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Satellite Communication 15EC755

Module - 1

Satellite Orbits and Trajectories

Syllabus:

Definition, Basic principles, Orbital parameters, injection velocity and satellite trajectory, Types of satellite orbits, Orbital perturbations, satellite stabilization, Orbital effects on satellite performance, Eclipses, Look angle Determination (Az & E).

A satellite in general is any natural or artificial body moving around a celestial body such as planets and stars.

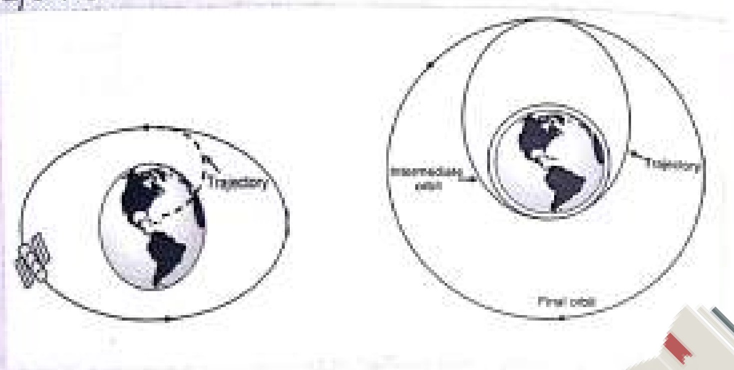
Applications of satellites

A satellite while in orbit performs the designated role throughout its lifetime. Satellites are used for variety of applications including

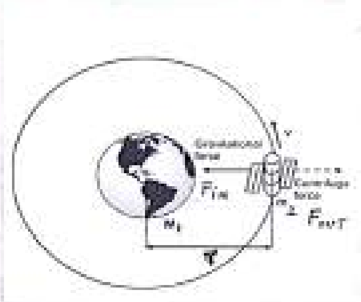
- Communication
- Weather forecasting
- Earth observation
- Navigation and scientific missions.
- Military satellites.

Orbit and Trajectory.

A trajectory is a path traced by a moving body, an orbit is a trajectory that is periodically repeated.



Expression for orbital period & velocity



According to Newton's law of gravitation, every particle irrespective of mass attracts every other particle with a gravitational force (F) whose magnitude is directly proportional to the product of the masses of two particles and inversely proportional to the square of the distance between them.

Mathematically,

$$F = \frac{G M_1 M_2}{r^2}$$

where M_1, M_2 are the masses of the two particles.
$r \longrightarrow$ distance between the two particles.
$G \longrightarrow$ gravitational constant $= 6.67 \times 10^{-11} N m^2/kg^2$

According to Newton's second law of motion,

$$F = m \times a$$

When the satellite is in its orbit, it experiences two forces viz centripetal and centrifugal force.

If both forces on satellite are equal then the satellite orbit Earth with uniform velocity 'v'.

$$\underbrace{\frac{G M_1 M_2}{r^2}}_{\substack{\text{Centripetal force} \\ F_{IN}}} = \underbrace{\frac{M_2 v^2}{r}}_{\substack{\text{Centrifugal force} \\ F_{OUT}}}$$

$$\therefore \quad v = \sqrt{\frac{G M_1}{r}} = \sqrt{\frac{\mu}{r}}$$

velocity with which satellite orbits in circular

where M_1 is mass of the Earth

$\mu = G M_1 = 3.986013 \times 10^5 \ km^3/s^2$

Then, the orbital period is given by

$$T = \frac{2\pi r}{v} \Rightarrow \frac{2\pi r \cdot r^{1/2}}{\sqrt{\mu}}$$

$$T = \frac{2\pi r^{3/2}}{\sqrt{\mu}}$$

In case of elliptical orbit, the Kinetic and potential energies of a satellite at any point at a distance 'r' from the center of Earth given by

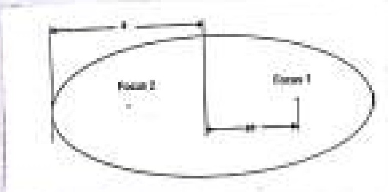
Kinetic Energy $= \frac{1}{2} M_2 v^2$

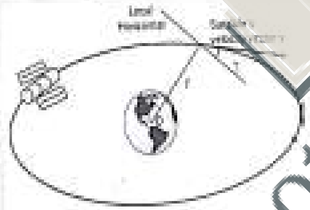
potential Energy $= -\frac{G M_1 M_2}{r}$

Sum of Kinetic and potential energies of satellite always remains constant, which is equal to

$$= \frac{-G M_1 M_2}{2a}$$

Where $M_1 \rightarrow$ mass of the Earth
$M_2 \rightarrow$ mass of the satellite
$a \rightarrow$ semimajor axis of the orbit





$$\therefore \frac{1}{2} M_2 v^2 - \frac{G M_1 M_2}{r} = -\frac{G M_1 M_2}{2a}$$

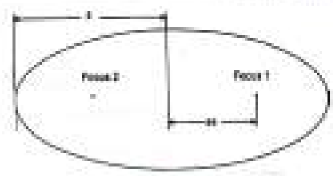
$$v^2 = G M_1 \left(\frac{2}{r} - \frac{1}{a}\right)$$

$$\therefore v = \sqrt{\mu\left(\frac{2}{r} - \frac{1}{a}\right)}$$

Kepler's Laws of planetary Motion

Kepler's First Law.

The path followed by a satellite around primary will be an ellipse.

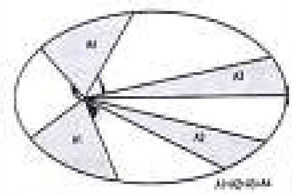


Where $e = \frac{\sqrt{a^2 - b^2}}{a}$ eccentricity

$v = \sqrt{\mu\left(\frac{2}{r} - \frac{1}{a}\right)}$ velocity of satellite in elliptical orbit.

Kepler's Second law:

for equal time intervals, a satellite will sweep out equal area in its orbital plane.



Where the rate of change of swept out area is given by

$$\frac{dA}{dt} = \frac{\text{Angular momentum of the satellite}}{2m}$$

where $m \rightarrow$ mass of the satellite.

Kepler's third law

The square of the time period of any satellite is proportional to the cube of semi-major axis of its elliptical orbit.

Considering a circular orbit of radius 'r' (where semi-major axis = semi minor axis).

Equating the forces on the satellites,

$$\frac{G M_1 M_2}{r^2} = \frac{M_2 v^2}{r}$$

Centripetal force — Centrifugal force

replacing 'v' by ωr, we get

$$\frac{G M_1 M_2}{r^2} = \frac{M_2 \omega^2 r^2}{r} = M_2 \omega^2 r$$

$$\Rightarrow \omega^2 = \frac{G M_1}{r^3}$$

Substituting $\omega = \frac{2\pi}{T}$, we get,

$$\left[\frac{2\pi}{T}\right]^2 = \frac{G M_1}{r^3}$$

$$T^2 = \frac{4\pi^2}{G M_1} \cdot r^3$$

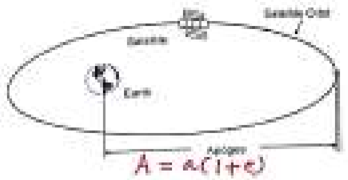
$\therefore$ orbital period $T = \frac{2\pi}{\sqrt{\mu}} r^{3/2}$

The above equation holds good for elliptical orbit, by replacing r by 'a' as

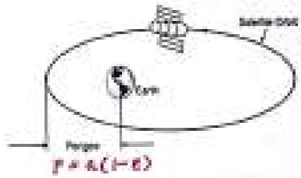
$$T = \frac{2\pi a^{3/2}}{\sqrt{\mu}}$$

Orbital parameters.

Apogee: Apogee is the point on satellite orbit that is at the farthest distance from center of the Earth.



$A = a(1+e)$



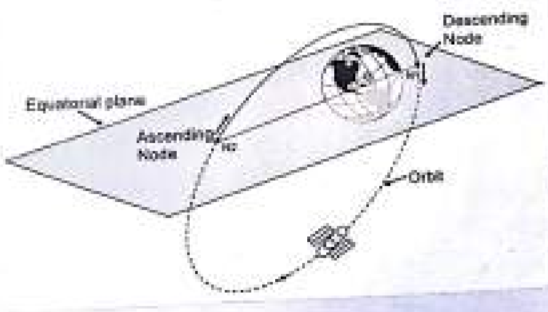
$P = a(1-e)$

perigee: perigee is the point on orbit that is nearest to the center of the Earth.

Line of apsides: The line joining the perigee and apogee through the center of the Earth.

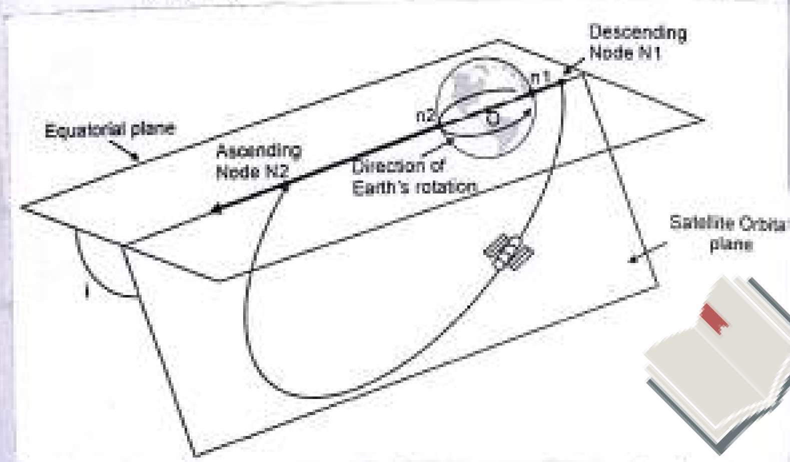
Ascending Node: The point where the orbit crosses the equatorial plane of Earth going from South to North (N_a).

Descending Node: The point where the orbit crosses the equatorial plane of Earth going from North to south (N_d)



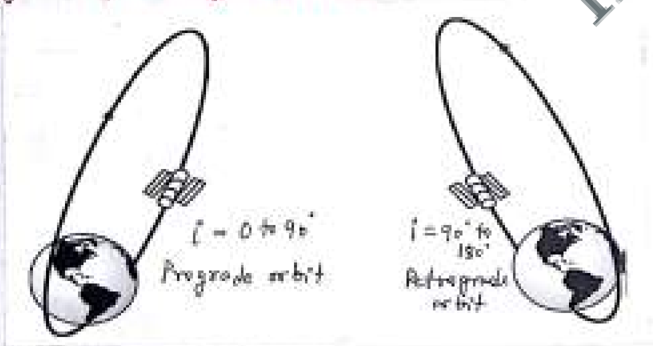
Line of Nodes: The line joining ascending and descending nodes through the center of earth.

Inclination: It is the angle that the orbital plane of satellite makes with the earth's equatorial plane.



It is measured from ascending node to the the orbit from the equatorial plane.

Prograde & Retrograde orbit.

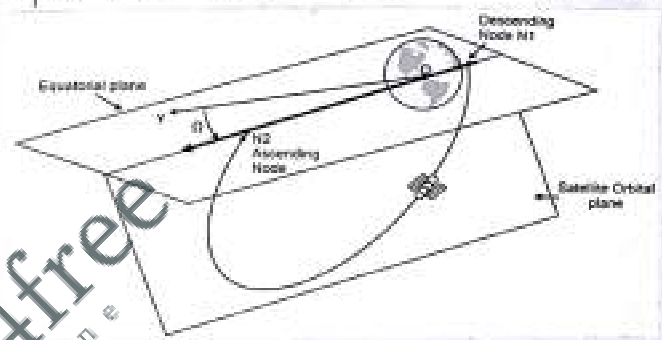


An orbit in which satellite moves in the same direction as earth's rotation known as Progrde orbit.

An orbit in which satellite moves in a direction counter to earth's rotation is retrograde orbit.

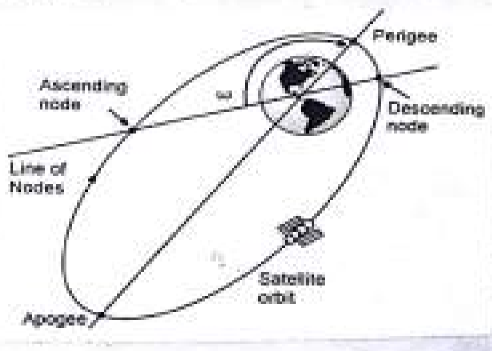
Right Ascension of Ascending Node: (Ω)

This is the angle made by line of nodes with respect to the direction of the vernal equinox. (γ)

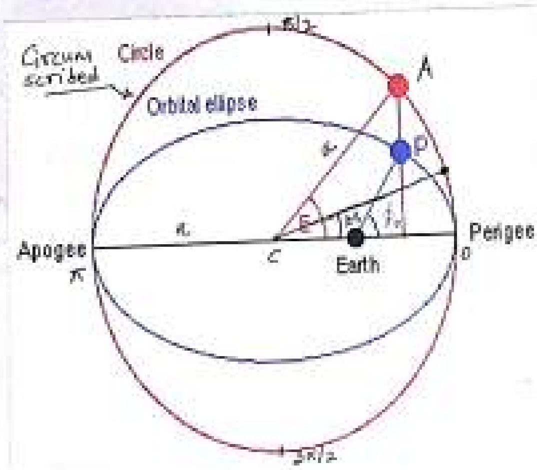


Argument of perigee: (ω)

This parameter defines the location of major axis of satellite orbit. It is measured between the line joining the perigee and center of the earth and line of nodes from ascending to descending nodes in the same direction as that of satellite orbit.



True anomaly, Mean Anomaly & Eccentric anomaly



True anomaly (ϕ_0): is the angle from perigee to the satellite position.

Mean anomaly (M): is the arc length (radians) that satellite would have traversed since the perigee passage if it is moving on a circumscribed circle at mean angular velocity η.

$$M = E - e\sin E$$

Eccentric anomaly (E): Angle made by drawing vertical line from position of satellite intersects circumscribed circle at A.

refer: www.youtube.com/watch?v=cf93h44kL20

Injection Velocity and Resulting Satellite trajectories.

The horizontal velocity with which a satellite is injected into space by the launch vehicle with the intention of imparting a specific trajectory to the satellite has a direct bearing on the satellite trajectory.

The general expression for the velocity of a satellite at the perigee point (V_p), assuming an elliptical orbit is given by

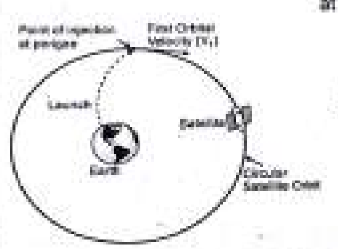
$$V_p = \sqrt{\mu\left(\frac{1}{P} - \frac{2}{A+P}\right)}$$

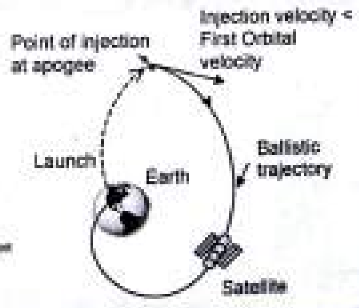
where A is the Apogee distance
P is the perigee distance
$\mu = GM$ = Kepler's constant.

First cosmic velocity V_1 is one at which apogee and perigee distances are equal, A = P and orbit is circular. Then the above expression reduces to

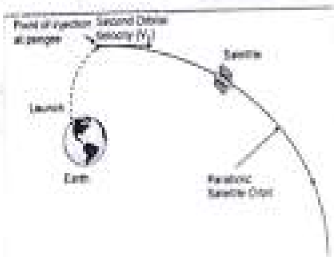
$$V_1 = \sqrt{\frac{\mu}{P}}$$

If the injection velocity < first cosmic velocity, the satellite follows a ballistic trajectory and falls back to Earth.





for injection velocity > first cosmic velocity and less than second cosmic velocity, ie $v > \sqrt{\mu/p}$ and $v < \sqrt{2\mu/p}$, the orbit is elliptical and eccentric. $(0<e<1)$.



When the injection velocity $= \sqrt{\frac{2\mu}{r}}$, the apogee distance becomes infinite and the orbit takes the shape of parabola. This velocity is known as second cosmic velocity v_2.

At this velocity, the satellite escapes from earth's gravitational pull.

if injection velocity > v_2, the trajectory is hyperbolic and $e>1$.

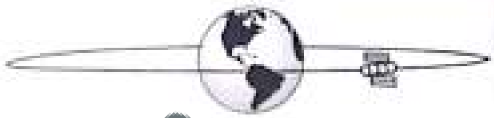
If the injection velocity is increased further a stage is reached where the satellite succeeds in escaping from the solar system.

Types of Satellite orbits

The satellite orbits can be classified on the basis of

1. orientation of orbital plane
2. eccentricity
3. Distance from Earth

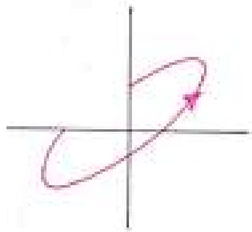
1. based on orientation of orbital plane



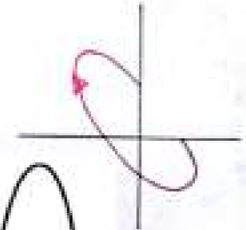
Equatorial orbit
inclination angle $i = 0°$

Polar orbit
inclination $i = 90°$

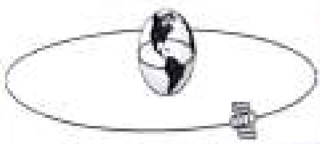
Prograde orbit
inclination angle $0°$ to $90°$



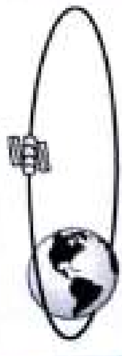
Retrograde orbit
inclination $i = 90°$ to $180°$



2. based on eccentricity



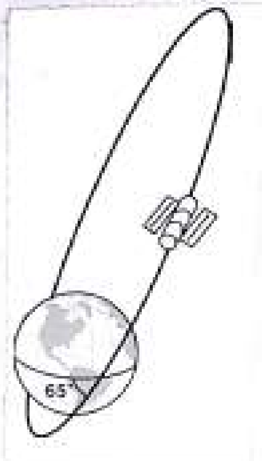
circular orbit



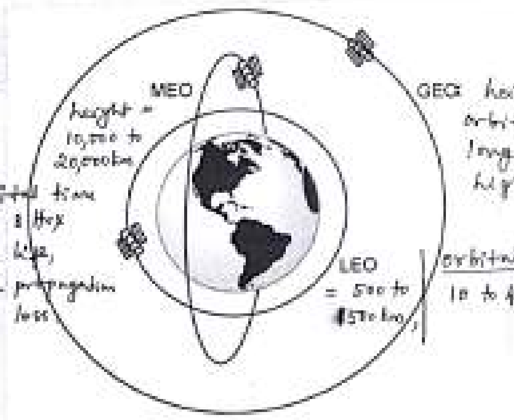
elliptical orbit

<u>Molniya orbit</u>

- ✓ Highly eccentric
- ✓ inclination I = 65°
- ✓ elliptical orbit to covers higher latitudes.
- ✓ e = 0.75 with h_p = 4000km, h_a = 40,000km
- ✓ 12 hour orbit time, satellite spends about 8 hours above a particular high northern latitude station before diving to a low perigee.



3. <u>based on distance from Earth</u>



Orbital Perturbation.

The Keplerian orbit described ideal in the sense that it assumes that the earth is a uniform spherical mass and that the only force acting is the centrifugal force resulting from satellite motion balancing gravitational pull of the earth.

The other forces significant are the gravitational pulls of sun and moon and atmospheric drag.

