SATELLITE COMMUNICATIONS

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SATELLITE COMMUNICATIONS

SYLLABUS

Unit 1 Introduction & Orbital Mechanics

Introduction: Background and History of satellite communications, Basic concepts of satellite communications, frequency allocations for satellite services, applications, and future trends.

Orbital Mechanics: Kepler's Laws, Orbital elements, look angle determination, orbital perturbations, orbit determination, Launch vehicles, Orbital effects in communication systems performance.

Unit 2 Satellite Subsystems

Attitude and Orbital Control System (AOCS), Telemetry, Tracking, Command and Monitoring (TTC&M), Power Systems, Communication subsystems, Satellite Antenna, Equipment Reliability and Space Qualification.

Unit 3 Satellite Link Design & Multiple Access

Basic Transmission Theory, System Noise Temperature and G/T Ratio, Design of Downlinks, Uplink Design, Propagation Effects and their impact on Links. Basic concepts of Multiple Access, Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Onboard Processing, Demand Assignment Multiple Access (DAMA), Code Division Multiple Access (CDMA).

Unit 4 Earth Station Technology, Leo and Geostationary Satellite Systems

Introduction, transmitters, receivers, Antennas, tracking systems, terrestrial interface, primary power test methods. Orbit consideration, coverage and frequency considerations, delay and throughput considerations, system considerations.

Unit 5 Satellite Navigation & The Global Positioning System

Radio and satellite navigation, GPS position location principles, GPS receivers, satellite signal acquisition, GPS navigation message, GPS signal levels, GPS receiver operation, Differential GPS.

SATELLITE COMMUNICATIONS

UNIT 1: INTRODUCTION & ORBITAL MECHANICS

INTRODUCTION:-

* Satellite is a microwave object which operates at higher frequencies.
* Satellite is also known as Transpoter, Transceiver.
* It contains both Transmitter and Receiver
* The sharing of information by means of satellite is known as satellite communication.

Eg: planets (Natural satellites)

* Author "clarke" - By using Rocket Science we can gather information around the World (1945) - 12 years.
* first satellite sputnik-1 by Russia (1957).
* Second Satellite U.S. Explorer-1

BACKGROUND AND HISTORY OF SATELLITE COMMUNICATIONS

Category	year	Activity	person/Agency/country
Geostationary concept	1945	Suggestion of Geostationary satellite communication feasibility	A. clarke (U.K)
Moon Reflection	1946	Detection of Lunar Echo by Radar	J. Mofenson (U.S.A)
	1954	passive relaying of Voice by moon reflection	J.H. Trexler (U.S.A)
	1960	Hawaii - Washington, DC. communication by moon reflection	U.S.A NAVY

Low Attitude orbit	1957	observation of signals from sputnik-1	U.S.S.R, Japan and others.
	1958	Tape-recorded Voice transmission by satellite SCORE	USA Air force.
	1960	Meteorological facsimile Trans mission by Satellite Trios-1	U.S.A NASA
	1960	passive relaying of telephone and television by Satellite Echo-1	U.S.A Army
	1960	Delayed relaying of recorded Voice by Satellite Courier-1B	U.S.A Army
	1962	Active transatlantic relaying of communication by Satellite Telstar-1	U.S.A, uk, Europe, France
	1963	Scatter communication by tiny needles in orbit (West ford project 6)	U.S.A MIT
	1963	Active transpacific relaying of communication by Satellite Relay 1	USA, NASA Japan
Synchronous Satellite	1963	USA-Europe-Africa communication by Satellite syncom 2	U.S.A NASA
	1964	olympic games Television relaying by satellite Syncom 3	USA, NASA Japan.
	1965	Commercial communication (Semi experimental) by Satellite Early Bird	INTEL-SAT

BASIC CONCEPTS OF SATELLITE COMMUNICATIONS:-

- A communication satellite is an orbiting artificial earth satellite that receives a communications signal from a transmitting ground station, amplifies and possibly processes, it, then transmits it back to the earth for reception by one (or) more receiving ground stations.

Evolution of Satellite communication:

- During early 1950s, both passive and active satellites were considered for the purpose of communications over a large distance.
- passive satellites though successfully used in the early years of satellite communications, with the advancement in technology active satellites have completely replaced the passive satellites.

passive satellites:

- A satellite that only reflects signals from one Earth station to another (or) from several Earth stations to several others.
- It reflects, the incident electromagnetic radiation without any modification (or) amplification.
- It can't generate power, they simply reflect the incident power
- The first artificial passive satellite Echo-1 of NASA was launched in August 1960.

Disadvantages:-

- Earth stations required high power to transmit signals.
- Large Earth stations with tracking facilities were expensive.
- A global system would have required a large number of passive satellites accessed randomly by different users
- Control of satellites not possible from ground.

Active satellites:

- In active satellites, it amplifies (or) modifies and retransmits the signal received from the earth.
- Satellites which can transmit power are called active satellite.
- Have several advantages over the passive satellites.
- Require lower power earth station.
- Not open to random use.
- Directly controlled by operators from ground

Disadvantages:-

- Requirement of larger and powerful rockets to launch heavier satellites in orbit.
- Requirement of on-board power supply.
- Interruption of service due to failure of electronics components

