink.

* The frequency translation transponder, also referred to as a non-regenerative repeater, receives the uplink signal and after amplification, retransmits it with only a translation in carrier frequency.

* On-board processing transponder, also called a regenerative repeater or smart satellite.

* The regenerative transponder performs amplification and frequency translation along with signal processing. (Error Correction, Coding, Switching, Reformatting).

Classification of transponder based on frequency conversion:

1. Single Conversion transponder.
2. Double Conversion transponder.

Single Conversion Transponder for 6/4 GHz :-

- * The Single Conversion transponder is simple, low cost and features a reduced part count compared to double conversion type.
- * This transponder type implies the availability of signal amp's - after the down-conversion - operating at relatively high freq's.

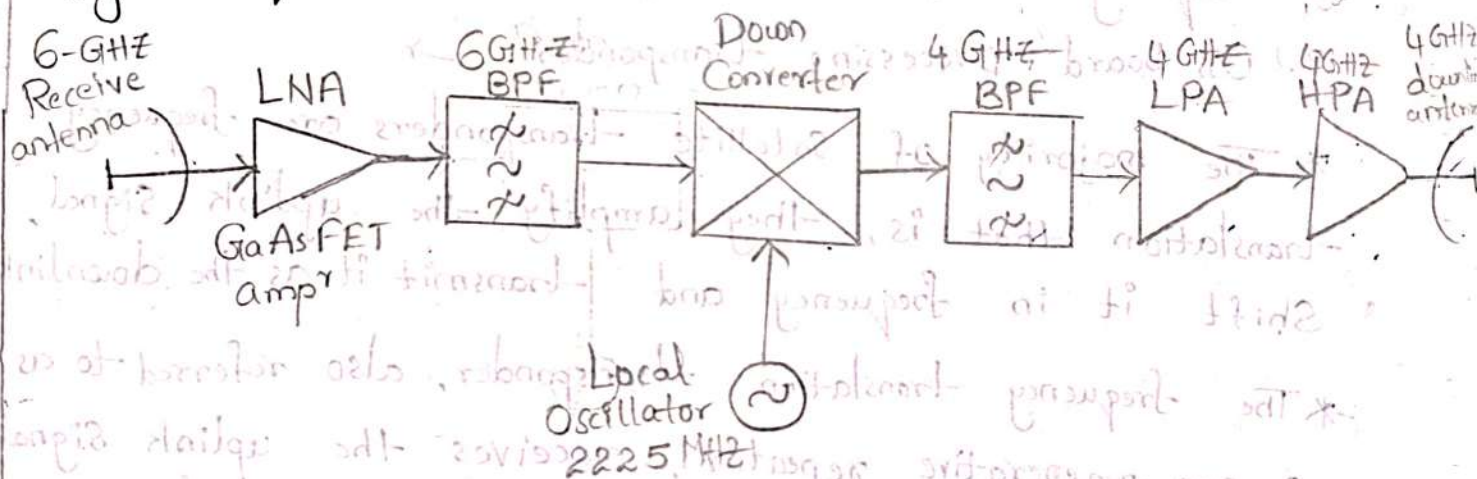


Fig: Simplified Single Conversion transponder for 6/4 GHz band

Double Conversion Transponder for 14/11 GHz :-

- * The double Conversion transponder is used for 14/11 GHz band. It is easier to make filters, amplifiers and Equalizers at an intermediate frequency (IF) such as 1100 MHz than at 14 or 11 GHz, so the incoming 14-GHz carrier is translated to an IF of around 1 GHz.

* The amplification and filtering are performed at 1 GHz and a relatively high-level carrier is translated back to 11 GHz for amplification by the HPA.

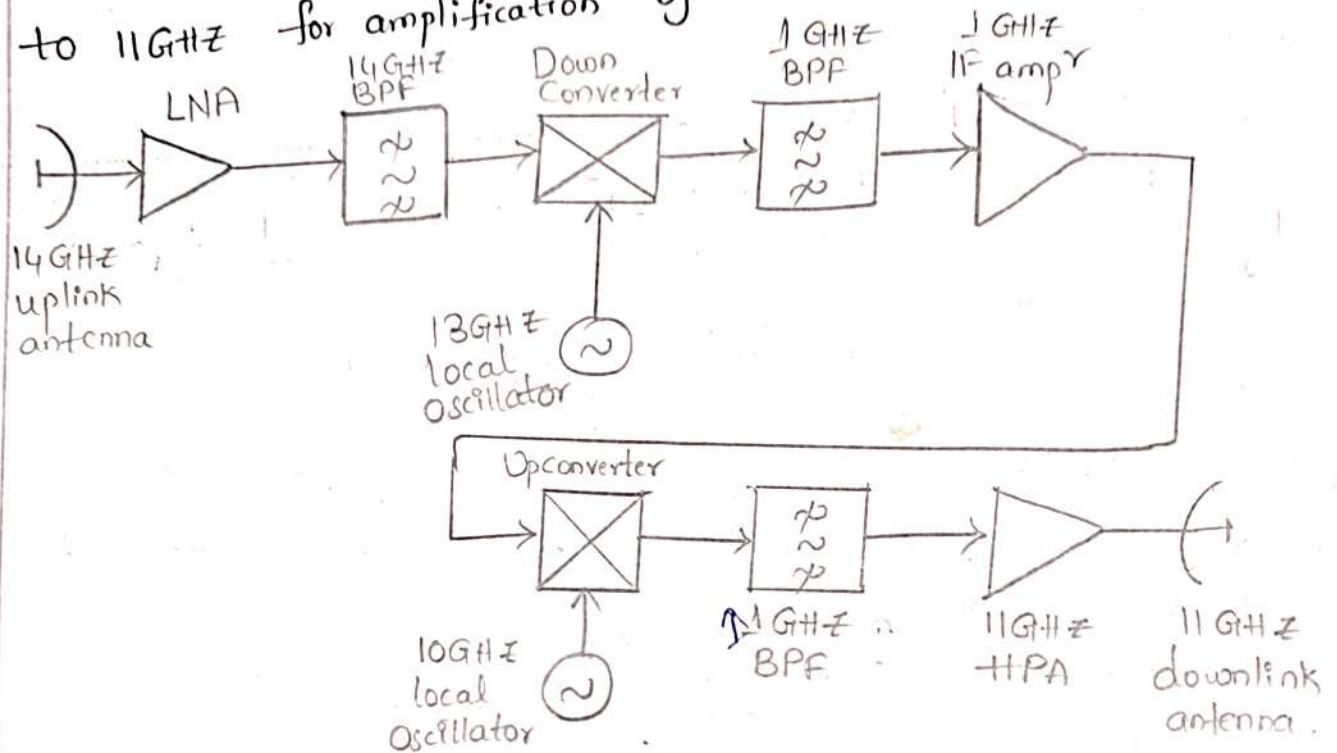


Fig: Simplified double Conversion Transponder for 14/11 GHz band.

* A considerable increase in the comm's capacity of a Satellite can be achieved by combining onboard processing with switched-beam technology.

* Onboard processing may also be used to advantage to switch b/w the uplink access technique (eg: MF-TDMA) and the downlink access technique (eg: TDM) so that small Earth stations may access each other directly via the Satellite.

* The processor can provide the data storage needed for a switched-beam system and also can perform error correction independently on the uplink and downlink.

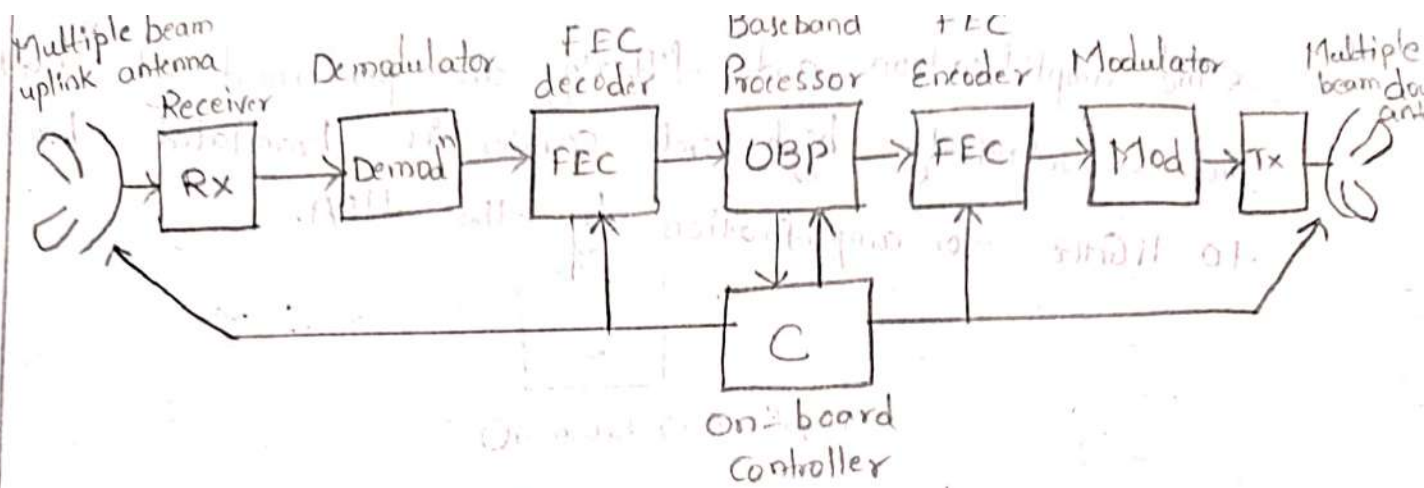


fig: Onboard Processing -transponder.

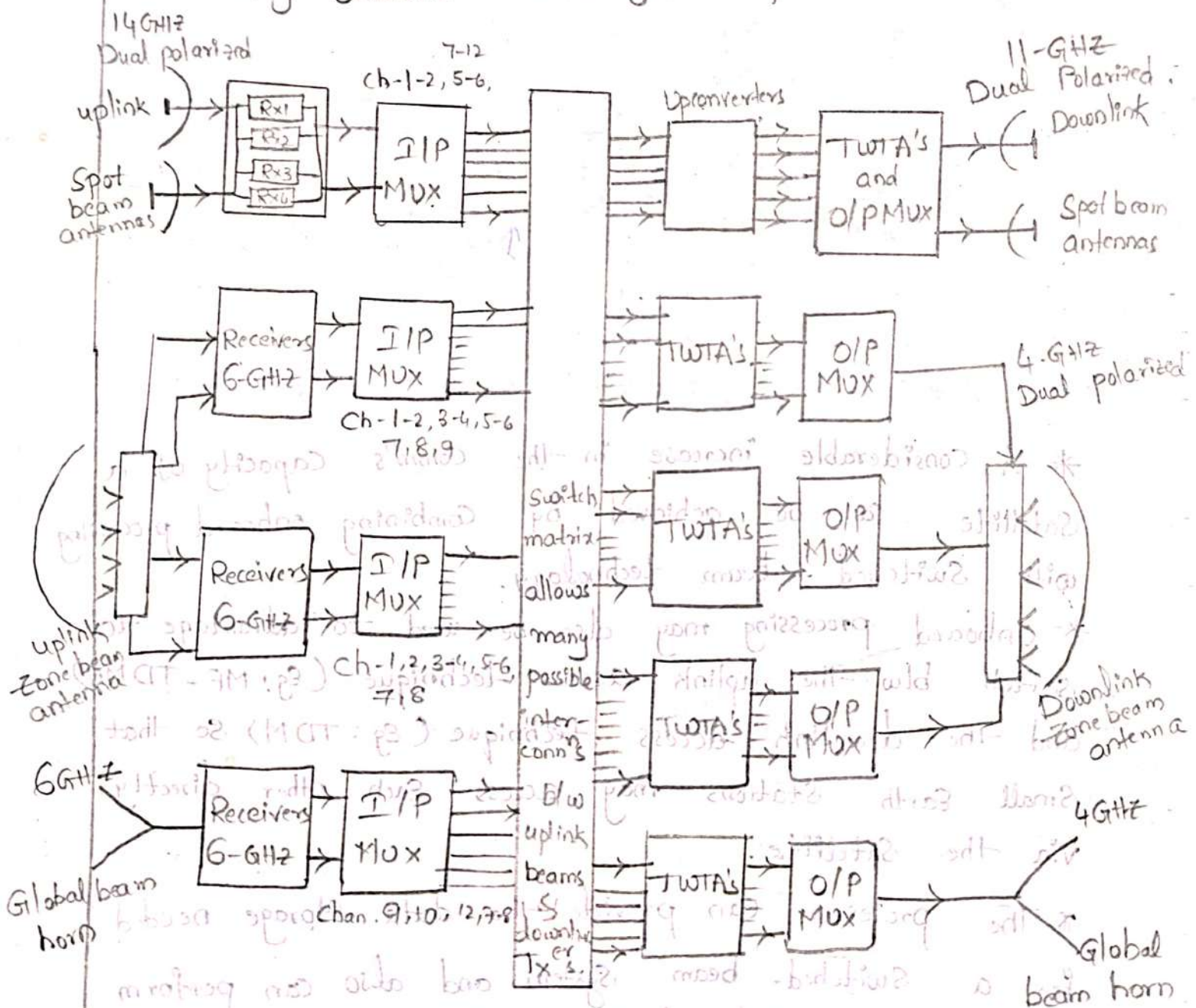


fig: Simplified block diagram of an INTELSAT - V Comm Sys.

Satellite Antennas : —

Basic Antenna Types and Relationships : —

Four main types of antennas are used on Satellites. These are

1. Wire antennas : monopoles & dipoles.

2. Horn antennas.

3. Reflector antennas.

4. Array antennas.

* Wire antennas are used primarily at VHF and UHF to provide Comm's for the TTC&M Systems. They are positioned on the body of the Satellite.

* The gain of an antenna is a measure of the antenna's capability to direct Energy in one direction, rather than all around.

* A useful principle in antenna theory is reciprocity.

* Reciprocity means that an antenna has the same gain and pattern at any given frequency whether it transmits or receives.

* An antenna pattern measured when receiving is identical to the pattern when transmitting.

* Satellite antenna is used to provide Coverage of a certain area or Zone on the Earth's Surface.

* Horn antennas are used at microwave freq's when relatively wide beams are required, as for global coverage.

* Horns are also used as feeds for reflectors.

- * Horns and reflectors are Examples of aperture antennas that launch a wave into free space from a waveguide.
- * It is difficult to obtain gains much greater than 23dB or beamwidths narrower than about 10° with horn antennas.
- * For higher gains or narrow beamwidths a reflector antenna or array must be used.

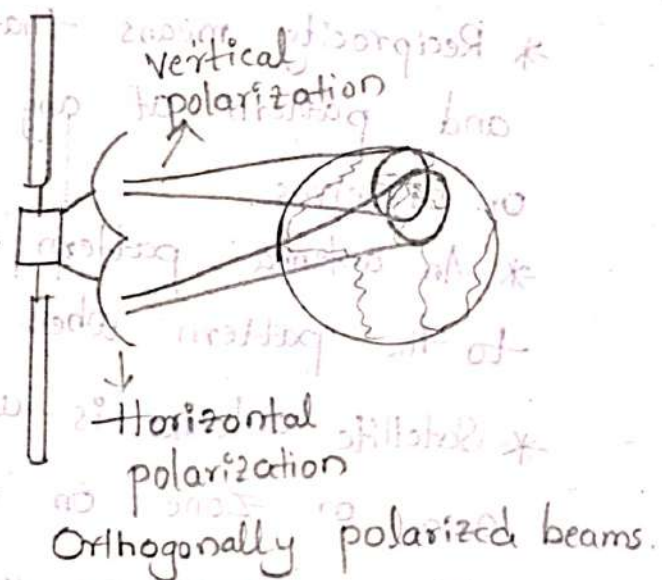
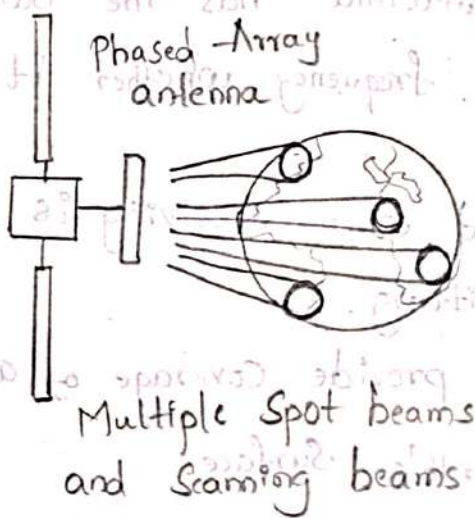
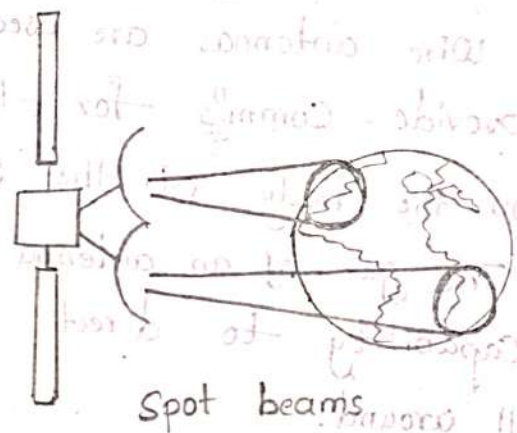
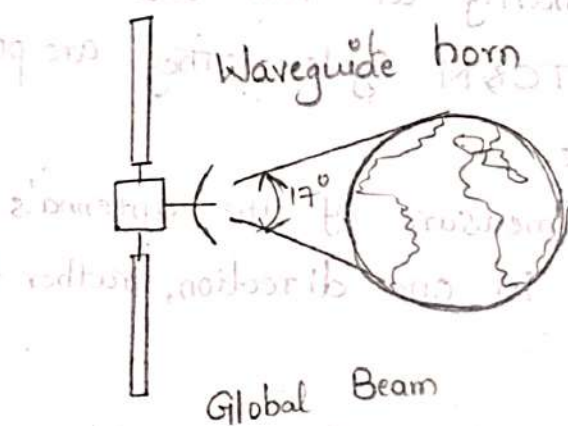


Fig: Satellite antenna patterns and Coverage Zones

* Reflector antennas are usually illuminated by ¹⁰ one or more horns and provide a larger aperture than can be achieved with a horn alone.

* Paraboloid is the basic shape for most reflector antennas. and is commonly used for Earth Station antennas.

* Phased array antennas are also used on satellites to create multiple beams from a single aperture.

* The following relationships will be used to guide the selection of antennas for a Comm's Satellite.

* An aperture antenna has a gain 'G' given by

$$G = \eta_A 4\pi A / \lambda^2$$

$A \rightarrow$ Area of the antenna aperture in meters.

$\lambda \rightarrow$ Operating wavelength in meters.

$\eta_A \rightarrow$ aperture efficiency of the antenna.

* If the aperture is circular, gain 'G' given by

$$G = \eta_A (\pi D / \lambda)^2$$

$D \rightarrow$ diameter of the circular aperture in meters.

* The beamwidth of an antenna is related to the aperture dimension in the plane in which the pattern is measured.

$$\Theta_{3dB} \approx \frac{75\lambda}{D} \text{ degrees.}$$

$\Theta_{3dB} \rightarrow$ beamwidth b/w half power points of the antenna pattern.

Equipment Reliability and Space Qualification :-

Communications Satellites have operational lifetimes of up to 15 Years. The Components that make up the Satellite must therefore have very high reliability in the environment of outer Space, and a strategy must be devised that allows some Components to fail without causing the entire Commⁿ Capacity of the Satellite to be lost.

∴ Two Separate approaches are used.

- 1) Space Qualification
- 2) Redundancy.

Space qualification of every part of the Satellite to ensure that it has a long life expectancy in orbit and redundancy of the most critical components to provide continued operation when one component fails.

Space Qualification :-

Outer Space, at geostationary orbit distances, is a harsh environment. There is a total vacuum and the Sun irradiates the Satellite with 1.4 kW of heat and light on each square meter of exposed surface. Electronic equipment can not operate at such extremes of temperature and must be housed within the Satellite and heated or cooled so that its temperature will fall toward stays within the range 0° to 75°C .

This requires a Thermal Control System that manages heat flow throughout a GEO Satellite as the Sun moves around once every 24 h.

The first stage in ensuring high reliability in a satellite is by selection and screening of every component used. Past operational and test experience of components indicates which components can be expected to have good reliability. Only components that have been shown to have high reliability under outer space conditions will be selected. Each component is then tested individually to ensure that it meets its specification.

This process is known as "quality control or quality assurance".

When a satellite is designed, three prototype models are often built and tested.

- 1) Mechanical model
- 2) Thermal model
- 3) Electrical model.

Testing carried out on the prototype models is designed to overstress the system and induce failure in any weak components.

Space qualification is an expensive process, and one of the factors that makes large GEO satellites expensive.

Most of the components on the Survey Satellites were not space qualified - they were subjected to shake and bake tests.

Reliability:

We need to be able to calculate the reliability of a Satellite Subsystem for two reasons.

- 1) we want to know, what the probability is that the Subsystem will still be working after a given time period.
- 2) we need to provide redundant components or subsystems where the probability of a failure is too great to be accepted.

The manufacturers of Satellites must provide their customers with predictions (or guarantees) of the reliability of the Satellite and Subsystems. To do this requires the use of reliability theory. Reliability theory is a mathematical attempt to predict the future.

The reliability of a component can be expressed in terms of the probability of failure after time t , $P_f(t)$. For most electronic equipment, probability of failure is higher at the beginning of life, i.e. the burn in period than at some later time. As the component ages, failure becomes more likely, leading to the bathtub curve.

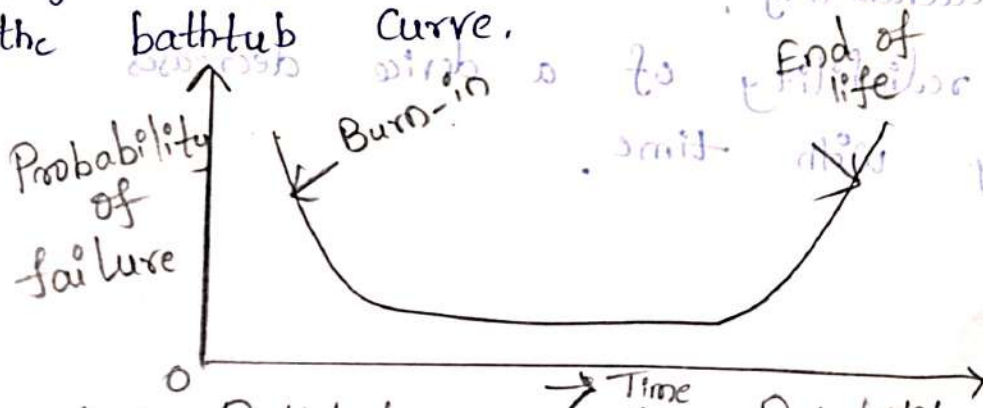


fig: Bathtub curve for Probability of failure

Components for Satellites are selected only after extensive testing. The aim of the testing is to determine reliability, causes of failure and expected life-time.

Testing is carried out under rigorous conditions, representing the worst operating conditions likely to be encountered in space and units that are exposed to the vacuum of space are tested in a vacuum chamber and components subjected to sunlight are tested under equivalent radiant heat conditions.

The reliability of a device or subsystem is defined as

$$R(t) = \frac{N_s(t)}{N_0} = \frac{\text{Number of Surviving Components at time 't'}}{\text{Number of Components at start of test period.}}$$

The number of components that failed in time 't' is

$$N_f(t) = N_0 - N_s(t).$$

$$R = e^{-\lambda t}$$

$\lambda \rightarrow$ average failure rate.

$R \rightarrow$ Reliability.

Thus the reliability of a device decreases exponentially with time.

Redundancy :

In a Satellite, many devices are used, Each with a different "mean time before failure (MTBF)" and failure of one device may cause failure of a complete Subsystem. If we incorporate redundant devices, the Subsystem can continue to function correctly.

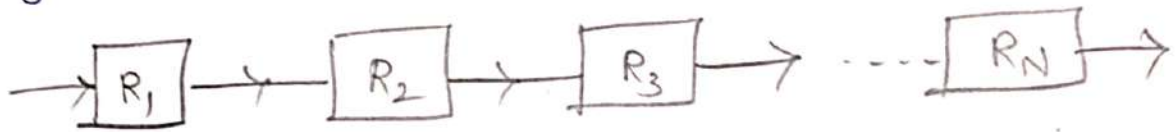


fig: Redundancy Series Connection.