<u>effect of a nonspherical earth.</u>

for a spherical earth of uniform mass, Kepler's third law given by

$$n_0 = \sqrt{\frac{\mu}{a^3}}$$

where n_0 = mean motion

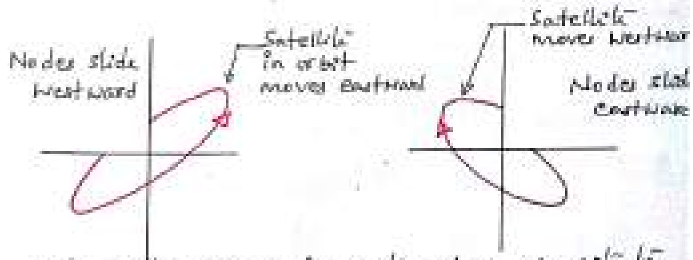
The anomalistic period is given by

$$P_A = \frac{2\pi}{n} \text{ seconds.}$$

where n is in radian/second

The oblateness of the earth also produces two rotations of the orbital plane.

→ regression of the nodes
→ rotation of line of apsides.



The nodes moves in a direction opposite to direction of satellite motion, Hence the name regression of the nodes.

for polar orbit ($i = 90°$) regression is zero.

The factor K given by

$$K = \frac{n K_1}{a^2(1-e^2)^2}$$

where n = mean motion
a = semimajor axis
e = eccentricity
$K_1 = 66063.1704 \ km^2$

Then rate of change of Ω is given by

$$\frac{d\Omega}{dt} = -K \cos i$$

if $i > 90°$, regression is eastward and the orbit is retrograde

$i < 90°$, regression is westward and the orbit is prograde.

The other effect produced by equatorial bulge is rotation of line of apsides given by

$$\frac{d\omega}{dt} = K(2 - 2.5 \sin^2 i)$$

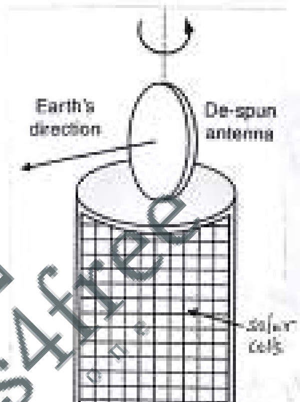
When $i = 63.435°$, no rotation takes place

Satellite stabilization

Commonly employed techniques for satellite attitude control includes

1. spin stabilization
2. 3-axis or body stabilization.

1. spin stabilization



Spin stabilized satellite are generally cylindrical in shape.

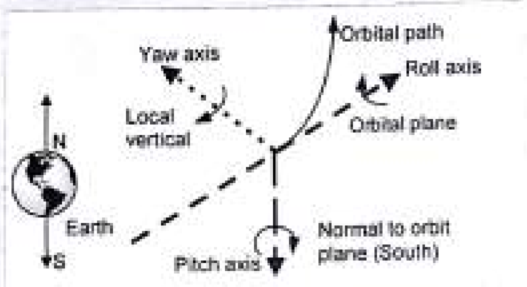
Here the satellite body is spun at a rate between 30 and 100 rpm about an axis perpendicular to the orbital plane.

The rotation of satellite body offers inertial stiffness to prevent satellite from drifting.

Spinning types

- Simple spinner
  - ✓ The satellite payload & other subsystems are placed in spinning section.
  - ✓ The antenna and the feed are placed in de-spun platform (moves opposite to the satellite spinning)
- dual spinner
  - ✓ entire payload and antenna, feed is placed on de-spun platform
  - ✓ other subsystem are located on spinning platform.

2. 3-axis or body stabilization.



The stabilization achived by controlling the movement of satellite along 3-axis that is
- yaw axis
- pitch axis
- roll axis.

The system uses reaction wheels or momentum wheels to correct the orbit perturbations.

The satellite body is generally box shaped for body stabilization.

Station keeping.

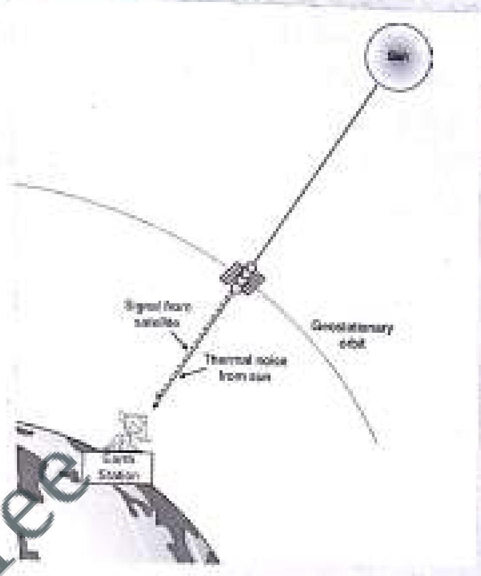
It is a process of maintaining satellite orbit against different factors that cause temporal drift.

✓ In spin stabilized satellites North-south station keeping maintained by firing thrusters parallel to spin axis. in continuous mode.

✓ East-west station keeping maintained by firing thrusters perpendicular to spin-axis.

✓ In body stabilization firing thrusters in east-west or north-south direction in continuous mode

Sun transit outrage.



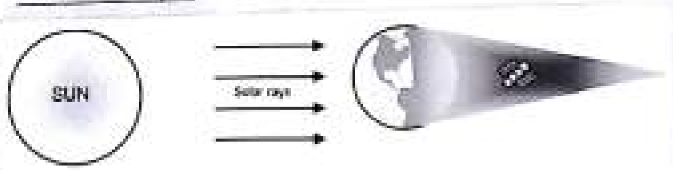
There are times when the satellite passes directly between the Sun and the Earth. The Earth station antenna receive signals from satellite as well as microwave radiation emitted by sun. This might cause temporary blanking the communication signal if solar radiation magnitude exceeds the fade margin of the receiver. This phenomenon of blanking satellite signal by hot sun is Sun transit outrage.

The traffic of satellite may be shifted to other satellite during sun transit outrage.

Eclipses.

an eclipse is said to occur when the sunlight fails to reach the satellite solar panel due to an obstruction from celestial body.

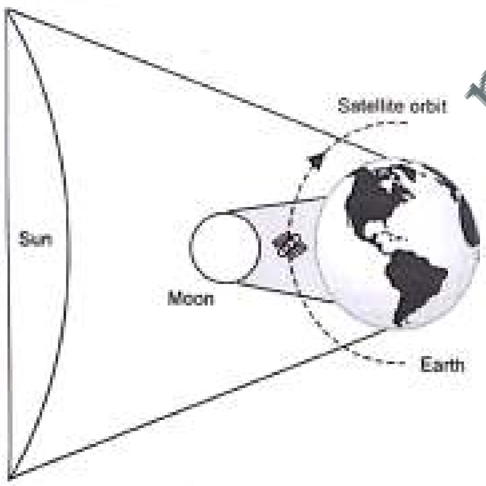
Solar eclipse.



The major and most frequent source of eclipse is due to the satellite coming in the shadow of earth, known as solar eclipse.

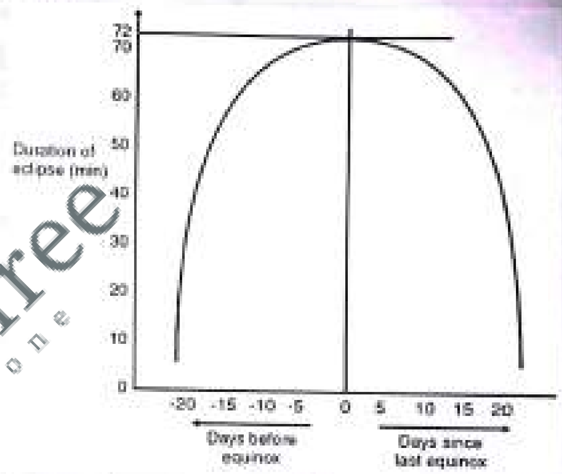
during equinoxes in March and september, the satellite, the Earth and the sun are aligned at midnight as per local time and satellite spends 72 minutes in total darkness.

Lunar eclipse

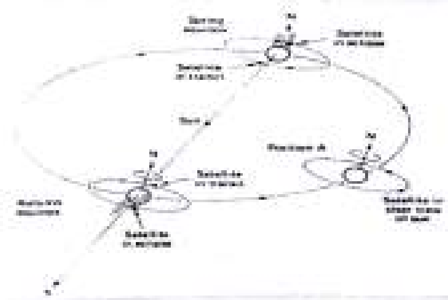


Another type of eclipse known as Lunar eclipse, when Moon's shadow passes across the satellite. This is less common phenomenon occur once in 29 years.

Duration of eclipse increases from 0 to 72 minutes starting 21 days before the equinox and then decreases from 72 to 0 during 21 days following the equinox.



During the period of eclipse, satellite is depleted of its electrical capacity as the sunlight fail to reach it. The high power satellites shut down for all but essential services.



Look angles of satellite

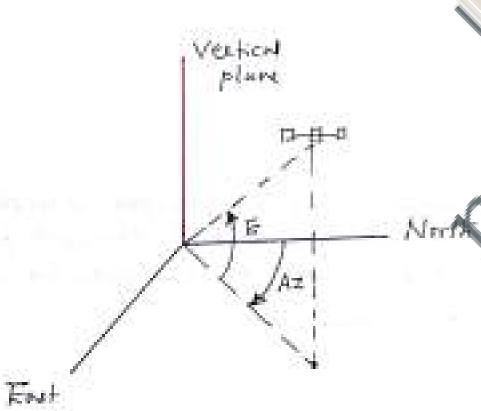
Look angle of a satellite refers to the co-ordinates to which an Earth station must be pointed in order to communicate with satellite and expressed in terms of Azimuth and Elevation angle.

Azimuth:

The angle measured Eastward (clockwise) from geographic North to the projection of satellite path on the horizontal plane at Earth station.

Elevation:

The angle measured upward from local horizontal at Earth station to satellite path.



$\theta_l > 0$, $\theta_L - \theta_s < 0$: $A_z = 180 - A$	$\theta_l > 0$, $\theta_L - \theta_s > 0$: $A_z = 180 + A$
$\theta_l < 0$, $\theta_L - \theta_s < 0$: $A_z = A$	$\theta_l < 0$, $\theta_L - \theta_s > 0$: $A_z = 360° - A$

where $\theta_l \rightarrow$ Latitude of Earth station

$\theta_L \rightarrow$ longitude of Earth station

$\theta_s \rightarrow$ longitude of satellite

Where $$A = \tan^{-1}\left[\frac{\tan|\theta_s - \theta_L|}{\sin\theta_l}\right]$$

Elevation E

$$E = \tan^{-1}\left[\frac{r - R\cos\theta_l \cos|\theta_s - \theta_L|}{R\sin\{\cos^{-1}(\cos\theta_l \cos|\theta_s - \theta_L|)\}}\right] - \cos^{-1}(\cos\theta_l \cdot \cos|\theta_s - \theta_L|)$$

Where $r \rightarrow$ orbital radius

$R \rightarrow$ Earth's radius

Module-2.

Satellite Subsystem:

powersupply subsystem, Attitude and Orbit control, TT&C and payload

Different subsystems of a typical satellite includes

Telemetry, Tracking & Command (TT&C)
This subsystem, monitors and controls the satellite right from lift-off stage to end of its operational life time.

Attitude and Orbit Control
This subsystem maintain and control orbital path of satellite and ensure the antenna remain pointed towards Earth fixed location.

payload Subsystem.
This subsystem carries desired instrumentation required for performing its intended function.

Antenna Subsystem
This subsystem provides dual function of receiving and transmitting signals.

power supply sub system.
main function is to collect solar energy and transform it to electrical power using solar cells and distribute to all subsystems.

Thermal control Subsystems.
This ensures to maintain the satellite platform within operating temperature limits for the type of equipment on board the satellite

propulsion sub system
This provides the trust required to impart the necessary velocity changes to execute all maneuvers during life time of satellite.

Mechanical structure
- mechanical structure provides the framework for mounting other subsystems.

Power supply subsystem

The power supply subsystem generates, controls and distributes electrical power to other subsystems on board the satellite platform.

Power supply for satellite application is based on

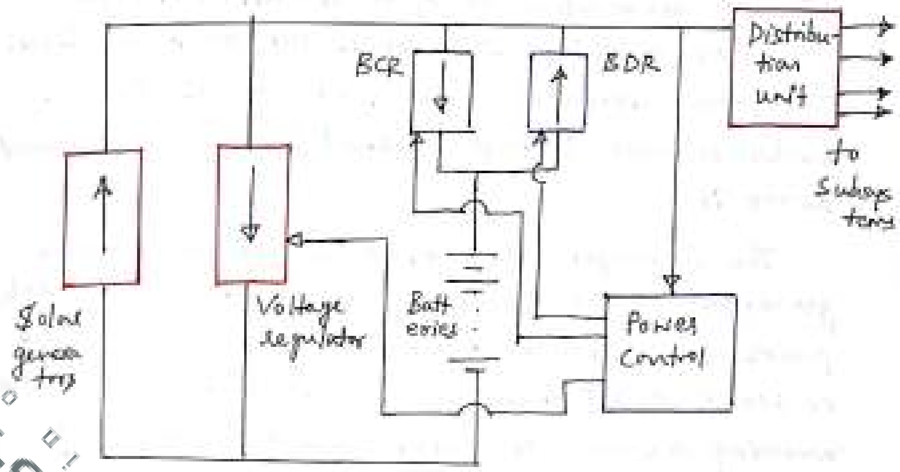
- → Chemical energy
- → Solar energy
- → Nuclear energy

Among these solar energy driven power supply is the favorite as uninterrupted solar energy available in free space. (radiant flux at Geo orbit is about 1370 W/m^2)

Batteries store electricity in the form of chemical energy and are used together with solar driven electrical power generators to meet the power requirement of the satellite. These never used as sole medium. The batteries used here are rechargeable and charged during when solar radiation is falling on the satellite.

Nuclear power even though advantageous for solar driven power supply, not exploited for commercial satellite because of cost and possible environmental hazards.

Block diagram of solar energy driven power system.



BCR → Battery charge regulator
BDR → Battery discharge regulator

The major components of solar power system are

- → solar panel
- → rechargeable batteries
- → regulators and inverters to generate various DC and AC voltage required by various subsystems.

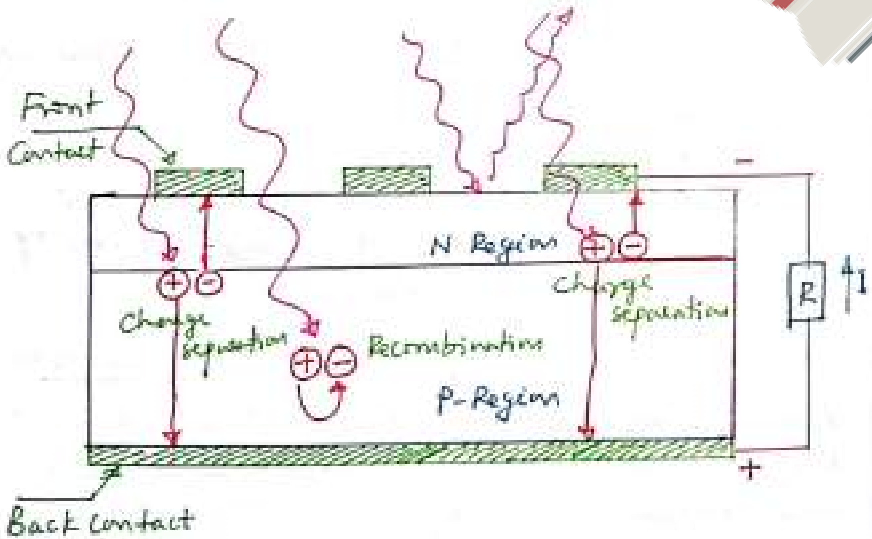
During sunlight condition	During eclipse condition
Battery is decoupled from bus by means of BDR and charged using BCR.	battery provides power to the bus by means of BDR.

principle of operation of Solar cell.

The operational principle of basic solar cell is based on the photovoltaic effect

According to the photovoltaic effect (PV), there is generation of open circuit voltage across PN junction when it is exposed to sun light. This open circuit voltage leads to the flow of electric current through a load resistance connected across it

The impinging of photon energy leads to the generation of electron-hole pair. The electron-hole pairs either either recombine and vanish and or start drifting in opposite direction with electrons moving towards N-layer and holes moving towards P-layer.



Current-voltage and power-voltage characteristic of a solar cell.

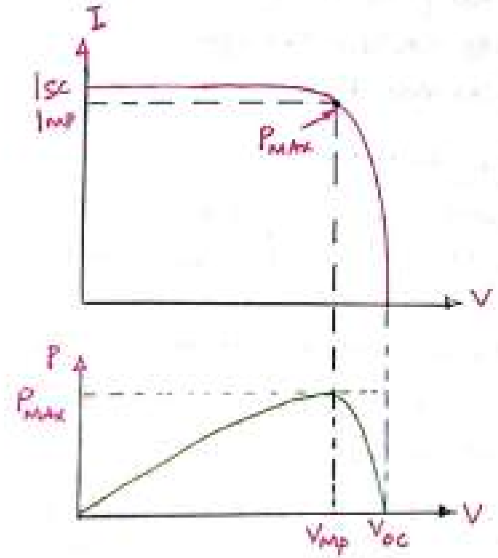


figure shows the I-V and P-V characteristic of solar cell. The solar cell generates its maximum power at a certain voltage. The power-voltage curve has a point of maximum power called P_{max}. The cell voltage and corresponding current at maximum power point are less than open circuit voltage and short circuit current, respectively.

Batteries used onboard satellites are
→ Ni-Cd (Nickel Cadmium)
→ Ni-MH (Nickel Metal Hydrogen)
→ Ni-H_2 (Nickel Hydrogen)
→ lithium ion battery.

Nickel Cadmium batteries:

This is the most commonly used rechargeable battery, for household appliances. The basic galvanic cell in Nicd battery uses cadmium anode, a nickel hydroxide cathode and an alkaline electrolyte.
These batteries are highly prone to memory effect, (battery is partially discharged before recharging repeatedly it can forget that it can be further discharged). The batteries need to be recycled or disposed properly as Cadmium is toxic in nature.
Nicd batteries are mostly used in LEO satellites.

Nickel metal Hydride battery:

These batteries are Cadmium free. The anode of the battery is made up of hydrogen storage metal alloy and cathode is made of nickel oxide. The basic cell produces 1.2V. These batteries have higher energy density compared to NiCd batteries. These batteries are less affected by memory effect. compared to NiCd batteries. But these batteries have problems at high and low temperature makes them unsuitable for space applications.

Nickel-Hydrogen batteries.

The NiH_2 battery combines the technology of batteries and fuel cells. The battery uses Nickel hydroxide as cathode and Hydrogen as the active element in the anode. Its repeated deep discharge resistance and tolerance for overcharging makes an ideal choice in many aerospace applications. The disadvantages include the high cost and low volumetric density.

Lithium ion battery:

Lithium ion batteries produce same energy as NiMH batteries but 30% weight less. These batteries do not suffer from memory effect as in Nicd & NiMH batteries. As Lithium ignites easily, hence special handling required. LEO, GEO and more satellites uses Lithium ion battery.

Spin stabilized satellite with cylindrical body diameter (D) and length (L) have area A_{spin}

$$A_{spin} = \pi \times D \times L$$

Three axis stabilized satellite with flat solar cell of width (D) and Length (L) have area A_{3-axis}

$$A_{3axis} = D \times L$$

$$\therefore \text{ ratio's of two areas} = \frac{A_{spin}}{A_{3-axis}} = \frac{\pi D \times L}{D \times L}$$

$$= \pi$$

Thus solar panel area required in case of spin stabilized cylindrical solar cell panel will be 'π' times [illegible] 3 axis stabilized satellites.

Expression for power is given by

$$\boxed{P = \phi \times n \times S \times \eta}$$

where P = power to be generated (Watts)
ϕ = Solar flux arriving normal to the solar array (W/m^2)
n = Number of solar cells
S = Surface area of each solar cells (m^2)
η = conversion efficiency of solar cell.

$$\therefore \boxed{n = \frac{P}{\phi \times S \times \eta}}$$

E_n = energy stored in n cell = Capacity of each cell (in Ah) × voltage of each cell (in V) × Depth of Discharge (DoD) × Discharge efficiency × n.