Two major elements of Satellite communications systems are:-

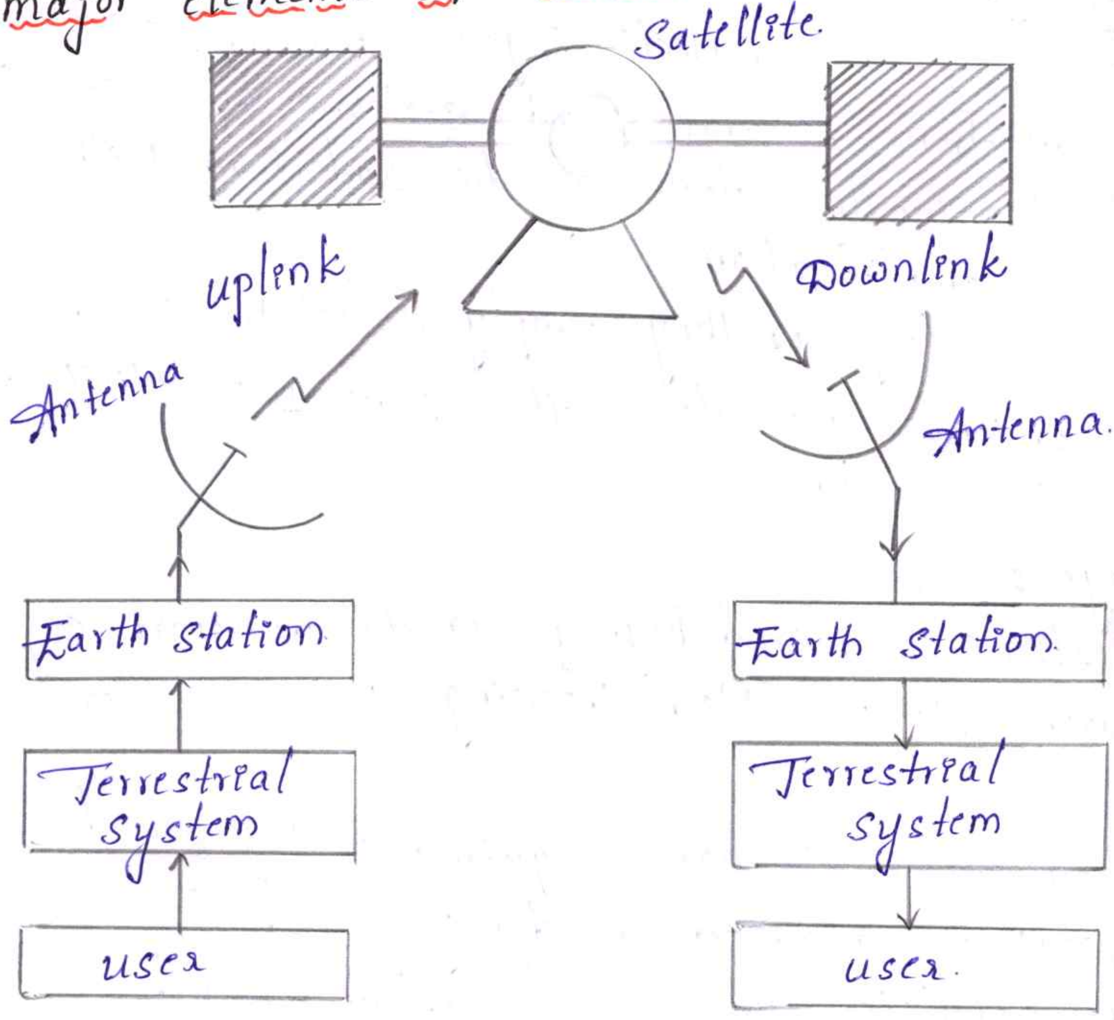


fig: General architecture of Satellite Communication

Space Segment:-

The elements of the space segment of a communications satellite system are shown in figure. The space segment includes the satellite (or satellites) in orbit in the system, and the ground station that provides the operational control of the satellite(s) in orbit. The ground station is variously referred to as the Tracking, Telemetry, Command (TT&C) or the Tracking, Telemetry, command and Monitoring (TTC&M) station. The TTC&M station provides essential spacecraft management and control functions to keep the satellite operating safely in orbit. The TTC&M links between the spacecraft and the ground are usually separate from the user communications links. TTC&M links may operate in the same frequency bands or in other bands. TTC&M is most often accomplished through a separate earth terminal facility specifically designed for the complex operations required to maintain a spacecraft in orbit.

Ground Segment:-

The ground segment of the communications satellite system consists of the earth surface area based terminals that utilize the communications capabilities of the space segment. TTC&M ground stations are not included in the ground segment. The ground segment terminals consists of three basic types:

- fixed (in-place) terminals;
- Transportable terminals;
- Mobile Terminals.

* fixed terminals are designed to access the satellite while fixed in-place on the ground. They may be providing different types of services, but they are defined by the fact that

they are not moving while communication with the satellite. Examples of fixed terminals are small terminals used in private networks (VSATs), or terminals mounted on residence buildings used to receive broadcast satellite signals.

* Transportable terminals are designed to be movable, but once on location remain fixed during transmissions to the satellite. Examples of the transportable terminal are satellite news gathering (SGN) trucks.

* Mobile terminals are designed to communicate with the satellite while in motion. They are further defined as land mobile, aeronautical mobile, or maritime mobile, depending on their locations on (or) near the earth surface.

Satellite Control centre function:

- Tracking of the Satellite
- Receiving data
- Eclipse Management of Satellite
- Commanding the satellite for station keeping
- Determining Orbital parameters from Tracking and Ranging data.
- Switching ON/OFF of different subsystems as per the operational requirements.

SATELLITE ORBITS

a. Equatorial-orbit satellite

b. Inclined-orbit satellite

c. polar-orbit satellite

Orbit:- The path a satellite follows around a planet is defined as an orbit.

- Satellite orbits are classified into two broad categories:

① Non-Geostationary Orbit (NGSO)
② Geo stationary orbit (GSO).

- Early Ventures With satellite communications used satellites in Non-geostationary low earth orbits due to technical limitations of the launch Vehicles in placing satellites in higher orbits.

Disadvantages of NGSO

- complex problem of transferring signal from one satellite to another.
- Less expected life of satellites at NGSO.
- Requires frequent replacement of Satellites compared to. Satellite in GSO.

Geo stationary Orbit (GSO):-

- There is only one geostationary orbit possible around the earth
- Lying on the earth's equatorial plane.
- The satellite orbiting at the same speed as the rotational speed of the earth on its axis.

Advantages:

- Simple ground station tracking
- Nearly constant range.
- Very small frequency shift

Disadvantages:

- Transmission delay of the order of 250msec.
- Large free space loss
- No polar coverage.

Note:- A geostationary orbit is a type of geosynchronous orbit. A geosynchronous orbit can be any orbit, like with an elliptical path, that has a period equal to the Earth's rotational period, Whereas a geostationary orbit has to be a circular orbit and that too placed above the equator.