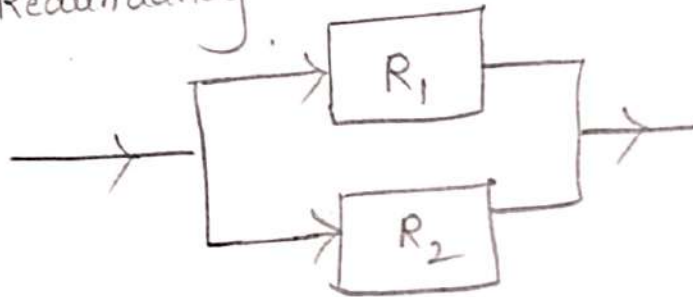


fig: Redundancy Parallel Connection.

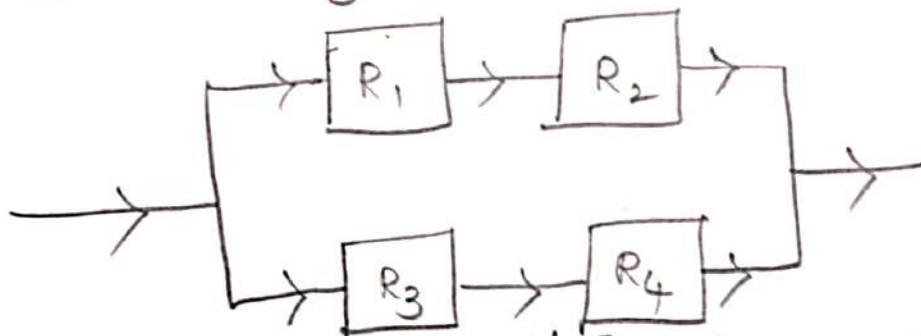


fig: Redundancy Series / Parallel connection

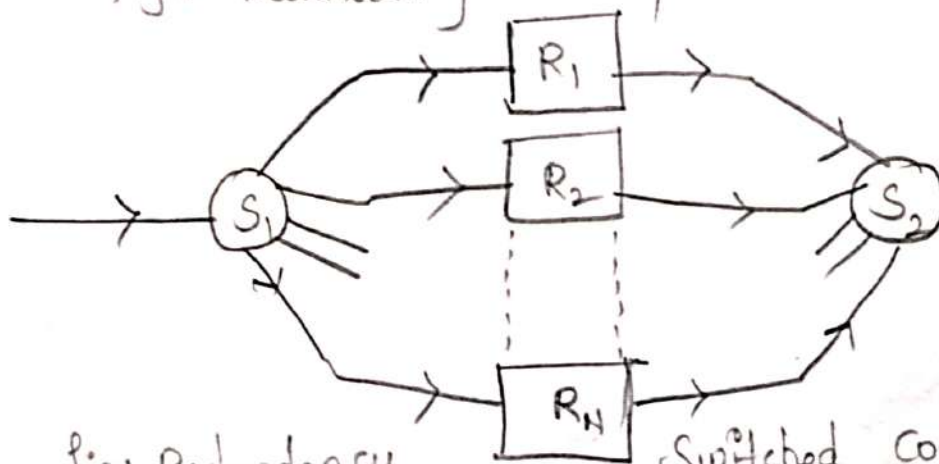


fig: Redundancy Switched Connection

The Switched Connection arrangement is also referred to as "ring redundancy".

UNIT - III

Part - I

Basic Transmission Theory:

* The calculation of the power received by an Earth Station from a Satellite transmitter is fundamental to the understanding of Satellite comm's.

* We need two approaches to this calculation.

ie The use of flux density and the link Equation.

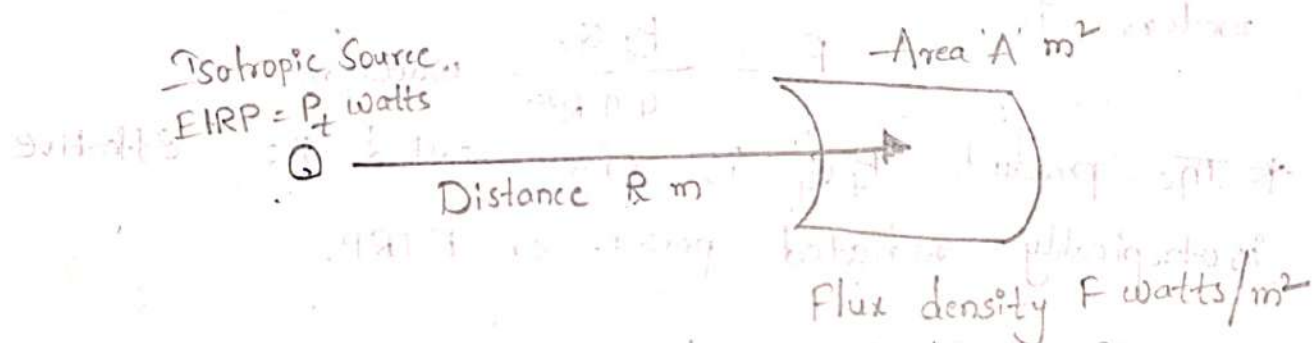


Fig: Flux density produced by an isotropic Source.

* Consider a transmitting Source, in free space, radiating a total power P_t watts uniformly in all directions. Such a Source is called isotropic.

* At a distance R meters from the isotropic Source transmitting RF power P_t watts, the flux density crossing the surface of a sphere with radius R is given by

$$F = \frac{P_t}{4\pi R^2} \text{ watt/m}^2$$

* All real antennas are directional and radiate more power in some directions than in others.

* Any real antenna has a gain $G(\theta)$, defined as the ratio of power per unit solid angle in a direction θ

$$G(\theta) = \frac{P(\theta)}{P_o / 4\pi}$$

where $P(\theta)$ is the power radiated per unit solid angle by the antenna.

$P_0 \rightarrow$ total power radiated by the antenna.

$G(\theta) \rightarrow$ gain of the antenna at an angle ' θ '.

* For a transmitter with o/p P_t watts driving a lossless antenna with gain G_t , the flux density in the direction of the antenna boresight at distance ' R ' meters is

$$F = \frac{P_t G_t}{4\pi R^2} \text{ watts/m}^2$$

* The product ' $P_t G_t$ ' is often called the "Effective isotropically radiated power." or EIRP.

Isotropic Source
EIRP = $P_t G_t$ watts

Incident flux density ' F '

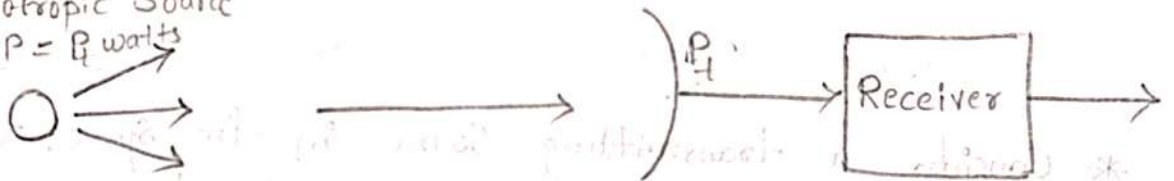


fig: Power received by an ideal antenna with area ' A_m^2 '

* If we had an ideal receiving antenna with an aperture area of $A \text{ m}^2$, we would collect power ' P_r ' watts given by

$$P_r = F \times A \text{ watts.}$$

* The effective aperture ' A_e ' of an antenna is given

by

$$A_e = \eta_A A_r$$

$\eta_A \rightarrow$ aperture Efficiency.

$A_r \rightarrow$ receiving area.

* A fundamental relationship in antenna theory is that the gain and area of an antenna are related by

$$G_r = \frac{4\pi A_e}{\lambda^2}$$

where $\lambda \rightarrow$ wavelength (in meters) at the freqⁿ of operation

$$A_e = \frac{G_r \lambda^2}{4\pi}$$

*
$$P_r = \frac{P_t G_t G_r}{\left(\frac{4\pi R}{\lambda}\right)^2} \text{ watts.}$$

* This Expression is known as the "link Equation", and it is essential in the calculation of power received in any radio link.

* The term $\left[\frac{4\pi R}{\lambda}\right]^2$ is known as "path loss", L_p . It is not a loss in the sense of power being absorbed.

$$\therefore \text{Power received} = \frac{\text{EIRP} \times \text{Receiving antenna gain}}{\text{Path loss}} \text{ watts.}$$

* In Communication Systems, decibel quantities are commonly used to simplify Equations.

* In decibel terms,

$$P_r = \text{EIRP} + G_r - L_p \text{ dB watt}$$

where

$$\text{EIRP} = 10 \log_{10} (P_t G_t) \text{ dB watt}$$

$$G_r = 10 \log_{10} (4\pi A_e / \lambda^2) \text{ dB}$$

$$\text{path loss } L_p = 10 \log_{10} \left[\left(\frac{4\pi R}{\lambda} \right)^2 \right] = 20 \log_{10} \left(\frac{4\pi R}{\lambda} \right) \text{ dB.}$$

* We will need to take account of a more complex situation in which we have losses in the atmosphere due to attenuation by oxygen, water vapor and rain, losses in the antennas at each end of the link.

$$\therefore P_r = EIRP + G_r - L_p - L_a - L_{ta} - L_{ra} \text{ dB watts.}$$

where L_a = attenuation in atmosphere

L_{ta} = losses associated with transmitting antenna.

L_{ra} = losses associated with receiving antenna.

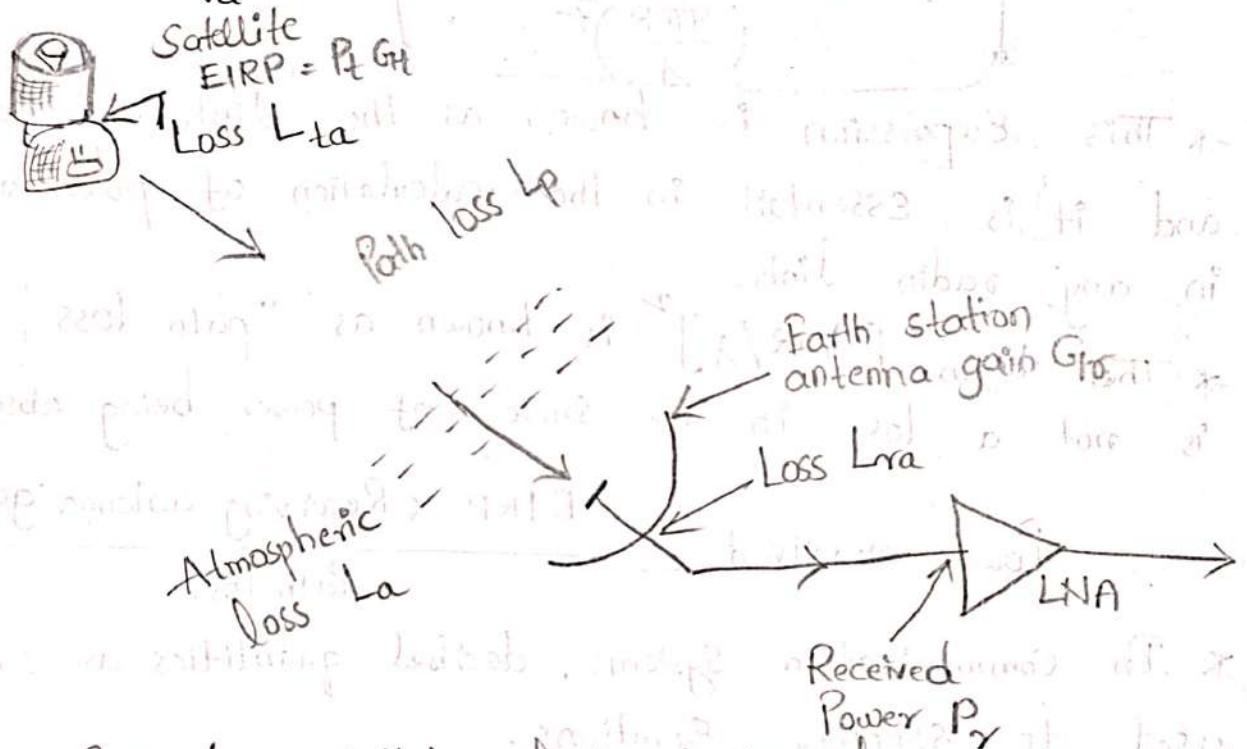


fig: A Satellite link. LNA, low noise amplifier.

System Noise Temperature and G/T Ratio : —

Noise Temperature : —

* Noise temperature is a useful concept in comm's receivers, since it provides a way of determining how much thermal noise is generated by active and passive devices in the Rxing Sys.

* At microwave frequencies, a body with a physical temperature, T_p degrees kelvin, generates electrical noise over a wide bandwidth.

* The noise power is given by

$$P_n = k T_p B_n$$

where k = Boltzmann's Constant = $1.39 \times 10^{-23} \text{ J/K} = -228.6 \text{ dBW/K}$

T_p = Physical temperature of source in kelvin degrees.

B_n = noise bandwidth in which the noise power is measured, in hertz.

* The term ' kT_p ' is a noise power spectral density.

* In Satellite Communication Systems we are always working with weak signals (because of the large distance involved) and must make the noise level as low as possible to meet the C/N ratio requirements.

* Noise temperatures increase with frequency.

* To determine the performance of a Receiving System we need to be able to find the total thermal noise power.

* We do this by determining the System noise temperature, T_s .

* If the overall End-to-End gain of the receiver is G_{rx} and its narrowest bandwidth is B_n Hz, the noise power at the demodulator i/p is

$$P_{no} = k T_s B_n G_{rx} \text{ watts.}$$

where G_{rx} is the gain of the receiver from RF input to demodulator input.

* The noise power referred to the input of the receiver is P_n where

$$P_n = k T_s B_n \text{ watts.}$$

* Let the antenna deliver a signal power P_r watts to the receiver RF input. The signal power at the demodulator input is $P_r G_{rx}$ watts.

* The carrier-to-noise ratio at the demodulator is given by

$$\frac{C}{N} = \frac{P_r G_{rx}}{k T_s B_n G_{rx}} = \frac{P_r}{k T_s B_n}$$

Calculation of System Noise Temperature : —

* The below fig. Shows a Simplified Communications receiver with an RF amplifier and single freqⁿ conversion, from its RF input to the IF output. This is the form used for all radio receivers, known as Superheterodyne.

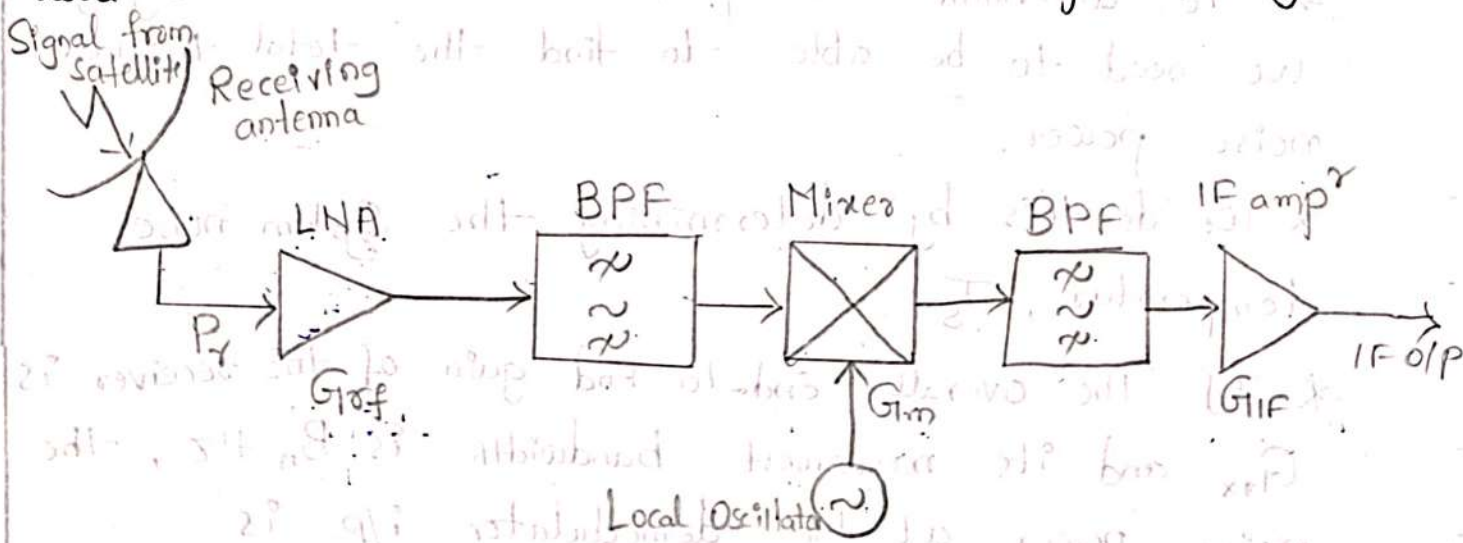


fig: Simplified Earth Station receiver.

* The Superhet receiver has three main subsystems :
 a front end (RF amp^r, mixer and local oscillator) an
 IF amp^r and a demodulator.

* The RF amp^r in a Satellite comm's receiver must
 generate as little noise as possible, so it is called
 a 'low noise amplifier' or 'LNA'.

* The mixer and local oscillator form a frequency conversion
 stage that downconverts the RF signal to a fixed
 intermediate frequency (IF), where the signal can be
 amplified and filtered accurately.

* Many Earth Station receivers use the double Superhet
 Configuration, which has two stages of freqⁿ conversion.

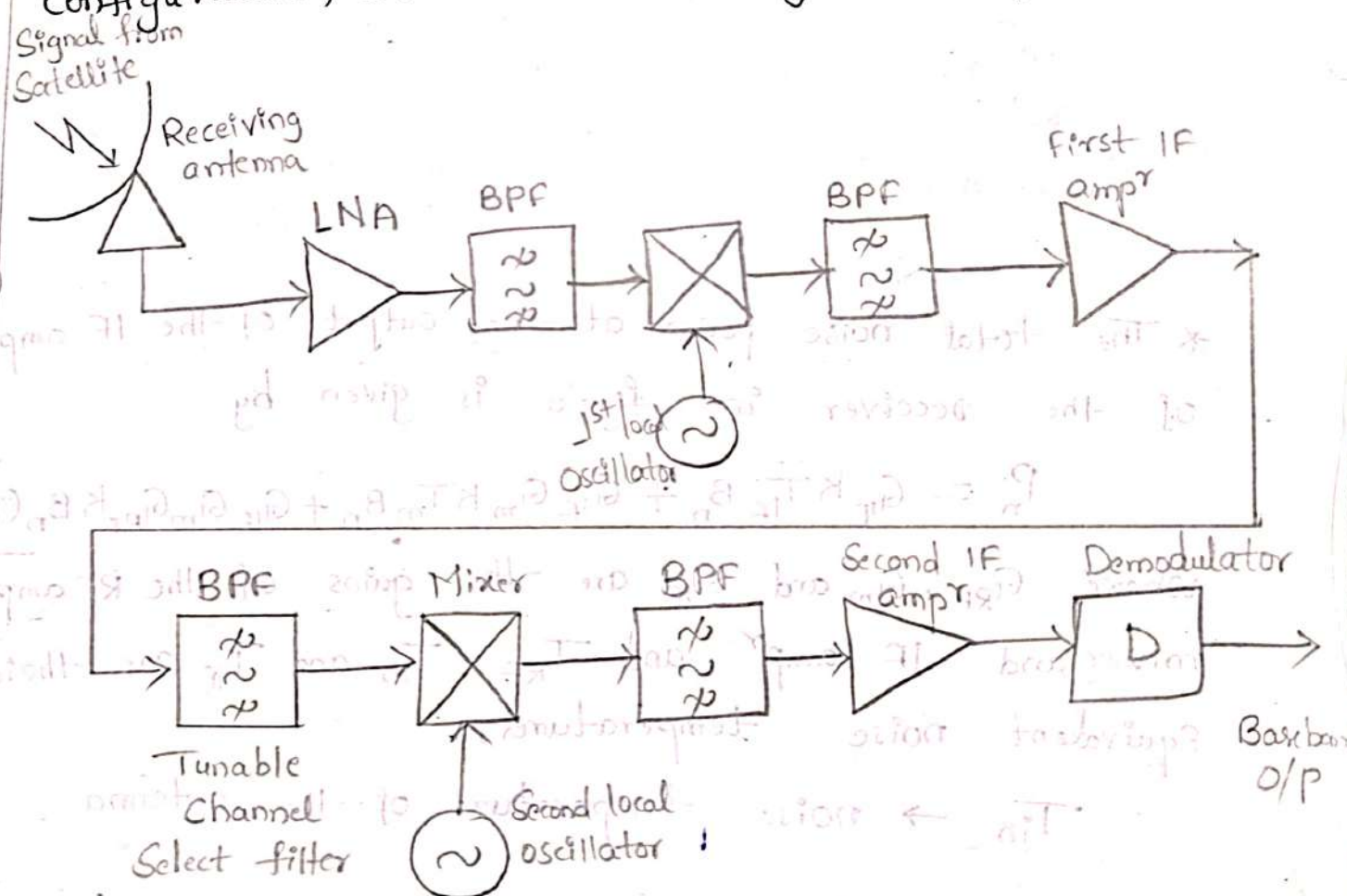
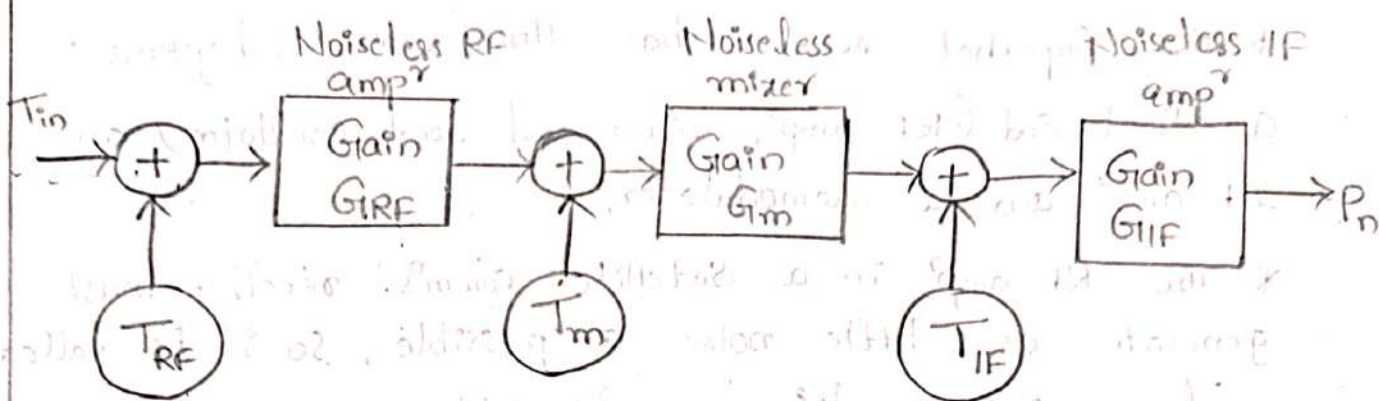


fig: Double Conversion Earth Station receiver.



Equivalent noise Sources

fig: (a) Noise model of receiver

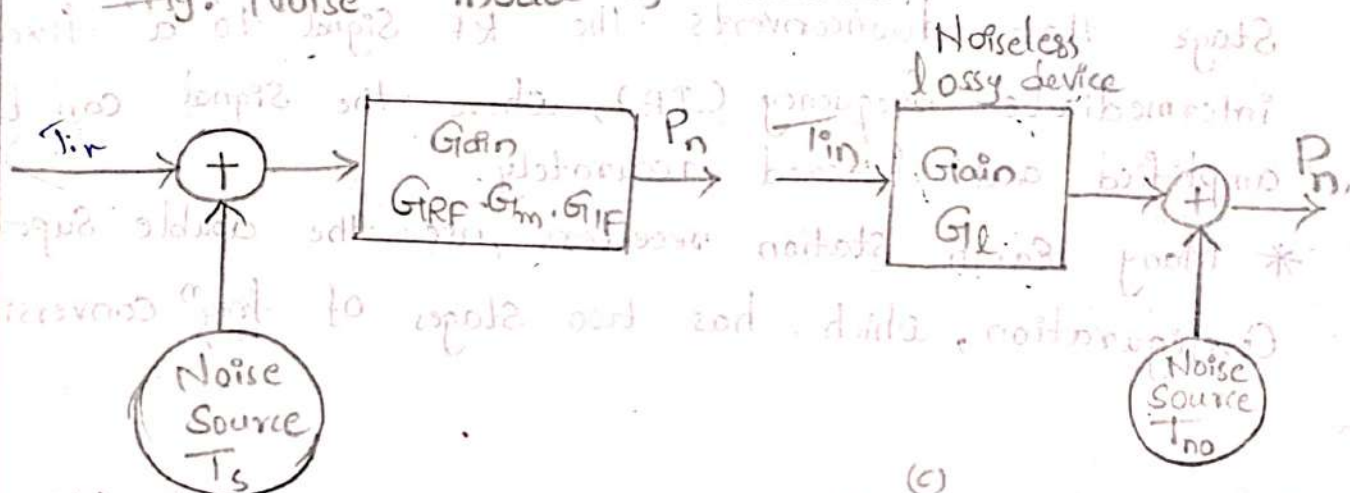


fig: (b) Noise model for no loss device fig: (c) Noise model for lossy device

* The total noise power at the output of the IF amp^r of the receiver in fig: a is given by

$$P_n = G_{IF} K T_{IF} B_n + G_{IF} G_m K T_m B_n + G_{IF} G_m G_{RF} K B_n (T_{RF} + T_{in}) \quad (1)$$

where G_{RF} , G_m and G_{IF} are the gains of the RF amp^r, mixer and IF amp^r and T_{RF} , T_m and T_{IF} are their Equivalent noise temperatures.