E_B = energy required to be stored in battery system = $\frac{\text{energy stored in n cell}}{DoD \times \eta}$

$\therefore$ mass of battery system = $\frac{E_B}{\text{specific energy specification (Wh/kg)}}$

Attitude and Orbit Control.

The attitude and orbit control system performs two functions of controlling orbital path, which is required to ensure the satellite is in the correct location in space to provide intended services and to provide attitude control, which is essential to prevent the satellite from tumbling in space. Also it ensures, the antennas remain pointed at a fixed point on the Earth's surface.

Attitude of satellite is its orientation determined by relationship between its axes (Yaw, Pitch & Roll).

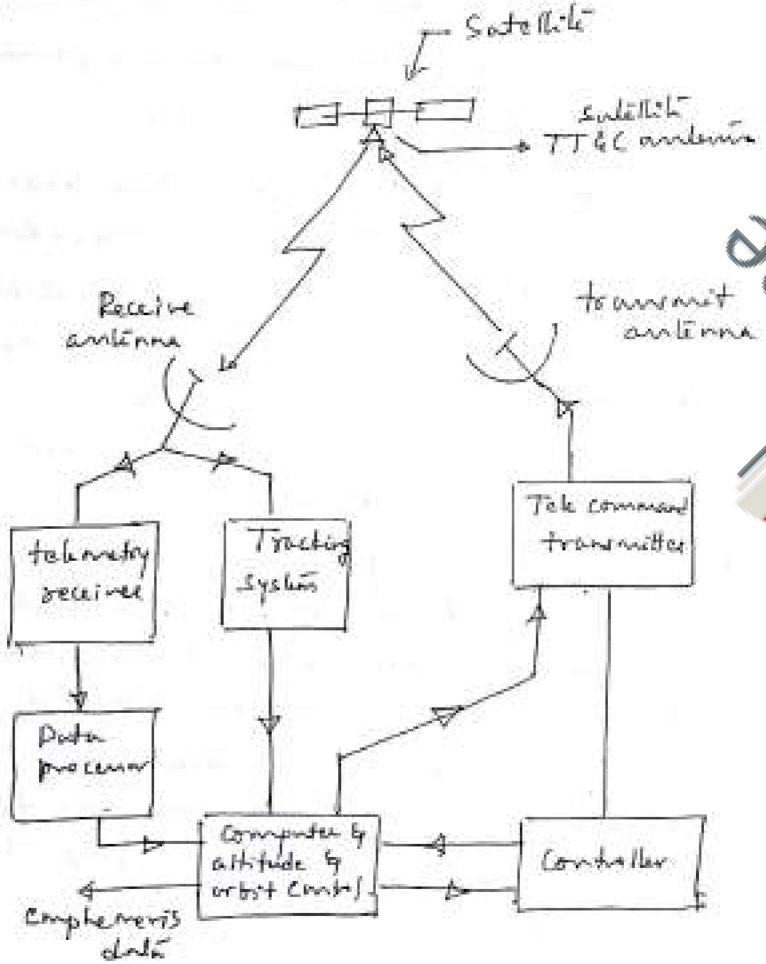
Spin stabilization and three-axis stabilization are the two types of attitude control systems used. When the satellite is in orbit, the attitude control system maintains antenna of satellite pointed accurately in the desired direction.

For Satellites orbiting low and medium earth orbits, Gravitational pull from Earth is very strong. Sensors are used to determine the position of satellite axis with respect to specified reference directions.

Orbit control is required to correct for the effects of perturbation forces. These perturbation forces may alter one or the other orbital parameters. This is done by firing thrusters.

Telemetry, tracking & Control/Command Sub system (TT&C)

The tracking, telemetry and command (TT&C) subsystem monitors and controls the satellite right from lift off stage to end of its operation in space.



The tracking part determines the position of the spacecraft and follows its travel using angle, range and velocity information.

The telemetry part gathers information on the health of various subsystems of the satellite. It encodes this information and transmits towards Earth control center.

The command element receives and executes remote control commands from the control center on Earth to effect changes to the platform functions, configuration, position and velocity.

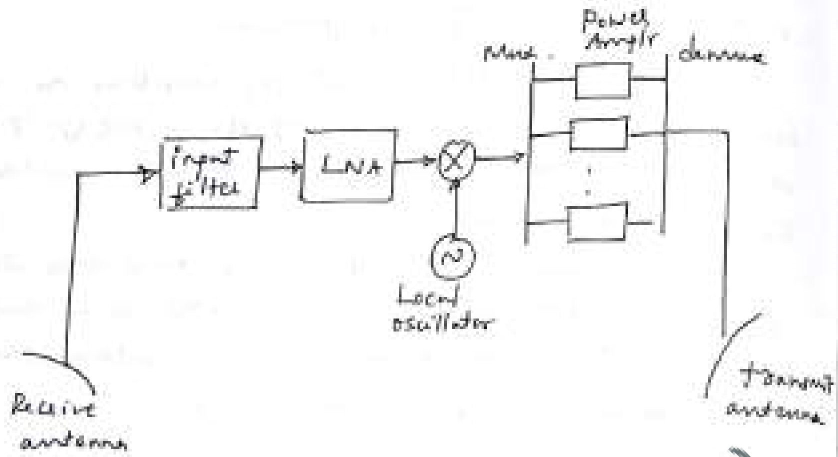
Payload:

payload is the most important subsystem of any satellite. It can be considered as the brain of satellite that performs intended functions, it depends on mission requirements.

payload in a communication satellite refers to transponder which acts as Receiver/Amplifier/transmitter.

Thus a transponder is combination of elements such as sensitive high gain transmit - receive antennas, filters, Low noise amplifiers, frequency mixers and power amplifiers.

Satellite employ L, S, C, X, Ku and Ka bands for communication purposes.



C band (6/4 GHz) is the most popular band used for providing domestic & international telephone services. Whereas Ku (12-18 GHz) and Ka (27-40 GHz) bands are also extensively used.

In case of weather forecasting satellites, radiometer is the most important payload. Radiometer is used as camera and has a set of sensors to detect radiation in visible, IR bands.

High resolution visible cameras, multispectral scanners and thematic mappers are the main payloads on board an Earth observation satellite.

Scientific satellites have payloads depending on their mission. Satellite observing stars carry telescopes to collect light from stars and spectrographs.

Satellites for planetary exploration have equipment like, plasma detectors to study solar winds & radiation belts, magnetometer to investigate possible magnetic field around planet, gamma spectrometer to determine radioactivity of surface rocks.

Earth station:

An earth station is a terrestrial station located on Earth's surface, it could even be airborne or maritime.

Major parts of Earth station include

- → transmitter system
- → receiver system
- → antenna system
- → tracking system
- → terrestrial interface system
- → primary power to run Earth station.
- → test equipment for routine maintenance of Earth station & terrestrial interface

Earth stations are classified on the basis of services provided and depending on the usage.

Based on the services provided, Earth station classified as

- Fixed Satellite services (FSS) Earth station
- Broadcast satellite services (BSS) Earth station
- Mobile satellite services (MSS) Earth station.

Based on the usage, Earth station are divided into the following categories.

- Single function stations
- Gateway stations
- Teleports.

Fixed Satellite Services Earth Station.

Depending on G/T the FSS Earth stations are classified as

Large Earth station	$G/T \cong 40\ dB/K$
Medium Earth station	$G/T \cong 30\ dB/K$
Small Earth station	$G/T \cong 25\ dB/K$
Very small terminals with Transmit/Receive function	$G/T \cong 20\ dB/K$
Very small terminals with receive only functions	$G/T \cong 12\ dB/K$

The services involves the use of geostationary communication satellites for telephony, data communication, and radio and television broadcast feeds.

FSS operates either in C band or Ku band.

FSS operate at relatively lower power levels as compared to BSS and therefore require much larger dish.

FSS transponder uses linear polarization.

Broadcast satellite Services Earth station.

Under this group we have,

Large Earth station $G/T \cong 15\ dB/K$
(for community reception)

Small Earth station $G/T \cong 8\ dB/K$
(for individual reception).

ITU defines the following bands 10.7 - 12.75 GHz in ITU Region-1 (Europe, Russia, Africa), 12.2 - 12.7 GHz in ITU Region-2 (North & South America), 11.7 - 12.2 GHz in ITU Region-3 (Asia, Australia).

DTH (Direct to Home) cover both analog & digital video, audio services received by relatively small dishes.

Mobile satellite Services Earth station.

Under this group, we have

Large Earth station	$G/T \cong -4\ dB/K$
Medium Earth station	$G/T \cong -12\ dB/K$
Small Earth station	$G/T \cong -24\ dB/K$

While large and medium Earth station require tracking and small MSS doesnot require tracking.

Satellite phone is the most commonly used mobile satellite service. It is a type of mobile that connects satellites instead of terrestrial network.

Mobile satellite services are provided both by GEO and LEO satellites.

Iridium and Globalstar are the two major LEO satellites offering Mobile satellite services. Globalstar uses 44 satellites and iridium operates 66 satellites.

Single function stations:

These stations may be transmit only, receive only or both. Some common example of single function station include TVRO (television receive only) terminals for TV reception by an individual, Satellite radio terminal, two way VSAT (very small aperture terminal) used at retail store for POS.

Gateway stations:

Gateway stations serve as an interface between the satellite and terrestrial network and also the satellites. These serve as transit point between satellites. These stations are connected to terrestrial network by various transmission technologies both wired co-ax and optic fibres and wireless by microwave towers.

A gateway receives large variety of signals at any given time. These include, telephone signals, television signals, data streams and so-on.

All these signals come in different format, use of various levels of multiplexing and telecommunication standards.

A lot of signal manipulation activities to be carried on these signals before routed to intended satellite.

Teleports:

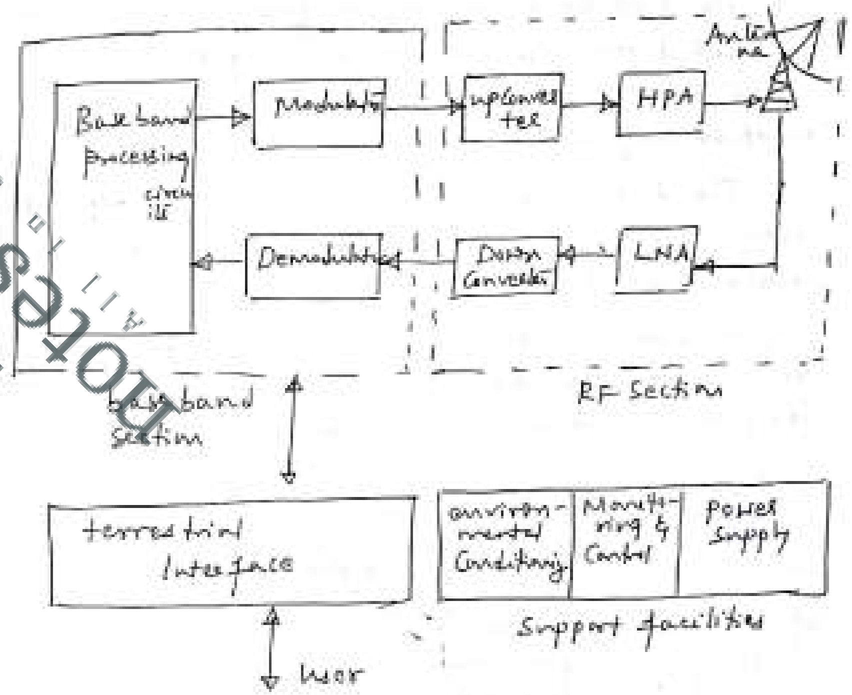
Teleport is a type of gateway operated by firms. They are useful for business houses located in crowded places inhibiting LOS to satellite of interests due to proximity of another tall building or some other obstacle. These are located outside the city and a hub provides the connectivity, where all subscribers are linked to hub and in turn connected to teleport through fibre optic or microwave link.

Earth station Architecture:

major components of Earth station include

- RF Section
- base band equipment
- terrestrial interface.

in addition to this other support facility like power supply with back up, monitoring and control equipment, thermal and environment conditioning unit.



The RF section mainly consisting of antenna subsystem, up-converter and HPA (high power Amplifier) in the uplink channel and antenna, LNA and down converter in down link channel.

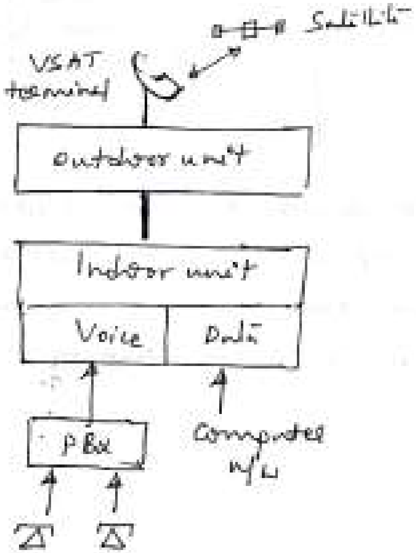
The job of upconverter is to convert the base band signal to desired band. The up converted signal is then amplified to desired level before fed to feed system for the transmission to the intended satellite. Similarly LNA amplifies weak signal received by the antenna, then down converted to IF level before it is fed to modem in base band section.

The base band section performs modulation/demodulation function depending upon the modulation technique and multiple access method employed.

The baseband section connected to terrestrial network through a suitable interface known as terrestrial interface.

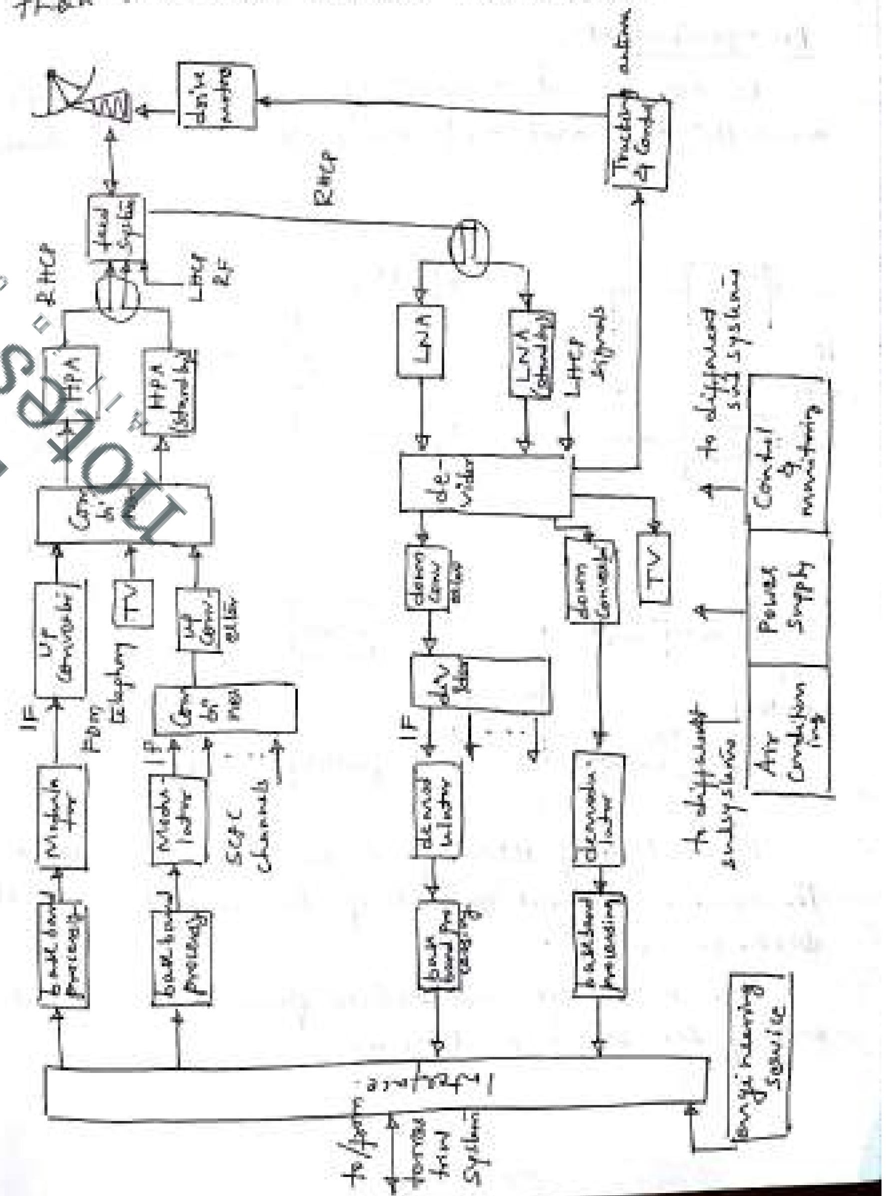
In addition Earth station has support to monitor & control, power supply (back up) environmental conditioning units.

<u>A VSAT remote terminal.</u>



A VSAT terminal contains RF section. The dish antenna is typically 0.55–2.4m diameter. The indoor unit size of video recorder contains baseband section. includes modulator, demodulator, multiplexer and demultiplexer with interfaces.

The complexity of Earth station depends upon the application. Ex. TVRO Earth station is far less complex than FSS earth station shown below.



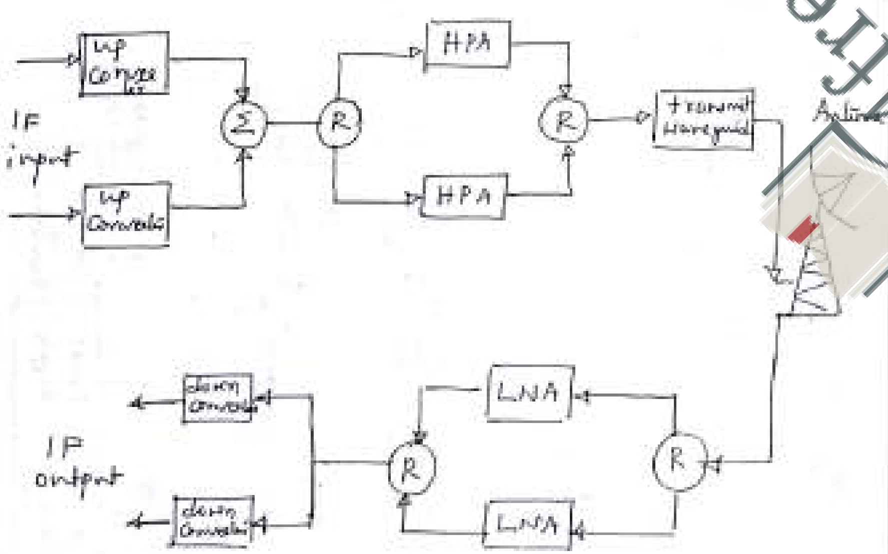
Earth station Hardware:

Most of the Earth station Hardware categorized into one of the three groups.

→ RF equipment
→ IF and baseband equipment
→ Terrestrial interface equipment.

RF equipment:

RF equipment consists of up-converters, HPA's and the transmit antenna in the transmit channel.



The output of HPA feeds the transmit antenna, The receive channel consists of Receive antenna, LNA, down converter.

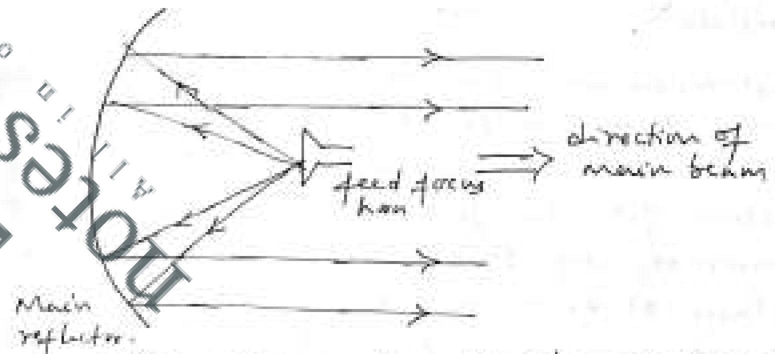
The transmit and receive function is carried out by the same antenna.