Satellite Orbits in terms of the height:

- According to distance from earth:
  - Geosynchronous Earth orbit (GEO)
  - Medium Earth orbit (MEO)
  - Low Earth orbit (LEO)

Comparision of LEO, MEO, GEO:-

parameters	LEO	MEO	GEO
Definition	It is an orbit with an altitude between 200km and 2000km (500 to 1500kms)	It is an orbit with an altitude between 3000km and 30,000kms.	Around 35,000 kms. (35,786)
coverage area	Small	Larger area	Largest area.
Number of satellites required	30 to 60	10 to 20	3 to 4
orbital period	1.5 hrs	5 to 12 hrs	24 hrs
cost	Low	Moderate.	High
propagation Loss	less	Higher	Highest
life time.	5 years	10-15 years	10-15 years
Applications	Weather forecasting, Mobile communication	communication & Navigation purpose like GPS	Broadcasting, Data, TV, mobile Communication

Advantages and Disadvantages of an orbits (LEO, MEO, GEO):-

Advantages of LEO:-

① A LEO satellite proximity to earth compare to a GEO satellite gives the better signal strength.

② It is better for point to point communication. ⑤

Disadvantages of LEO:-

① Network of LEO satellites is needed which can be costly.

② Atmospheric drag effects LEO satellites causing gradual orbital detortion (or) destruction.

Advantages of MEO:-

① A MEO satellites longer duration of visability and wider footprint means fuel satellites are needed in a LEO network compare to a MEO.

Disadvantages of MEO:-

① A MEO satellite distance gives a longer time delay and weaker signal than a LEO satellite.

Advantages of GEO:-

① Less number of satellites are used

② Gives the more coverage area.

Disadvantages of GEO:-

① Larger Antennas are needed

② The transmit power needed is relatively high which causes problem for battery power devices.

③ Due to Large footprint either the frequency cannot be reuse and the GEO satellite needs special antennas in order to focus on a smaller footprint.

④ Transfering the satellite into the orbit is very expensive

Advantages of Satellite communications:-

- universal
- Reliable
- Versatile
- fast

- flexible
- expandable
- High quality
- Quick provision of Services
- Mobile and Emergency communication
- Suitable for both Analog and digital transmission

FREQUENCY ALLOCATIONS FOR SATELLITE SERVICES:-

Allocation of frequencies to Satellite Services is a complicated process which requires international co-ordination and planning. This is done as per the International Telecommunication union (ITU). To implement this frequency planning, the World is divided into three regions:

Region 1: Europe, Africa and Mongolia

Region 2: North and South America and Greenland

Region 3: Asia (excluding region 1 areas), Australia and south-West pacific.

Within these regions, the frequency bands are allocated to Various satellite Services. Some of them are listed below.

- Fixed Satellite Service: provides Links for existing Telephone Networks used for transmitting television Signals to cable companies.
- Broadcasting satellite Service: provides Direct Broadcast to homes. E.g. Live Cricket matches etc..
- Mobile satellite Services: This includes services for: Land Mobile, Maritime, Aeronautical mobile.
- Navigational satellite Services: Include Global positioning system.
- Meterological satellite Services: They are often used to perform Search and Rescue Service.

Below are the frequencies allocated to these satellites:

Frequency Band (GHz) Designations:

VHF : 0.1-0.3

UHF : 0.3 - 1.0

L-band: 1.0 - 2.0

S-band: 2.0 - 4.0

C-band: 4.0 - 8.0

X-band: 8.0 - 12.0

ku-band: 12.0 - 18.0 (ku is under k Band)

ka-band: 18.0 - 27.0 (ka is Above k Band)

V-band: 40.0 - 75.0

W-band: 75 - 110

Mm-band: 110 - 300

μm-band: 300 - 3000

Based on the Satellite Service, following are the frequencies allocated to the satellites:

Frequency Band (GHz) Designations:

Frequency Band (GHz) Designations: Satellite Services

VHF: 0.1-0.3 --- Mobile & Navigational Satellite Services

L-band: 1.0-2.0 --- Mobile & Navigational Satellite Services

C-band: 4.0-8.0 --- fixed satellite service

ku-band: 12.0-18.0 --- Direct Broadcast Satellite Services

Band	frequency Range	Total BandWidth	General Application
L	1 to 2GHz	1GHz	Mobile Satellite Service (MSS)
S	2 to 4GHz	2GHz	MSS, NASA, deep space research
C	4 to 8GHz	4GHz	Fixed Satellite Service (FSS)
X	8 to 12.5GHz	4.5GHz	FSS military, terrestrial earth exploration & Meterological satellites
ka	12.5 to 18GHz	5.5GHz	FSS, Broadcast Satellite Service (BSS)
k	18 to 26.5GHz	8.5 GHz	BSS, FSS
ka	26.5 to 40GHz	13.5 GHz	FSS

APPLICATIONS OF SATELLITE COMMUNICATION:-

1) Weather forecasting: Certain Satellites are specifically designed to monitor the climatic conditions of earth. They continuously monitor the assigned areas of earth and predict the weather conditions. These satellites are exceptionally useful in predicting disasters like hurricanes, and monitor the changes in the Earth's vegetation, sea state, ocean color and ice fields.

2) Radio and TV Broadcast:- These dedicated satellites are responsible for making 100s of channels across the globe available for everyone.

3) Military Satellites: These Satellites are often used for gathering intelligence, as a communications satellite used for military purpose.

4) Navigation Satellites: The system allows for precise localization world-wide, and with some additional, the precision is in the range of some meters.

5) Global Telephone: One of the first applications of satellites for communication was the establishment of international telephone backbones. Using satellites, to typically reach a distance approximately 10,000 kms away, the signal needs to travel almost 72,000 kms, that is, sending data from ground to satellite and (mostly) from satellite to another location on earth.

6) Connecting Remote Area: Due to their geographical location many places all over the world do not have direct wired connection to the telephone network (or) the internet (e.g., researchers on Antarctica).

7) Global mobile communication: The basic purpose of satellites for mobile communication is to extend the area of coverage. cellular phone systems, such as AMPS and GSM (and their successors) do not cover all parts of a country. The base-stations communicate with satellites using a gateway-link (GWL) Sometimes it becomes necessary for satellite to create a communication link between users.

FUTURE OF SATELLITE COMMUNICATIONS :-

Future communication satellites will have.

- More onboard processing capabilities,
- More power, and
- Larger-aperture antennas that will enable satellites to handle more bandwidth.
- The demand for more bandwidth will ensure the long-term viability of the commercial satellite industry well into the 21st century.