$T_{in} \rightarrow$ noise temperature of the antenna.

* Eqn (1) can be rewritten as

$$P_n = G_{IF} G_m G_{RF} \left[\frac{(k T_{IF} B_n)}{(G_{RF} G_m)} + \frac{(k T_m B_n)}{G_{RF}} + (k B_n (T_{RF} + T_{in})) \right]$$

$$= G_{IF} G_m G_{RF} k B_n \left[(T_{RF} + T_{in}) + \frac{T_m}{G_{RF}} + \frac{T_{IF}}{G_{RF} G_m} \right] \quad (2)$$

* The single source of noise in fig'b' with noise temperature T_s generates the same noise power ' P_n ' at its o/p if

$$P_n = G_{IF} G_m G_{RF} k T_s B_n \quad (3)$$

* The noise power at the o/p of the noise model in fig'b' will be the same as the noise power at the o/p of the noise model in fig'a' if

$$k T_s B_n = k B_n \left[(T_{in} + T_{RF} + T_m / G_{IF} + T_{IF} / G_m G_{RF}) \right]$$

$$T_s = \left[T_{in} + T_{RF} + \frac{T_m}{G_{RF}} + \frac{T_{IF}}{G_m G_{RF}} \right]$$

where $T_s \rightarrow$ System noise temperature.

* The noise model for an equivalent output noise source is shown in fig'c', and produces a noise temperature T_{no} given by

$$T_{no} = T_p (1 - G_L)$$

where $G_L \rightarrow$ linear gain of the attenuating device.

$T_p \rightarrow$ Physical temperature in degrees kelvin

$$G_L = 10^{A/10}, \quad A \rightarrow \text{attenuation}$$

Noise Figure and Noise Temperature :

* Noise figure is frequently used to specify the noise generated within a device. The operational noise figure (NF) is defined by the following formula

$$NF = \frac{(S/N)_{in}}{(S/N)_{out}}$$

* Because noise temperature is more useful in satellite commⁿ systems, it is best to convert noise figure to noise temperature. The relationship is

$$T_s = T_0 (NF - 1)$$

$T_0 \rightarrow$ reference temperature used to calculate the standard noise figure.

G/T Ratio for Earth Stations :

* The link Equation can be rewritten in terms of (C/N) at the Earth station

$$\frac{C}{N} = \left[\frac{P_t G_t G_r}{K T_s B_n} \right] \left[\frac{1}{4\pi R} \right]^2 = \left[\frac{P_t G_t}{K B_n} \right] \left[\frac{1}{4\pi R} \right]^2 \left[\frac{G_r}{T_s} \right]$$

* Thus $\frac{C}{N} \propto \frac{G_r}{T_s}$

* Since increasing $\frac{G_r}{T_s}$ increases the received $\frac{C}{N}$ ratio.

Design of Downlinks: —

- * The downlink of any Satellite Commⁿ System must be designed with the following Objectives.
- * To guarantee continuity of the link for a specified percentage of the time.
- * To carry the maximum no. of channels at a minimum Capital and maintenance cost.
- * The first objective requires a minimum (C/N) ratio at the receiver input for 99.9 percentage of time and will almost certainly require a modulation technique that gives a $(\frac{S}{N})$ improvement over the receiver.
- * The Second objective brings in series of compromises b/w antenna cost, receiver cost, tracking accuracy, station manning, modulation and multiple access techniques.

Rain Effects on Downlink: —

Attenuation and increase of sky noise: —

- * All Satellite Commⁿ links are affected by rain attenuation.
- * When it rains, 0.01% of the time, the receiving Earth Station experiences attenuation of 5 dB. Path attenuation from atmosphere is then 5.5 dB.
(0.5 dB corresponds to antenna temperature).
- * Sky temperature is then $270(1 - 10^{-5.5/10}) = 194K$.
- * In 6/4 GHz band the effect of rain on the link is small.
- * In the 14/11 GHz (Ku) band and 30/20 GHz (Ka) band rain attenuation becomes significant.

* Satellite links are designed to achieve reliabilities of 99.5 to 99.99%, averaged over a year.

* $(\frac{C}{N})$ ratio in the receiver will fall below minimum permissible value for proper operation of link for b/w 0.5 and 0.01% of the year. This is called link outage.

* C-band links are designed to have 99.99% reliability because rain attenuation rarely exceeds 1 or 2dB.

Downlink Budgets: —

* A link budget is a tabular method for evaluating the received power and noise power in a radio link.

* Since it is usually impossible to design a satellite link at the first attempt, link budgets make the task much easier because, once a link budget has been established, it is easy to change any of the parameters and recalculate the result.

* The link budget determines the antenna size to deploy, power requirements, link availability, bit error rate, as well as the overall customer satisfaction with the satellite service.

* Link budget simplifies C/N ratio calculations.

* The link budget must be calculated for an individual transponder, and must be recalculated for each of the individual links.

Link Budget Parameters: —

1. Transmitter power at the antenna
2. Antenna gain compared to isotropic radiator.

3. EIRP
4. Free Space path loss
5. System noise temperature
6. Figure of merit for receiving system
7. Carrier to thermal noise ratio
8. Carrier to noise density ratio
9. Carrier to noise ratio.

Downlink Power budget : —

- * P_t - Satellite Transponder o/p power, 20W — 13dB
- * B_o - Transponder o/p backoff — 2dB
- * G_t - Satellite antenna gain, on axis 20dB
- * G_r - Earth Station antenna gain 49.7dB
- * L_p - Free Space path loss at 4 GHz — 196.5dB
- * L_{ant} - Edge of beam loss for Satellite antenna — 3dB
- * L_a - clear atmospheric — 0.2dB
- * L_m - Other losses — 0.5dB
- * P_r - Received Power at Earth Station — 119.5 dBW

Downlink noise power budget in clear air : —

- * k = Boltzmann's constant — 228.6 dBW/K/Hz
- * T_s = System noise temperature, 75K 18.8dBK
- * B_n = Noise bandwidth 27 MHz 74.3 dBHz
- * N = Receive noise power — 135.5 dBW

Receiving C-band Earth Station : —

- * Downlink Freqⁿ 4 GHz
- * Antenna gain on axis at 4GHz 49.7dB
- * Receiver IF bandwidth 27 MHz
- * Receiving System noise temperature 75K

Downlink Received Power : —

* The calculation of carrier to noise ratio in a satellite link is based on eqⁿs for received signal power ' P_r ' & receiver noise power.

$$P_r = EIRP + G_r - L_p - L_a - L_t - L_r \quad (\text{dBW})$$

EIRP $\rightarrow$ Effective radiated Power

G_r $\rightarrow$ Receiving antenna gain

L_p $\rightarrow$ Path loss

L_a $\rightarrow$ Atmospheric attenuation loss

L_t $\rightarrow$ Transmitting antenna losses

L_r $\rightarrow$ Receiving antenna losses.

Downlink Noise Power : —

* A receiving terminal with a system noise temperature $T_s K$ and a noise bandwidth $B_n \text{ Hz}$ has a noise power P_n referred to the o/p terminals of the antenna where:

$$P_n = K T_s B_n \text{ watts.}$$

* The receiving system noise power is usually written in decibel units as

$$N = K + T_s + B_n \quad \text{dB watts.}$$

where $K \rightarrow$ Boltzmann's constant (-228.6 dBW/K/Hz)

$T_s \rightarrow$ System noise temperature in dBK

$B_n \rightarrow$ noise bandwidth of the receiver in dBHz

Uplink Design : —

* Earth Station transmitter power is set by the power level required at the i/p of the transponder. This can be done in one of two ways :

- (i) Achieving a specific flux density at the satellite
 - (ii) Achieving a specific power level at the i/p of transponder : —
- * This method is adopted as it helps finding the uplink C/N ratio.

* The uplink design is easier than the downlink design in many cases :

- 1) An accurately specified carrier power must be presented at the satellite transponder.
- 2) Use of higher power transmitters at Earth Station is possible.

Finding $(C/N)_{up}$: —

* The uplink C/N ratio be calculated in the bandwidth of the receiver.

* Noise power at the transponder i/p is N_{xp} watt.

$$\text{where, } N_{xp} = k + T_{xp} + B_n$$

* Power received at the i/p of transponder is

$$P_{xp} = P_t + G_t + G_r - L_p - L_{up}$$

where, $P_t G_t$ is the uplink Earth Station EIRP

$G_r \rightarrow$ Satellite antenna gain,

$L_p \rightarrow$ Path loss.

$L_{up} \rightarrow$ all uplink losses other than path loss.

* value of $(C/N)_{up}$ at the LNA i/p of satellite receiver is given by:

$$C/N = P_{xp} - N_{xp}$$

* Finding the Earth Station Transmitter o/p power (P_t) :-

* When C/N ratio is specified / known, the required transmit power at the Earth Station can be found from above Eqⁿ.

* It can also be calculated from the o/p power of the transponder and the transponder gain when these parameters are known.

$$P_{rxp} = P_{sat} - G_{xp} - BO_o$$

P_{sat} → Saturated power of the transponder in dBw.

G_{xp} → Gain of the transponder in dB.

BO_o → output back off in dB.

* Use this value in $P_{rxp} = P_t + G_t + G_r - L_p - L_{up}$ to find ' P_t '.

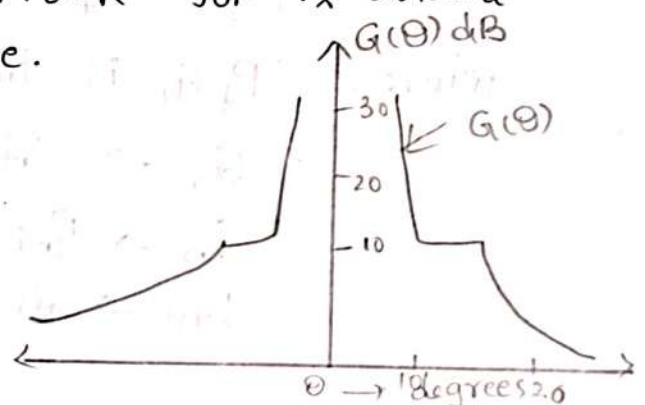
Choice of EIRP for Uplink :-

* For the same P_{rxp} , one has choice to increase transmit EIRP by either transmit power ' P_t ' or antenna gain ' G_t '.

* But, this is not always a trade-off b/w ' P_t ' & antenna size.

* There is a specification by ITU-R for Tx antenna pattern to minimize interference.

fig: Antenna Sidelobe Specifications.



Uplink Power Control (UPC) :-

- * UPC can be used to combat uplink rain attenuation.
- * The transmitting Earth Station monitors a beacon signal from the satellite, and watches for reduction in power indicating rain fading on the downlink.
- * Automatic monitoring and control of transmitted uplink power is used in uplink Earth Station to maintain the uplink C/N ratio in the satellite transponder during the periods of rain attenuation.

Design for Specified C/N :-

- * The complete satellite circuit consists of an uplink & downlink.
- * When more than one (C/N) ratio is present in the link, then overall (C/N) ratio is

$$(C/N)_0 = \frac{1}{\left[\frac{1}{(C/N)_1} + \frac{1}{(C/N)_2} + \dots + \frac{1}{(C/N)_n} \right]}$$

$$(C/N)_0 = \frac{1}{\left[\frac{1}{(C/N)_{up}} + \frac{1}{(C/N)_{dn}} \right]}$$

- * If there are intermodulation products as a result of non-linear transfer characteristic of the transponder, then the carrier to interference ratio should also be considered.

$$(C/N)_0 = \frac{1}{\left[\frac{1}{(C/N)_{up}} + \frac{1}{(C/N)_{dn}} + \frac{1}{(C/I)} \right]}$$

* The overall (C/N) i.e. $(C/N)_o$ can be determined easily using the following rules.

* ① If the (C/N) values are equal, $(C/N)_o$ is 3dB lower than either value.

② If one $[C/N]$ value is 10dB smaller than the other, $[C/N]$ is 0.4dB lower than the smaller of the $[C/N]$ values.

③ If one $[C/N]$ value is 20dB or very greater than the other $[C/N]$ value then $[C/N]_o$ will be less than or equal to smaller $[C/N]$ value.

Overall $(C/N)_o$ with uplink and Downlink Attenuation: —

* Most Satellite links are designed with link margins to allow for attenuation that may occur in the link or rise in noise power caused by interference.

* The effect of a change in the uplink (C/N) ratio has a different impact on $(C/N)_o$ depending on the type of the transponder.

Linear Transponder:

$$[P_{out}] = [P_{in}] + [G_{xp}] \text{ dBW}$$

Non linear Transponder:

$$[P_{out}] = [P_{in}] + [G_{xp}] - \Delta G \text{ dBW}$$

Regenerative Transponder: $[P_{out}] = \text{Constant dBW}$

P_{in} → Power at the transponder i/p (delivered by Satellite's Rx antenna)

P_{out} → Power delivered by transponder to the Satellite's Rx antenna i/p

G_{xp} → Gain of the transponder, ΔG → loss of gain

Uplink and Downlink Attenuation in Rain: —

- * Rain attenuation affects uplink & downlinks differently.
- * It is usually assumed that rain attenuation occurs on either the downlink or the uplink, not on both at the same time.

$(C/N)_0$ uplink: —

- * Rain attenuation on the uplink path to the Satellite reduces the power at the Satellite receiver i/p & thus reduces $(C/N)_0$ up in direct proportion to the attenuation on the link.

- * If the transponder is of linear type,

$$[C/N]_{0 \text{ uplink rain}} = [C/N]_{0 \text{ clear air}} - [A]_{up}$$

- * If the transponder is non-linear type,

$$[C/N]_{0 \text{ uplink rain}} = [C/N]_{0 \text{ clear air}} - [A]_{up} + [\Delta G]$$

- * For regenerative transponder, or AGC,

$$[C/N]_{0 \text{ uplink rain}} = [C/N]_{0 \text{ clear air}}$$

Downlink Attenuation & $(C/N)_0$ dn: —

- * The Earth Station receiver noise temperature can change significantly when rain is present in the downlink path from the Satellite.

- * The Sky noise temperature can increase to close to the physical temperature of individual rain drops in heavy rain.

$$[C/N]_{\text{down rain}} = [C/N]_{\text{down clear air}} - [-A]_{\text{rain}} + [\Delta N]_{\text{rain}}$$

$$[C/N]_0 = \frac{1}{\left[\frac{1}{(C/N)_{\text{down rain}}} + \frac{1}{(C/N)_{\text{up}}} \right]}$$

UNIT - III, Part - II
Multiple Access

3-1

Introduction : —

* Multiple access is the technique of sharing or dividing Channel (transmission medium) among number of stations.

Three most commonly used multiple access methods are

- 1) Frequency Division Multiple Access (FDMA)
- 2) Time Division Multiple Access (TDMA)
- 3) Code Division Multiple Access (CDMA)

Multiple Access has many advantages : —

- 1) Increases Efficiency for provider
- 2) Reduces costs to user
- 3) Enhances network control
- 4) Enables more flexible designs.

Frequency Division Multiple Access (FDMA) : —

In FDMA the available bandwidth is divided into M number of smaller frequency bands called subbands. Each station transmits its information continuously on an assigned subband. To reduce co-channel interference guard band between two subbands is provided.

If W = Available bandwidth of channel

R = Data rate of channel

M = Number of stations.

Then the transmit rate of each station is R/M .

* For analog communication (voice and video), frequency modulation is used in the satellites. Several users share satellite link so that many signals from the earth station are transmitted. These FM signals are in FDM. For digital modulation, the satellite link uses time division multiplexing (TDM).

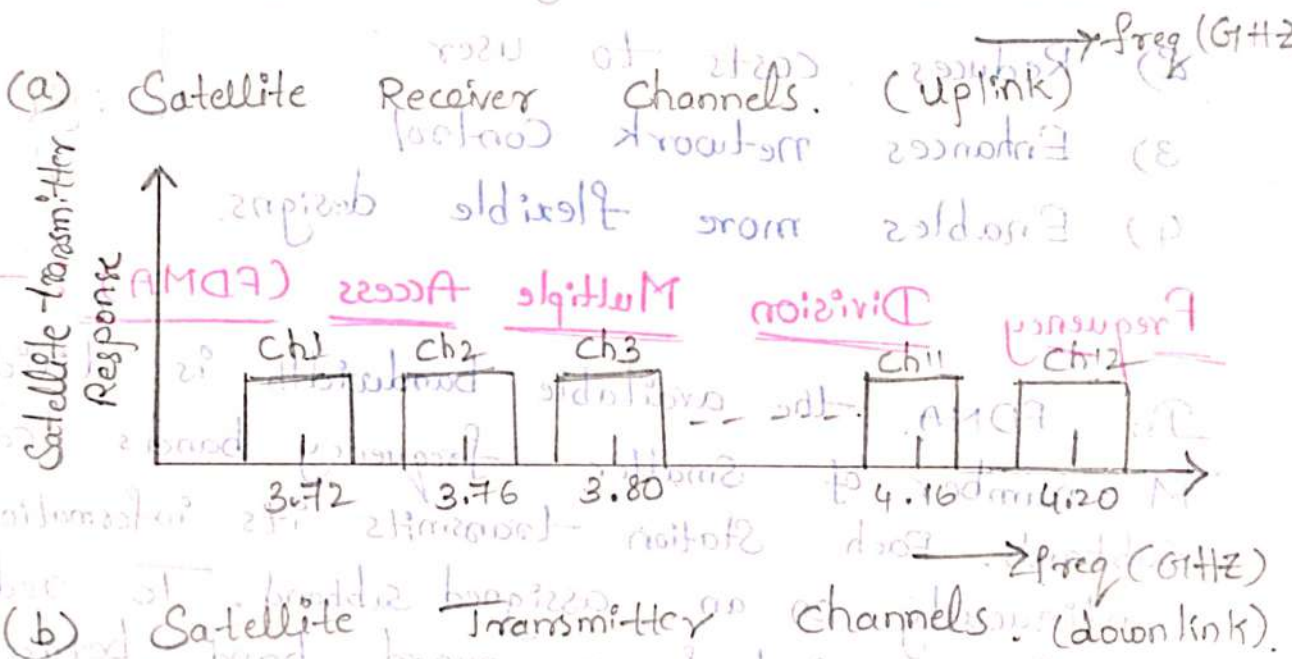
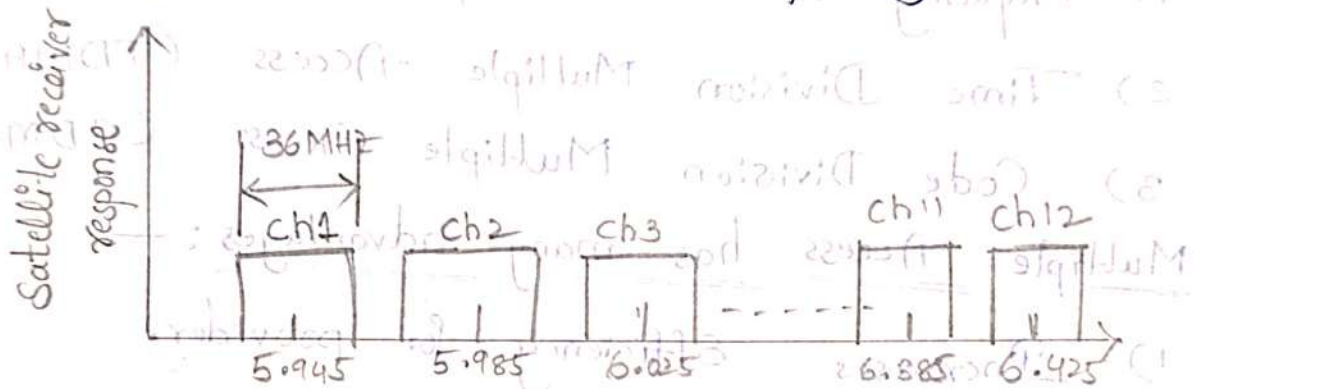


fig: Frequency division multiplexing for C-band Satellite

Fig 1 (a) Shows that the uplink frequency range of 5.925 MHz to 6.425 MHz of C-band has 12 channels. Each channel is allotted the bandwidth of 36 MHz with 4 MHz spacing between the channels. Thus 12 channels take $(36 + 4 = 40) \times 12 = 480$ MHz bandwidth of the satellite. Remaining 20 MHz is used for transmission of Command and Control of telemetry channel.

The transponder converts the uplink frequencies to downlink frequencies. The channels has same bandwidth of 36 MHz and spacing of 4 MHz as shown in fig (b).

The advantage of frequency division multiplexing is that the power required for the transmitter at Satellite as well as Earth Station is dependent on the number of channels being transmitted.

The signal to noise ratio of frequency modulation is improved, but it needs wider bandwidth.

Forms of FDMA: —

Two forms of FDMA are possible

- 1) Fixed - assignment multiple access (FAMA)
- 2) Demand - assignment multiple access (DAMA).

FDMA: The assignment of capacity within the overall Satellite channel is distributed in a fixed manner among multiple stations.

DAMA: The capacity assignment is changed as needed to respond optimally to demand changes among the multiple stations.

* The number of sub-channels provided within a Satellite channel via FDMA is limited by 3 factors.

1) Thermal noise

2) Intermodulation noise

3) Cross talk.

Intermodulation (IM): —

* When two or more signals are present in a channel, the signals can "mix" together to form some unwanted products, this process is called Intermodulation.

* With three signals, ω_1 , ω_2 and ω_3 present in a channel, inter-modulation products can be second-order, third-order, fourth order etc.

Order of IM Products: —

- Second-order is $\omega_1 + \omega_2$, $\omega_2 + \omega_3$, $\omega_1 + \omega_3$

- Third-order is $\omega_1 + \omega_2 + \omega_3$, $2\omega_1 - \omega_2$, $2\omega_2 - \omega_1$, ...

Usually, only the odd-order IM products fall within the pass-band of the channels.

Intermodulation Example :

* There are two 10 MHz signals at 6.01 GHz and 6.02 GHz centered in a 72 MHz transponder.

* 2-IM Product is at 12.03 GHz.

3-IM Products are at $[2(6.01) - 6.02] = 6.00 \text{ GHz}$

and $[2(6.02) - 6.01] = 6.03 \text{ GHz}$

Third-order IM is important because third-order IM products often have frequencies close to the signals that generate the intermodulation.

Calculation of C/N with Intermodulation :

Intermodulation between carriers in a nonlinear transponder adds unwanted products. For wideband carriers, the behavior of the IM products will be noise.

The overall $(C/N)_o$ ratio with Intermodulation is given by

$$(C/N)_o = \frac{1}{\left[\frac{1}{(C/N)_{up}} + \frac{1}{(C/N)_{dn}} + \frac{1}{(C/N)_{IM}} \right]}$$

$(C/N)_{up}$ = uplink C/N ratio

$(C/N)_{dn}$ = downlink C/N ratio

$(C/N)_{IM}$ = Intermodulation C/N ratio.

Time Division Multiple Access (TDMA) :-

TDMA is a method of time-division multiplexing of digitally modulated carriers. In TDMA, each station transmits digitally modulated carriers during a preassigned time slots, making use of the entire transmission channel during its transmission. The stations are synchronized such that only one carrier is present on the channel at any given time. Sufficient guard bands are also provided to ensure collision avoidance.