Antennas:

Different variants of reflector antennas are commonly used as Earth station antenna. These mainly include

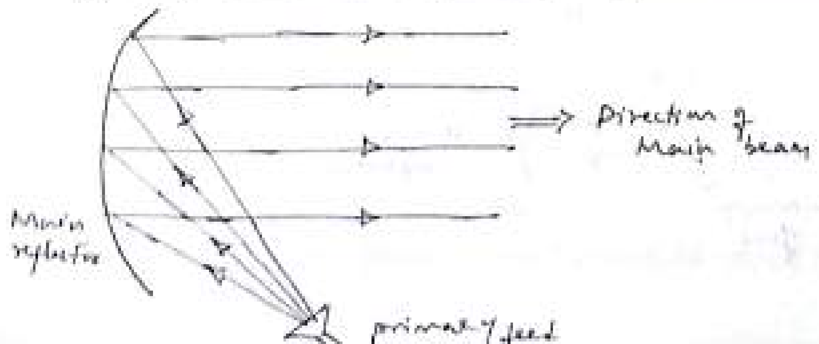
prime focus fed parabolic reflector antenna
offset fed sectioned parabolic reflector antenna
Cassegrain fed reflector antenna
offset fed Cassegrain antenna
Gregorian antenna
offset fed Gregorian antenna.

prime focus fed parabolic reflector antenna.



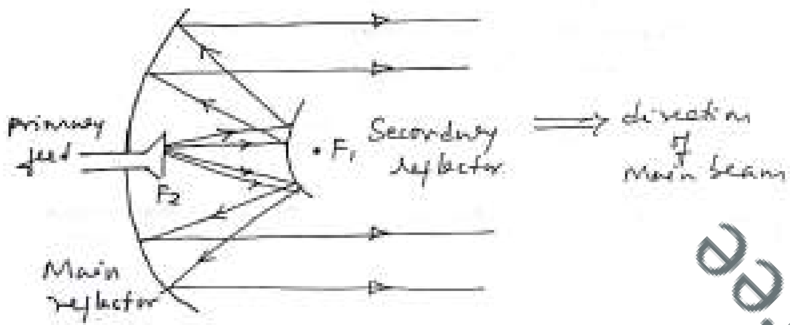
This antenna is used when antenna diameter is less than 4.5 m. for receive only Earth stations. The main drawback of this is blockage of main-beam due to feed and its mechanical support system.

offset fed sectioned parabolic reflector antenna.

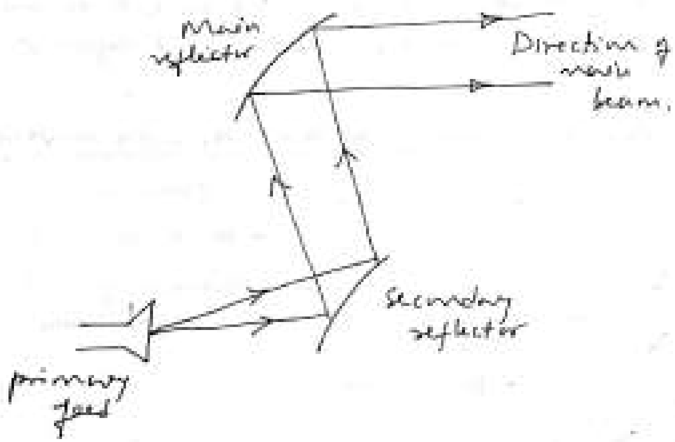


Offset feed configuration eliminates the blockage of main beam due to feed and its mechanical support system and improves antenna efficiency, reducing side lobe levels.

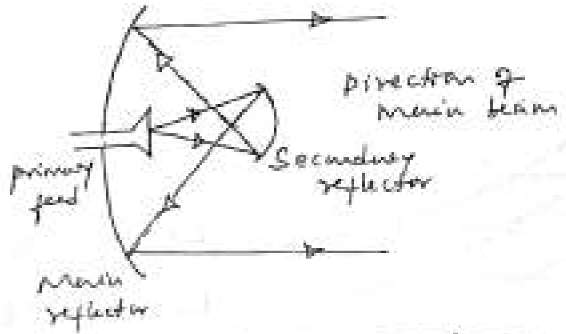
Cassegrain antenna:

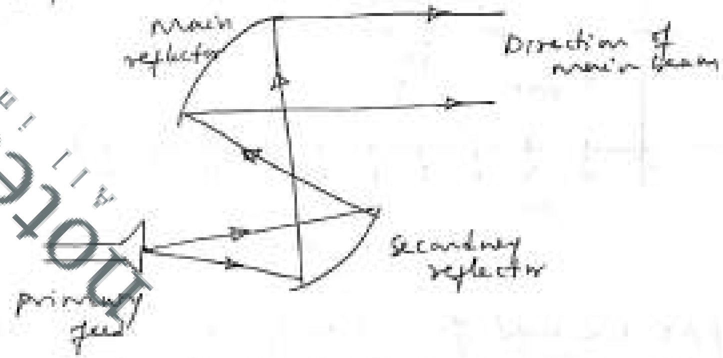


Cassegrain antenna overcomes the shortcoming of prime focus fed parabolic reflector antenna. This antenna uses hyperbolic reflector receiving the wave from the feed, which is placed infront of main reflector. Here the front and electronics is placed at the prime focus positioned on or even behind the dish. Offset feed configuration is also possible in Cassegrain antenna.



Another common antenna configuration is Gregorian antenna uses concave secondary reflector behind the primary focus which bounces the waves back towards the dish. Offset feed configuration is also possible in this type of antenna.





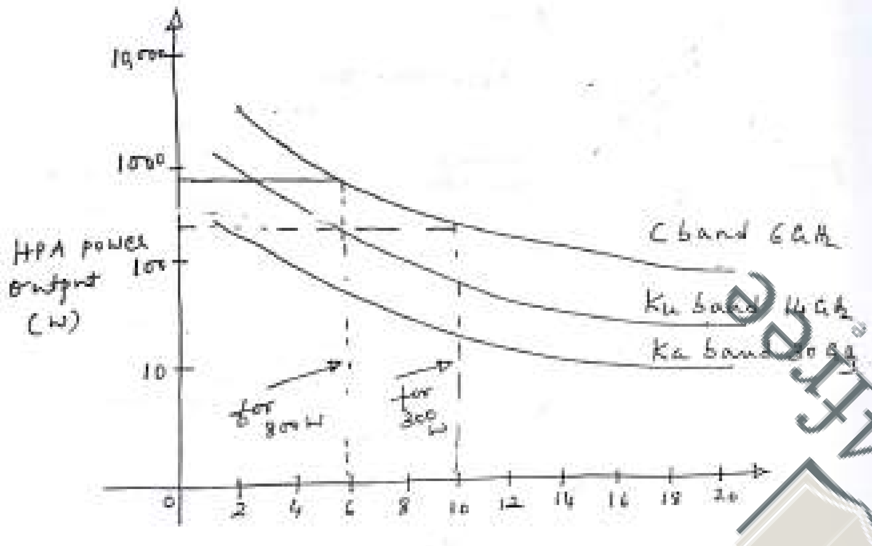
HPA: High power Amplifier.

EIRP, which is the product of power output of HPA minus waveguide losses and gain of the transmit antenna, is important factor deciding uplink performance of Earth station.

Different types of power amplifier used in Earth station include

- → travelling wave tube (TWT) Amplifiers
- → Klystron Amplifiers
- → Solid state Power Amplifiers (SSPA's)

HPA output versus antenna diameter is depicted below. For C band transponder to have 800 W, HPA antenna diameter found to be 6m and if diameter increased to 10m, power reduces to 300 W HPA.

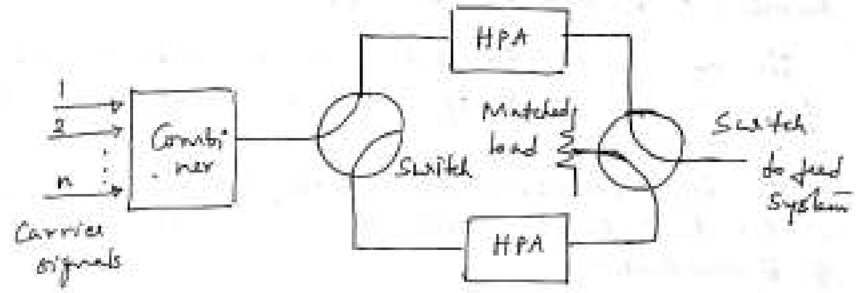


Antenna diameter (m)

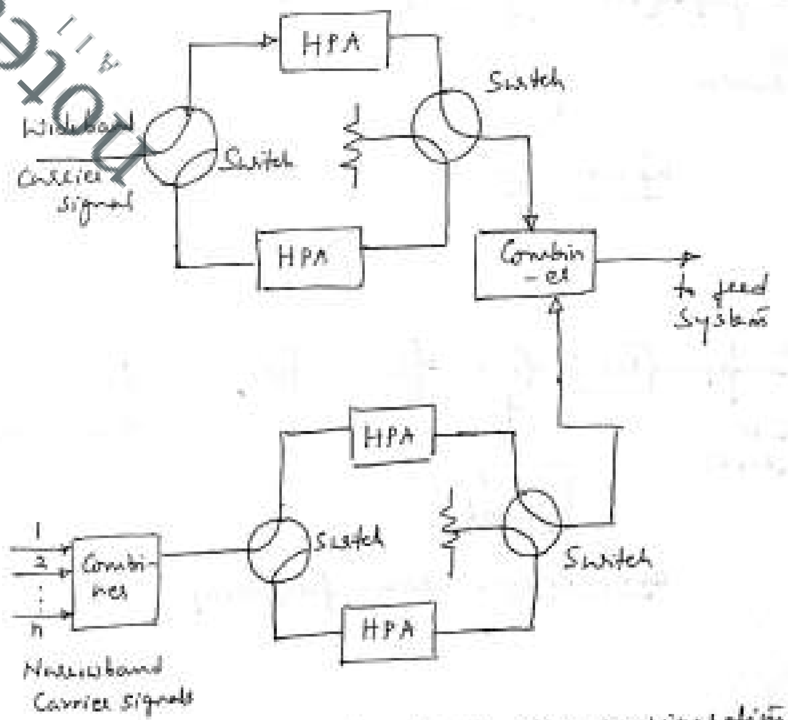
SSPA's are used for relatively lower power apply while tube based amplifiers used when the required power level are high.

Klystron is narrowband width device providing a bandwidth of the order of 40-80 MHz tunable over 500 MHz range where as TWT is a wideband Ampl. offering bandwidth as large as 500 MHz or more. Klystrons are less expensive, simple to operate & easy to maintain. Where as SSPA's are reliable and cheaper compared to klystron and TWT Amplr.

Commonly used amplifier configuration for multi carrier operation include single amplr and multiple amplifier as shown.



Single Amplifier HPA Configuration.



Multiple Amplifier HPA configuration.

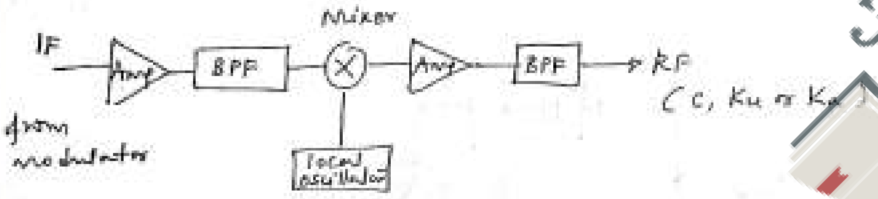
Up-Converters / Down Converters

Up-converters and down converters are frequency translators that convert the IF used in the modems and base band equipment to operating RF frequency bands (C, Ku and Ka) and vice-versa.

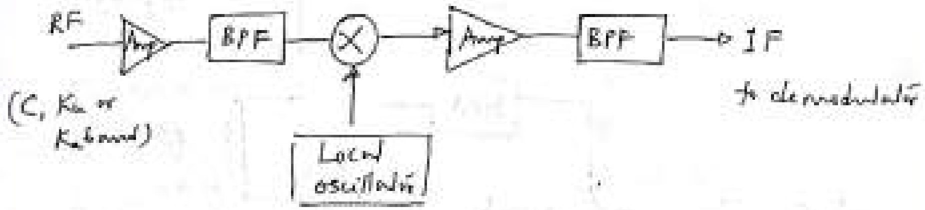
The upconverter translates IF signal at 70 MHz from modulator to operating RF frequency in C or Ku or Ka band.

The down converter translates received RF signal in C or Ku or Ka band into IF signal which is fed to demodulator.

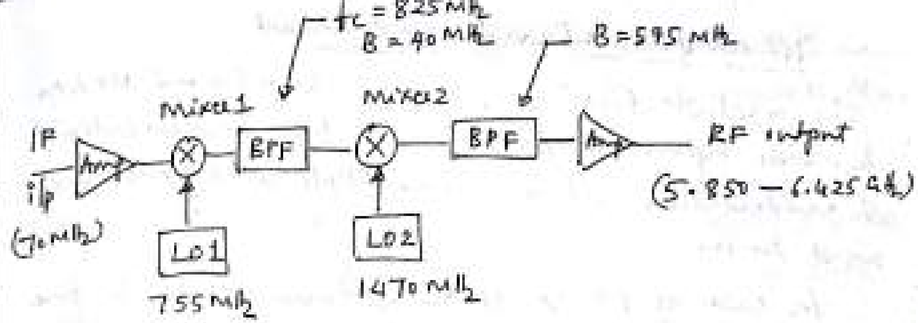
Single frequency conversion and double frequency conversion are shown below.

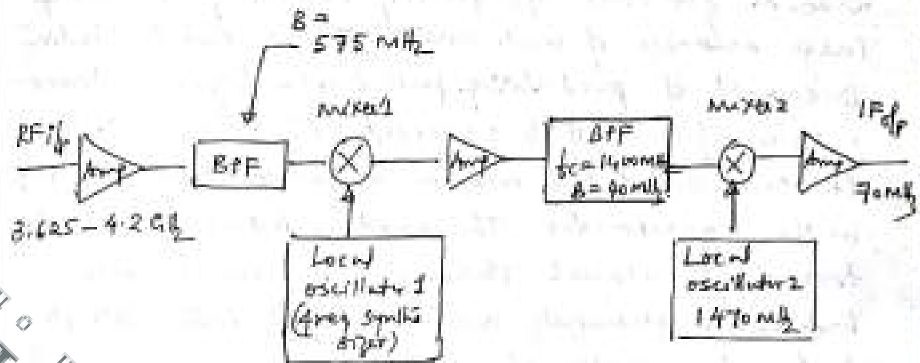


upconverter single frequency conversion



downconverter single frequency conversion.





double frequency conversion frequency converter upconverter and down converter

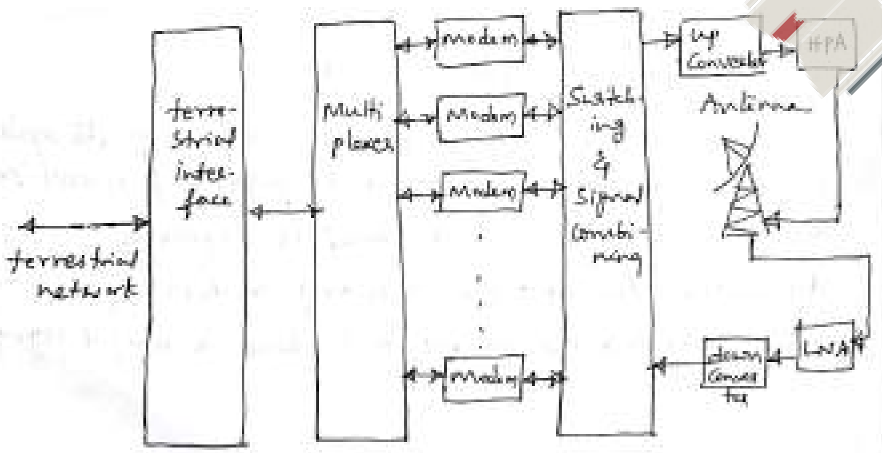
Low Noise Amplifier (LNA)

LNA is one of the key factor deciding the system noise temperature and hence figure of merit (FOM) G/T of the Earth station. Receiver figure of merit indicates how the receiving antenna performs with receiving electronics to produce a useful signal.

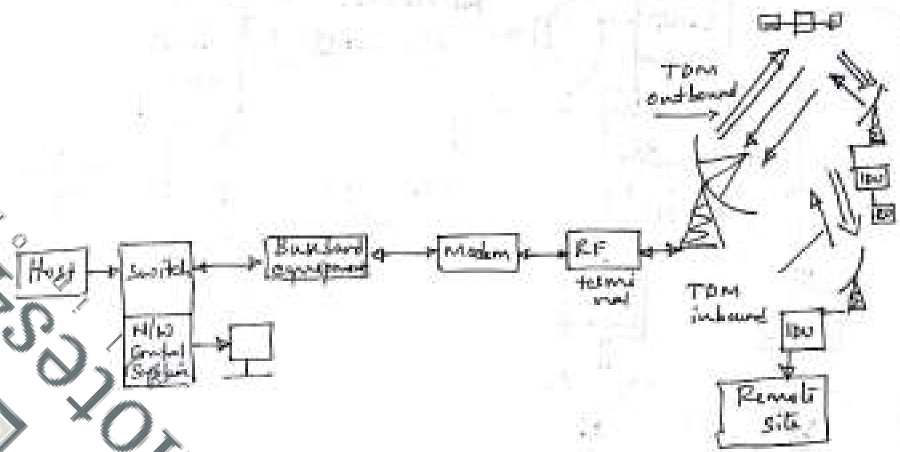
IF and baseband equipment.

The architecture of IF and baseband section depends upon the parameters like modulation/demodulation scheme, multiple access methods and so-on.

In case of FDMA station, there must be one modem for each frequency resulting in use of large number of such units. FDMA Earth station is capable of providing full duplex digital transmission for multiple carriers. Each carrier has its own dedicated modem tuned to separate freq in the transponder. The modem interface with the terrestrial network through TDM multiplexer. Individual channels are combined into a single higher bandwidth channel.



On the other hand a TDMA Earth station needs only one modem with larger bandwidth than FDMA station. In the case of TDMA, the frequency band occupied by the carrier is shared by several Earth station on time basis. The modem receives bursts of data from different station so that they do not overlap in time.



IDU → Indoor unit

Terrestrial Interface:

Terrestrial interface connects Earth station to the users. Its importance lies in service. Two major components of terrestrial network include

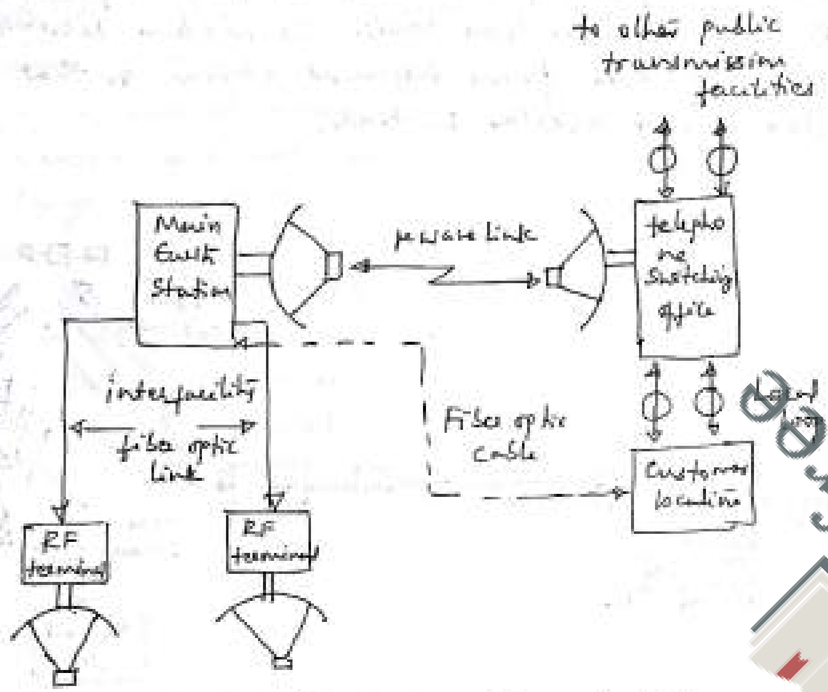
terrestrial tail

terrestrial interface.