Conclusion :-

By going through the above slides we came to know that satellite is mostly responsible for:

- Telecommunication transmission
- Reception of television signals
- Whether forecasting.

Which are very important in our daily life.

ORBITAL MECHANICS AND LAUNCHERS

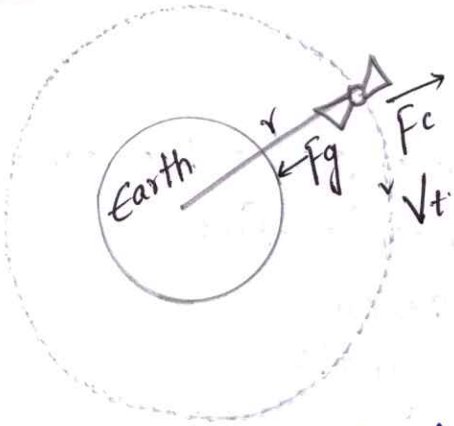
ORBITAL MECHANICS :-

- To achieve a stable orbit around the earth, a spacecraft must first be beyond the bulk of the earth's atmosphere, i.e., in what is popularly called space.
- According to Newton's law of motion $F=ma$. where a=acceleration, F= force acting on the object and m=mass of the object. It helps us understand the motion of satellite in a stable orbit.
- ($F=ma$) states that the force acting on a body is equal to the mass of the body multiplied by the resulting acceleration of the body.
- Thus, for a given force, the lighter the mass of the body, the higher the acceleration.

• When in a stable orbit, there are two main forces acting on a satellite: a centrifugal force due to the kinetic energy of the satellite, which attempts to fling the satellite into a higher orbit, and a centripetal force due to gravitational attraction of the planet about which the satellite is orbiting, which attempts to pull the satellite towards the planet.

• If these two forces are equal the satellite remains in a stable orbit.

Forces involved in orbital mechanics:-



There are two relevant forces involved they are:

1. Gravitational force: attraction between any two objects.
2. Centrifugal force: outward-directed force that normally balances the inward directed centripetal force.

Kepler's Laws:-

Kepler's Laws of planetary motion apply to any two bodies in space that interact through gravitation. The laws of motion are described through three fundamental principles.

Kepler's first Law:- as it applies to artificial satellite orbits, can be simply stated as follows:

"The path followed by a satellite around the earth will be an ellipse, with the center of mass of earth as one of the two foci of the ellipse." This is shown in figure:

The satellite will eventually settle in an elliptical orbit, with the earth as one of the foci of the ellipse.

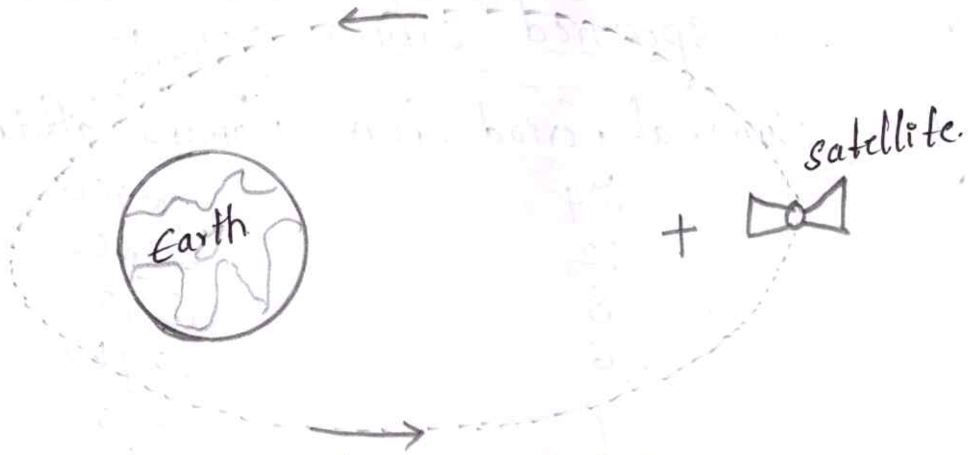


fig: kepler's first Law.

⇒ The 'size' of the ellipse will depend on the satellite mass and its angular velocity.

kepler's Second Law: can likewise be simply stated as follows: 'for equal time intervals the satellite sweeps out equal areas in the orbital plane demonstrates this concept.

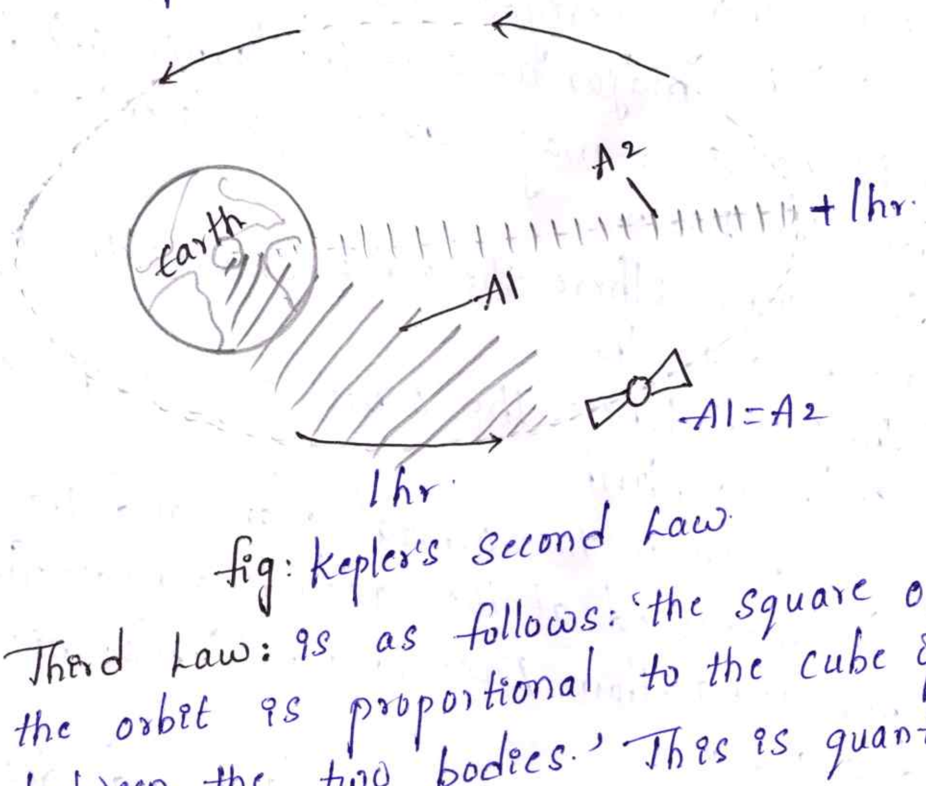


fig: kepler's Second Law

kepler's Third Law: is as follows: 'the square of the periodic time of the orbit is proportional to the cube of the mean distance between the two bodies.' This is quantified as follows:

$$T^2 = \left[\frac{4\pi^2}{\mu}\right] a^3$$

Where, T = orbital period in s; a = distance between the two bodies, in km; μ = kepler's constant = 3.986004 X105 km^3/s^2.

If the orbit is circular, then a = r, and

$$r = \left[\frac{\mu}{4\pi^2}\right]^{1/3} T^{2/3}$$ Orbit Radius = [constant] X (orbit period)$^{2/3}$

Orbit altitudes for specified orbital periods:-

Revolutions/day	Nominal period (hours)	Nominal altitude (km)
1	24	36000
2	12	20200
3	8	13900
4	6	10400
6	4	6400
8	3	4200

ORBITAL ELEMENTS:-

Apogee: A point for a satellite farthest from the Earth. It is denoted as ha

perigee: A point for a satellite closest from the Earth. It is denoted as hp.

Line of Apsides: Line joining perigee and apogee through centre of the Earth. It is the major axes of the orbit. One-half of this line's length is the semi-major axis equivalents to satellite's mean distance from the Earth.

Ascending Node: The point where the orbit crosses the equatorial plane going from north to south.

Descending Node: The point where the orbit crosses the equatorial plane going from south to North.

Inclination: The angle between the orbital plane and the Earth's equatorial plane. Its measured at the ascending node from the equator to the orbit, going from East to North, Also this angle is commonly denoted as i

Line of Nodes: The line joining the ascending and descending nodes through the centre of Earth.

prograde orbit: an orbit in which satellite moves in the same direction as the Earth's rotation. Its inclination is always between 0° to 90°. Many satellites follow this path as Earth's velocity makes it easier to launch these satellites.

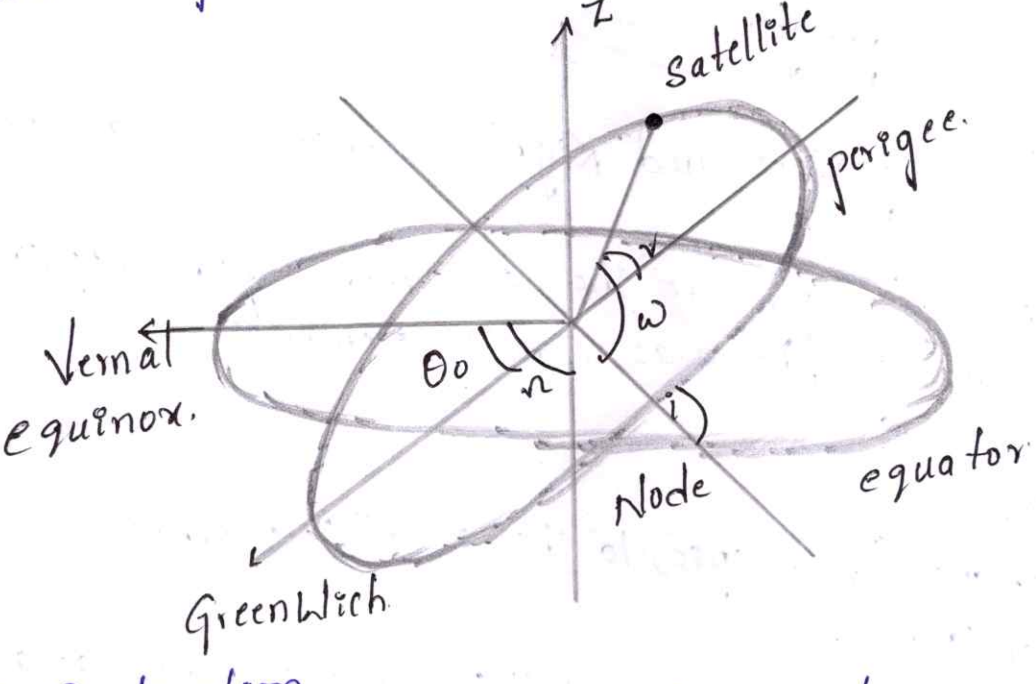
Retrograde orbit: an orbit in which satellite moves in the same direction counter to the Earth's rotation.

Argument of perigee: An angle from the point of perigee measure in the orbital plane at the Earth's centre, in the direction of the satellite motion.

Right ascension of ascending node: The definition of an orbit in space, the position of ascending node is specified. But as the Earth spins, the longitude of ascending node changes and cannot be used for reference. Thus for practical determination of an orbit, the longitude and time of crossing the ascending node is used. It could also be defined as "right ascension of the ascending node; right ascension is the angular position measured eastward along the celestial equator from the vernal equinox vector to the hour circle of the object".

Mean anamoly: It gives the average value to the angular position of the satellite with reference to the perigee.

True anamoly: It is the angle from point of perigee to the satellite's position, measure at the Earth's centre.



i Inclination

Ω Right Ascension of ascending node.