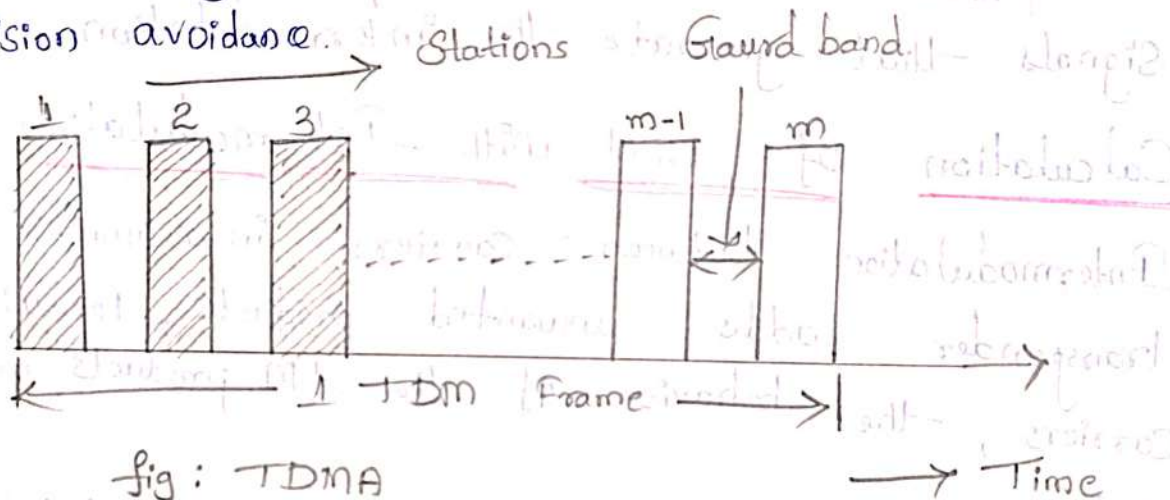


Fig: TDMA

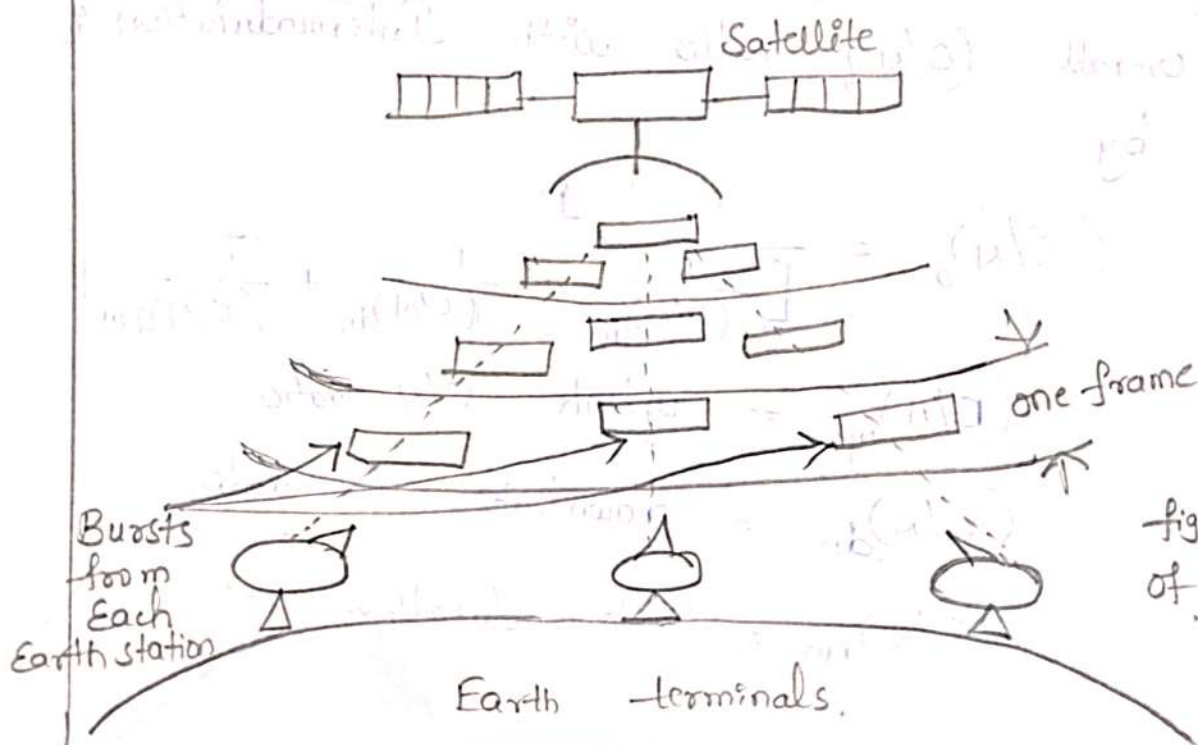


Fig: Illustration of TDMA with 3 Earth stations

At any time, the amplifier in the transponder amplifies only one carrier signal. Hence intermodulation is absent. TDMA is mainly suitable for transmission of digitally modulated signals.

Capacity and Efficiency of TDMA:

Time allocated for data transmission

$$T_d = \left[T_{\text{frame}} - \sum_i (T_p + T_g) \right] \approx T_{\text{frame}} - N(T_p + T_g)$$

$T_p \Rightarrow$ Preamble Time

$T_g \Rightarrow$ Guard band Time

Efficiency $\eta = \frac{T_d}{T_{\text{frame}}} \times 100 \%$

TDMA Frame Structure:

In TDMA, a preamble or reference burst is transmitted at the beginning of every TDMA frame. The reference burst is normally transmitted by one of the Earth stations to designate it as master station.

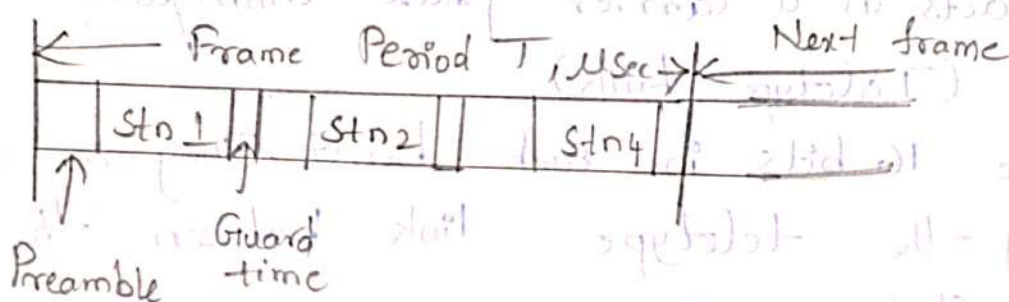


Fig: TDMA frame with four transmitting Earth stations.

CTBR	UW	TTY	SC	VOW	VOW	Data from different channels
------	----	-----	----	-----	-----	------------------------------

Preamble or reference burst

Data from different Earth Stations

Fig: TDMA frame by some Earth station

Operating in TDMA through Intelsat Satellite.

CTBR: — (Carrier and Bit Timing Recovery)

It enables the receiving Earth station to recover remainder of the burst. CTBR contains the sequence of predetermined signals. These signals are used for synchronization of the bit clock.

UW: — (Unique Word)

Length of the unique word is 20 to 48 bits. The unique word serves following purposes:

- i) Unique word acts as a station identifier
- ii) It provides start of frame (SOF)
- iii) It acts as burst marker
- iv) It acts as a carrier phase ambiguity detector.

TTY: — (Teletype Link)

These are 16 bits in each burst. They are used to identify the teletype link between the Earth Stations.

SC :- (Service channel)

These are 16 bits. They are used for management of the TDMA system along with TTY and VOW.

Voice Order Wire :- (VOW)

This field is 64 bits. These are two fields of VOW. They are used in digital voice links between the Earth Stations.

* The remaining part of the TDMA frame consists of data from various channels.

TDMA Synchronization :-

Successful operation of TDMA system depends on network wide synchronization.

With demodulate Burst PSK carrier, it must recover carrier and bit timing in starting parts inversion recovery of every frame.

Every Burst Signal should be timed. This kind of synchronization can prevent frames which from all Earth Stations to be overlapped in satellite repeater, which is called frame synchronization.

* To minimize guard bands, Synchronization must be used.

Methods of Frame Synchronization

1) Synchronization of global beam : —

Every transmitting station acquires the timing error by checking the received signal sequence.

2) Synchronization of feedback : —

After having checked the timing error, the receiving station or reference station sends the frame position error information to sending station by means of control channel.

3) Synchronization of open loop : —

Confirming transmitting timing by computing or measuring the distance from every station to satellite.

Two types of TDM-A Synchronization can be used :

1) Open loop

2) Closed loop.

Open loop : —

Each earth station maintains an accurate clock, independent of other earth stations. Open loop Synchronization is easy to implement. Guard band in the order of $100\mu\text{sec}$ is achieved.

Closed loop: —

These synchronizations require that every station can receive the sent frame.

Synchronization is achieved through continuous adjustment of the burst position based on real time measurements. Received burst is compared with desired T_a , and a correction $(T_m - T_m)$ is applied to the initial estimate in the next transmission.

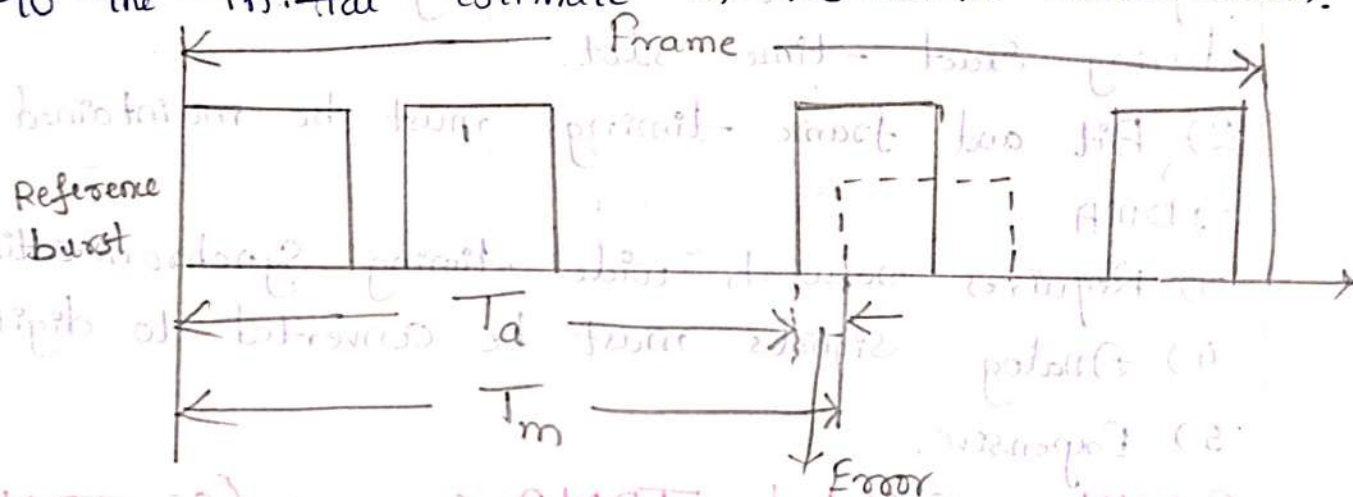


Fig: TDMA Synchronization.

Advantages of TDMA: —

- 1) At a given time only one carrier is present on the channel hence intermodulation distortion is eliminated.
- 2) TDMA transmission is separated in time domain. Processing of signal in time domain is easier.
- 3) TDMA is most efficient method of transmission because of efficient use of transmission resources.

4) TDMA can accommodate a wider range of bit rates by allowing a station to be allocated several slots. Thus TDMA is more flexible than FDMA.

5) Saturated transponder operation possible

Disadvantages of TDMA:

1) Precise Synchronization between stations is required. Transmission of every station must occur during exact time slot.

2) Bit and frame timings must be maintained by TDMA

3) Requires network-wide timing synchronization.

4) Analog signals must be converted to digital.

5) Expensive.

Satellite - Switched TDMA : — (SS-TDMA)

A Satellite - Switched TDMA system is an efficient TDMA system with multiple spot beam operation for the uplink and downlink transmissions. The interconnection between the uplink and downlink beams is performed by a high-speed switch matrix located at the heart of the satellite.

* A SS-TDMA scheme provides a full interconnection of TDMA signals among various coverage regions by means of interconnecting the corresponding uplink and downlink beams at a switching time.

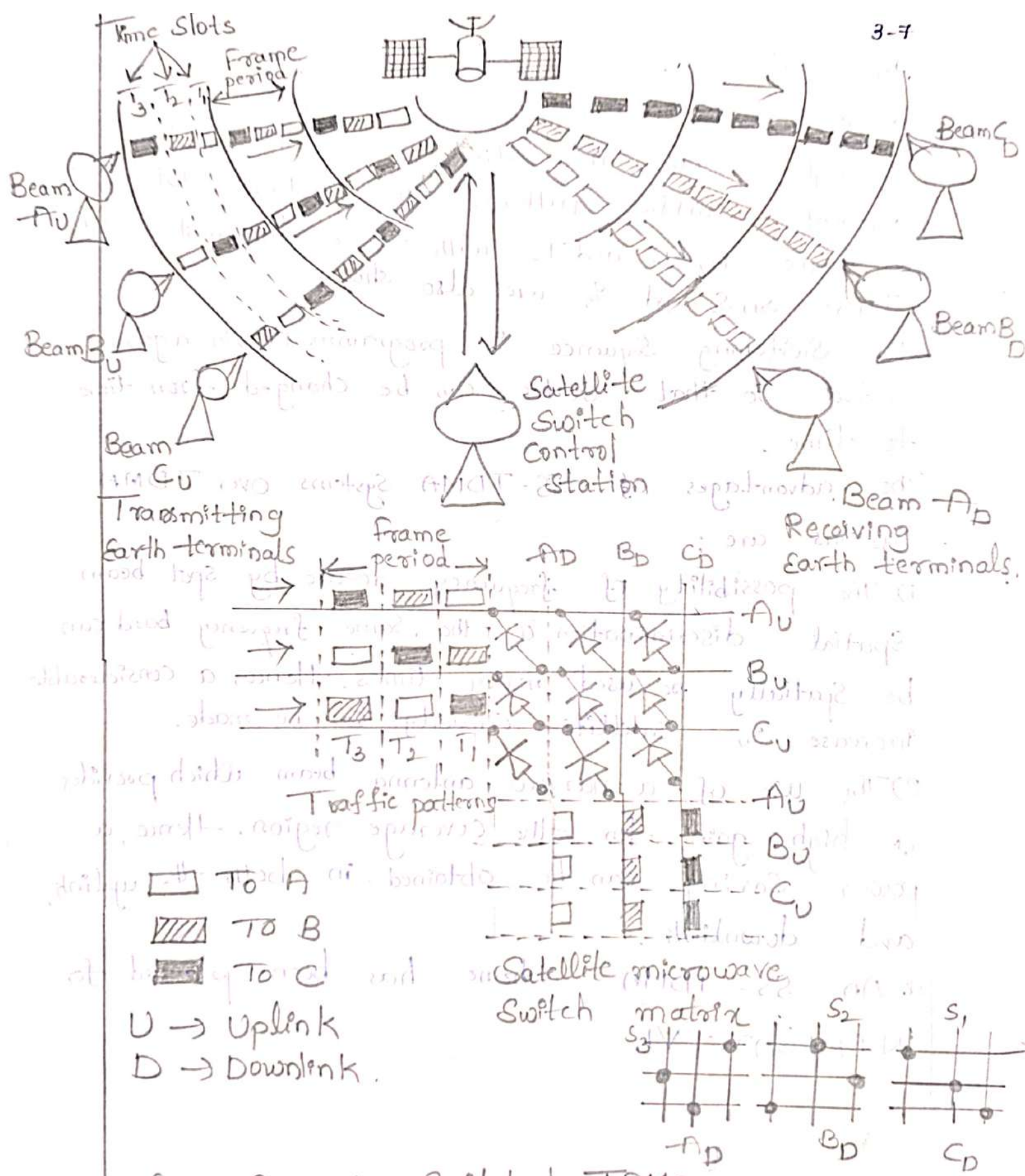


fig: Satellite Switched TDMA

The switch matrix is configured in a crossbar design in which only a single row is connected to a single column at a time. In this figure, three different traffic patterns during time slot intervals T_1 , T_2 and T_3 with three different switch states S_1 , S_2 and S_3 are also shown.

The switching sequence is programmed via a ground control so that states can be changed from time to time.

The advantages of SS-TDMA systems over TDMA systems are:

- 1) The possibility of frequency re-use by spot-beam spatial discrimination i.e. the same frequency band can be spatially re-used many times. Hence, a considerable increase in satellite capacity can be made.
- 2) The use of a narrow antenna beam which provides a high gain for the coverage region. Hence, a power saving can be obtained in both the uplink, and downlink.

*An SS-TDMA scheme has been planned for INTELSAT VI.

Code Division Multiple Access (CDMA): —

Code division multiple access (CDMA) is also called as Spread Spectrum Communication. The term "Spread Spectrum" refers to the expansion of signal bandwidth, by several orders of magnitude.

In CDMA, the transmitted signals are not discriminated by their frequency assignment (as in FDMA) nor by their time slot assignment (as in TDMA), but by a characteristic code which is superposed on the information signals. This feature has allowed CDMA to gain attention in commercial satellite communication.

CDMA was adopted in cellular mobile telephone. All concerned earth stations simultaneously share the same bandwidth and recognize the signals by various processes such as code identification.

CDMA Techniques: —

1) DSSS (Direct Sequence Spread Spectrum)

2) FHSS (Frequency hopping Spread Spectrum).

DSSS is also called pseudo-noise (PN) modulation, which is the dominant technique.

Pseudo Noise codes so called because they are not real Gaussian noise.

Features of Spread Spectrum :-

- 1) Simplified multiple access : No requirement for coordination among users.
- 2) Selective addressing capability if each station has a unique chip code sequence - provides authentication.
- 3) Interference rejection : The Spread-spectrum receiver treats the other DSSS signals as thermal noise and suppresses narrowband interference.

Direct Sequence Spread Spectrum :- (DSSS)

Direct Sequence Spread Spectrum is a modulation technique where the transmitted signal takes up more bandwidth than the information signal that is being modulated. Direct Sequence Spread Spectrum transmissions multiply the data being transmitted by a noise signal. The noise signal is the pseudo random sequence and has a frequency much higher than that of the original signal.

The polar signal $c(t)$ representing this binary sequence is the pseudo-random carrier that is used to multiply the message signal $m(t)$.

Signal $c(t)$ is a pseudorandom signal as it appears to be unpredictable though it can be generated by deterministic means.

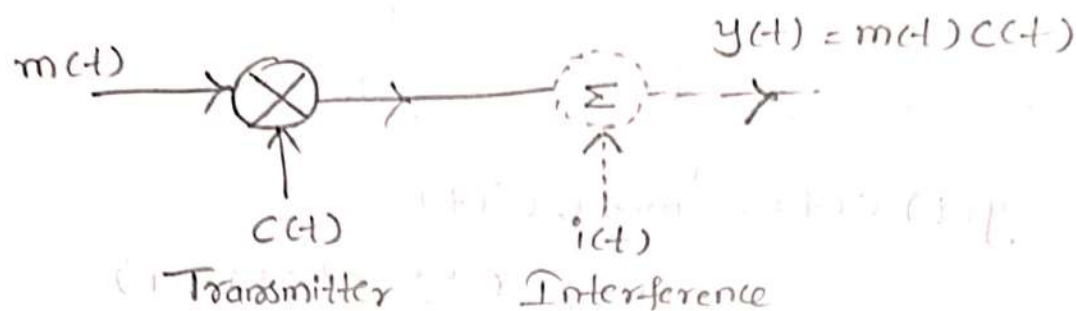


Fig: DSSS generator

The bit rate of $c(t)$ is much higher than the bit rate of $m(t)$.

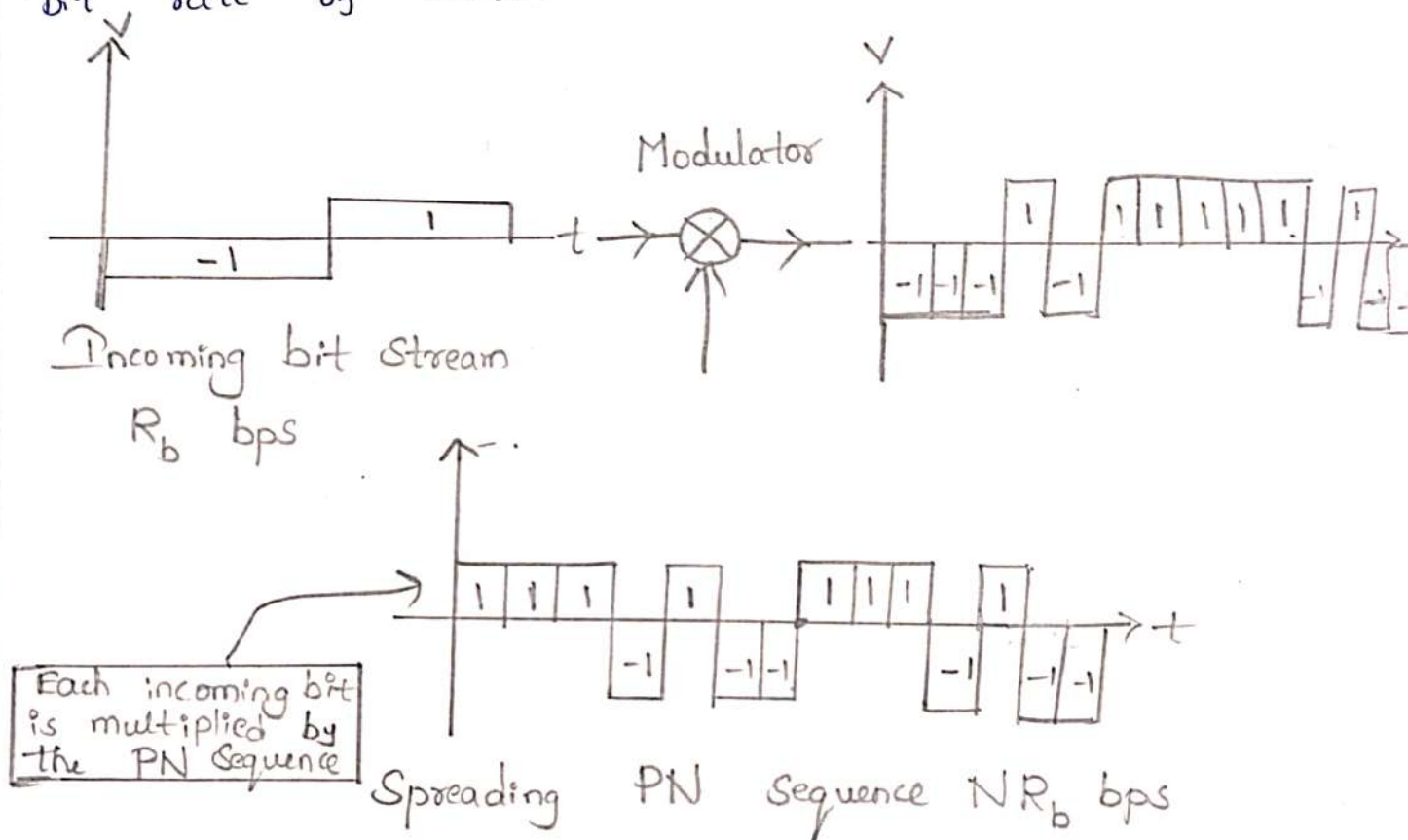


Fig: Principle of Direct Sequence Spread Spectrum

At the receiver for detection a synchronous pseudorandom sequence $c(t)$ similar to transmitter is used.