Terrestrial tail needed to connect the main Earth station to one or more remote user location with line of sight (LOS) and fiber optic cable.

Common interface needed in satellite link & terrestrial network include telephone interface (voice), data transmission (data) and television interface (video).

a typical setup depicting tail links connecting various centers are shown below.



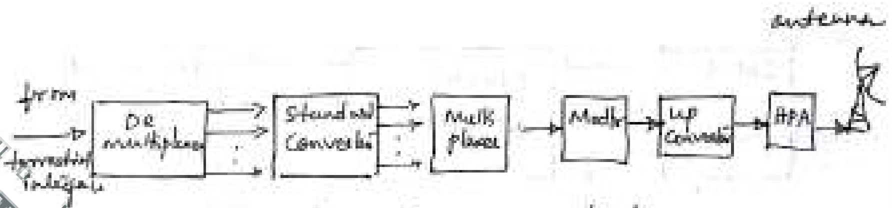
The figure shows a fiber optic link connecting RF link and Earth station main building, a micro wave tail connecting Earth station and switching office, which in turn connects to user location through public or private loops and alternative fiber optic link between Earth station and customer location.

fiber optic is preferred choice if the tail in the case is short to connect Earth station and other facilities, for long and elaborate tails, μwave link is better.

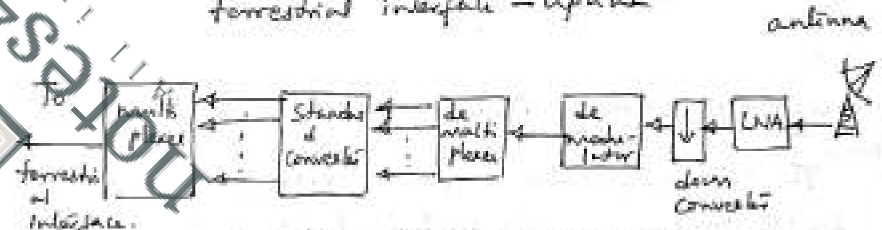
terrestrial Interface:

Large commercial earth stations are required to handle massive traffic comprising of hundreds of telephone channels together with data and video reaching the station through μwave and fiber optic system using TDM or FDM.

Signals received from terrestrial n/w therefore need to be demultiplexed from existing terrestrial format to format suitable for satellite transmission.



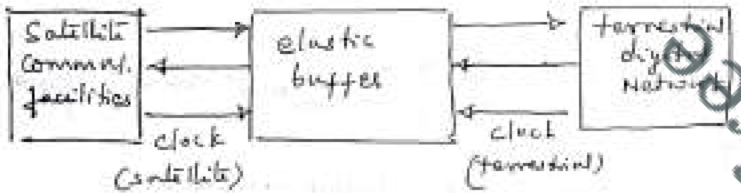
terrestrial interface – uplink



terrestrial interface – downlink

After the signals conversion, they are processed in uplink chain of Earth station. On the downlink side, the signal received from satellite processed in downlink and send to standard converter. after reformatting, signals are multiplexed and put on the terrestrial network.

Another interface related issue is to handle digital signal arises out of variation in data rate, at receiving station. [due to variation in path length due to variation in inclination & eccentricity of orbit]. hence, elastic buffer [FIFO] is introduced between satellite communication facilities and terrestrial digital network. This buffer should be large enough to absorb peak-to peak data rate variations.



Earth station Design consideration.

The key performance parameter governing Earth station design include EIRP and figure of merit (G/T).

EIRP (effective or equivalent Isotropic radiated power)

EIRP gives the combined performance of HPA and transmitting antenna. It is given by the product of power output of HPA and gain of the transmitting antenna. EIRP is expressed in dB.

EIRP is defined for both Earth station Transmitting antenna and Satellite transmitting antenna.

Receiver Figure of Merit (G/T)

This indicates how the receiving antenna performs together with receiving electronics to produce a useful signal. figure of merit tells about the sensitivity of the receiving antenna. The larger value of G/T, the better will be the sensitivity.

Environmental & site considerations:

environmental and location factors plays important role in deciding site of an Earth station. environmental factors like, external temperature, humidity, rainfall and snow, wind condition, likelihood of Earth quakes, corrosive conditions of atmosphere and so-on.

RFI and EMI is another requirement, as EMI and RFI produced by Earth station can cause interference to other RF installations. It is normally necessary to carry out RF survey at various possible sites before final choice is made on the Earth station location.

reliable electric power, easy transportation and availability of sufficient space for earth station equipment are some of the other requirements.

Earth station testing.

It is important to ensure that the equipment would meet specified requirement of intended earth station. Also it is necessary to ensure that the earth station would not cause any problems to other users of satellite or to any adjacent satellites.

Unit / Component level testing:

This is usually done at manufacturer premises. The test data are made available to the subsystem engineer/ designer who is making use of these components.

Subsystem level testing:

different subsystems are comprehensively checked for their electrical, mechanical and environmental specifications. Test data generated as a part of testing and supplied to the user.

System level testing:

This is carried out after subsystem testing integration has been completed, where the complete system has been ordered on a single supplier. The system is also tested for its adherence to international regulatory standards.

The test fall into two broad categories, namely

→ Mandatory tests

→ Additional tests

Mandatory test include the following measurements.

→ Transmit cross polarization isolation

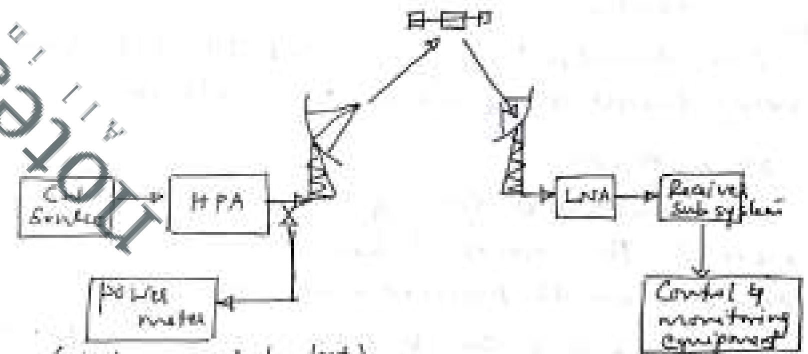
→ Receive figure of merit

→ EIRP stability

→ Spectral shape.

Transmit cross polarization isolation:

This test is performed to guarantee that the power level of the cross polarized component is either nil or within the tolerance limit so as not to cause any significant interference to other users.

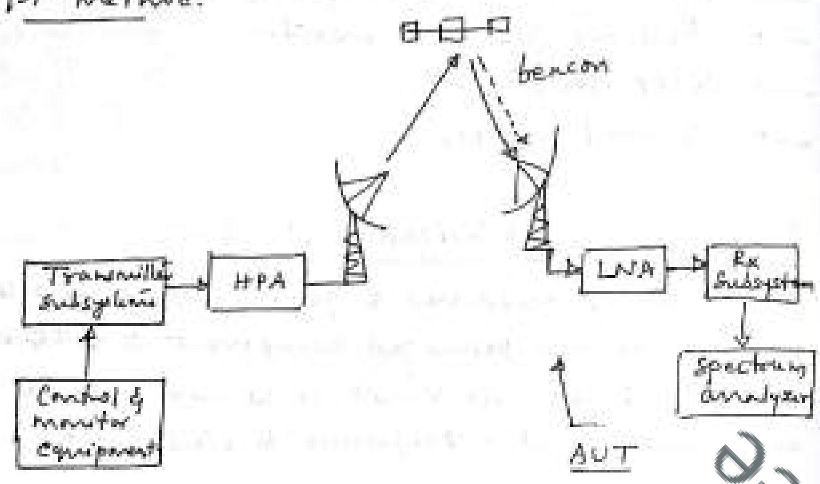


(Antenna Under test)

The antenna under test (AUT) is driven to transmit lower level carrier at test frequency. Once AUT is boresighted, next step is to optimize of the polarization angle of AUT by observing power level of the cross polarized component as AUT rotates the feed.

Receive figure of merit measurement:

1st method:



Control & monitor station.

Here downlink C/N₀ and satellite EIRP measured using downlink equation G/T is obtained.

2nd method:

This method is gain & system temperature method. This method leads to more accurate results than the previous method.

Receive gain can be measured by either pattern integration technique or by determination of 3 dB & 10 dB beamwidth.

In case of pattern integration techniques, Az and E narrowband patterns are measured. Then directive gain of antenna measured through integration of sidelobe patterns.

In beamwidth measurement, AUT measures corrected Az and E 3dB/10dB beamwidths.

Receiving gain of antenna is computed from equation.

$$G_1 = 10\log_{10}\left[\frac{1}{2}\left\{\frac{31000}{\theta_{3dB}\times\phi_{3dB}}\right\}+\left\{\frac{91000}{\theta_{10dB}+\phi_{10dB}}\right\}\right]$$

Where G_1 is gain of receiving antenna.

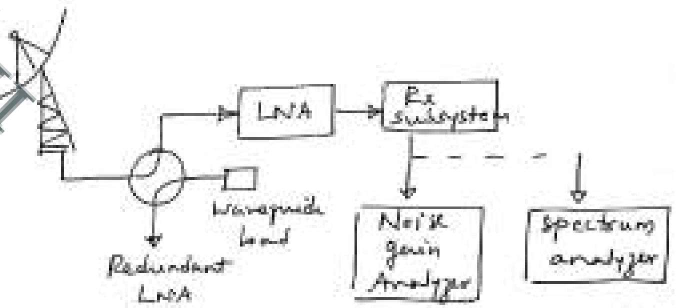
θ_{3dB} = corrected Az 3° Beam width (in deg)

ϕ_{3dB} = corrected E 3° beamwidth (in deg)

θ_{10dB} = corrected Az 10° beamwidth (in deg)

ϕ_{10dB} = corrected E 10° beamwidth (in deg).

To measure system noise temperature, noise power is measured for hot and cold load condition. The AUT is pointed towards clear sky to simulate cold load condition. Input waveguide at ambient temp. provides hot load.



The difference between hot and cold load is Y factor.

$$T_{SYS} = \left[\frac{T_{LOAD} + T_{LNA}}{Y}\right]$$

Then $G/T = G_R - 10\log_{10} T_{SYS}$

Module 3:

Multiple Access Technologies:

Multiple access means access to a given facility or resource by multiple users.

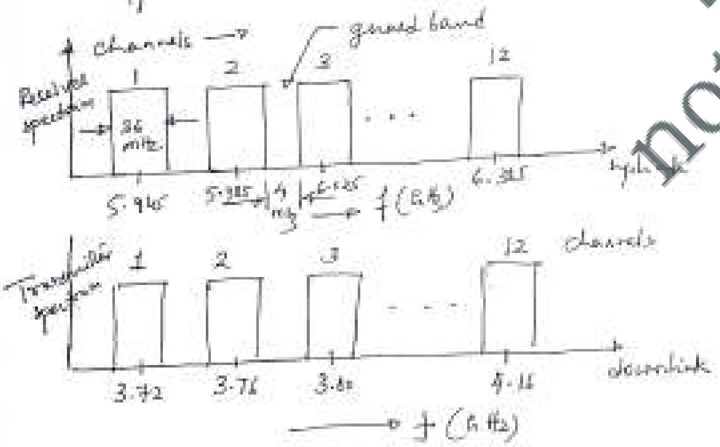
Commonly used multiple access techniques are

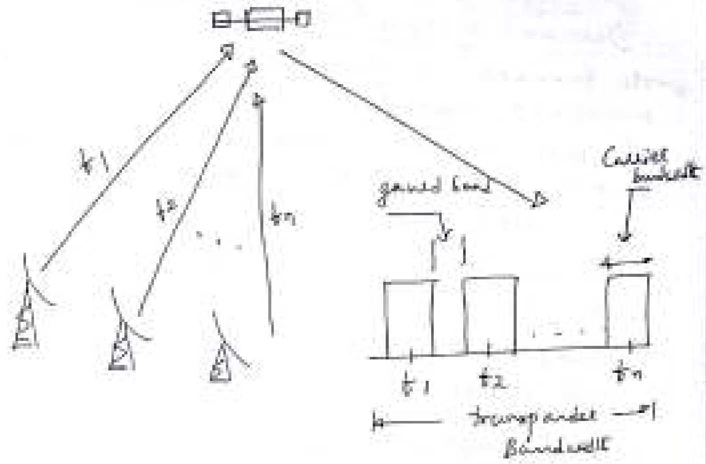
- Frequency division multiple access (FDMA)
- Time division multiple Access (TDMA)
- Code division multiple Access (CDMA)
- Space domain multiple Access (SDMA)

Frequency division multiple Access (FDMA)

In FDMA, different Earth stations are able to access the total bandwidth of satellite transponder by the virtue of their different carrier frequencies.

Typical C-band transponder is shown below.





Major advantage of FDMA

- Earth station equipment are simple
- No complex timing & synchronizing techniques needed.

Drawback of FDMA

- due to large number of carriers, intermodulation problems exists in TWTA amplifier.

Types of FDMA

- Demand assigned FDMA
  - polling method
  - the random access method
- Pre assigned FDMA.

Demand assigned FDMA

- The transponder frequency is subdivided into number of channels.
- The Earth station is assigned a channel depending upon request raised by the Earth station by a control station.
- Demand assignment may be carried out either by using
  - → polling method
  - → random access method

In polling method, the master Earth station continuously polls all of the earth stations in sequence. If the request is encountered, frequency slots are assigned to that Earth station which had made the request.

The main drawback of polling is delay when the number of Earth station is large.

In the case of centrally controlled random access, the earth station make requests through the master Earth station as the need arises.

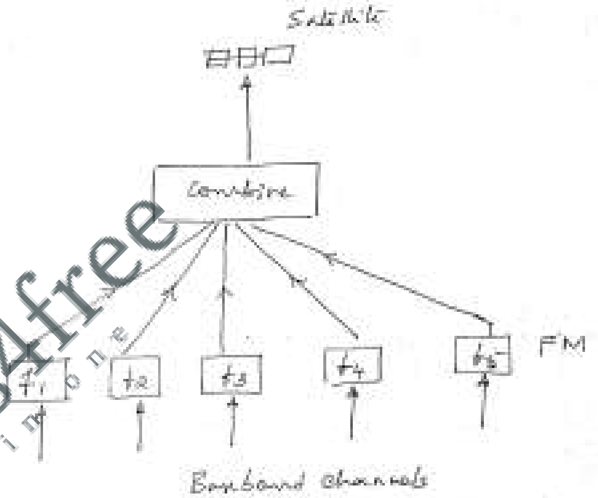
In the case of distributed control random access, the control is exercised at each Earth station.

In pre-assigned FDMA, the frequency slots are pre-assigned to the Earth stations. The slot allocations are pre determined. This do not offer flexibility. The main drawbacks are the slots are sitting idle when no traffic and problem of over traffic.

Single channel per carrier (SCPC) systems

- ↳ SCPC/FM/FDMA system
- ↳ SCPC/PSK/FDMA system

SCPC/FM/FDMA Systems



Here each signal channel modulates a separate RF carrier. The modulation scheme used here is FM. The modulated signal is then transmitted to the FDMA transponder.

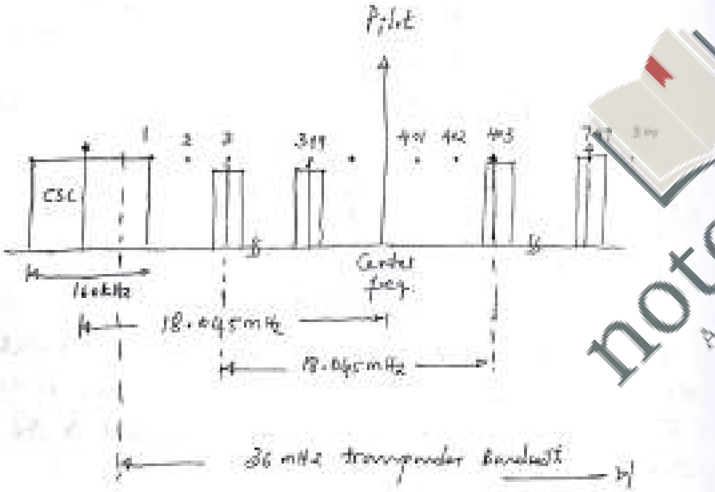
The advantages of SCPC/FM/FDMA facilitates the use of voice activated carriers, means when there is no speech activity carriers are switched off, which provides more transponder power & higher channel capacity.

The main drawback is the presence of Inter-modulation distortion resulting from the use of multiple carriers.

SCPC / PSK / FDMA System:

This is the digital form of SCPC, which uses PSK as modulation scheme.

Example: SPADE (SCPC PCM multiple access Demand assignment equipment)



In SPADE, CSC (common signalling channel) bandwidth is 160kHz and its centre frequency is 18.045 MHz below the pilot frequency.

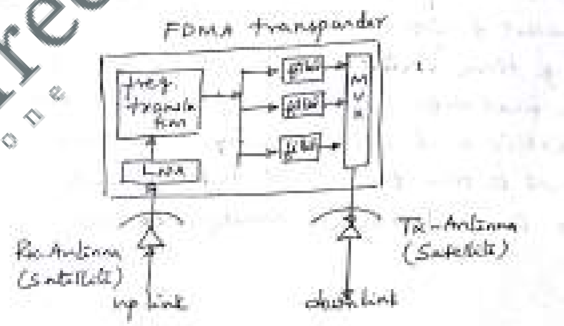
To avoid interference with the CSC, voice channels 1 and 2 are left vacant on right and left side of the pilot frequency. Also channels 400 and 800 left vacant for duplex matching, hence leaving a total of 794 one way or 397 full duplex voice circuits.

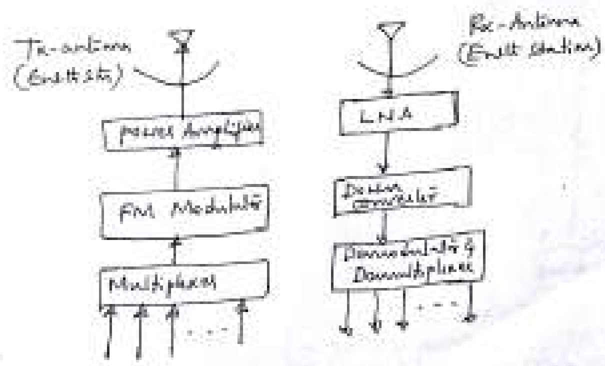
Multiple channels per carrier (MCPC) systems.

↳ MCPC / FDM / FM / FDMA System

↳ MCPC / PCM-TDM / PSK / FDMA System

MCPC / FDM / FM / FDMA System:





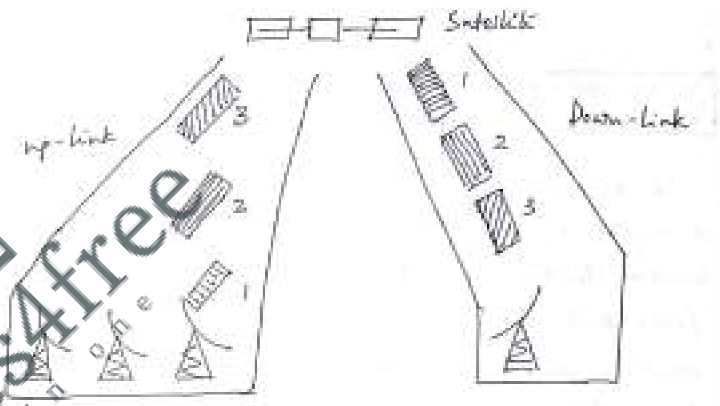
Multiple base band signals are grouped together by using FDM to form FDM base band signals. The FDM base band assembles frequency modulate pre assigned carriers and then transmitted to the satellite. The FDMA transponder receives multiple carriers, with the help of appropriate filters individual carriers are separated. Multiple carriers are then multiplexed and transmitted back to Earth over the downlink

MCPC / PCM – TDM / PSK / FDMA System

here multiple base band signals are first digitally encoded using the PCM technique, then grouped together to form a common base band assembly using time ~~division~~ multiplexing (TDM). bit stream then modulates a common RF carrier using PSK as carrier modulation technique. The modulated signal is then transmitted to the satellite which uses FDMA to handle multiple carriers.