ω Argument of perigee, ν True anamaly

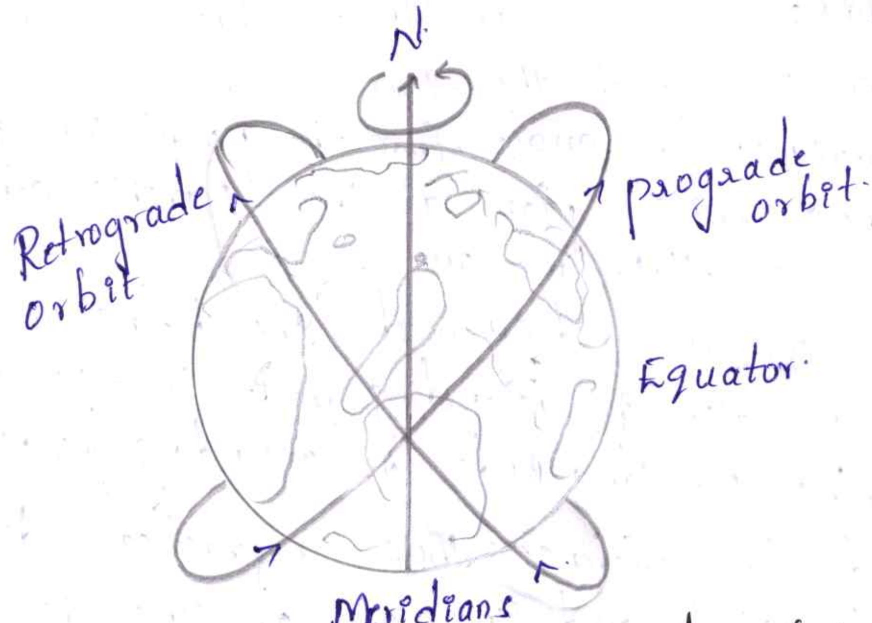


fig: prograde and Retrograde orbits.

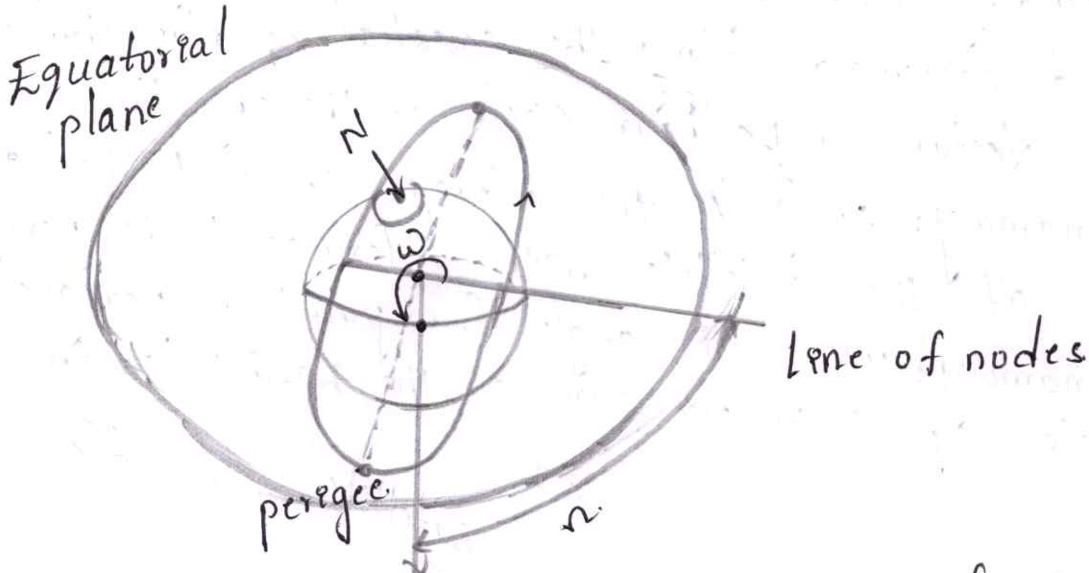


fig: Argument of perigee and Right ascension of ascending node.

Orbital Elements following are the 6 elements of the keplerian Element set commonly known as orbital elements.

* Semi-Major axis(a)
* Eccentricity (e)

They give the shape (of ellipse) to the satellite's orbit

3. Mean anomaly (MO)

It denotes the position of a satellite in its orbit at a given reference time

4. Argument of perigee.

It gives the rotation of the orbit's perigee point relative to the orbit's nodes in the earth's equatorial plane.

* Inclination
* Right ascension of ascending node.

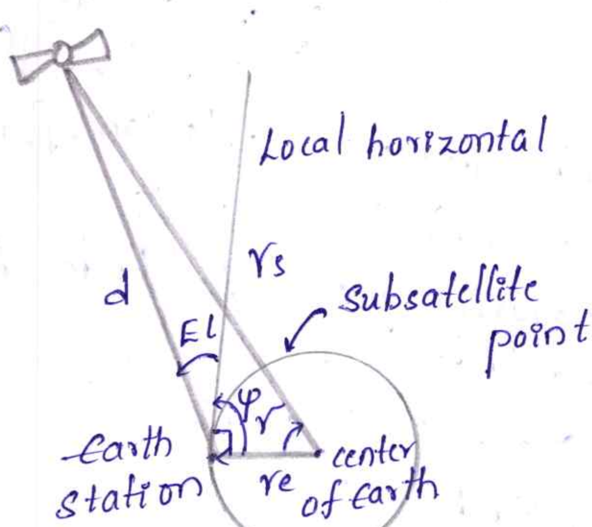
Look Angle Determination:-

- The look angles for the ground station antenna are Azimuth and Elevation angles. They are required at the antenna so that it points directly at the satellite. Look angles are calculated by considering the elliptical orbit. These angles change in order to track the satellite.

The following information is needed to determine the look angles of geostationary orbit.

- Earth station Latitude.
- Earth station Longitude
- Sub-Satellite point's Longitude.
- ES: position of Earth station
- SS: sub-satellite point
- S: satellite.
- Range from ES to S
- Angle to be determined.

Geometry of Elevation Angle:-



- plane in picture is the one that includes center of the earth, Earth Station and Satellite
- Subsatellite point will also be on the same plane

$El = \psi - 90°$

γ = central angle

r_s = radius to the satellite

r_e = radius of the Earth

Satellite coordinates

- SUB-SATELLITE POINT

  Latitude L_s

  Longitude l_s

- EARTH STATION LOCATION

  Latitude L_e

  longitude l_e.

Calculate γ, Angle at earth centre

Central Angle.

γ is defined so that it is non-negative and

$$\cos(\gamma) = \cos(L_e)\cos(L_s)\cos(l_s - l_e) + \sin(L_e)\sin(L_s)$$

The magnitude of the vectors joining the center of the earth, the satellite and the earth station are related by the law of cosine:

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

Elevation Angle calculation

By the sine law we have

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

Which yields

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

Azimuth Angle calculation for GEO Satellites

- SUB-SATELLITE POINT

  Equatorial plane, Latitude $L_s = 0°$

  Longitude l_s

- EARTH STATION LOCATION

  Latitude L_e

  longitude l_e.