The received DS/SS signal $y(t)$ is multiplied by $C(t)$ to recover desired signal $m(t)$.

$$\begin{aligned} \therefore y(t) C(t) &= m(t) \cdot C^r(t) \\ &= m(t) \quad (\because C^r(t) = 1) \end{aligned}$$

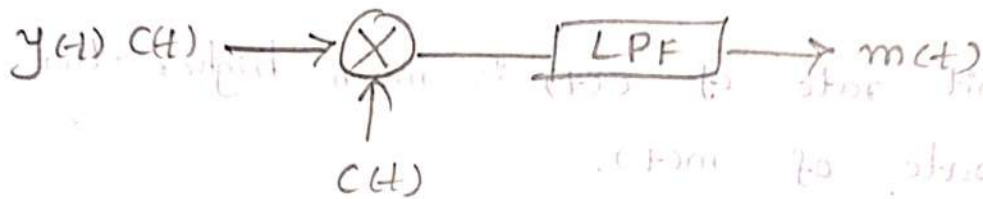
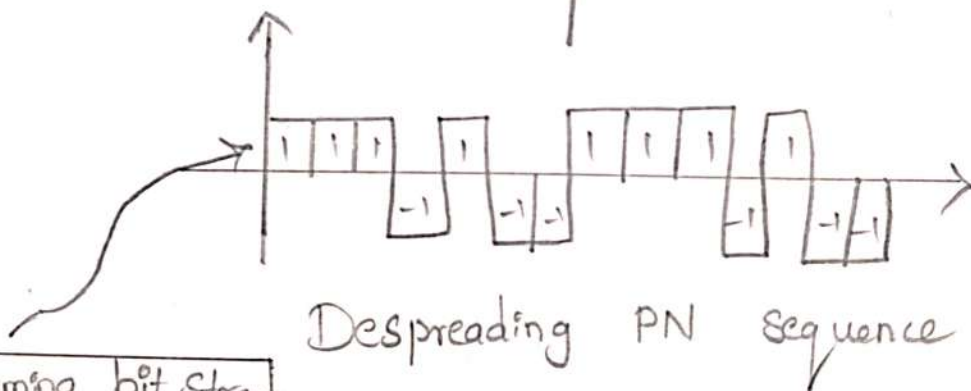
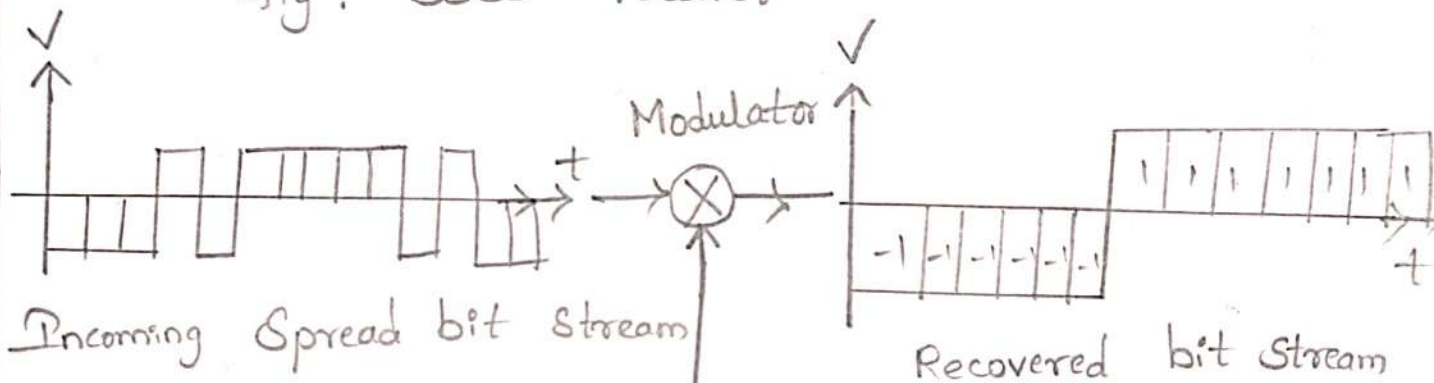


fig: DSSS receiver



Incoming bit Stream
multiplied by a
Synchronized Copy
of the PN Sequence

fig: De-Spreading signal.

Features of DSSS :

1) Secure Communication :

In DSSS, the signal can be detected at the receiver if the pseudorandom code used at transmitter is known. This prevents unauthorized access of signal.

2) Hiding of Signal :

The DSSS signal spectrum is spread over a wide band, the signal PSD is very small. Hence it is easy to hide the signal within the noise floor.

3) Jamming resistance :

The DS/SS signal spectrum power is distributed over a wide band, hence these signals are difficult to jam. Because of spectral spreading PSD of jamming signal decreases by factor N .

4) Multiple access (Several users on same band) :

Several users can utilize the same band with better signal to noise ratio.

5) Advantages of CDMA :

The DSSS supports greater capacity of communication channels. Several users can occupy irrespective of separation distance between them. Since each

User has a unique spreading codes. This feature allows code-division multiple access (CDMA).

6) Resistance to Multipath fading:

Because DSSS signal has a unique feature of low auto correlation with its delayed version i.e. interfering signal will not be despread by CCA. Alternatively this minimizes the effect of multipath signals.

7) Near-far problem:

The DSSS suffers from the near-far problem. The near-far problem occurs because of unequal received power by the user.

Advantages of DSSS:

- 1) DSSS system has best noise and anti-jam performance.
- 2) Unidentified receivers find it most difficult to detect direct sequence signals.
- 3) DSSS has best discrimination against multipath signals.

Disadvantages of DSSS:

- 1) DSSS requires wideband channel with small phase distortion.
- 2) DSSS has longer acquisition time.
- 3) The pseudo noise generator should generate sequence at high rates.

Earth Station Technology

Introduction :

- * The Earth Segment of a Satellite Comm's System consists of transmit and receive Earth Stations.
- * An Earth Station is any transmitting or receiving system that sends signals or receives signals from a satellite.
- * An Earth station is a collection of equipment for communicating with the satellite regardless of whether it is fixed mobile, aeronautical or marine terminals.
- * An Earth Station comprises an antenna, tracking system, receiver, transmitter, multiplexer (combiner) and terrestrial links via a modem (or codec).
- * The Commⁿ is established to the satellite through Earth station. The Earth station can be located on the ship at the sea, or it can be located on the spacecraft or actually on the earth. The location of the Earth station is decided depending upon the ease of control of satellite and the function of the satellite.
- * The type of Earth station depends upon the
 - (a) Function of the station
 - (b) Type of service
 - (c) Frequency bands used
 - (d) Transmitters
 - (e) Receivers and
 - (f) Antenna characteristics.

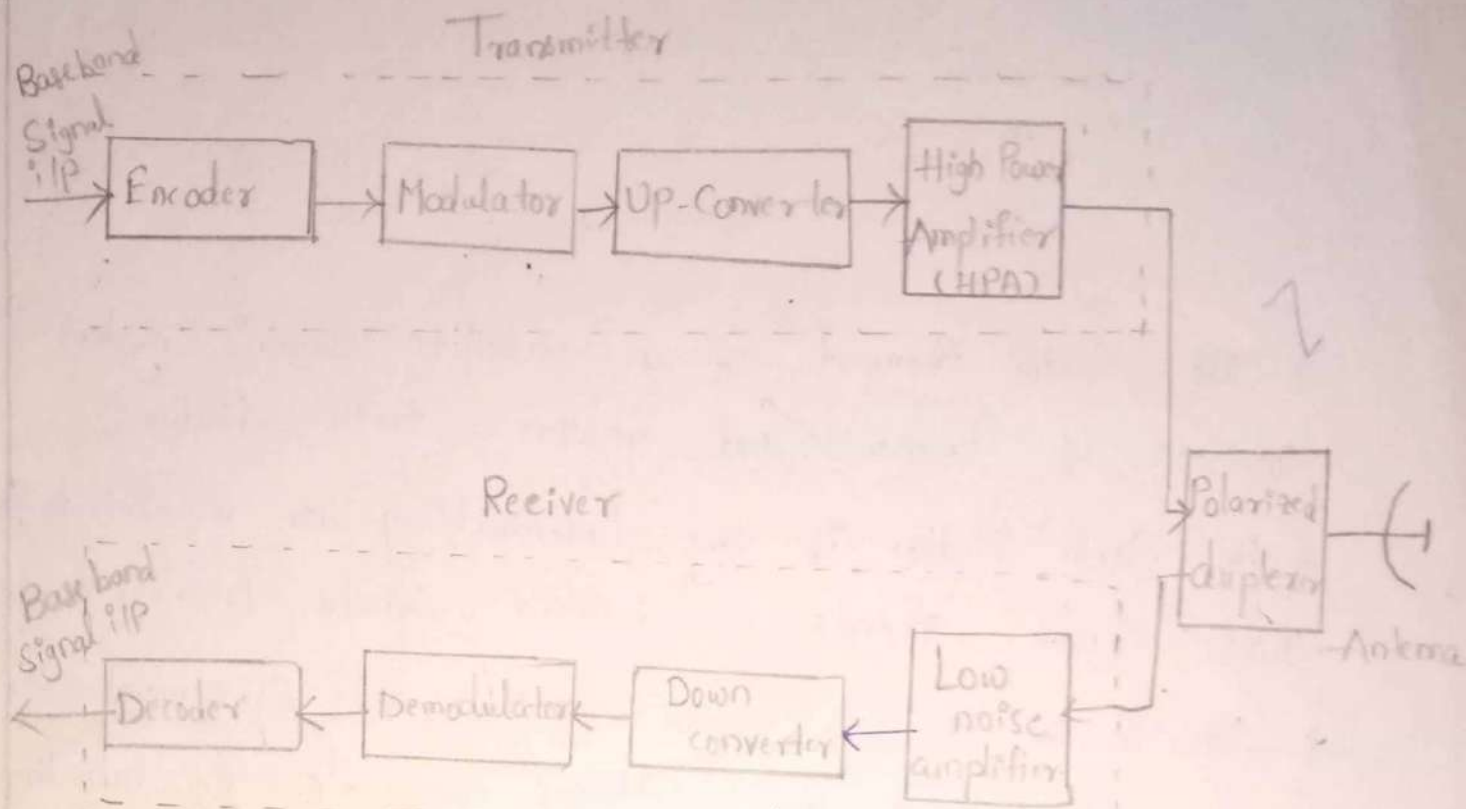


Fig: Basic Block diagram of an Earth station

* The four major subsystems of any Earth station are receiver, antenna, transmitter and tracking equipment.

The Special Earth Stations like TVRO (TV receiver only or direct broadcast Satellite receivers) does not have transmitting funⁿ. Some other Earth Stations are very Special, like tracking and control of Satellite.

* The baseband signal is applied to the encoder. Encoder converts the format ready for modulation. The carrier is modulated by the encoded baseband signal. The modulated carrier is then upconverted to the uplink freqⁿ of the Satellite. The amplifier then amplifies this signal to high power level, ready for transmission. The signal is then passed through the polarization feed of the antenna.

* The signal received from the antenna is of different frequency (downlink freq) and is very small in amplitude. This signal is amplified by the low noise amplifier it is then down converted to the intermediate freqⁿ by the down converter. This signal is then demodulated and decoded to get base-band signal.

Transmitters : —

* In the large Earth stations many channels are required to be transmitted. The amp^rs used are HPAs. These amplifiers have wide bandwidth at microwave frequencies. These amp^rs are normally klystron or Travelling Wave Tubes (TWT) based. The power capacity of these amplifiers varies from 500 to 2000 watts.

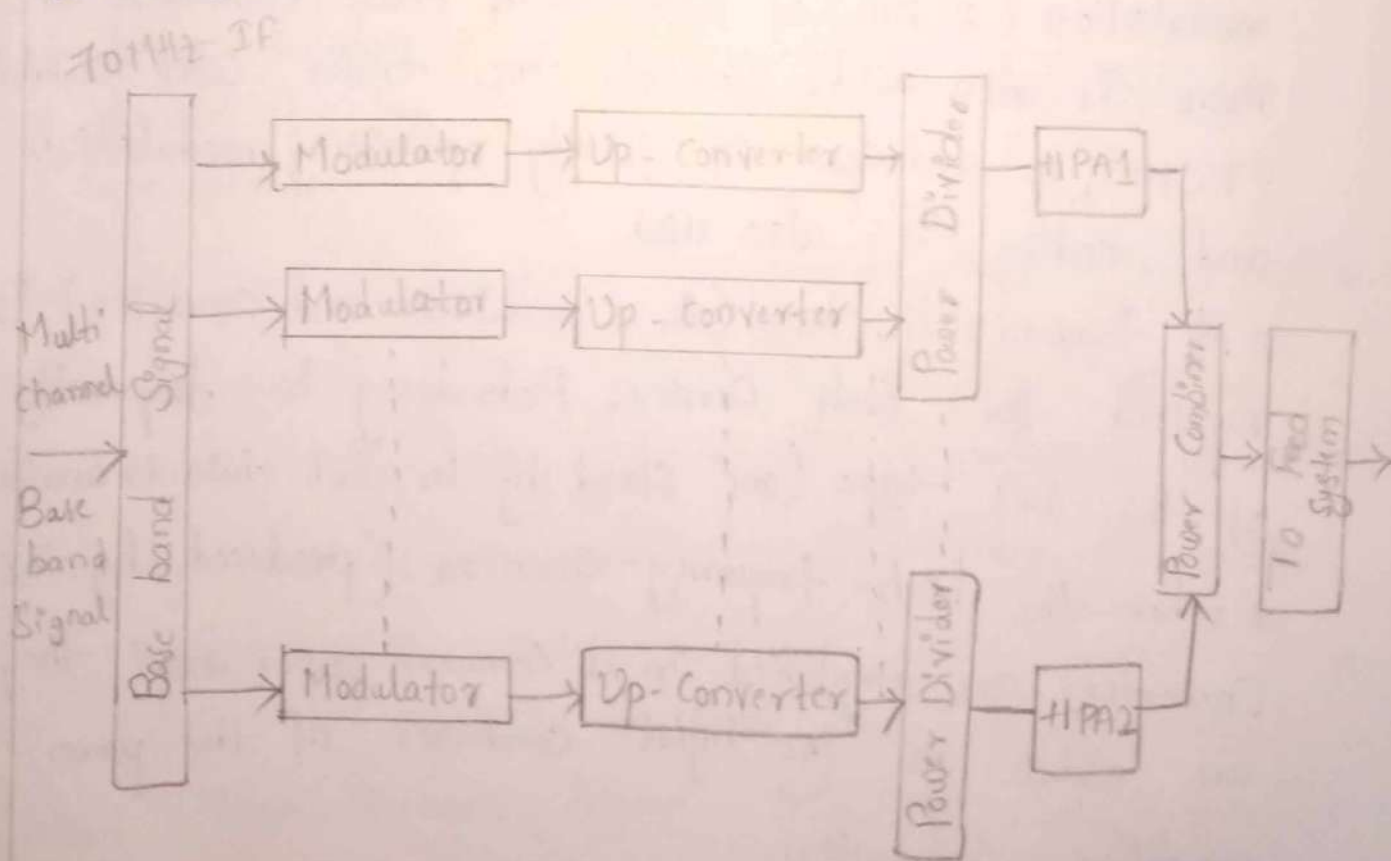


fig: BLOCK DIAGRAM OF TRANSMITTER

* The o/p's of the HPA are combined through bandpass filters. The 70MHz IF is upconverted. The configuration of HPAs to be employed depend on the no. of carriers to be transmitted and type of multiplexing used.

Modulator / Demodulator : —

* Modulator Superimposes the audio-frequency signals on the IF carrier (modulators) or Extracts them from the IF carrier. (demodulators).

* In analogue transmission frequency modulation is the normal process whereas for digital transmission phase modulation (PSK) is used, frequently four phase (4-PSK).

* Modulation with two phase conditions called bi-phase modulation (2-PSK) or with eight phase conditions or more is also used. Recently the trellis coded modulation (TCM), a technique of jointly optimizing modulation and coding is also used.

* A transmission chain (i.e. a modulator and converter) is required for each carrier. Redundancy is frequently of the 1+1 type (one stand by for each chain in service).

* When the high-frequency carriers (produced by the converters are amplified in a common power amp^r they are added in the input combiner of the power amplifier subsystem.

Up Converter : —

* Up Converters change intermediate frequency (IF) signals (ex: IF of 70MHz, 140MHz, 1GHz etc) from the modulator into radio-frequency signals (eg: in the 6GHz or 14GHz band). These signals are then amplified by the power amplifier before being transmitted through the antenna.

High Power Amplifier (HPA) : —

* Small Earth Stations are using solid state power amp^s (0.25 watt) and large Earth Stations are using TWT amplifiers, klystrons (10-15kw)

* Important considerations for HPA are :

- (1) Intermodulation noise arises during multicarrier operation
- (2) Power requirements.
- (3) Method of combining of carriers & scope for future expansion.

* High power TWT amplifiers provide bandwidth of 500MHz and maximum power upto 10kw use of linearizer improves the linearity of amp^r in multicarrier operation.

* klystrons are narrow band devices provides bandwidth of 40MHz and maximum power upto 3kw. when large bandwidth is required, multiple amp^r configuration is used. klystrons have higher efficiency, longer tube life, lower cost, simpler to maintain and operate compared to TWTs.

HPA Configurations: —

* For multicarrier operation, two types of configurations are possible.

(i) Single amplifier Configuration.

(ii) Multi amplifier Configuration.

Single Amplifier Configuration: —

* In single amplifier configuration all the carriers are combined before amplifier hence only one HPA is required. HPA is operated on linear portion of its characteristics to reduce intermodulation noise below fig shows high power single amplifier configuration.

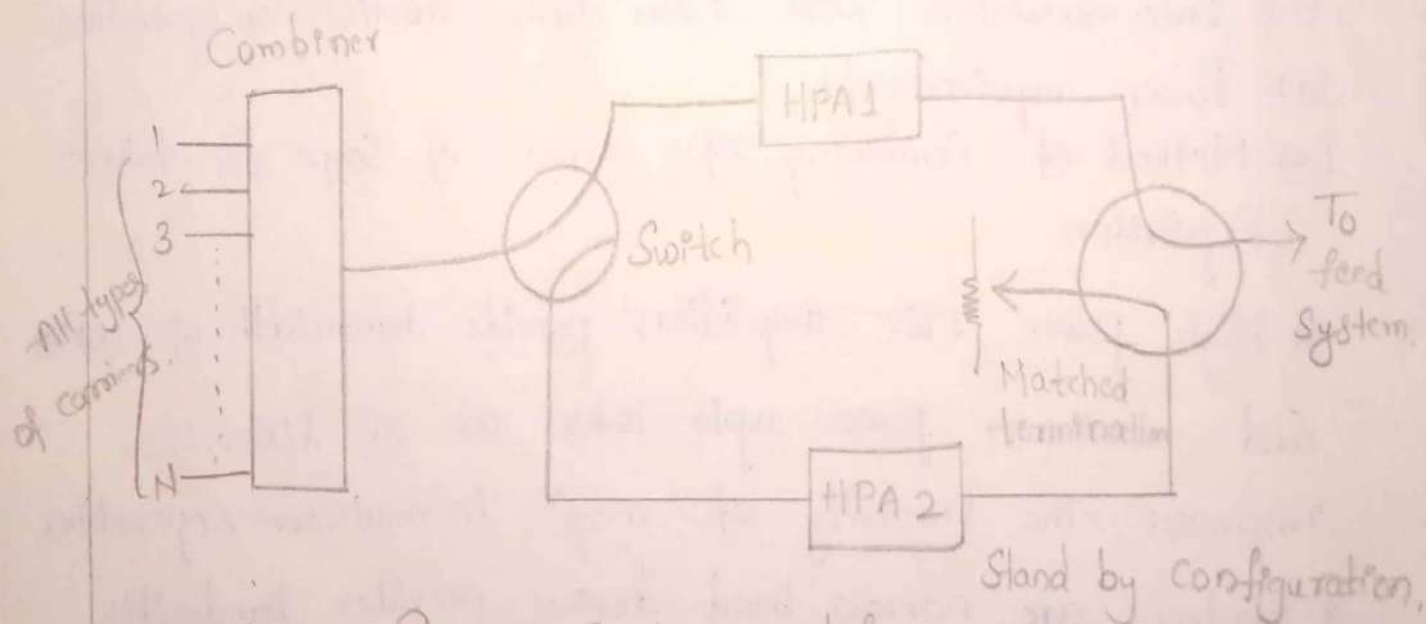


Fig: High Power Single amplifier Configuration.

Multiple Amplifier Configuration: —

* In multiple amplifier configuration Each HPA amplifies one or few of total carriers. The amplified carriers

are then combined at o/p of HPAs. Therefore it is possible to operate HPAs near to their full power rating which improves overall Efficiency of Earth Station. But at the cost of large numbers of expensive HPAs.

* As many Earth Station failure occurs due to HPAs, Standby HPAs provide redundancy to improve the reliability. The Standby HPA is terminated into matched load. The Switches at input/output can be operated manually or automatically.

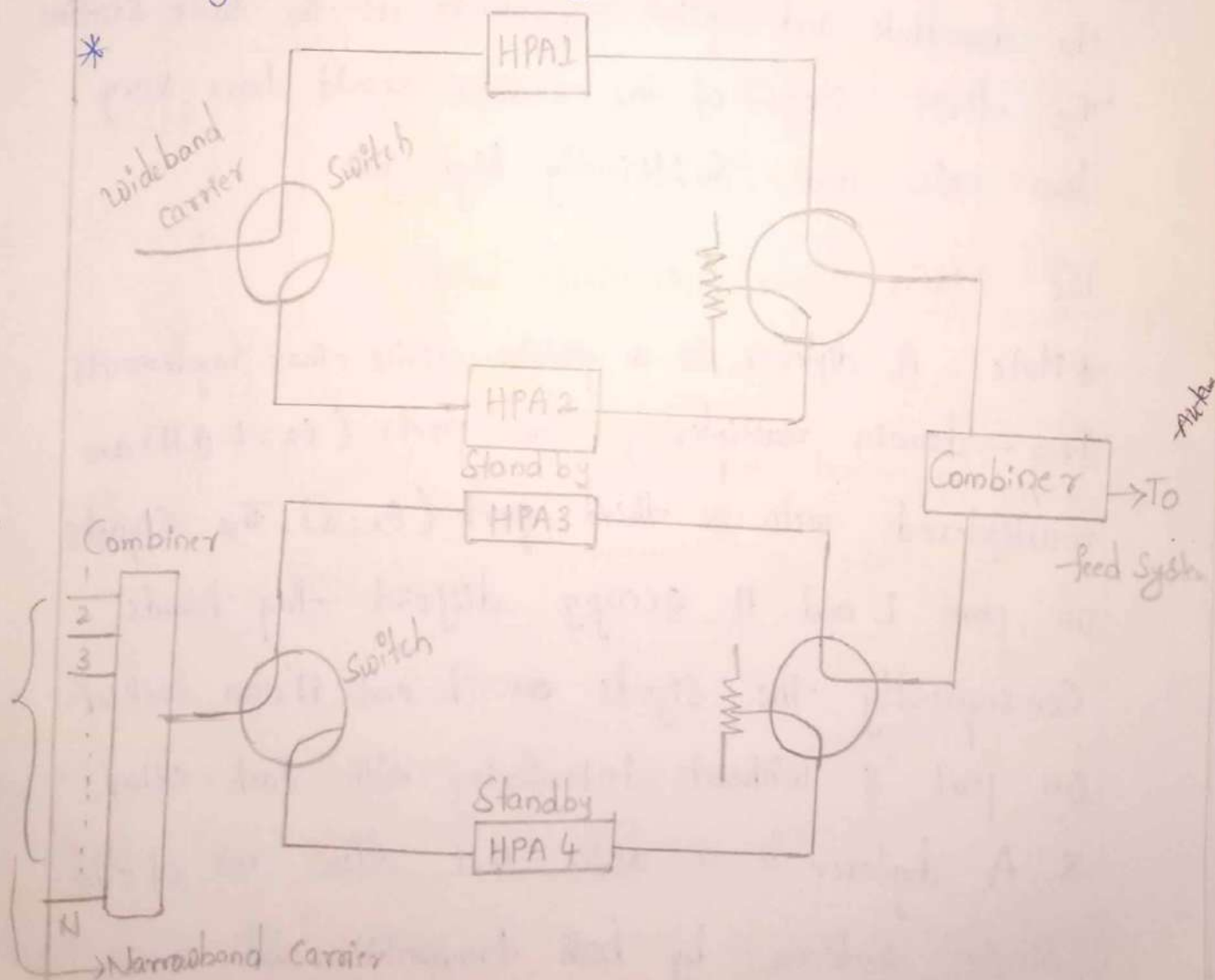


fig: High Power - Multi-amplifier Configuration.

4-11
As many Earth Station failure occurs due to HPAs, Standby HPAs provide redundancy to improve the reliability. The standby HPA is terminated into matched load. The switches at input/output can be operated manually or automatically.

Receivers : —

* Fig. Shows the receiver section of the Earth Station. The receiver has low noise amplifier (LNA), down converter demodulator, decoder and baseband signal treatment equipment. Normally the same antenna diplexer separates the downlink and uplink frequencies at the Earth Station. The first stage of the receiver should have very low noise and sufficiently high gain.

The LNAs cover 500 MHz band.

* Note : A diplexer is a passive device that implements freq - domain multiplexing. Two ports (Ex: L & H) are multiplexed onto a third port (Ex: S). The signals on port L and H occupy disjoint freq bands.

Consequently the signals on L and H can coexist on port 'S' without interfering with each other.

* A duplexer is a device that allows use of the single antenna by both transmitter and receiver.