Time Division Multiple Access (TDMA)

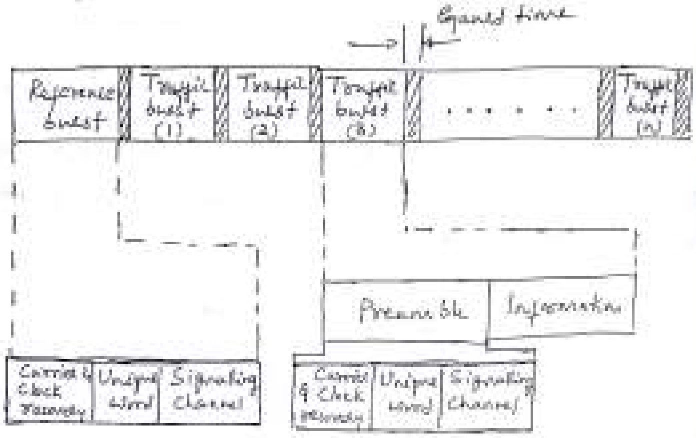
TDMA generally used for digital transmission only. here each station transmit information in burst. one of the Earth station made as reference station which transmits the first burst called reference burst (RB) in TDMA frame followed by information burst from the remaining Earth station.



TDMA types

TDMA
- pre-assigned TDMA
  - Each earth stn/ allotted a specific time slot
- Demand assigned TDMA
  - The time slots are allotted to each stn on request from Control station
- Satellite Switched TDMA
  - Several antenna spot beams used to provide services
- Limited pre-assigned TDMA
  - traffic handled during busy hours by demand

General TDMA frame structure.



A typical TDMA frame structure starts with a reference burst transmitted from a reference station in the network. The reference burst is followed by traffic bursts from various earth stations with a guard band between various traffic bursts from different stations.

Reference burst: This is usually a combination of two reference bursts (RB-1 and RB-2). This will switches over to the secondary reference burst in the event of primary reference station fails to provide reference burst to TDMA frame. The reference burst doesnot carry any traffic information and used to provide timing references to various station accessing the TDMA transponder.

Traffic burst:

The reference burst provides timing reference to stations for transmitting their traffic bursts so to ensure that they arrive at the satellite transponder, within their designated positions in the TDMA frame.

Guard time: different bursts are separated from each other by a short guard time, which ensures bursts from different stations do not overlap.

The preamble usually consists of three adjacent parts namely,

- carrier and clock recovery sequence
- the unique word
- the signalling channel.

Carrier and clock recovery sequence: different earth stations have slight differences in frequency and bit rate. hence, the receiving station must be able to establish accurately the frequency and bit rate of each other burst. This is achived with the help of carrier and clock recovery sequence bits.

Unique word: This provides timing marker to allow the earth stations to extract their part of traffic burst.

Signalling channel: The signalling channel is used to carry out system management and control function.

Advantage of TDMA over FDMA

- ✓ The bit capacity of TDMA system is independent of number of accesses.
- ✓ The power amplifier in transponder of TDMA system can operated in the saturation mode.
- ✓ Duty cycle of Earth station of TDMA system is less.
- ✓ TDMA allows the use of digital techniques.
- ✓ TDMA offers more flexibility due to use of high-speed logic circuits and processors which offers high data rates.
- ✓ TDMA systems can tolerate higher level of interference noise.

Disadvantages of TDMA over FDMA

- ✓ The peak power of amplifier in TDMA system is always large.
- ✓ The TDMA system is more complex compared to FDMA system.
- ✓ Earth station of TDMA system requires more clock recovery, synchronization, burst control of data processing before transmission.
- ✓ TDMA system uses high speed PSK/FSK circuits.

CODE DIVISION MULTIPLE ACCESS (CDMA)

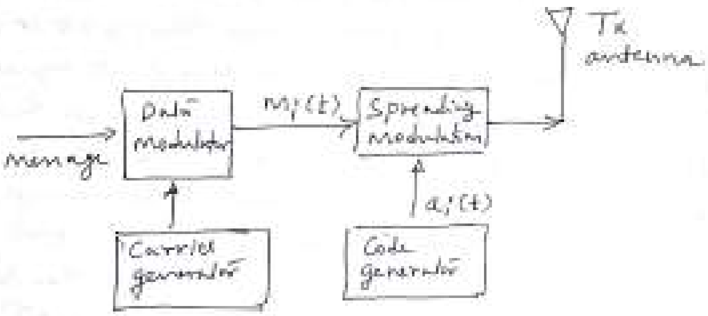
CDMA allows multiple earth stations to access the same carrier frequency and bandwidth at the same time. Each transmitter spreads its signal over the entire bandwidth, which is much wider than that required by the signal. It is assumed that message signal is PCM bit stream. Each message bit (low bit rate) is combined with a PN signal. The bit rate of PN sequence is kept higher than the bit rate of message signal. The PN sequence bits are often referred to as 'chips' and the transmitting rate as 'chip rate'.

The receiver is able to retrieve the message addressed to it by using replica of PN sequence used at the transmitter, which is synchronized with the transmitted PN sequence.

CDMA types:

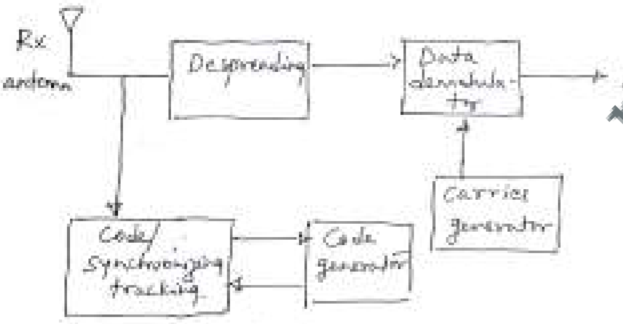
- ↳ Direct sequence CDMA [DS-CDMA]
- ↳ Frequency hopping CDMA [FH-CDMA]
- ↳ Time hopping CDMA [TH-CDMA].

DS-CDMA transmission & Reception



The transmitter generates a bit stream by multiplying in time domain message bit stream $M_i(t)$ and code information $a_i(t)$. This product produces a signal whose spectrum is convolution of spectrum of $m_i(t)$ and $a_i(t)$.

DS – CDMA Reception.



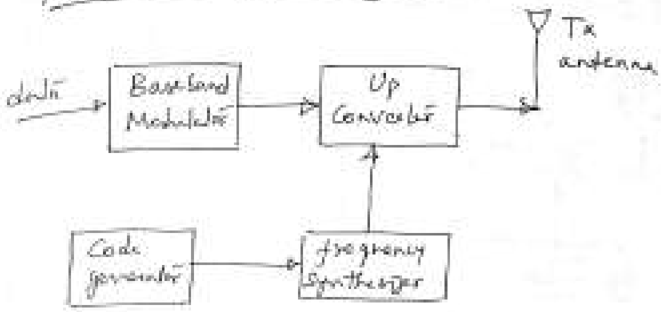
The receiver in this case generates a code signal $a_i(t)$ synchronized with received message.

Cross correlation of two orthogonal codes is zero and auto correlation is unity

$$\int_0^T a_i^2(t) = 1 \quad \text{for } i = j \qquad \Big| \qquad \int_0^T [a_i(t)][a_j(t)] = 0 \quad \text{for } i \neq j$$

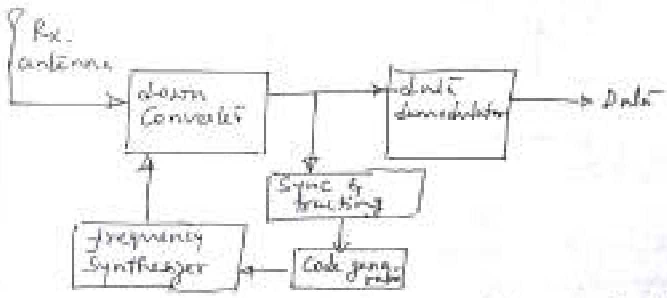
Frequency hopping CDMA System

FH-CDMA transmission.



here the carrier is sequentially hopped into a series of frequency slots spread over the entire bandwidth of satellite transponder. The transmitter transmits a short burst of data in narrowband and then tunes to another frequency and transmits again. The transmitter thus hops several times / second. This is achieved by using frequency synthesizer whose output is controlled by PN code sequence.

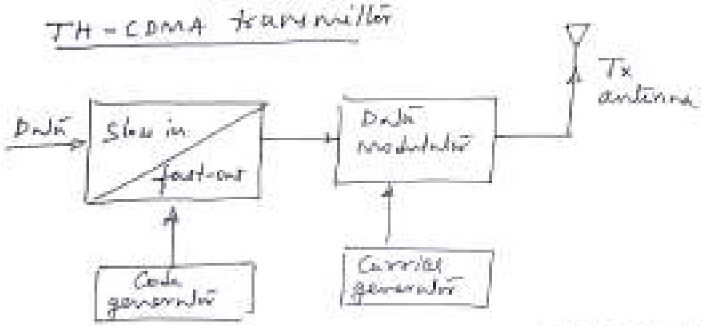
FH-CDMA receiver



On the receiver side the data can be received by using identical frequency synthesizer controlled by identical PN sequence.

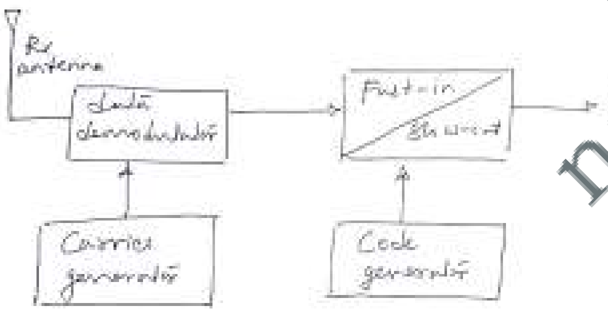
Time hopping CDMA (TH-CDMA)

TH-CDMA transmitter

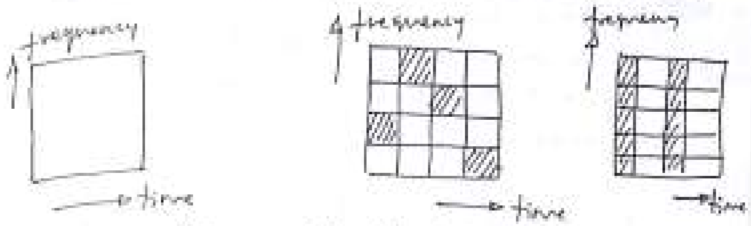


In case of TH-CDMA, PN sequence determines the instant of transmission of information. A given user transmit only during one of the M time slots each frame has been divided into.

TH-CDMA Reception:



Comparision of DS-CDMA, FH-CDMA & TH-CDMA



DS-CDMA system occupies the whole of the available bandwidth when it transmits

FH-CDMA system uses only a small part of bandwidth at a given time when it transmits

TH-CDMA uses the entire bandwidth for short periods of time.

Space Division Multiple Access (SDMA)

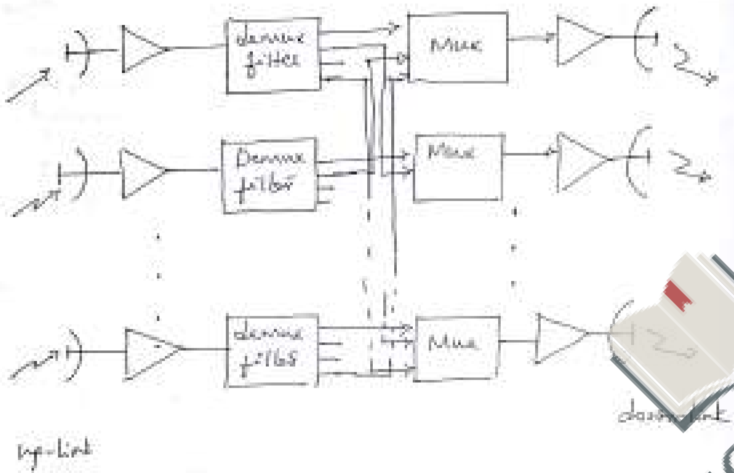
SDMA is a technique that primarily allows frequency re-use where adjacent Earth stations within the footprint of satellite can use same carrier transmission frequency and avoids co-channel interference by using orthogonal antenna beam polarization.

SDMA

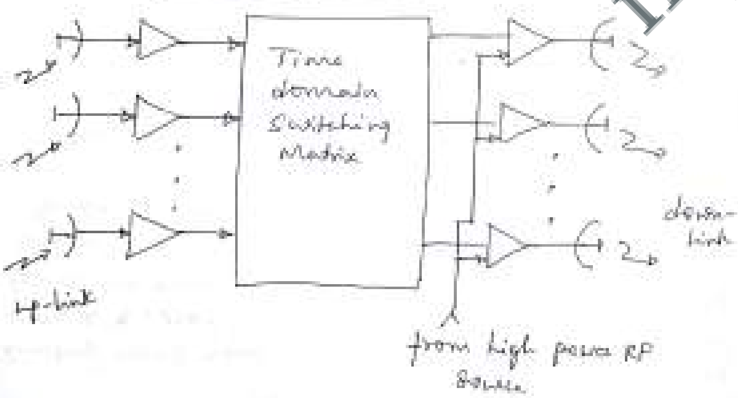
- Beam separation → here two beams are so shaped that they illuminate two different regions on the surface of Earth without overlapping.
- Beam polarization → uses two orthogonally polarized electromagnetic waves (horizontal/vertical/ LHCP/RHCP) to transmit & receive same frequency band.

SDMA/FDMA System

The satellite uses multiple antennas to produce multiple beams. The transmitting antenna-receiving antenna combination defines the source and destination earth stations.



SDMA/TDMA System



This system uses a switching matrix to form uplink / downlink beam pairs. This system allows TDMA traffic from uplink beams to be switched to the downlink beams during the course of a TDMA frame.

Satellite Link Design fundamentals.

Transmission equation

The transmission equation relates
- Received power level at the destination
- Transmitted RF power
- The operating frequency
- The transmitter and receiver distance.

Friis transmission equation.

The power flux density (W/m^2) due to the radiated power in the direction of the antenna bore sight at a distance 'd' meters is given by

$$P_{RD} = \frac{P_T G_T}{4\pi d^2}$$

The product $P_T G_T$ represents effective isotropic radiated power (EIRP). The radiating aperture of antenna and gain related by the expression

$$G_T = \frac{4\pi A_T}{\lambda^2}$$

$$G_R = \frac{4\pi A_R}{\lambda^2}$$

where A_T & A_R are the aperture area of transmitting antenna & receiving antenna.

The received power is given by

$$P_R = \frac{P_T G_T}{4\pi d^2} \cdot A_R$$

$$= \frac{P_T G_T}{4\pi d^2} \times \frac{G_R \lambda^2}{4\pi}$$

$$= \frac{P_T G_T G_R \lambda^2}{(4\pi d)^2}$$

$$P_R = \frac{P_T G_T G_R}{(4\pi d/\lambda)^2} = \frac{P_T G_T G_R}{L_P}$$

where L_P is the free space path loss.

Then received power expressed in dB as

$$10 \log P_R = 10 \log P_T + 10 \log G_T + 10 \log G_R - 10 \log L_P$$

$$P_R(dBW) = EIRP(dBW) + G_R(dB) - L_P(dB)$$

If atmospheric attenuation, transmitting & receiving antenna losses included then

$$P_R = EIRP + G_R - (L_P + L_A + L_{TA} + L_{RA})$$

Satellite link parameters

The parameters that influence the design of a satellite communication link are

- choice of operating frequency
- Propagation considerations
- Noise considerations
- Interference-related problems.

Choice of operating frequency.

Various band used in satellite are L, S, C, X, Ku, K, Ka, V, W.

FSS primarily uses two frequency bands

→ C band (6/4 GHz)

→ Ku band (14/11 GHz, 14/12 GHz).

BSS uses

→ Ku band (18/12 GHz)

→ Ka band (30/20 GHz).

MSS uses

→ L band (2/1 GHz)

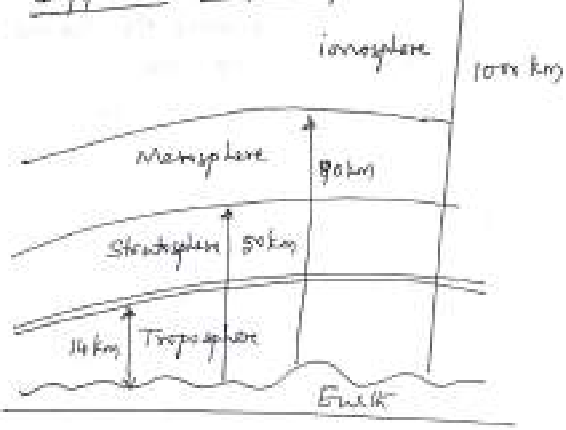
→ S band (4/2.5 GHz)

Propagation considerations:

The effect of atmosphere on the signal is mainly due to

- atmospheric gaseous absorption
- cloud attenuation
- tropospheric scintillation
- rain attenuation & depolarization
- ionospheric scintillation.
- free space loss
- signal fading due to refraction & multipath signals

different layers of Earth's atmosphere



Free space Loss: (FSL)

FSL is the loss of signal strength only due to the distance from the transmitter.

$$L_{FS} = \left(\frac{4\pi R}{\lambda}\right)^2 = 20\log\left(\frac{4\pi R}{\lambda}\right) \text{ dB}$$

if c is taken in km/s, f in MHz, then

$$FSL = 32.4 + 20\log R + 20\log f$$

Gaseous absorption:

EM waves gets absorbed and converted into heat due to gaseous absorption as it passes through the troposphere. This absorption is primarily due to the presence of molecular oxygen and uncondensed water vapour.

resonance phenomenon in H_2O vapour occurs at 22.2 GHz and in oxygen (O_2) at 60 GHz. hence these two bands not employed for either uplink or downlink.

Attenuation due to rain:

losses due to rain increases with increase in frequency and reduction in elevation angle.

rain attenuation is estimated from

$$\alpha = aR^b$$

a and b are frequency and temperature dependent constants and R is rain rate at location of interest.

cloud attenuation:

Attenuation due to cloud is more or less irrelevant for lower frequency bands, but largely relevant for satellite systems employing Ka and V bands.

Signal fading due to refraction:

Refraction of satellite beam occurs in the troposphere due to variations in the Refractive index of the air column. This effect is more severe for terrestrial links and not too worrisome for satellite links.

Ionospheric related effects:

The ionosphere is an ionized region in space, extending from 100 to 1000 km formed by interaction of solar radiation with different constituent gases of the atmosphere

→ polarization rotation / Faraday effect
→ Ionospheric scintillation

Faraday effect: When an EM wave passes through a region of high electron content like the ionosphere, the plane of polarization of the wave gets rotated due to the interaction of EM wave with the Earth's magnetic field. The rotation of polarization is directly proportional to total electron content of ionized region and inversely proportional to the square of operating frequency.

Ionospheric scintillation: This occurs due to small scale refractive index variations caused by local electron concentration fluctuations. This effect is inversely proportional to the square of the operating frequency.

Fading due to multipath signals: Multipath signals results from reflection and scattering from obstacles such as buildings, trees, hills and other man made objects. As long as satellite remain same in position with respect to satellite terminal. In the case of mobile satellite terminal, the mobile terminal could receive direct signal and reflected signals from trees and other sharp objects, if the relative phase difference between two signals either produce a signal enhancement or fading.