The original calculation previously shown:

$$\cos(\gamma) = \cos(L_e)\cos(L_s)\cos(l_s - l_e) + \sin(L_e)\sin(L_s)$$

Simplifies using $L_s = 0°$ since the satellite is over the equator:

$$\boxed{\cos(\gamma) = \cos(L_e)\cos(l_s - l_e)}$$

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

case 1: Earth station in the Northern Hemisphere with
(a) Satellite to the SE of the earth station: $Az = 180° - \alpha$.
(b) Satellite to the SW of the earth station: $Az = 180° + \alpha$.
case 2: Earth station in the Southern Hemisphere with
(c) Satellite to the NE of the earth station: $Az = \alpha$
(d) satellite to the NW of the earth station: $Az = 360° - \alpha$.

ORBITAL PERTURBATIONS:-

- Theoretically, an orbit described by kepler is ideal as Earth is considered to be a perfect sphere and the force acting around the Earth is the centrifugal force. This force is supposed to balance the gravitational pull of the earth.
- Effect of sun and Moon is more pronounced on geostationary earth satellites where as the atmospheric drag effect is more pronounced for low earth orbit satellites.
- Due to the non-spherical shape of Earth, one more effect called as the "satellite Graveyard" is seen. The non-spherical shape leads to the small value of eccentricity at the equatorial plane. This cause a gravity gradient on GEO satellit and makes them drift to one of the two stable points which coincide with minor axis of the equatorial ellipse.

Atmospheric Drag

- For low Earth orbiting satellites, the effect of atmospheric drag is more pronounces. The impact of this drag is maximum at the point of perigee. Drag (pull towards the Earth) has an effect on velocity of satellite (velocity reduces)

ORBIT DETERMINATION:-

Orbit determination requires that sufficient measurements be made to determine uniquely the six orbital elements needed to calculate the future of the satellite, and hence calculate the required changes that need to be made to the orbit to keep it within the nominal orbital location. The control earth stations used to measure the angular position of the satellites also carry out range measurements using unique time stamps in the telemetry stream or communication carrier. These earth stations generally referred to as the TTC&M (telemetry tracking command and monitoring) stations of the satellite network.

LAUNCHES AND LAUNCH VEHICLES:

A satellite cannot be placed into a stable orbit unless two parameters that are uniquely coupled together the velocity vector and the orbital height are simultaneously correct.

- A geostationary satellite for example must be in an orbit at height 35,786.03km above the surface of the earth with an inclination of zero degrees an ellipticity of zero, and a velocity of 3074.7m/s tangential to the earth in the plane of the orbit.

Launch Vehicle Selection factor:-

- price/cost
- Reliability - Recent launch success/failure history
- Dependable launch schedule - urgency of the customer
- performance
- Spacecraft fit
- Safety issues
- Launch site location
- Availability - launch site; vehicle; schedule;
- Market conditions - What the market will bear

LAUNCHING ORBITS:

- Low Earth orbiting satellites are directly injected into their orbits. This cannot be done incase of GEOs as they have to be positioned 36,000kms above the Earth's Surface. Launch Vehicles are hence used to set these satellites in their orbits. These Vehicles are reusable. They are also known as, "Space Transportation system" (STS) (12)

- The transfer orbit is selected to minimize the energy required for the transfer. This orbit forms a tangent to the low altitude orbit at the point of its perigee and tangent to high altitude orbit at the point of its apogee.

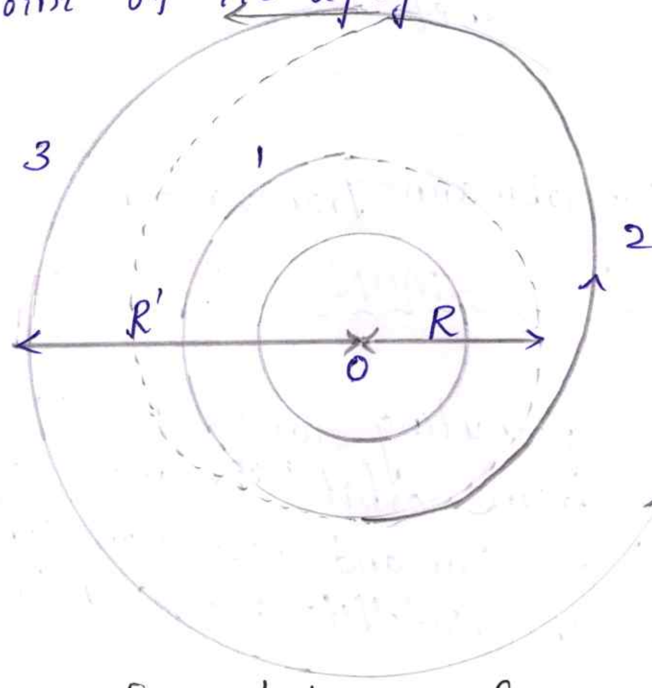


fig: orbit Transfer positions

- About Hohmann Transfer obit: This manoeuvre is named for the German civil engineer who first proposed it, Walter Hohmann
- The transfer orbit is selected to minimize the energy required for the transfer. This orbit forms a tangent to the low attitude orbit at the point of its perigee and tangent to high altitude orbit at the point of its apogee
- Generally it takes 1-2 months for the satellite to become fully functional. The Earth station performs the Telemetry Tracking and commond function to control the satellite transits and functionalities.
- It is better to launch rockets closer to the equator because the Earth rotates at a greater speed here than that at either pole.