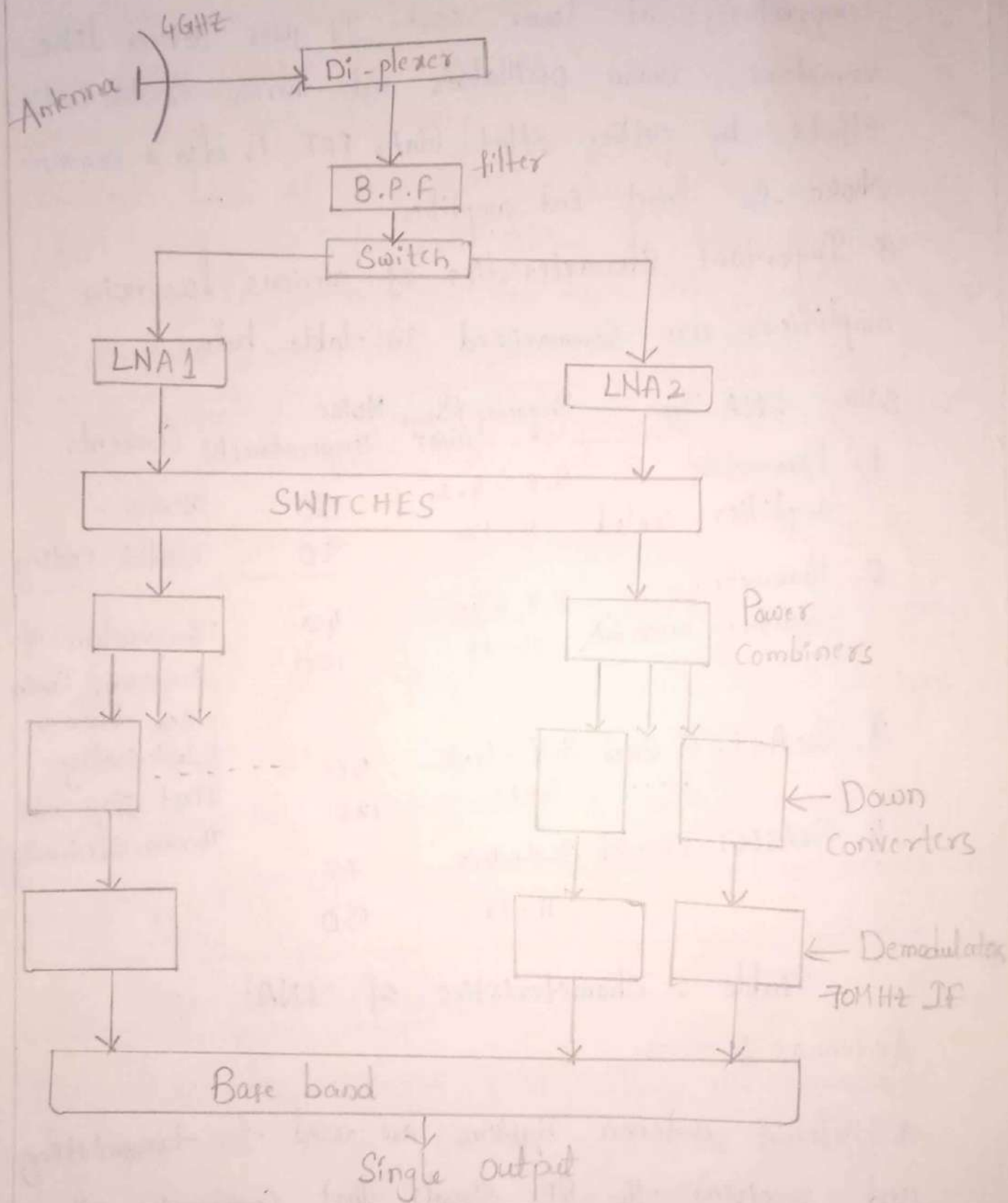


Fig: Block Diagram of Receiver.

Low Noise Amplifier (LNA): —

* Parametric amplifiers are used as front-end amplifier. These amplifiers provide wide bandwidth with low-noise

temperatures at lower cost. It uses devices like Varactors, Gunn oscillators and -thermo-electric cooling effects by peltier effect. GaAs FET is also a common choice for front end amplifier.

* Important characteristics of various low-noise amplifiers are summarized in table below.

S.No	LNA Type	Frequency Range (GHz)	Noise Temperature (K)	Comments.
1.	Parametric amplifier-cooled	3.7 - 4.2 11 - 12	30 90	Thermo - Electric Cooling
2.	Parametric amplifier-uncooled	3.7 - 4.2 11 - 12	40 100	Temperature of Enclosure Controlled thermo-electrically
3.	GaAs FET-cooled	3.7 - 4.2 11 - 12	50 125	First stage cooled Thermo-electrically
4.	GaAs FET-uncooled	3.7 - 4.2 11 - 12	75 150	

Table : Characteristics of LNAs.

Antennas : —

* Different antenna systems are used for transmitting and receiving the RF signals that comprise the space links of the communications channels.

* The antennas of Earth Stations are common to Tx and reception and must have the following performance features :

- 4-11
4-6
4-11
The great
- 1) High gain for transmission and reception requiring reflectors which are large in relation to the wavelength and have high Efficiency.
 - 2) Low level of interference (for Txⁿ) and of Sensitivity to interference (for Rxⁿ) Calling for radiation diagrams with low levels outside the main lobe (Small side lobes)
 - 3) Radiation with high polarization purity.
 - 4) For reception, low Sensitivity to thermal noise due to ground radiation and various losses.

Aperture Antennas : —

* Antennas can be broadly classified by the frequency Spectrum in which they are commonly applied by basic mode of radiation.

* In Satellite Communication the most commonly used aperture antennas are horn antennas, reflector antennas and lenses.

Main Types of Antennas : —

* Four reflector antenna Configurations are commonly Employed for Earth Station applications namely :

- | | |
|-------------------------------|-------------|
| ① Prime focus axisymmetric | Prime focus |
| ② Axisymmetric dual reflector | Cassegrain |
| ③ Single Offset | Offset feed |
| ④ Dual Offset | |

Horn Antenna : —

* A waveguide can radiate energy into the open space when it is excited at one end & open at the other end. The disadvantage is that only a small proportion of the forward energy in the waveguide is radiated. The much of the energy is reflected back by the open circuit because of discontinuity and mismatching of open circuit. Also the diffraction around the edges of guide gives a poor, non-directional radiation pattern. To overcome these problems the mouth of open end is flared out (opened out) so that it takes the shape of a horn and so it is called Horn antenna. The change of open ended waveguide into horn antenna increases the directivity and diffraction is reduced because the abrupt discontinuity is replaced by gradual transformation.

* A horn antenna is an aperture antenna which is used to properly match the waveguide or any guiding system to a large radiating aperture by shaping the transition gradually. The large aperture is necessary to improve directivity and to produce efficient radiation with proper matching with free space.

* Several horn configurations are possible. Some commonly used horn configurations are

- | | |
|---------------------------|----------------------------|
| (i) Sectoral E-plane horn | (ii) Sectoral H-plane horn |
| (iii) Pyramidal horn | (iv) Conical horn |

4-11

* If flaring is done in one direction only, then Sectoral horn is produced.

(i) Sectoral E-Plane Horn : —

* When the horn is flared out in the plane of Electric field 'E' then it is called as Sectoral E-plane-horn.

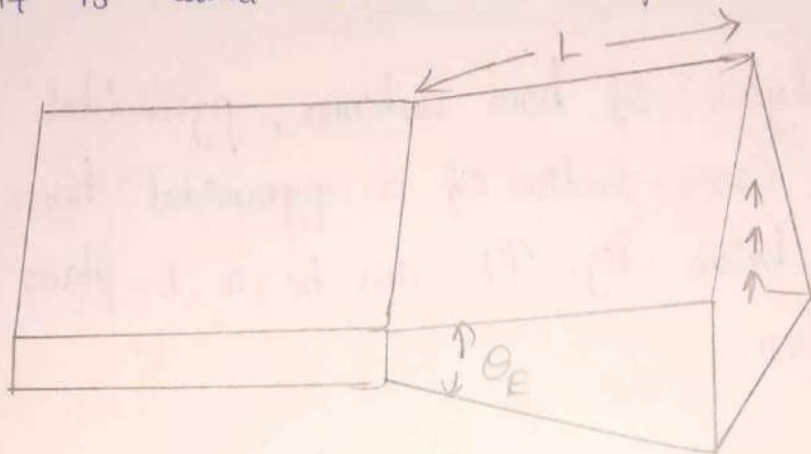


Fig: Sectoral E-plane Horn

(ii) Sectoral H-plane Horn : —

* When the horn is flared out in the plane of magnetic field - H then it is called as Sectoral H-plane horn.

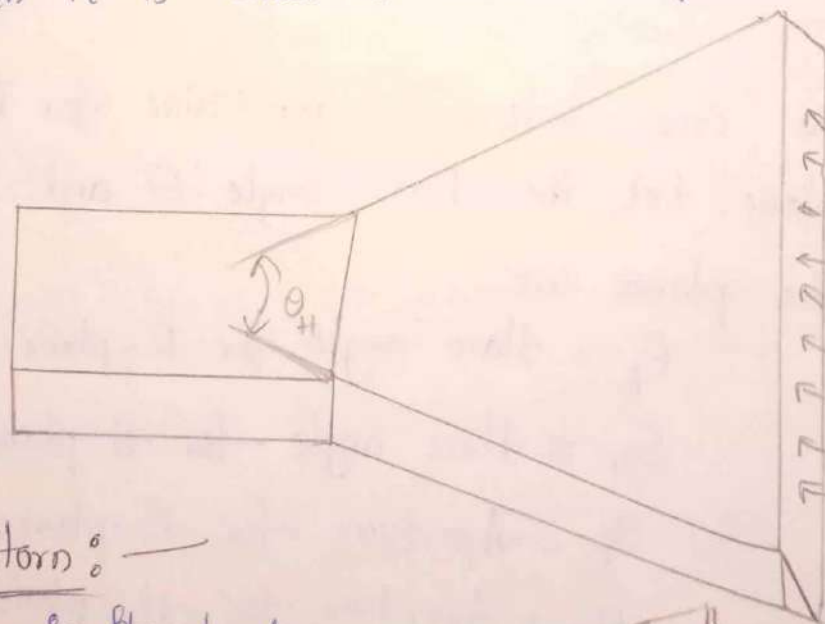


Fig: Sectoral H-plane horn

Pyramidal Horn : —

* When the horn is flared out in both the planes i.e. in E-plane & H-plane of the rectangular waveguide then it is called as Pyramidal Horn.

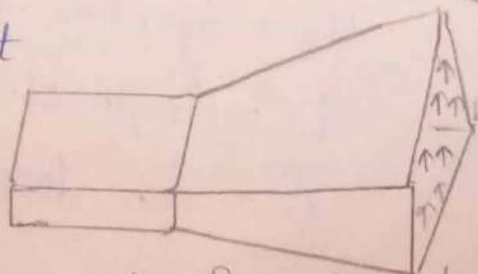
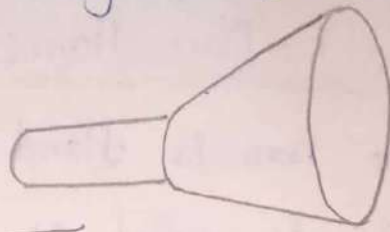


Fig: Pyramidal horn

(iv) Conical Horn : —

* When the walls of circular waveguide is flared out, it is called as conical horn.

Fig: Conical Horn



Analysis of Horn Antenna : —

* For analysis of horn antenna, pyramidal horn antenna is used. Cross section of a pyramidal horn antenna is shown in below fig. It can be a E-plane or H-plane Cross-section.

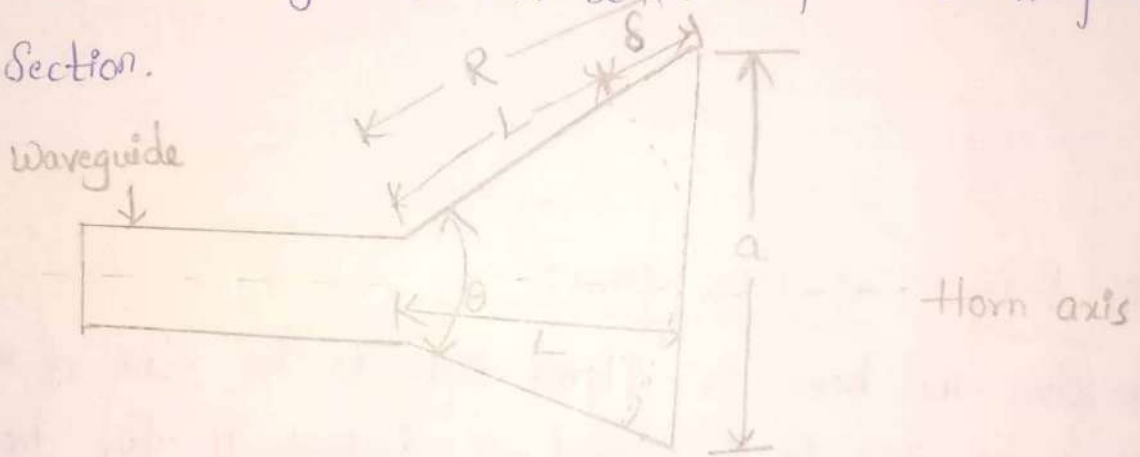


Fig: Cross-section of Pyramidal Horn

* As the cross section is applicable for either E-plane or H-plane. Let the flare angle ' θ ' and aperture 'a' for both the planes are

θ_E = flare angle for E-plane

θ_H = flare angle for H-plane

a_E = Aperture for E-plane

a_H = Aperture for H-plane

L = length of horn (flare length)

S = Path difference or area factor.

* From the geometry of cross-section

$$\sin \theta/2 = \frac{a}{2(L+\delta)}$$

$$\cos \theta/2 = \frac{L}{L+\delta}$$

$$\therefore \tan \frac{\theta}{2} = \frac{\sin \theta/2}{\cos \theta/2} = \frac{a}{2L}$$

$$\therefore \theta = 2 \tan^{-1} \frac{a}{2L}$$

Also $(L+\delta)^2 = L^2 + \left(\frac{a}{2}\right)^2$

$$L^2 + \delta^2 + 2L\delta = L^2 + \frac{a^2}{4}$$

$\therefore$ '8' is very small hence δ^2 can be neglected.

$$2L\delta = \frac{a^2}{4}$$

$$\boxed{L = \frac{a^2}{8\delta}}$$

* Flare angles for half power beam width (HPBW):

For HPBW the optimum flare angles are given as

$$\theta_E = \frac{56\lambda}{a_E} \text{ degrees and } \theta_H = \frac{67\lambda}{a_H} \text{ degrees}$$

Directivity 'D' of a horn antenna assuming no loss is given as

$$\boxed{D = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi E_{ap} A_p}{\lambda^2}}$$

Where A_e = Effective aperture, A_p = Physical Aperture

E_{ap} = Aperture Efficiency ($E_{ap} = \frac{A_e}{A_p}$)

for a rectangular horn $A_p = a_e a_H$

Parabolic Reflector Antenna / Paraboloid :

* Parabolic reflector antennas are based on the geometric optical principles and metallic plate of paraboloidal curvature is referred as parabolic reflector or paraboloid.

* Consider a point source at focus (F) of parabolic reflector.

By the property of parabola following points can be noted.

(i) All the waves originating from focus will be reflected

by the parabola and the

reflected waves are parallel to the parabolic axis regardless of θ value.

(ii) All the reflected waves reaching the aperture plane are in-phase.

* The above geometrical properties of parabola provides an excellent reflector at low frequency, which leads to a concentrated radiation beam.

* A paraboloid reflector antenna has nearly same characteristics both for Txⁿ and Reception. Thus it can act as high gain directional antenna. The radiation pattern of a paraboloid reflector has a very sharp main lobe and surrounding the main lobe are minor

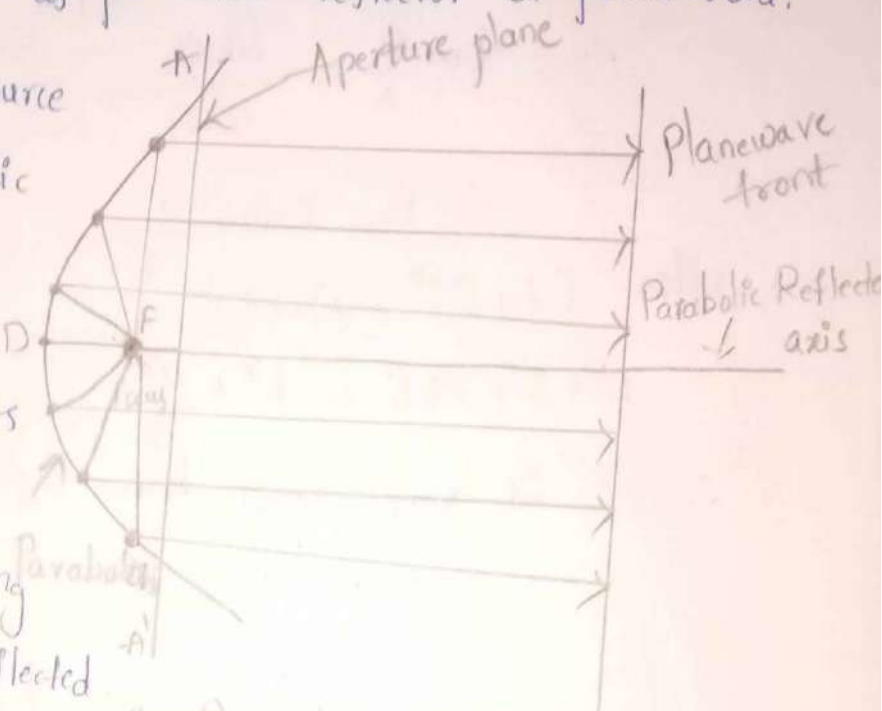
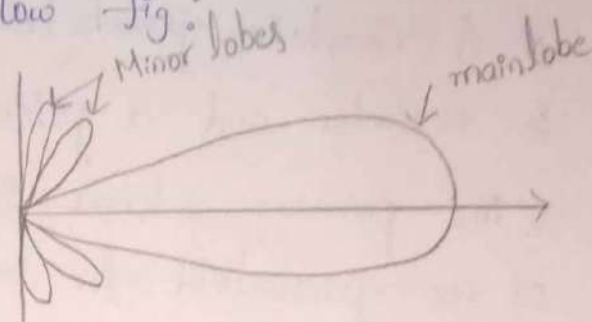


Fig. Parabolic Reflector.

lobes of very small size. The radiation pattern of a paraboloid is shown in below fig:

fig: Paraboloid

radiation pattern.



Analysis of Paraboloid:

* Beamwidth between half-power points (BWHP)

* The beamwidth between half-power points (ϕ) is

given as $\phi = \frac{70\lambda}{D}$ degrees where $D =$ mouth diameter.

Beamwidth between first nulls (BWFN)

BWFN (ϕ_0) is given as $\phi_0 = 2\phi$

$$\phi_0 = \frac{140\lambda}{D} \text{ degrees.}$$

Half Power Beamwidth (HPBW)

HPBW for a circular aperture is given as

$$\text{HPBW} = \frac{58\lambda}{D}$$

$D \rightarrow$ Directivity, $D = \frac{4\pi A}{\lambda^2}$, where $A \rightarrow$ area of aperture.

* For a circular aperture $A = \frac{\pi D^2}{4}$

$$D = \frac{4\pi \cdot \frac{\pi D^2}{4}}{\lambda^2}$$

$$D = 9.87 \left(\frac{D}{\lambda}\right)^2$$

* Power gain (G_p), $G_p = 6 \left(\frac{D}{\lambda}\right)^2$

Feed Systems for Paraboloid: —

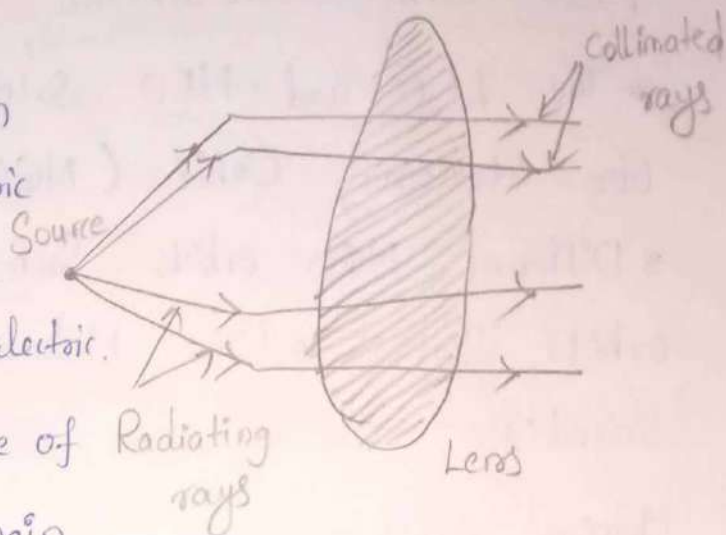
- * A Complete paraboloid consists of two main components i.e. reflector and a primary antenna (Source radiation).
- * The primary antenna is usually placed at the focus of the paraboloid for best results in Tx. The primary antenna is known as feed radiator and the reflector is known as Secondary radiator.
- * In ideal feed system the entire surface of the reflector is illuminated and no energy is spread out in any other directions, various Spill-feed mechanisms used are

- ① Dipole End-fire feed
- ② Spherical reflector feed
- ③ Horn feed
- ④ Cassegrain feed.

Lens Antenna: —

- * In optics a lens for obtaining a parallel beam of light from a point source is used as shown in the figure. The source is located at the focus of the lens. The refraction takes place and the rays at the edges are refracted more than those near the center. Thus a divergent beam is collimated. Similarly a parallel beam of light converging at a point is also true. The same is true for electromagnetic waves also.

* The only difference is that the lens is not an optical glass but a dielectric lens made of polystyrene or Lucite or artificial dielectric.



* There are several type of lens antennas. The two main types are:

fig: Lens Principle

- ① H-plane metal plate lens (Delay lens)
- ② E-plane metal plate lens (Fast lens)

* In H-plane metal plate antennas, the travelling wavefronts are delayed or retarded by lens mediums shown in below fig.

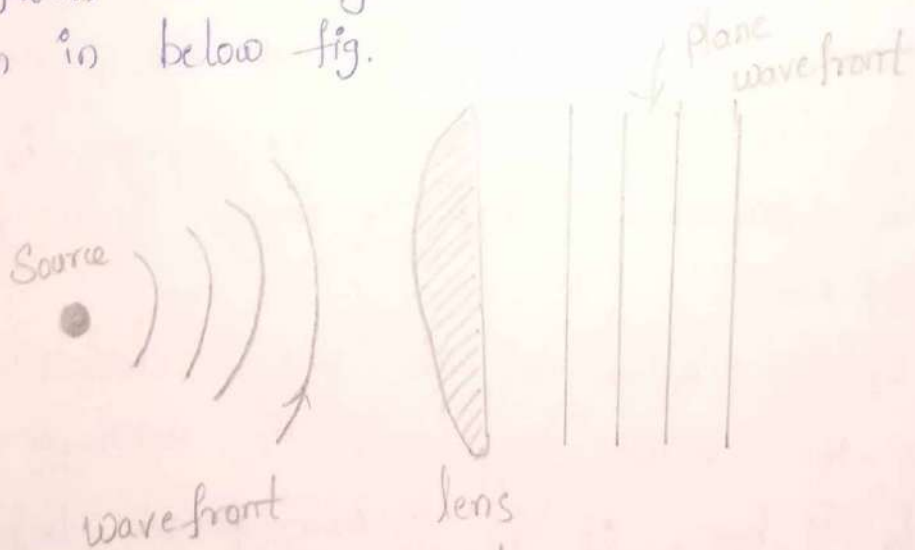


fig: H-plane lens

* Molniya Orbits fill the area that is not

Lower Orbit Considerations: —

- * The LEO and MEO Satellites are referred as Non-Geo-Stationary Orbit (NGSO) Satellites.
- * Different NGSO orbits such as Equatorial orbits, inclined orbits, elliptical orbits, Molniya orbits are used for Scientific, military and Commercial Satellite applications.

Molniya Orbit: —

- * The name Molniya is derived from the Russian word for "lightning".
- * It is an Earth Satellite orbit designed for communications Satellite Service coverage at high latitudes, with an orbital period of slightly less than 12 hours (Semisynchronous orbit), inclination of 63.4° , and high Eccentricity (0.722), so that the apogee is at 25,000 miles (40,000 km) and the perigee is at only 300 miles (500 km).
- * Because of its inclination, the perigee doesn't rotate so that the Satellite "hangs" over the northern hemisphere for nearly 11 hours of its 12-hour period before it whips "quick as lightning" through perigee in the Southern hemisphere.
- * Molniya orbit is 12-hour highly elliptical and inclined orbit. Because of the Earth's size, geostationary Satellites are not visible north of 55 degrees, which includes much of Russia.

* Molniya Orbits fill the gap. Their great Eccentricity means they travel slowly at apogee, allowing long periods of contact. Three Molniya Satellites allow continuous coverage.

* The orbital inclination is 63.4 degrees, which results in zero precession of the major axis of the orbit, so the apogee remains fixed above the northern hemisphere.

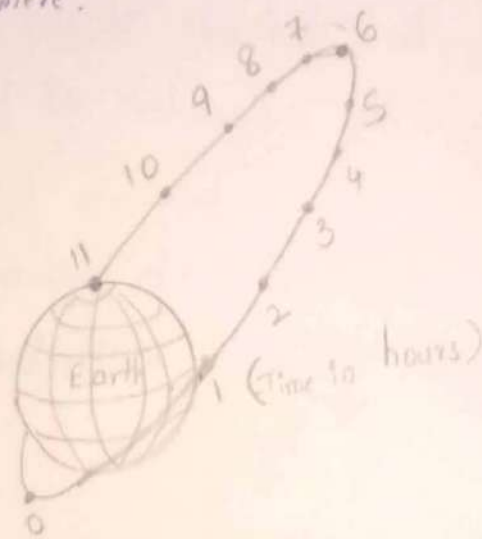


Fig. Molniya Orbit

* Molniya orbits also offer better coverage of latitudes above 80 degrees north.