Noise considerations:

Thermal noise is generated in any resistor or resistive component of any impedance due to random motion of molecules, atoms and electrons.

Noise Figure: (F)

defined as

$$F = \frac{S_i/N_i}{S_o/N_o} = \frac{N_o}{(S_o/S_i)N_i} = \frac{N_o}{N_i \cdot G_i}$$

where G_i = power gain over specified bandwidth

Now, Noise power at the input is given by

$N_i = kT_i B$; $T_i \rightarrow$ ambient temp r/.

$$\therefore F = \frac{N_o}{G_i k T_i B}$$

The actual amplifier, however introduces some noise, which is added to the output noise power.

Then $N_o = N_i + \Delta N$

$= G_i k T_i B + \Delta N$

$$\therefore F = \frac{G_i k T_i B + \Delta N}{G_i k T_i B} = 1 + \frac{\Delta N}{G_i k T_i B}$$

Now, noise generated by device

$\Delta N = G_i k T_e B$ $\quad T_e$ = noise temperature

$$\therefore F = 1 + \frac{G_i k T_e B}{G_i k T_i B} = 1 + \frac{T_e}{T_i}$$

$$\therefore T_e = T_i (F - 1)$$

If L is the loss factor, then

$T_e = T_i(L-1)$ hence, for Lossy network

$F = L$

Noise figure and temperature of cascaded stages

total noise power at the output

$$N_{T0} = G_3 k T_3 B + G_3 G_2 k T_2 B + G_3 G_2 G_1 k T_1 B$$

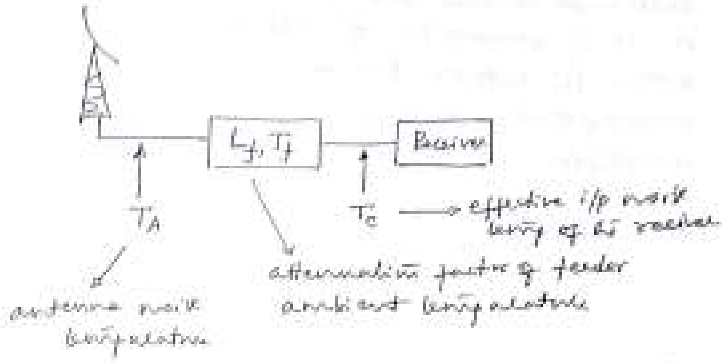
$$N_{T0} = G_3 G_2 G_1 k T_e B$$

$$G_3 G_2 G_1 k T_e B = G_3 k T_3 B + G_3 G_2 k T_2 B + G_3 G_2 G_1 k T_1 B$$

$$\therefore T_e = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + \ldots$$

hence, the noise performance of overall system is largely governed by noise performance of the first stage.

Overall system noise temperature:



expression for system noise temperature with reference to the output of antenna (T_{SAO}) is

$$T_{SAO} = T_A + T_F(L_F - 1) + T_e L_F$$

noise temperature referred to input of the Receiver

$$T_{SRI} = \frac{T_A}{L_F} + T_F\frac{(L_F-1)}{L_F} + T_e$$

Interference related problems

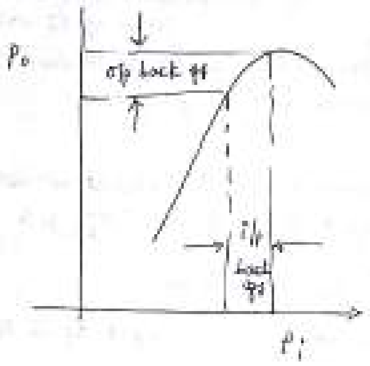
The major sources of interference are

→ intermodulation distortion

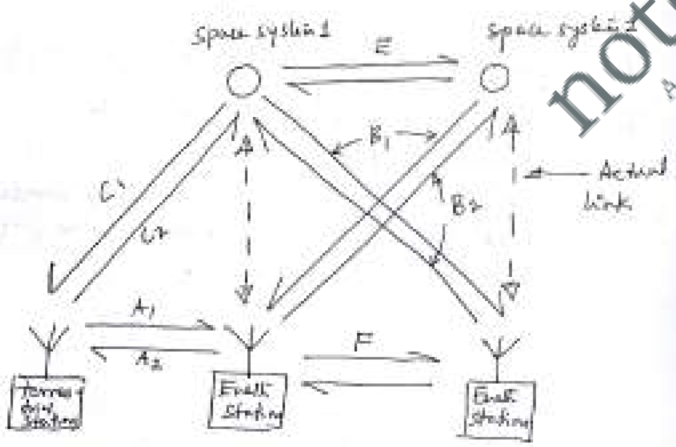
→ interference between satellite & terrestrial link, and satellites sharing same frequency band.

intermodulation distortion:

intermodulation distortion is caused as a result of generation of intermodulation products within the satellite transponder as a result of amplification of multiple carriers in power amplifier. ie TWTA.



interference between satellites and terrestrial links.



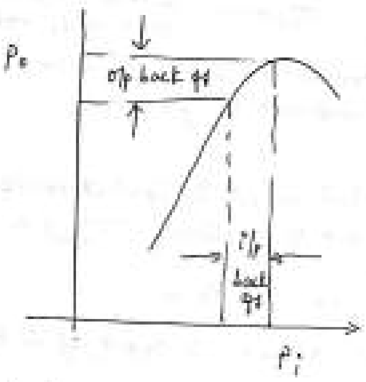
modes of interference mode A, B, C, E, F.

Module 4:

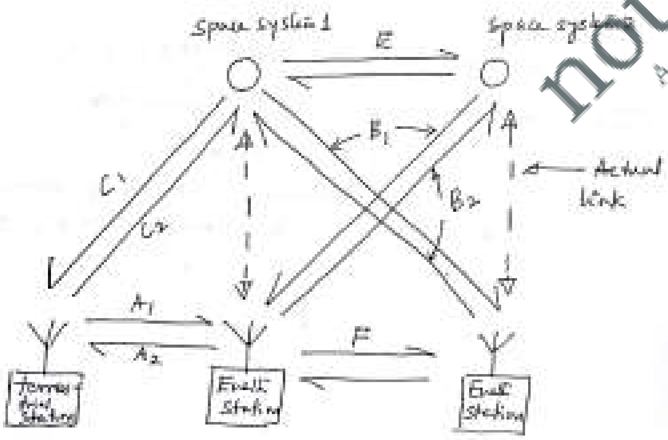
Communication satellite.

Intermodulation distortion

Intermodulation distortion is caused as a result of generation of intermodulation products within the satellite transponder as a result of amplification of multiple carriers in power amplifier. ie TWTA.



Interference between satellite and terrestrial links.



modes of interference mode A, B, C, E, F.

Module 4:

Communication Satellites.

Communication satellite acts as repeater stations that provide either point to point, point-to-multipoint or multipoint interactive services.

Communication related applications:

Telecommunication satellites provides a varied range of services mainly including

- Television broadcasting
- international telephony and
- data communication services.

Satellite TV refers to the use of satellites for relaying TV programs from a point where they originate to a larger geographical area. GEO satellites are employed for satellite TV applications viz, TVRO (television receive only) and DBS (Direct broadcast System).

Satellite telephony provides long distance point-to point or trunk telephony services as well as mobile telephony services.

Satellite also provides data communication services including data, broadcast and multimedia services such as data collection and broadcasting, image and video transfer, voice, internet, two-way computer interactions and database inquiries.

Broadcasting services like TV, radio and telephony services remain in domain of GEO satellites & newer services like messaging, voice, fax, data & video conferencing suited to LEO, MEO or HEO satellite constellation.

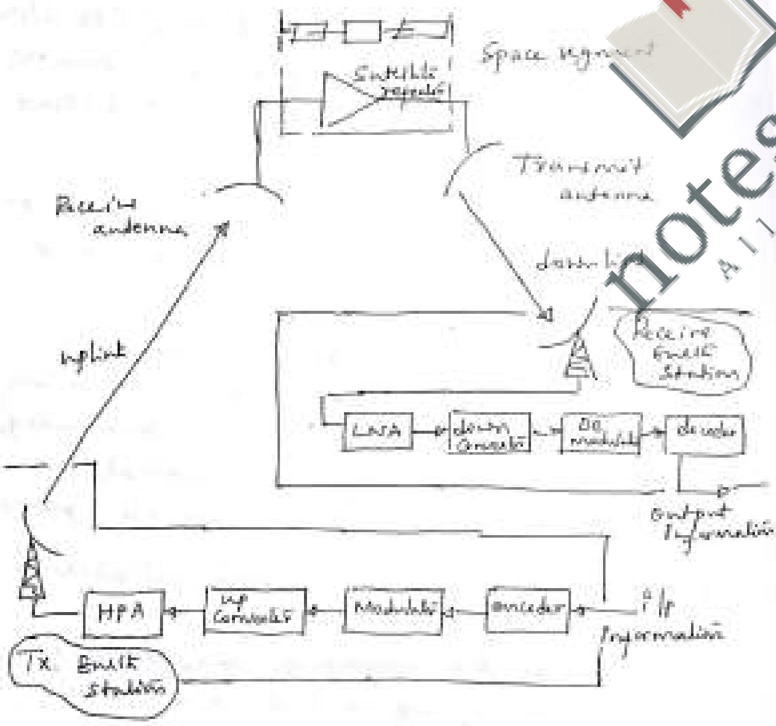
Frequency bands:

Satellite communication employs EM waves for transmission of information between Earth and space. Various bands used in satellite communication includes L, S, C, X, Ku, K & Ka.

Payloads:

Transponder is the key payload for any communication satellite.

Basic elements of satellite communication system is depicted below.



The information to be transmitted (voice channels for telephone service, a composite video signal or digital data) is modulated using analog or digital means, up-converted to the desired microwave frequency band, amplified to the required level and then beamed up to the satellite from transmitting earth station.

The received signals are amplified by the satellite, down converted to a different frequency and then re-transmitted towards Earth. The device on board satellite performs amplification and frequency conversion known as transponder is the main payload for any communication satellite.

Satellites carry a number of these transponders varying from 10 to as many as 100 on high capacity satellites.

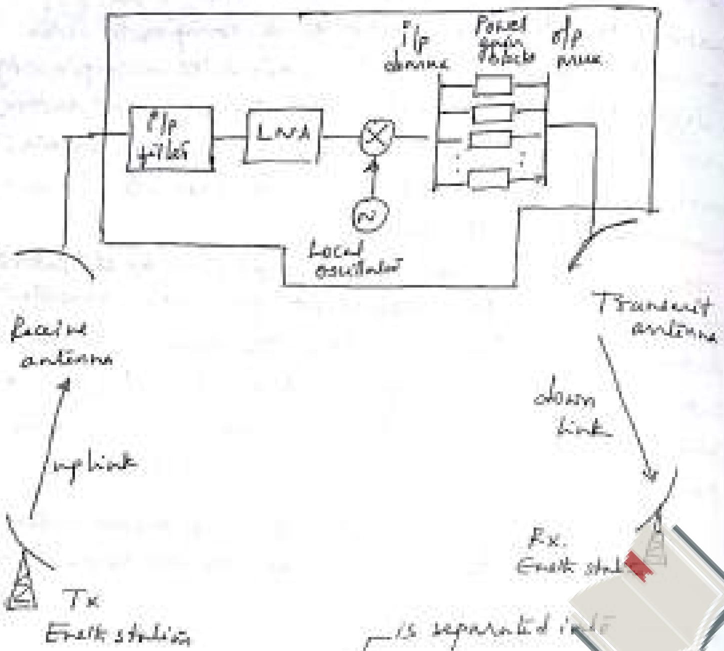
Types of transponders:

Transponders may be broadly classified into two following types

→ Transparent or bent pipe transponders.
→ regenerative transponders.

Transparent or bent pipe transponders

This type of transponder provides only amplification of signal and frequency translation, the modulation and spectral shape of the signals are not affected. As they simply transmit information back to earth, these referred as bent-pipe transponders.



The full bandwidth is separated into individual transponder channels by bank of radio frequency filters. The output of filter is amplified by separate power amplifiers (TWTA) and then combined and fed to common transmitting antenna for down-beaming the signals on to the Earth.

Regenerative transponders:

Here some onboard processing is done and the received signal is altered before transmission. The on-board processing helps to improve throughput and error performance. These repeaters uses various digital techniques like narrow band channel selection, limiting, demodulation, error correction, reformatting of data for processing the received signal.

Satellite v/s terrestrial network

The advantages of satellite over terrestrial n/w are

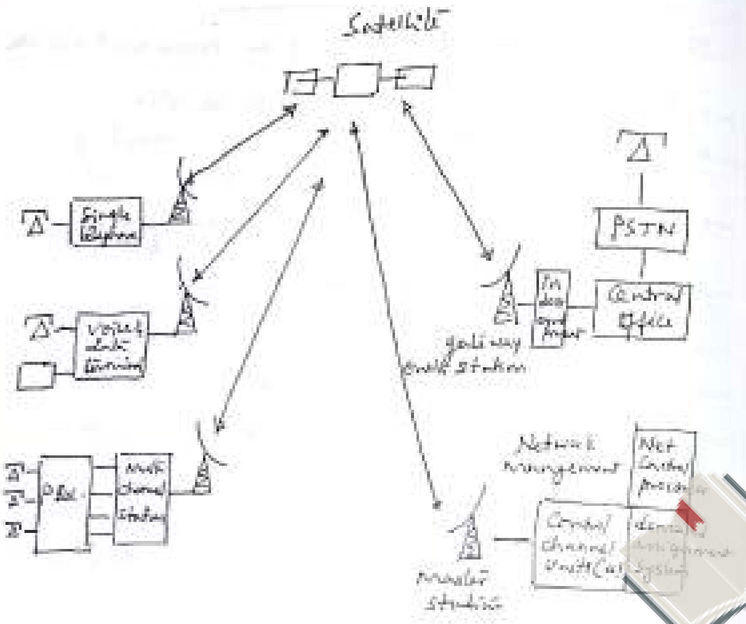
- → broadcast property – wide coverage area
- → Wide bandwidth – high transmission speed & large transmission capacity
- → Geographical flexibility – Independence of location
- → Easy installation of ground stations
- → Uniform service characteristics
- → Immunity to natural disasters
- → Independence from terrestrial infrastructure.
- → Cost aspects – low cost per added site and distance insensitive cost.

Disadvantages w.r.t terrestrial networks

- → Transmission delay
- → Echo effects
- → Launch (cost) of satellite

Satellite telephony:

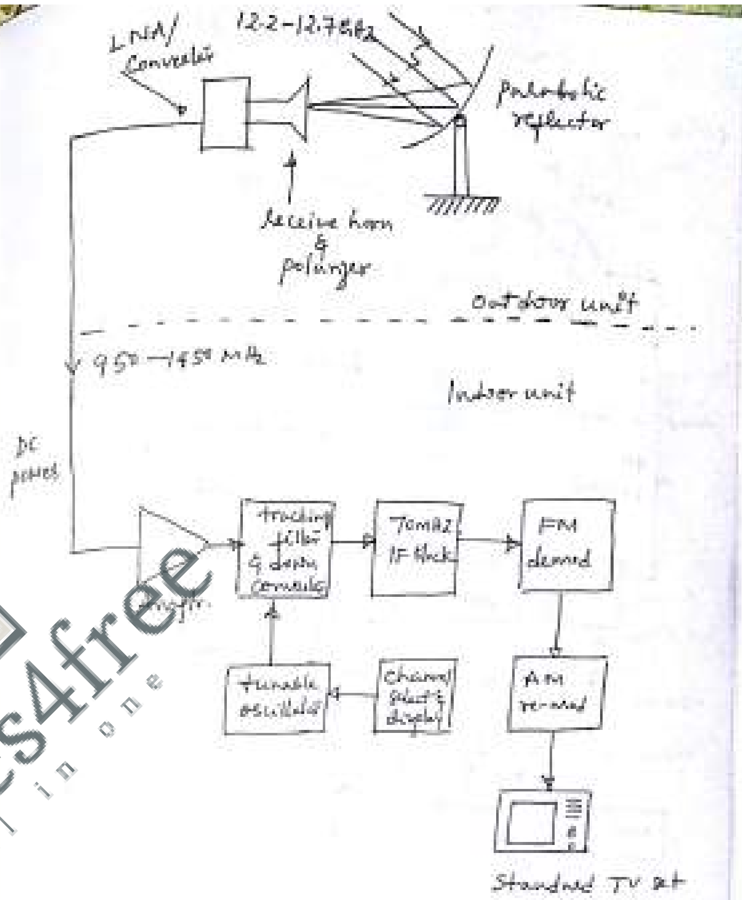
Satellite provides both long distance point-to-point trunk telephony services as well as mobile telephony. Potential users of these services include people living in remote areas, international business travellers. Satellite telephony network employ point-to-point duplex satellite links enabling simultaneous comm. in both directions.



Satellite TV :

Receive only home TV systems : DBS TV/TV ...

This consist of a receiving antenna feeding directly into LNA. The signal is fed to indoor unit normally a sideband signal converting range 950 - 1450 MHz. This is amplified and passed to tracking filter which selects desired channel. The selected channel is again down converted, from 950-1450 MHz to fixed IF of 70 MHz which is demodulated and baseband information is used to generate a VSSB signal which is fed into one of VHF/UHF channels of standard TV set.

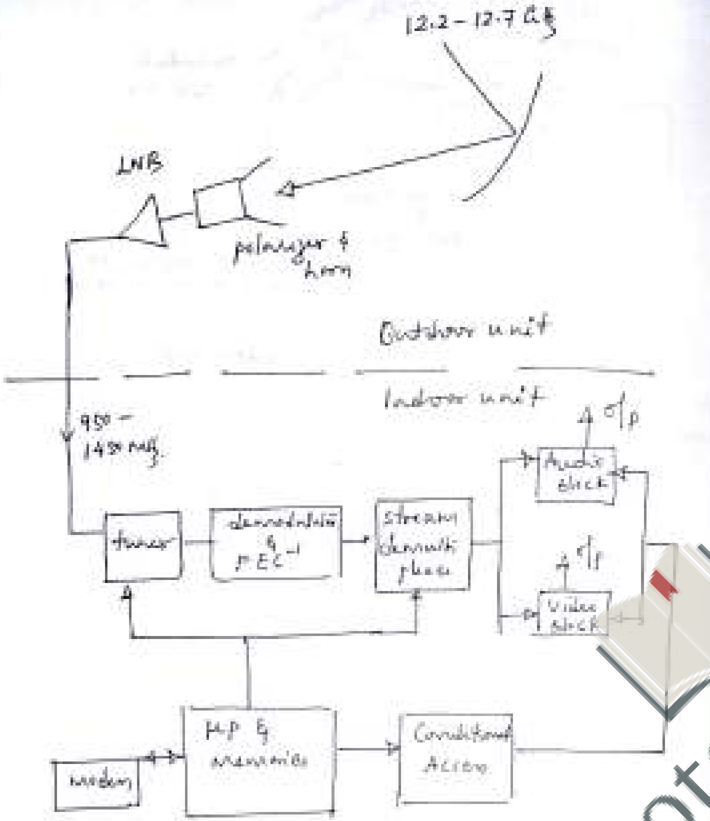


DBS : Direct broadcast System

DBS includes audio, television and internet services. DBS TV is also called digital TV.