Features of Molniya Orbit : —

- 1) Covers northern polar areas for long periods of time
- 2) Has a low launch-cost.
- 3) Requires continuous changing of antenna pointing angles.
- 4) Requires Satellite Station keeping.
- 5) Has a period of 12 hours.
- 6) Has an altitude of $40,000$ km at apogee & an altitude of 500 km at perigee.
- 7) Has an inclination angle of 63.14 degrees.

Sun-Synchronous Orbit (SSO): —

* A Sun-Synchronous orbit of the Earth's Satellite is a geometric orbit which combines altitude and inclination in such a way that an object on that orbit ascends or descends over any given point of the Earth's surface at the same local mean solar time.

* In Sun-Synchronous orbit the plane of the satellite orbit is always the same in relation to the Sun.

* It can also be defined as an orbit for which the satellite crosses the Equator at the same local time each day.

* Sun-Synchronous orbit is circular, near polar and slightly retrograde orbits with inclinations of 90° degrees.

* Typical Sun-Synchronous orbits are about 600-800 km in altitude, with periods in the 96-100 minute range, and inclinations of around 98° . Variations on this type of orbit are possible;

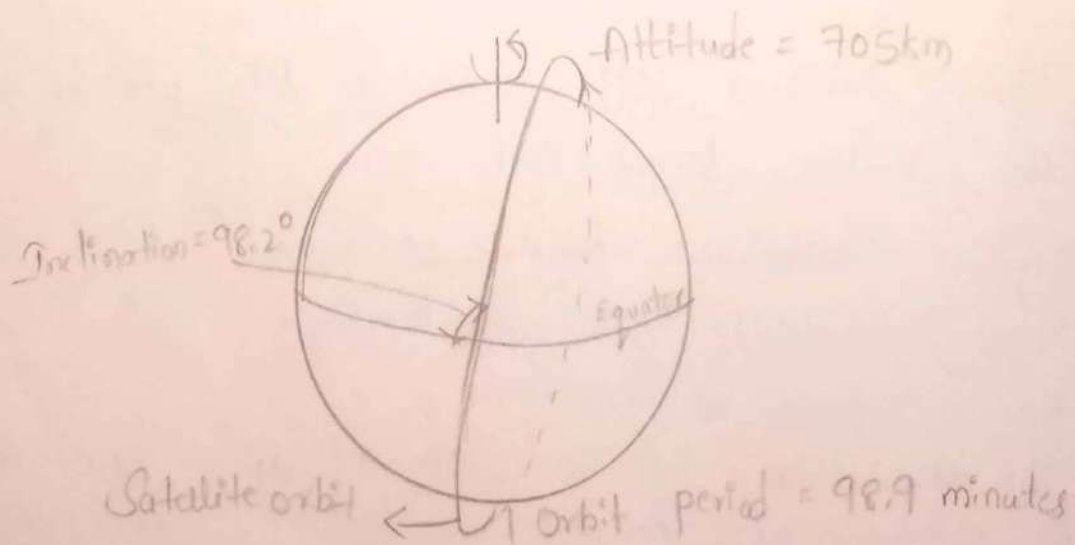


Fig: Sun Synchronous Orbit.

Coverage and Frequency Considerations:

General Aspects:

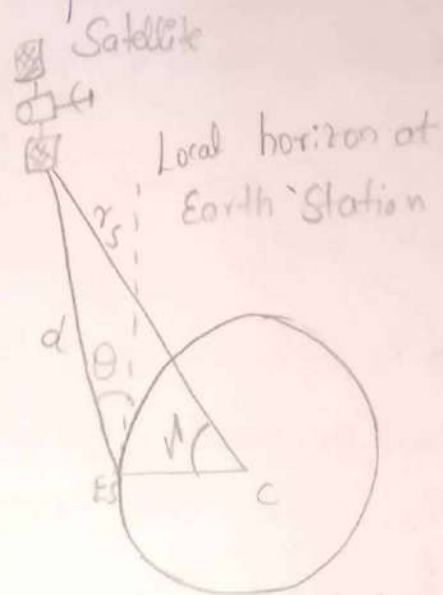
* Coverage area is dependent on ground and in space and other environment.

* The Elevation angle (θ) is the angle between the local horizon and the satellite at Earth station.

* The Satellite is at distance 'd' from Earth station and at

distance ' r_s ' from Earth Center 'C'. fig: Geometry for calculating Earth area.

technology used on aspects such as radiation



$$\therefore \left[\frac{r_s}{\sin(90^\circ + \theta)} \right] = \left[\frac{d}{\sin \psi} \right]$$

$$\Rightarrow \cos \theta = r_s \cdot \left[\frac{\sin \psi}{d} \right]$$

* θ , r_s and 'd' are important parameters of Satellite system design. The angle ' ψ ' gives the coverage area on the surface of the Earth.

Frequency Band:

* LEO Satellite Systems use lowest available RF frequency.

* Let a LEO Satellite with coverage zone on Earth surface area has ' A ' m². The average flux density across the coverage zone is given as

$$F = \frac{P_t \cdot G_t}{-A} \text{ watts/m}^2$$

where $P_t \cdot G_t$ is EIRP of Satellite.

* The flux density is independent of frequency.
 The effective receiving area of antenna is given by

$$A_e = \frac{G_r \lambda^2}{4\pi}$$

where, G_r is receiver gain (typically $< 3\text{dB}$).

* The received power at Earth Station is

$$P_r = F \times A$$

$$P_r = \frac{P_t G_t G_r \lambda^2}{4\pi A} \text{ watts.}$$

* Therefore, received power at mobile terminal with an omnidirectional antenna increases as the square of wavelength.
 The lower the RF freqⁿ the greater the received power for given coverage zone.

Elevation Angle Consideration: —

* Higher the Elevation angle, the lower the rain attenuation for a given rain-fall rate.

* For a minimum Elevation angle and a orbital height, the geometry Setup can be used to develop a coverage area assuming that Satellite has a Symmetrical beam aimed at nadir.

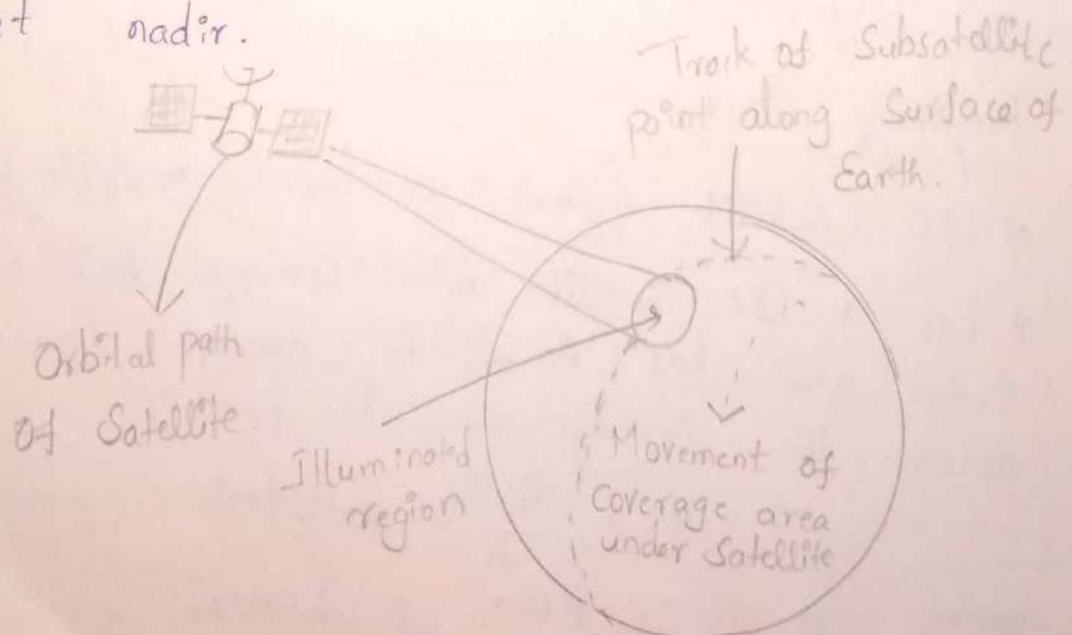


Fig: Coverage area under Satellite

* The Satellite antenna has a finite usable beamwidth which allow a given portion of the surface to be illuminated at the same time.

* Increasing the altitude of the Satellite's orbit increases the coverage area. Alternatively, the beam-width is increased to cover larger surface area.

* For instantaneous coverage on Earth surface uses spectrum reuse pattern.

Number of Beams Per Coverage: —

* Some Satellites are much far from Earth compared to Globalstar Satellites, hence they need to generate many beams per satellite for achieving sufficient capacity / km² within coverage.

SATELLITE PACKET COMMUNICATION

Satellite Communication refers to radio-link (microwave line of sight) communication using one or more radio frequency re-transmitters located at great distances from the terminal earth stations.
→ The use of satellite in communication systems has become so 'habitual' it is almost taken for granted.

* The use of satellite technology for commⁿ purposes comes with attendant important features which are not readily available through other means of communication namely:

① A satellite in the geosynchronous orbit effectively ~~lower~~ orbit covers close to 120 degree sector of the earth surface thus making beyond - LOS commⁿ a reality i.e., commⁿ is possible beyond earth curvature (which sets the limit line of sight).

② Satellite commⁿ is not concerned with either political or geographical boundaries.

③ Satellite provide both fixed and mobile commⁿ service the former is called fixed satellite service (FSS). while the latter interconnects with moving object (eg aircraft) from a ground control station.

④ Satellite commⁿ is employed in remote sensing.

for prospecting natural resources as well as monitoring atmospheric conditions.

⑤ Three Communication Satellites situated at the geostationary altitude & spaced 120° apart could interconnect over 90% of earth.

⑥ A satellite commⁿ network is easily expandable.

* Every commⁿs satellite in its simplest form performs the task of transmitting information from a source earth station to the satellite (this is called uplink). This is followed by a retransmission of the received and processed information from the satellite back to the ground. (this is called the downlink). The downlink may either be to a select no. of ground stations or it may be broadcast to all receiving terminals in the satellite's footprint.

→ we focus on specific protocols or methods guiding access to the medium used for Txⁿ and Re-Txⁿ of packets (messages) to and from the satellite.

→ These protocols are referred to as Medium Access Schemes. Medium Access Control (MAC) schemes are mechanism for sharing a single link. MAC schemes are essentially multiplexing schemes.

* Message access on any system can be of 3 types:

① conflict free scheme

② contention (random access) scheme.

③ Reservation (Controlled Access) Scheme

→ There are also hybrid schemes b/w contention & reservation, consider message Txⁿ by FDMA using M/C/I Queue under the conflict free scheme & message transmission by TDMA using pure ALOHA, Tree Algorithm & Packet reservations under the contention/Random Access Scheme.

Packet Switching Systems:-

→ The majority of satellite comm systems have been designed for voice & data traffic with fixed (or) demand assignment using a multiple access protocol such as FDMA or TDMA. Such systems thus work as ckt switching n/w's. (a voice telephone n/w). where a complete physical path is established from sender to the Rx^{er} that remains in effect for the duration of the connection.

The process of selecting a path (or) ckt establishment may take on the order of seconds for a complex n/w. Once the ckt is established, data transfer is continuous thro' the n/w & no delays are added by the switches. End to end transmission time thro' the n/w is limited only by the propagation of the ckt medium employed which is dominated by the satellite propagation delay. ckt switching systems are efficient for voice calls or data with long compared messages compared to the time required to make new ckt allocations data traffic, however has more diverse chgs than voice traffic.

where $x^*(s)$ is the Laplace transform of the s -time. (B-4)

Message Transmission by TDMA

In the time division multiple Access (TDMA) scheme the entire time frame is divided into time slots, pre-assigned to the different stations. Every station is allowed to transmit freely during the slot assigned to it i.e., during the assigned slot the entire system resources are devoted to that station.

Techniques based on contention are suitable for traffic that is bursty in nature. centralized control is absent in a contention based system as such when a node needs to transmit data, it contends for control of T_x medium. The major advantage of contention techniques is simplicity as they are easily implementable in individual nodes. The contention techniques are efficient under light to moderate n/w load but performance rapidly degrades with per load level. Message T_x by TDMA can be done using ALOHA scheme was invented at University of Hawaii for purpose of interconnecting remote stations & data terminals to a central server over a packet radio n/wk.

The ALOHA model Satellite Communications uses satellite connections b/w earth stations. The model

of 2 - top level modules & an earth station (PTD)

(Earth Segment), or Central Satellite Station, (Space Segment) that serves as the Communications link b/w the earth stations & a statistics module.

Towards achieving the objective of a simple design some functions such as satellite round-trip delay, collision detection and Tx delay are implemented on the satellite. Any collision detected during the receipt of a packet by the satellite is tagged before onward broadcast to receiving earth stations. A continuous retransmit process is initiated by the transmitting earth station until it receives the original packet back without the collision flag. At which point the packet is discarded & the transmission of the next packet in queue commences. Suffice to note here that all packets are equal in size & both pure & slotted ALOHA operations are supported by the earth station module.

Pure ALOHA

In pure (or) unslotted Aloha users transmit data packets as soon as they are formed. If we neglect the capture effect then packets that overlap in time are assumed to be received in error & must be

(7-5)

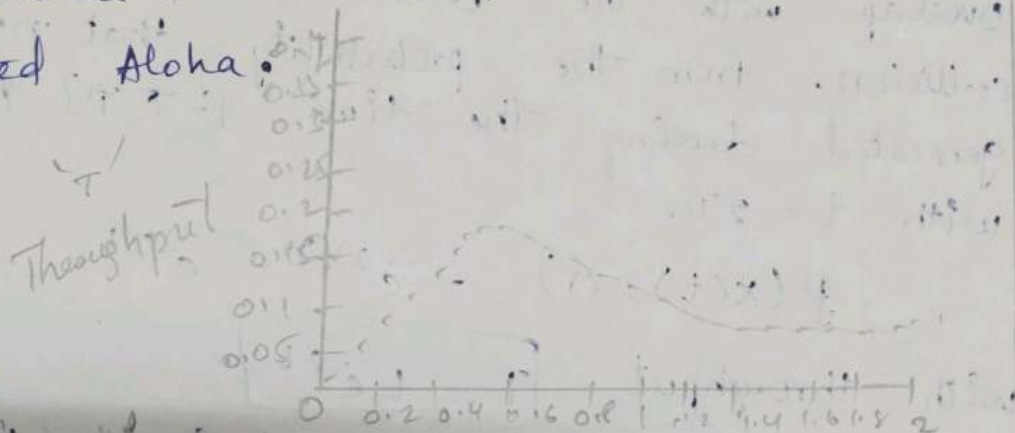
retransmitted. If we also assume packets that do not collide are successfully received (i.e., there is no channel distortion or noise) - then the throughput equals the offered load times the probability of no collisions. $T = Lp$ (no collision). Suppose a given user transmits a packet of duration τ during time $[0, \tau]$ then if any other user generates a packet during time $[-\tau, \tau]$, that packet of duration τ , will overlap with the transmitted packet, causing a collision. From the probability that no packets are generated during the time $[-\tau, \tau]$ is given by with $t = 2\tau$.

$$p(x(t)=0) = e^{-2L\tau} = e^{-2L}$$

with throughput $T = Le^{-2L}$.

→ This throughput is plotted in fig (1) where we see that throughput rises with offered load upto a max throughput of approx 0.18 for $L=0.5$ after which point it decreases. In other words the data rate is only 18% of what it would be with a single user transmitting continuously on the system. The reason for this max. is that for small values of L there are many idle periods when no user is transmitting, so throughput is small. As L increases the channel is utilized more but collisions also start to occur.

→ Part of the reason for the inefficiency of pure ALOHA is the fact that users can start their packet transmissions at any time, & any partial overlap of two or more packets destroys the successful Rxⁿ of all packets. By synchronizing users such that all packet transmissions are aligned in time, the partial overlap of packet transmissions can be avoided. That is the basic promise being slotted Aloha.



SLOTTED ALOHA:-

→ The pure Aloha implemented with a slotted channel variation is known as slotted Aloha protocol. For the slotted Aloha variant, all packets are of equal length & time is slotted. The packet transmission time is a full slot packets are only transmitted in the next subsequent slot to their arrival slot. It also assumes that there is no transmit time slot, in which case, the station would have needed to buffer one or more packets to accommodate the

"no buffering" assumption it assumes that there is an infinite no. of stations with each new arriving from a new source station. Inevitable collision occurs if more than one station venture to transmit packets in one & the same time slot. and consequently the receivers cannot receive the packets correctly. "successful rx" happens only when there is exactly one packet transmitted in a slot. If no packet is transmitted in a slot, the slot is the clipped binary-tree protocol. This improved on each mechanism by adopting the rule that whenever a collision is followed by too successive successful transmissions, the packet the slot is called idle.

transmissions, the packet is retransmitted in a slot, the slot is called idle if there is a collision the colliding packets are retransmitted at a later slot after a randomly chosen back-off period. such packets are also back logged packets.

Retransmitted in a slot, the slot is called as back logged packets. Such packets are also chosen back-off period. This reduces the vulnerability of packet. This reduces the probability of collision. In this protocol, the efficiency of pure ALOHA is improved only at the beginning of a slot. This reduces the probability of collision. In this protocol, the efficiency of pure ALOHA is improved only at the beginning of a slot. This reduces the probability of collision.

Channel utilization measured as throughput is given by turns of the available channel capacity. It is given by $s = G \cdot e^{-G}$. This gives a max throughput of 37% at $G=1$ i.e. 100% of offered channel capacity.

In slotted ALOHA, time is assumed to be slotted in the slots of duration τ and users can only start their packet transmission at the beginning of the next time slot after the packet has joined. Thus there is no partial overlap of transmitted packets which increases throughput. Specifically a packet transmitted over the time period $[0, \tau]$ is successfully received if no other packets are transmitted during this period. This probability is obtained from eq 1 with $t = \tau$.

$$P(X(t) = 0) = e^{-G}$$

with throughput $T = G \cdot e^{-G}$

This though put is also slotted in fig 1, where we see that throughput is with offered load upto a max throughput of approx. $T = 0.37$ for $G = 1$ after which point it decreases. Thus slotted ALOHA has double the max throughput as pure ALOHA & achieves the max at a higher offered load while this may represent a marked improvement over pure ALOHA. The effective utilization is still less than 40% of

low transmission rate, this is extremely wasteful of the limited wireless R.F. spectrum. Satellite communication techniques are needed to get efficiency.

Packet Reservation

Two main types of satellite multiple access schemes for packet transmission: channel fixed assignment, such as FDMA & TDMA which are appropriate for a small user population with high traffic density but perform poorly for a large Aloha & slotted Aloha which are independent of user population but yield poor throughput.

To overcome the drawbacks of above two schemes a no. of protocols called packet reservation have been proposed that work like slotted Aloha when the channel is low and move gradually to TDMA when the channel throughput exceeds 1/2. Packet reservation like random access is intended for use when a satellite channel is shared by a large no. of earth stations. The satellite capacity is demand or assigned to individual packets or messages from earth stations. The objective of reservation is to avoid the collision of packets that occur with random access and the packet reservation is an FDMA packet or message delay of at least twice the satellite round-trip delay due to make service time (one round trip delay) to coordinate all the reservation of it is successful). To

Stations, a global queue is maintained for satellite channel access. When it has a packet in the buffer, each station generates a request to reserve a place in the queue of fraction of satellite capacity it used to accommodate. Reservation request traffic since the earth stations are geographically distributed the multiple access problems in the reservation request channel still exists along with the problem of maintaining information on the status of the global queue to make decisions on when to access the channel.

Tree Algorithms:-

The pure Aloha and slotted Aloha are random multiple access protocols where the conflict is resolved by randomized retransmissions. We discuss an alternative algorithm called a tree algorithm for resolving the conflict as in slotted Aloha, the channel we consider is divided into slots of equal length. The length of each slot equals the packet length. Also we consider the satellite to have a broadcast capability, hence each can detect a packet collision population is infinitely large & that packet arrive at the satellite channel.

According to a poisson process with an arrival rate of λ packet per slot the λ is the channel up rate. Since the no. of users is infinite but the channel up rate is finite, the probability that any

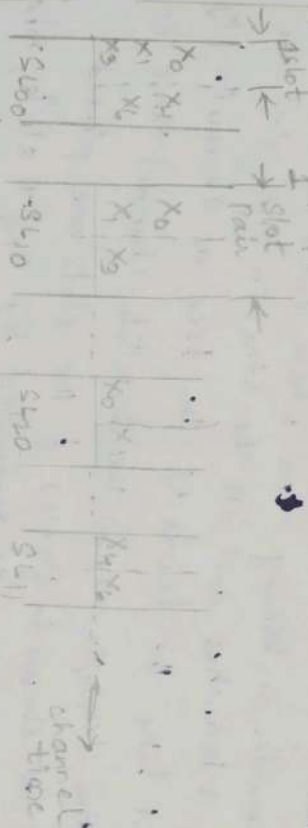
station will have more than one packet, assigned in
 a finite interval to geo. Also if a second packet
 arrives at stn it will not be tried until the first packet
 has been successfully ^{tried}.
 The tree algorithm for conflict resolution is based on the
 observation that the contention among active stations
 (stns with one packet to transmit) can be resolved if
 all the stns can be divided into groups such that
 each group contains only one active stn. The tree
 algorithm can be best described by an example.
 First consider a binary tree where each node consists
 of only 2 branches and all the stns in the n/w are
 arranged like the leaves of the tree as shown in fig 2.
 For stns $(x_0, x_1, x_2, \dots, x_7)$ the satellite channel time is
 slotted as shown in fig (3) & the slots are paired.
 Each slot pair slot is repeated by $R \times P$ slots, where
 P is the satellite round-trip delay and P is the slot
 length & both are in seconds. $[P = b/R]$ whose R is
 the channel capacity in bits per second & b is the
 packet length in bits. In the binary tree algorithm
 the stns in the tree transmit in the slot pairs
 no slot. Now assume that no collision exists until
 time to the start of slot pair slot where stns
 $x_0, x_1, \dots, x_3, x_4, x_5, x_6$ becomes active then the binary
 tree algorithm takes the following steps in the

Indicated slot pair:

Slot 0: All the active stations in tree T_{10} (ie X_0, X_1, X_3, X_4, X_5) transmit in the 1st slot & active stations in tree

T_{11} (ie, X_4, X_5) transmit in the 2nd slot. This results in 2 collisions one b/w X_0, X_1 & X_3 and other b/w X_4 & X_5 .

Since there are at least one collision in Slot 0, new packets generated at these active stations will not be transmitted until the conflict is resolved.



For Slot 0, Pair in Tree Algorithm

Slot 0: Since there is a collision in tree T_{10} , T_{10} transmits in the slot pair slot 0. Active stations in tree

T_{20} (ie, X_0, X_1) transmit in the first slot causing a collision on which the only active station

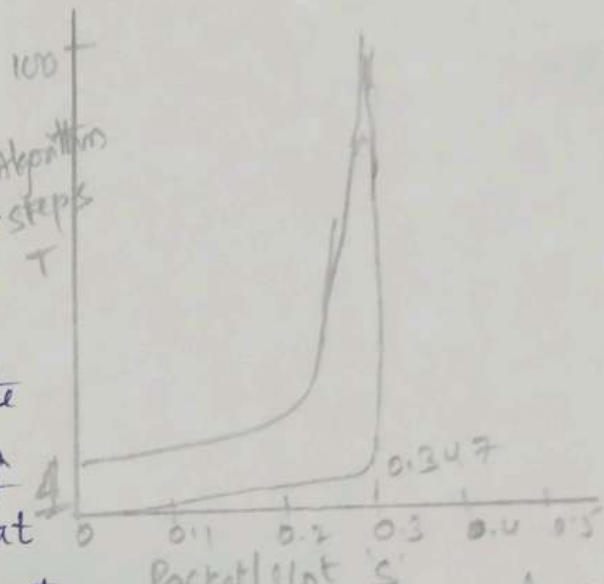
X_3 in tree T_{21} transmits in the second slot resulting in a successful transmission.

Slot 1: A collision causes tree T_{20} to transmit in slot pair slot 0 so that active stations X_0 & X_1 transmit in the first & second slots respectively.

resulting in two successful transmissions. (5-9)

SL₁₁:- Since there is a collision in tree T_1 , trees T_{23} & T_{23} transmit in the first & second slots of SL_{11} resulting in 2 successful transmissions by stations X_4 & X_6 . the process is repeated for newly generated packets.