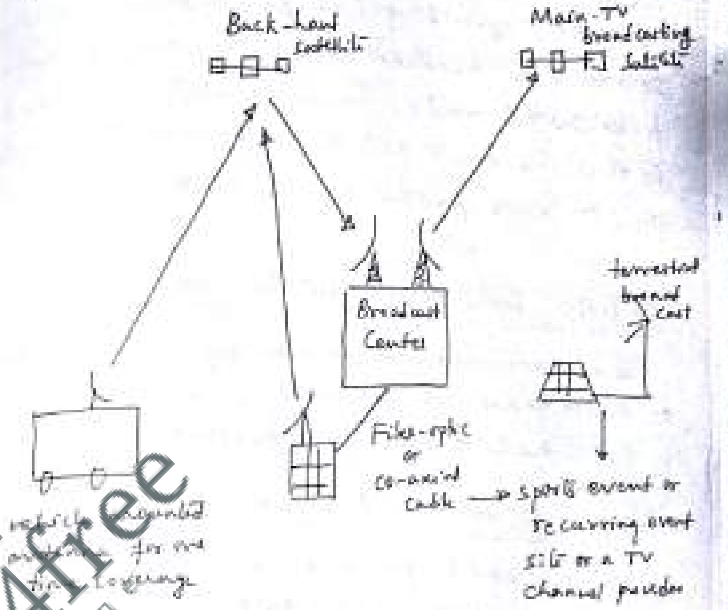
The home receiver consists of two units, an outdoor unit and an indoor unit.

The down link signal is focused by the antenna into the receive horn. downconverter converts 12.2 - 12.7 GHz band to 950 - 1450 MHz, frequency better suited to transmission through connecting cable to the indoor unit.



The carrier is demodulated, QPSK modulation ... being converted to a bit stream. Error correction is carried out in the decoder block. The demultiplexer separates individual programs, which is stored in buffer memories for further processing. Such as conditional access.

A typical Satellite TV network



Uplink section consists of 3 main components,

→ programming source
→ the broadcast center
→ main broadcasting satellite

Programming source comprise TV channel networks, Cable TV programmers, etc that provides various TV programming signals like TV channels, sports coverage, news coverage or local recorded TV pgms to broadcast center either through terrestrial means like line of sight μwave link, fiber optic cable or using satellite referred to as back-haul satellite.

Satellite Radio.

A satellite providing high fidelity audio broadcast services to the broadcast radio stations is referred to as satellite radio. Sound quality is excellent in this case due to wide audio bandwidth of 5-15kHz and low noise provided over the satellite link.

Satellite Data Communication Services.

data communication services refers to unidirectional or bidirectional data broadcasting services provided by GEO satellites through VSAT networks.

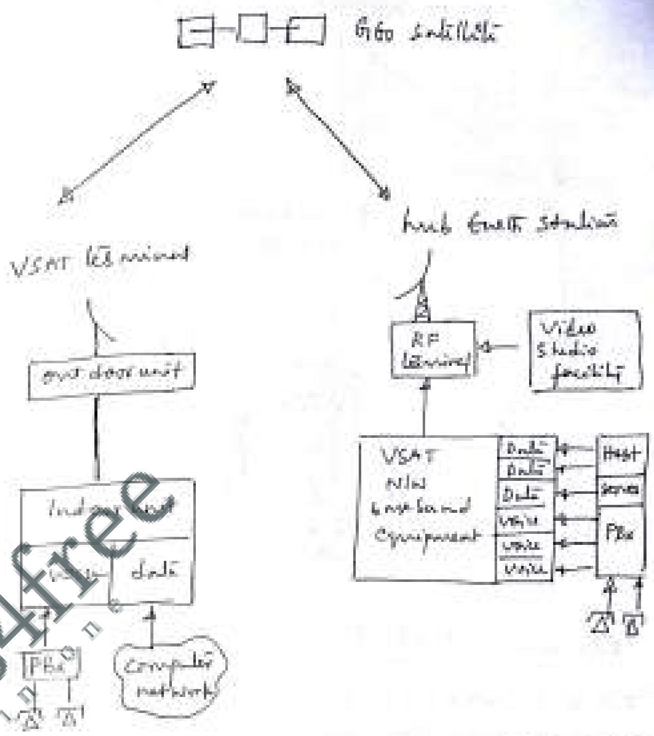
Very small Aperture terminals (VSAT)

VSAT's are used to provide one way or two-way data broadcasting services, point-to-point voice services and one-way video broadcasting services. VSATs are ideal for centralized networks.

Typical examples are

- small and medium business with a central office
- banking institutions with branches all over the country
- reservation systems of airline ticketing system.

Typical VSAT network ground segment consists of high performance hub earth station and a large number of low performance terminals referred to as VSATs. The space segment comprises a GEO satellite links between hub stations & VSAT terminals.

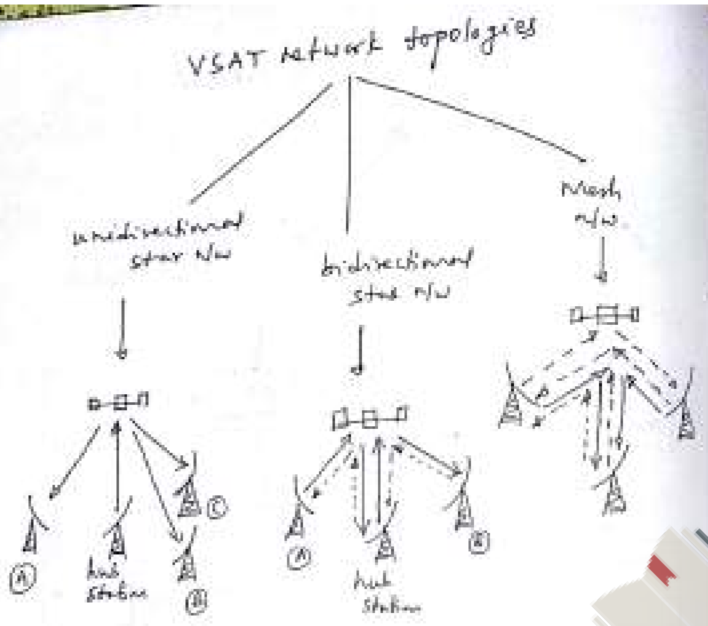


The hub station is normally large, high performance earth station consisting of outdoor antenna (6m to 9m diameter), RF terminal to provide uplink, baseband equipments like modems, multiplexers, encoders, a control center to monitor and manage networks.

VSAT terminals are smaller, comprising of outdoor antenna (0.5m to 2.4m diameter), RF equipment (LNB and baseband equipment). VSAT N/W employ C band or Ku band for transmission & reception.

VSAT N/W generally employ TDMA scheme for data transmission.

VSAT network topologies



Regional satellite systems:

One of the drawbacks of international satellite systems is that they are not optimized to the needs of the individual countries. Regional satellite mission were established with an aim of strengthening the communication necessities of countries belonging to same geographical area.

Example: Eutelsat
Arabsat
AsiaSat
Measat
Asia Global Satellite
Thuraya.

✓ Eutelsat (European telecommunication Satellite organization).

This provides television, telephony and data transmission services on regional basis. 20 satellites in the GEO orbit operated by Eutelsat covering 90% of world population.

Eutelsat-1F series, Eutelsat-2F series and Eutelsat-W series have been launched. Eutelsat covers Europe, Asia and Africa.

National Satellite Systems:

This service refers to as domestic satellite systems provide services to a particular country. National satellite systems were originally developed (established by) countries like United States, USSR and Canada, depending upon specific needs. Later on developing countries like India, China, Japan etc have their own satellite systems.

Example: Galaxy, Satcom, Echostar, telestar of U.S.
Brazilstar of Brazil
INSAT of India,
Optus of Australia,
Sinosat of China.

INSAT (Indian national satellite) is joint venture of Department of Space (DOS) of India, dept of telecom of India (DOT), Indian meteorological dept. (IMD), All India Radio and Doordarshan (AIR).

Various series are INSAT-1A, 1B, 1C, 1D.
INSAT-2A, 2B, 2C, 2DT, 2E
INSAT-3B, 3C, 3A, 3E
INSAT-4A, 4B, 4CR

Module 5:

Remote sensing Satellites, Weather forecasting and Navigational Satellites

Remote sensing satellites

Remote sensing is defined as the science of identifying, measuring and analyzing characteristic features of object of interest without actually being in contact with them.

Classification of remote sensing satellite Systems.

Remote sensing system classified on the basis of
- ✓ Source of radiation
- ✓ Spectral regions used for data aquisition

→ based on source of radiation, they can be classified as
- passive remote sensing system
  - ↳ detection of solar radiations reflected by objects on the surface of Earth or detection of thermal or μ wave radiation emitted by them
- Active remote sensing systems
  - This involves the use of artificial active sources of radiations generally mounted on remote sensing platform.

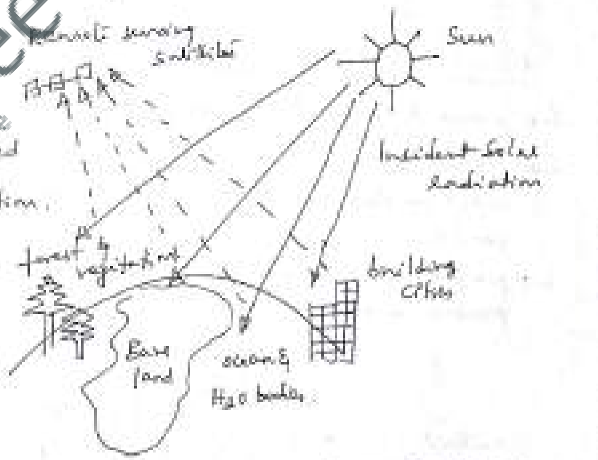
↳ based on spectral radiation, they classified as
- optical remote sensing systems
- Thermal infrared Remote Sensing Systems
- Microwave remote sensing systems.

optical remote sensing systems

↳ make use of visible (0.3–0.7 μm), near IR (0.72–1.30 μm) and short wave IR (1.3–3.0 μm) wavelength band to form images of the Earth's surface.

↳ works on the principle of different material reflect and absorb differently at different wavelength in optical band.

↳ In optical band, shades of grey indicate different level of reflectivity, white color means most reflective surface while least reflective surface represented by black color.

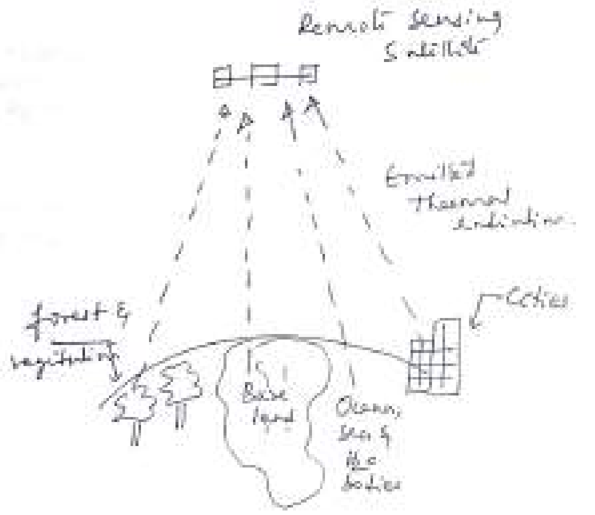


Thermal Infrared remote sensing Systems:

↳ This employ wavelength band midwave IR (3–5 μm) and longwave IR (8–14 μm).

↳ The image is derived from thermal radiation emitted by Earth's surface and other objects.

↳ These comes under passive remote sensing systems.

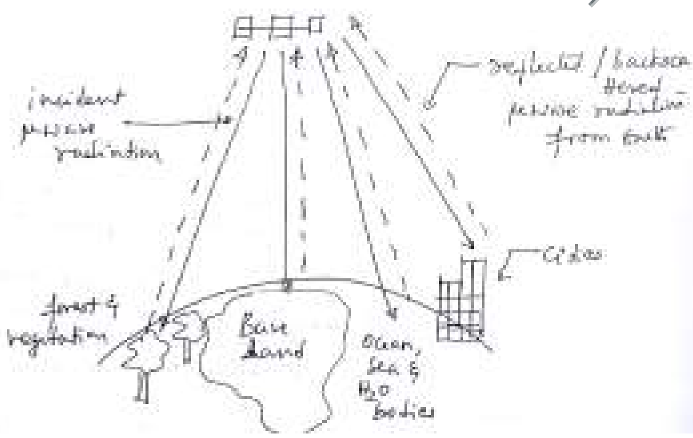


Microwave remote sensing system.

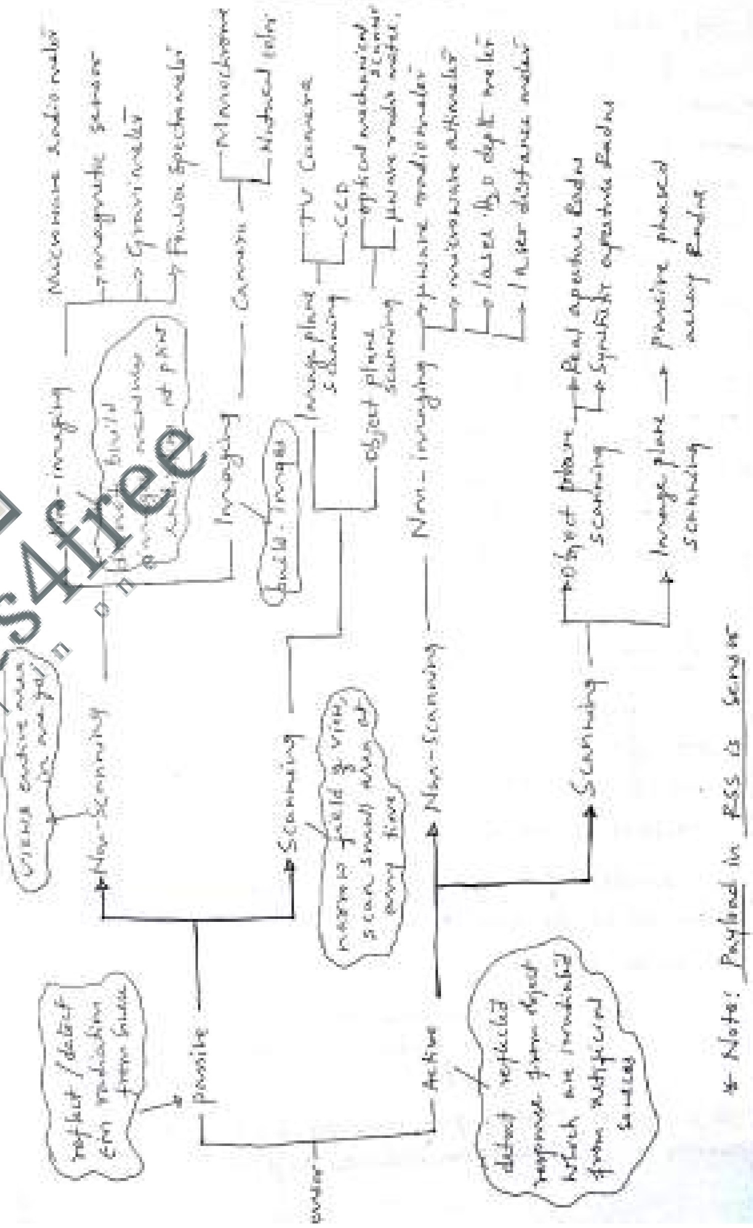
↳ generally operate in 1cm–1m wavelength band.

↳ μwave systems work both during day as well as night as they are independent of solar illumination condition.

↳ μwave remote sensing system can be both passive as well as active.



Classification of Sensors on board Remote Sensing Satellites



Application of Remote Sensing Satellites

The application of remote sensing satellites are

- → Land cover classification
- → Land cover change detection
- → Water quality monitoring & management
- → flood monitoring
- → Urban monitoring & development
- → measurement of sea surface temperature.
- → Deforestation
- → Global monitoring
- → prediction of disasters

Major Remote sensing satellite missions

- ✓ Landsat satellite systems
- ✓ SPOT satellites.
- ✓ Radarsat satellite system

Weather forecasting Satellites

Information from weather satellites are used for short term weather forecast as well as reliable prediction of the movements of tropical cyclones, re-routing of ships.

Weather forecasting satellites take images mainly in visible, IR and Microwave bands.

Visible images:

↳ satellite measures reflected or scattered sunlight in the wavelength region of 0.28 to 3.0 μm.

↳ Shades of grey indicates low reflectivity white tones indicates high reflectivity.

IR Images:

↳ This is the radiation emitted by the clouds & the earth's surface in IR band (10 to 12 μm).

↳ Grey images corresponds to high temperature and lighter shades corresponds to lower temperature.

Water Vapor Images:

↳ Radiation around the wavelength 6.5 μm is absorbed as well as emitted by water vapor.

↳ measurement of water vapor movement is used to calculate upper air winds. however water vapor images show upper level moisture only.

↳ Water vapor imagery is useful only in those areas where there are no clouds.

Microwave images:

↳ uses microwave bands within the region 0.1 to 10 cm.

↳ This uses active as well as passive techniques for measurements in the microwave bands.

↳ amount of microwave radiation emitted by an object is related to its temperature. hence measurements of temperature of cloud and Earth's surface is possible.

↳ also helps to determination of snow cover, precipitation, & thunderstorms and measurement of rainfall.

Images formed by active probing:

↳ active probing involves the use of active microwave sensors.

↳ medium to longer microwave wavelengths in the frequency band near 3, 5, 10 and 15 GHz are primarily used for observation of rainfall.

Weather forecasting satellites: payloads.

- Radiometer: which makes quantitative measurements of electromagnetic radiation incident on it from given area within a specified wavelength band.

Weather forecasting satellites: Applications.

- measurement of cloud parameters
- rainfall
- wind speed and direction
- Ground level temperature measurements
- Air pollution and Haze
- Fog
- Oceanography
- Severe storm support
- snow and ice studies.

major weather forecasting satellite missions

- GOES: Geostationary operational environment satellites
- Meteosat satellite system:
- Advanced TIROS-N (ATN) NOAA satellite system.

Navigation satellites

Navigation is the art of determining the position of a platform or an object at any specified time.

GPS (Global positioning satellite) system:

GPS system comprises

- space segment
- control segment
- User segment.

Space segment: space segment comprises 28 satellite constellation out of which 24 satellites are active and remaining 4 are used as an orbit spares. The satellites are placed in six orbital planes and 4 satellites in each plane.

The satellite orbit in circular MEO orbits at an altitude of 20,200 km with an inclination of 55° to the equator.

The orbital period of each satellite is around 12h (11h 58 min).

All GPS satellites are equipped with atomic clock having high accuracy of the order of few nanoseconds.

These satellites transmits signals, synchronized with each other on two microwave bands L1 and L2.

Control segment: This section consists of a worldwide network of five monitor stations, four ground antenna station and a master control station.

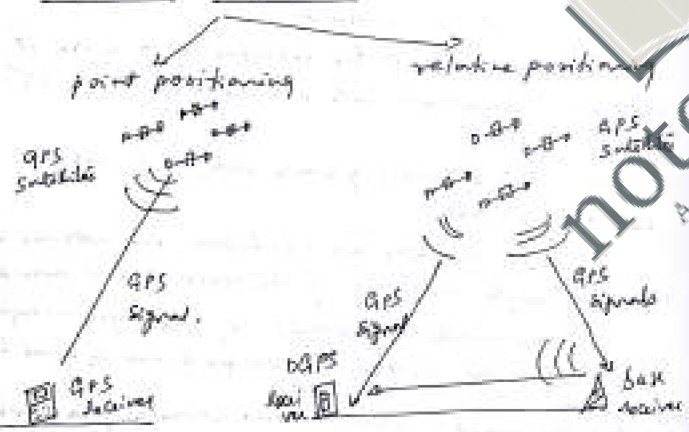
User segment: includes GPS receivers to provide position, velocity and time information.

Working of GPS:

In the GPS system, position of any receiver is determined by calculating its distance from four satellites. This distance is referred to as 'pseudo range'.

This information from three satellites is sufficient for calculating the longitude and the latitude positions. however from the fourth satellite is necessary for altitude calculation. hence the receiver is located on Earth, then the position can be determined on the basis of information of its distance from three satellites.

GPS positioning modes:



Applications of Satellite Navigation Systems

- military applications
  - weapon guidance, navigation, tracking,
- civilian applications
  - construction and surveying
    seismic surveying, airborne mapping, vehicle navigation, automation, marine, military and aviation surveying.

——— END ———