→ For the binary tree algorithm it has been shown that avg. throughput the fraction of slots that contain exactly one packet each when the channel is at equilibrium is of the satellite channel can achieve a max^m of 0.347 packet per slot. Note that



at equilibrium the avg throughput is equal to the avg channel ifp rate. The avg. packet delay T versus the avg channel ifp rate S for the tree algorithm is normally expressed in terms of the no. of algorithm steps (an algorithm step is equal to a satellite round trip delay plus two slots).

→ There is no closed form expression for T however T is characterized by its upper & lower bounds as given in fig 3.

Introduction: —

- * The GPS System, Originally called NAVSTAR, was developed as a military navigation system for guiding missiles, ships and aircraft to their targets.
- * GPS Satellites transmit L-band signals that are modulated by several codes.
- * The first commercial use of GPS was in surveying, but by 1990 several companies had produced low-cost, handheld GPS receivers for general position location and navigation. GPS receivers are now a consumer product, and will soon be found in every car and cellular telephone.
- * The GPS system has been successful because it provides a direct readout of the present position of a GPS receiver with a typical accuracy of 30m.
- * GPS is a worldwide radio navigation system consisting of a constellation of 24 satellites and multiple ground stations.

GPS Satellites:

Name : NAVSTAR

Altitude : 20,200 km (MEO $\rightarrow$ Medium Earth Orbit)

Weight : 1877 kg.

Orbital Period : 11 hours 58 min

Orbital Inclination : 55° to Equatorial plane.

Design Life : 10 Years.

Current Constellation : 24 Block II Production Satellites.

* The position of a GPS receiver is found by trilateration, which is one of the simplest and most accurate methods of locating an unknown position.

* In trilateration, the distance of the unknown point from three known points is measured. The intersection of the arcs corresponding to three distances defines the unknown point relative to the known points. Since three measurements can be used to solve three equations to give latitude, longitude and elevation of the receiver. The distance b/w a transmitter and a receiver can be found by measuring the time it takes for a pulse of RF Energy to travel b/w the two.

Radio and Satellite Navigations: —

* Navigation is a field of study that focuses on the process of monitoring and controlling the movement of a craft or vehicle from one place to another.

* The field of navigation includes four general categories: Land navigation, marine navigation, aeronautic navigation and Space navigation. All navigational techniques involve locating the navigator's position compared to known locations or patterns.

* "Radio Navigation" is the application of radio frequencies to determine a position on the Earth.

* A "radio direction finder", also known as a "radio compass", used a loop antenna mounted on the back of an aircraft. If the plane of this antenna

pointed to a radio beacon, the signal strength was a maximum, while a signal facing the loop induced voltages that canceled each other out, resulting in a weak or null signal.

- * Satellite navigation systems can provide far higher accuracy than any other current long and medium range navigation system. Specifically, in the case of GPS, differential techniques have been developed which can provide accuracies comparable with current landing systems.
- * The NAVigation Satellite Timing and Ranging (NAVSTAR) GPS is an all-weather, radio based, satellite navigation system that enables users to accurately determine 3-dimensional position, velocity and time worldwide.

Global Positioning System (GPS):—

- * GPS is a popular application of spread spectrum. The GPS is now used in ship and aircraft navigation, geological surveys. GPS is used to determine the precise location of any object on the Earth within the accuracy of inches. Also it is used for measuring the velocity of moving object.
- * Typical applications of GPS are
 - 1) To pin-point locate the destination by delivery vehicle.
 - 2) To guide emergency vehicle through electronic map.

3. To monitor continuously the movement of cargo or any vehicle.

4. A GPS assisted navigation systems airlines can fly more direct routes, saving time for passengers & fuel.

GPS Position Location Principles: —

* In a considerably simplified approach, each satellite is sending out signals with the following content: I am satellite X , my position is Y and this information was sent at time Z . In addition to its own position, each satellite sends data about the position of other satellites. These orbit data (Ephemeris & almanac data) are stored by the GPS receiver for later calculations.

* For the determination of its position on Earth, the GPS receiver compares the $\approx$ the time when the signal was sent by the satellite with the time the signal was received. From this ^{time} difference the distance between receiver and satellite can be calculated.

* If data from other satellites are taken into account, the present position can be calculated by —
- trilateration (i.e. determination of a distance from three points). This means that at least three satellites are required to determine the position of the GPS receiver on the Earth surface.

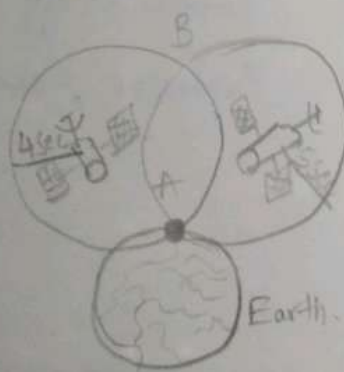
9-3

* The Calculation of a position from 3 Satellites signals is called 2D-position fix (two-dimensional position determination). It is only two dimensional because the receiver has to assume that it is located on the Earth Surface (on a plane two-dimensional surface).

* By means of four or more Satellites, an absolute position in a three dimensional space can be determined. A 3D-position fix also gives the height above the Earth Surface as a result.

How the Position determination by GPS works.

* For simplification, in the first step we assume that the Earth is a two-dimensional disk. This allows us to do some understandable sketches for illustration. The principle can then be transferred to the model of a three-dimensional globe.



—fig: Position determination with two Satellites
(in a 2-dimensional world)

* In the Example, the time needed by a signal to travel from the first of two Satellites to the receiver was determined to be 4Sec. Based on this information, we can state that the receiver is positioned somewhere on a circle with a radius of 4Sec around the first Satellite (left circle). If we perform the same procedure with a second Satellite (right circle), we get two points of intersection.

* On one of the two points the receiver must be situated. Now we have used two Satellites. But the process is called trilateration, not dilateration so don't we need a third Satellite? We may use a third Satellite but we could also assume that the receiver is located somewhere close to the Earth's Surface and not deep in space, so we can neglect point 'B' and know that the receiver must be found on point 'A'.

* GPS receivers are based on conventional quartz clocks which are comparatively inaccurate. Atomic clocks being too expensive. Hence there is clock Error.

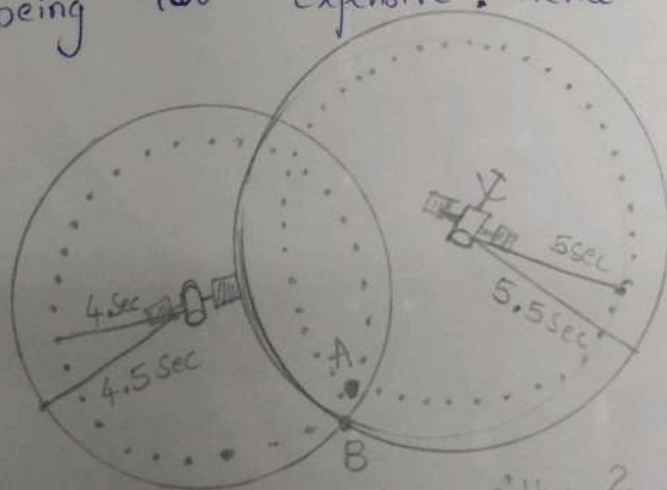


Fig: 2D Position determination with 2 Satellites and clock Error

* Four Satellites are used to determine the exact location of a receiver.

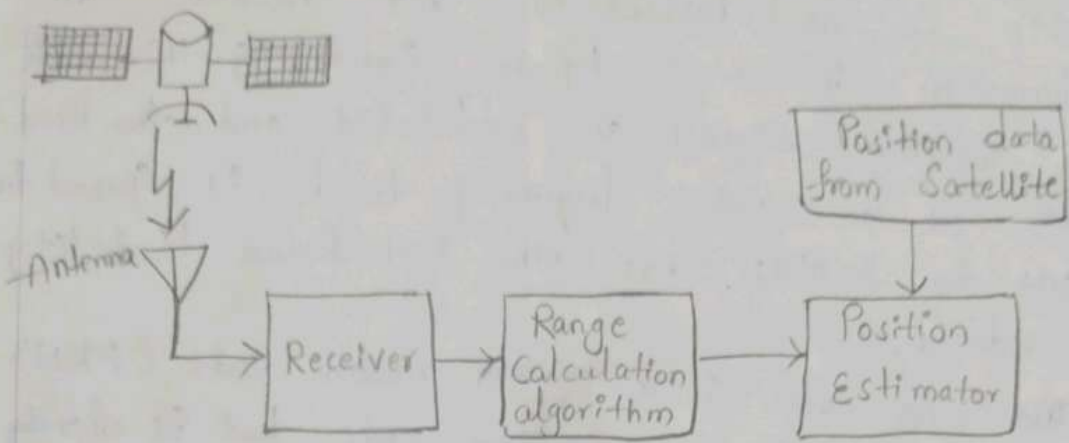


Fig: GPS receiver

* The data received from Satellite and known carrier the GPS receiver is given to position Estimator. It computes the exact position of receiver.

Role of L_1 and L_2 Carriers :-

* Data are transmitted from each satellite on two carrier frequencies designed as L_1 (1575.42 MHz) and L_2 (1227.60 MHz). The L_2 signal is modulated with 10.23 Mbps PN bit sequence called the 'P' code. The precise positioning is obtained by L_1 and L_2 carriers.

C/A and P-Code :-

* The carrier phases are modulated by three different binary codes: first there is the C/A Code (coarse acquisition). This code is a 1023 "chip" long code, being transmitted with a frequency of 1.023 MHz.

* A "chip" is the same as a "bit", and is described by the numbers "one" or "zero". The name "chip" is used instead of "bit" because no information is carried by the signal. By this code the carrier signals are modulated and the bandwidth of the main frequency band is spread from 2MHz to 20MHz. Thus the interference liability is reduced.

* The C/A code is a pseudo random code (PRN) which looks like a random code but is clearly defined for each satellite. It is repeated every 1023 bits or every millisecond. Therefore each second 1023000 chips are generated. Taking into account the speed of light the length of one chip can be calculated to be 300m.

Pseudo Random Numbers (PRNs) :-

* The satellites are identified by the receiver by means of PRN-numbers. Real GPS satellites are numbered from 1-32. These PRN-numbers of the satellites appear on the satellite view screens of many GPS receivers. For simplification of the satellite network 32 different PRN-numbers are available, although only 24 satellites were necessary and planned in the beginning.

* The P code (P = precise) modulates the L_1 as well as the L_2 carrier frequency and is very long pseudo random code.

- * In this Example Suppose the clock in our receiver is 0.5 seconds Early compared to the clock in the Satellite. The runtime of the signal seems to be 0.5 sec longer than it actually is. This leads to the assumption that we are on point 'B' instead of point 'A'.
- * The circles that intersect in point 'B' are called pseudoranges. They are called "pseudo" as long as no correction of the Synchronisation Errors of the clocks has been performed.
- * Depending on the accuracy of the clock in the GPS receiver, the determined position will be more or less wrong.
- * A clock error of $1/100$ second, which is difficult to imagine but quite common from car races, would in GPS navigation lead to a mistake in the position of about 3000 km. To achieve an accuracy of 10m of the position, the runtime of the signal must be precise to 0.00000003 seconds.
- * As atomic clocks are no option in GPS receivers, the problem is solved in another and quite elegant way is "using third satellite".
- * If a third satellite is taken into account for the calculation of the position, another intersection obtained.

In case that all clocks are absolutely precise, point 'A' would be obtained, corresponding to the actual position of the receiver.

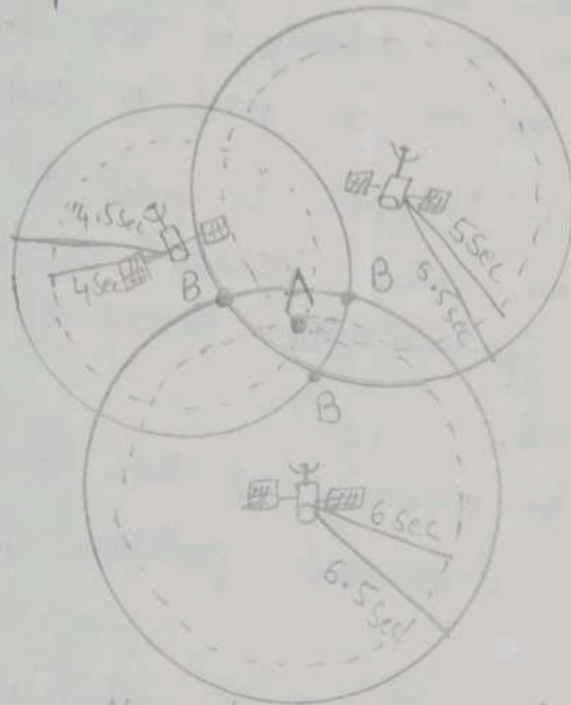


Fig: 2D position determination with '3' Satellites and Corrected clock Error.

- * In case of the receiver clock being 0.5 Sec Early, the three intersection points 'B' are obtained. In this case the clock Error stands out immediately.
- * If now the time of the receiver clock is shifted until the three intersection points B merge to A, the clock Error is corrected and the receiver clock is synchronized with the atomic clocks in the Satellites.
- * The GPS receiver can now be regarded as an atomic clock itself. The distances to the Satellites, formerly regarded as pseudoranges, now correspond to the actual distances & the determined position is accurate.

Position Determination with GPS :-

* The principle of position determination by GPS and the accuracy of the positions strongly depend on the nature of the signals. A variety of criteria was considered in the development of a suitable signal structure.

* In consequence the GPS signal is quite complex and offers the possibility of determining the following parameters: One-way position determination, Exact distance and direction determination (Doppler Effect), transmission of navigation information, simultaneous receiving of several satellite signals, provision of corrections for ionospheric delay of signals and insusceptibility against interferences and multi path effects. In order to fulfil all these requirements, the signal structure described was developed.

GPS Receivers and Codes :-

* The GPS system can be divided into three basic segments.

- 1) Space Segment (Satellites)
- 2) Control Segment (Control Stations)
- 3) User Segment (GPS receiver)

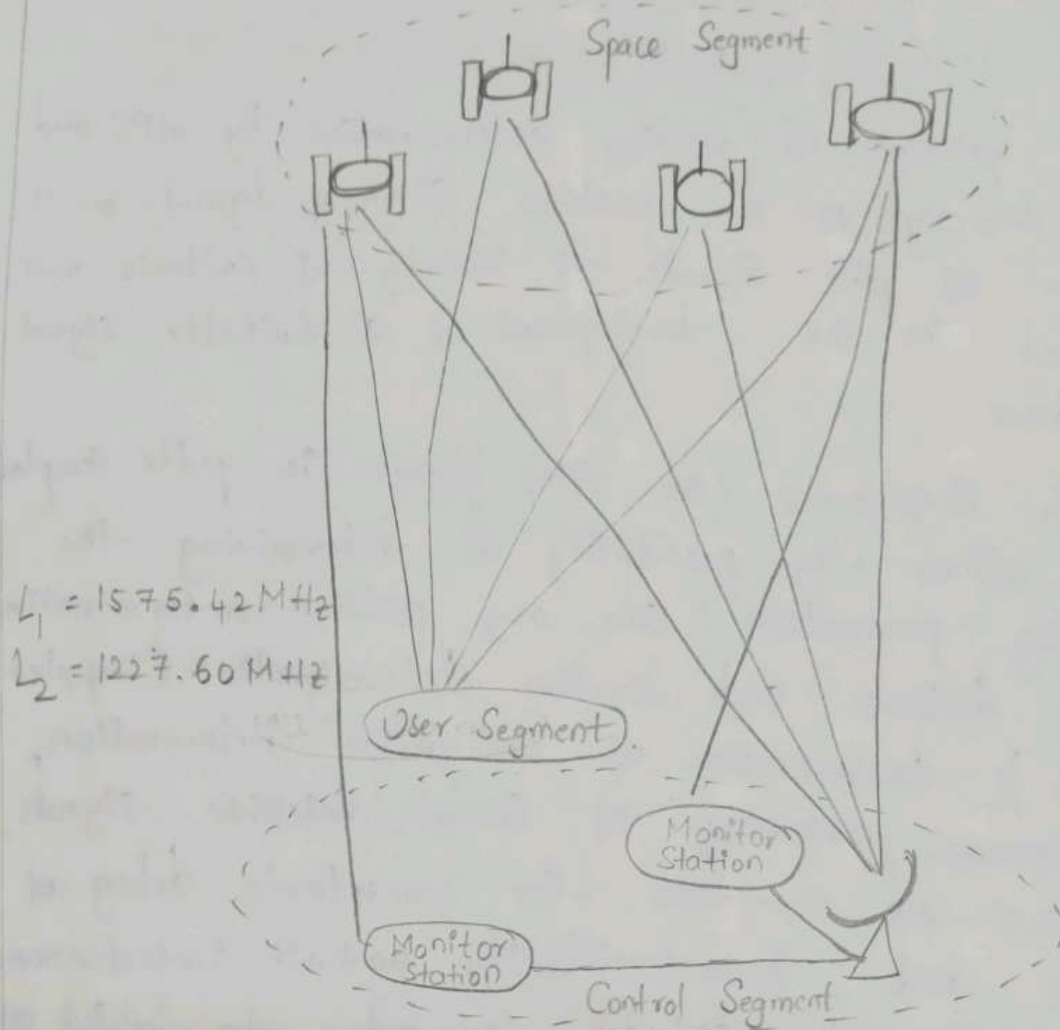


Fig: GPS System.

GPS Receiver :-

* The GPS System uses 24 Satellites in Six orbital planes at 22,200 km height from Earth. All the Satellites are controlled by Earth Station. All Satellites and Earth Station have highly precise atomic clock for time Synchronization for generating PN Code. Satellites continuously transmit this PN code and information about location and time. A GPS receiver on ground generates same PN code.

for protection against interfering signals transmitted by an possible enemy, the P-code can be transmitted is encrypted. During this anti-spoofing (AS) mode the P-code is encrypted in a Y-code.

* The encrypted code needs a special AS-module for each receiving channel and is only accessible for authorized personnel in possession of a special key.

* The 'P' and Y-code are the base for the precise position determination.

GPS Accuracy and Limitations :-

* GPS is proven to be a very valuable tool for the purposes of surveying and navigation however its users must be aware of its characteristics and cautions of its limitations.

* Common factors affecting the accuracy of GPS are :

- 1) GPS Technique Employed.
- 2) Surrounding conditions (Satellite visibility & multipath)
- 3) Number of Satellites in view.
- 4) Satellite Geometry.
- 5) Distance from Reference Receiver
- 6) Ionospheric Conditions.
- 7) Quality of GPS receiver.

Precision and Accuracy :-

* Although precision and accuracy are often assumed to be

- The same thing, technically they are slightly different.
- * Precision refers to the closeness to the mean of observations and accuracy refers to the closeness to truth.
 - * The precision or accuracy quoted by many GPS manufacturers is often done using a statistic known as CEP (Circular Error Probable) and are usually tested under ideal conditions.

S_p = Standard deviation of latitude

S_l = Standard deviation of longitude.

$$CEP = 0.59 [S_p + S_l]$$

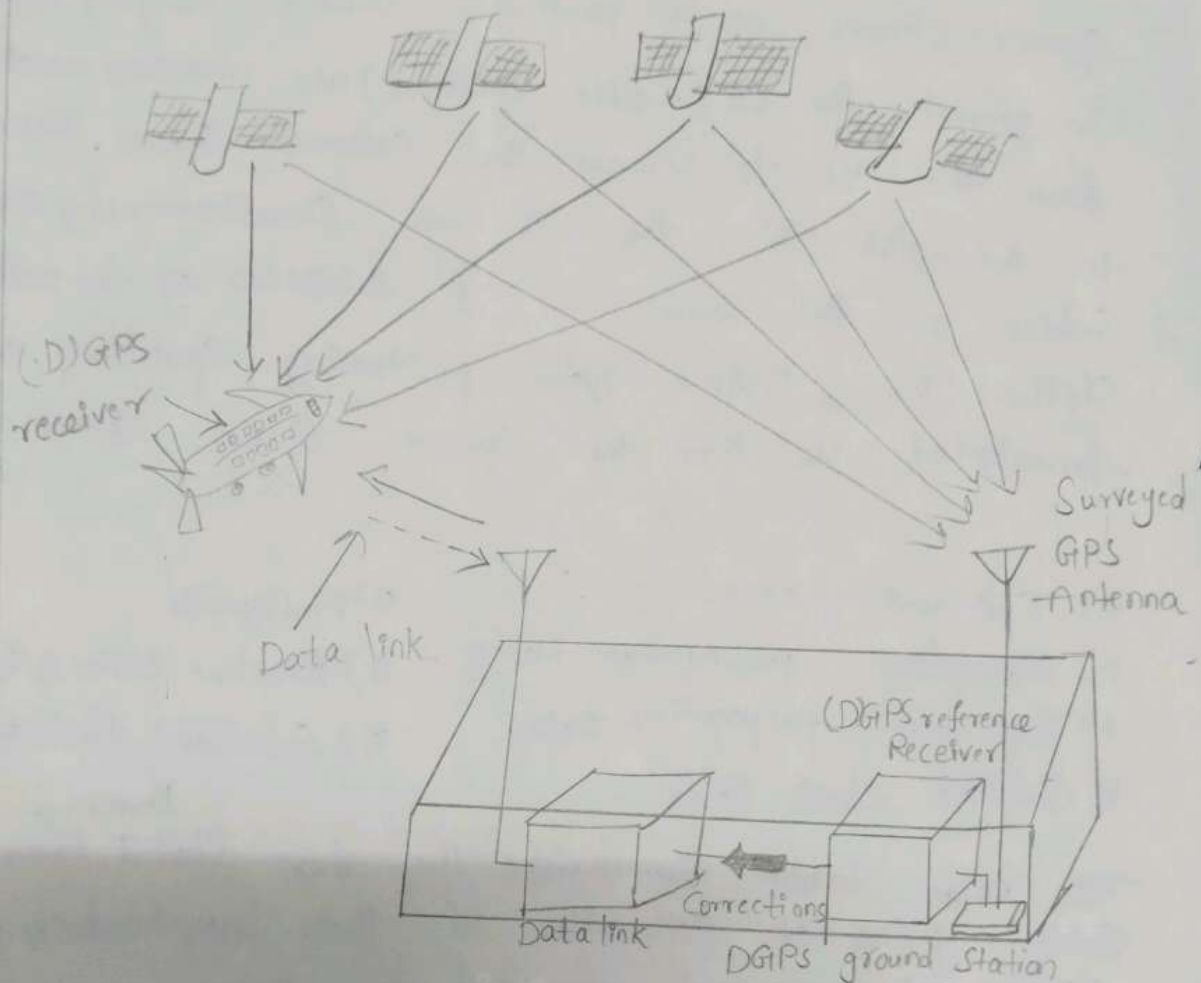
Errors in GPS : —

- 1) Accuracy in atomic clocks affects the position location error.
 - 2) DRMS (Distance Root Mean Square) Error.
 - 3) C/A code Sequence Error.
- * The accuracy of atomic clock can be increased by using highly stable oscillator.
 - * DRMS Error can be reduced by controlling clock bias.

Differential GPS (DGPS) Techniques : —

- * The idea behind all differential positioning is to correct bias errors at one location with measured bias errors at a known position. A reference receiver or base station, computes corrections for each satellite signal.

* DGPS removes Common mode Errors, — those Errors Common to both the reference and remote receivers. 5-8



— fig: DGPS Architecture.

* The System Consists of a Reference Receiver (RR) located at a known location that has been previously surveyed and one or more DGPS User Receivers (UR)

* The RR antenna, differential correction processing system and datalink equipment are collectively called the Reference Station (RS). Both the UR and the RR data can be collected and stored for later processing, or sent to the desired location in real time via the datalink,

* DGPS is based on the principle that receivers in the same vicinity (neighbours) will simultaneously experience common errors on a particular satellite ranging signal. In general, the UR (mobile receivers) use measurements from the RR to remove the common errors. In order to accomplish this, the UR must simultaneously use a subset or the same set of satellites as the reference station. The DGPS radio positioning equations are formulated so that the common errors cancel.

DGPS Error Sources: —

- 1) Ephemeris Error
- 2) Ionospheric propagation Delay
- 3) Tropospheric propagation Delay.
- 4) Satellite clock drift.
- 5) Multipath.
- 6) Receiver Noise & clock Drift
- 7) Selective Availability Errors.

The below table summarises the above stated error sources giving an estimation of their magnitudes & the possible improvement provided by DGPS.

Error Source	Stand Alone (m)	DGPS (m)
Ephemeris	5-20	0-1
Ionosphere	15-20	2-3
Troposphere	3-4	1
Satellite clock	3	0
Multipath	2	2
Receiver Noise	2	2
Selective Availability	50	0

Table : Error Sources in DGPS