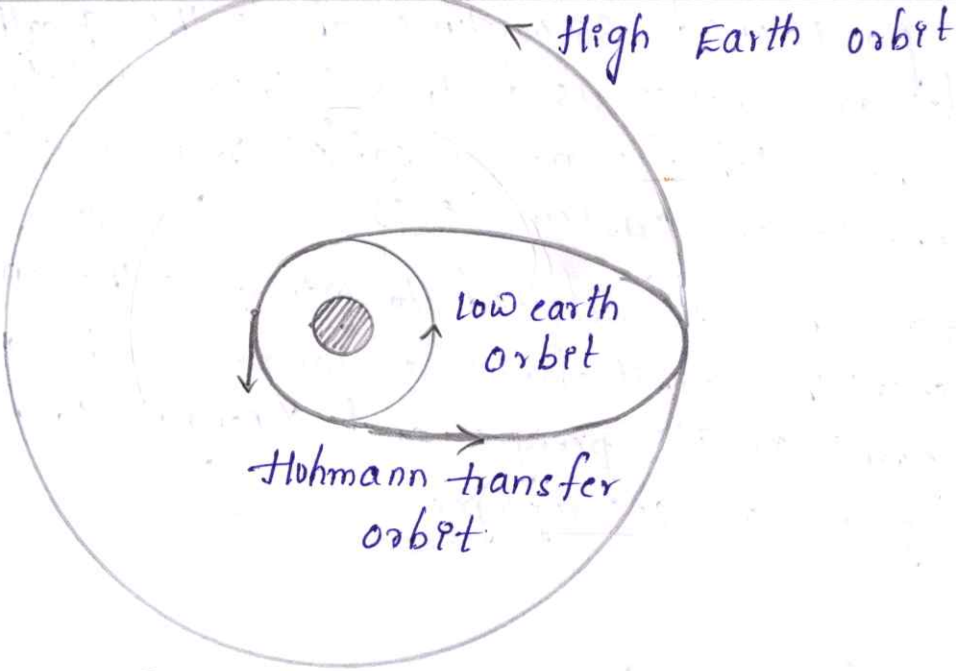


figure:- Hohmann Transfer orbit

ORBITAL EFFECTS IN COMMUNICATION SYSTEMS

PERFORMANCE :-

There are a number of perbuting forces that cause an orbit to depart from ideal keplerian orbit. The most effecting ones are gravitational fields of Sun and moon, non-spherical shape of the Earth, reaction of the satellite itself to motor movements within the satellites.

Doppler Effect

To a stationary observer, the frequency of a moving radio transmitter varies with the transmitter's velocity relative to the observer. If the true transmitter frequency (i.e, the frequency that the transmitter would send when at rest) is f_T, the received frequency f_R is higher than f_T when the transmitter is moving toward the receiver and lower than f_T when the transmitter is moving away from the receiver

Range Variations

Even with the best station keeping systems available for geostationary satellites, the position of a satellite with respect to earth exhibits a cyclic daily variation. The variation in position will lead to a variation in range between the satellite and user terminals. If the time division Multiple access (TDMA) is being used, careful attention must be paid to the timing of the frames within the TDMA bursts so that the individual user frames arrive at the satellite in the correct sequence and at the correct time.

Earth Eclipse of A satellite.

- It occurs when Earth's Equatorial plane coincides with the plane of the Earth's orbit around the Sun. Near the time of spring and autumnal equinoxes, when the sun is crossing the equator, the satellite passes into sun's shadow. This happens for some duration of time everyday.
- These eclipses begin 23 days before the equinox and end 23 days after the equinox. They lost for almost 10 minutes at the beginning and end of equinox and increase for a maximum period of 72 minutes at a full ellipse. The solar cells of the satellite become non-functional during the eclipse period and the satellite is made to operate with the help of power supplied from the batteries.

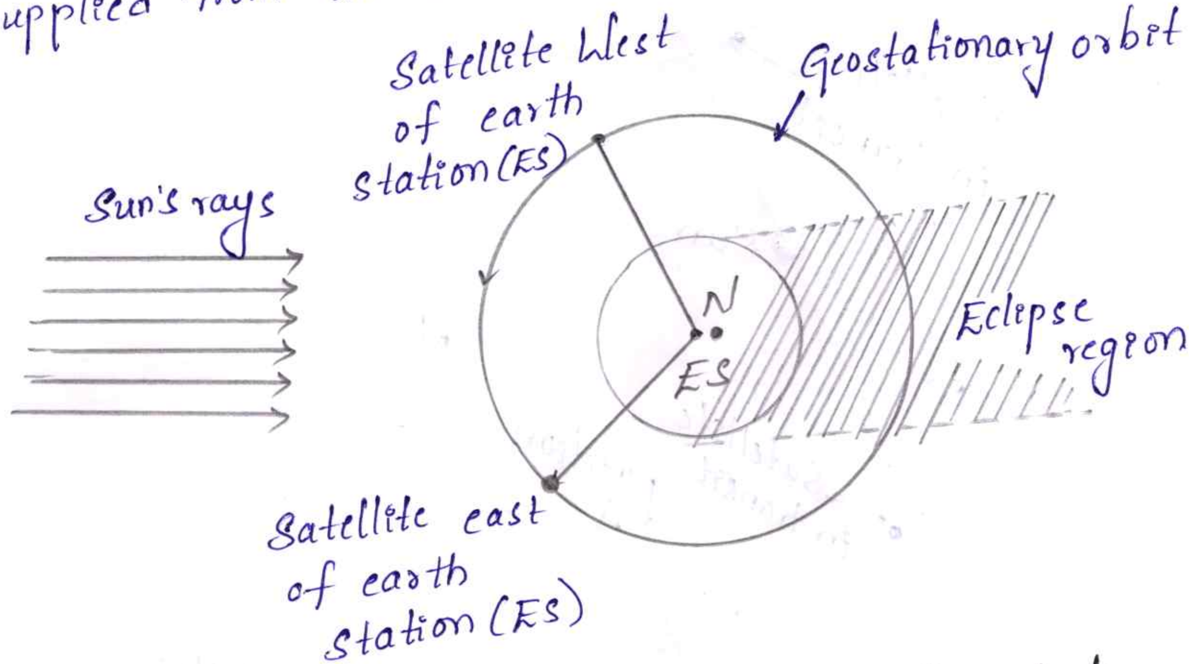


figure: A satellite east of the earth station enters eclipse during daylight (busy hours) at the earth station.
A satellite west of earth station enters eclipse during night and early morning hours (non busy time).

Sun Transit Outage:

Sun transit outage is an interruption in or distortion of geostationary satellite signals caused by interference from solar radiation. Sun appears to be an extremely noisy source which completely blanks out the signal from satellite. This effect lasts for 6 days around the equinoxes. They occur for a maximum period of 10 minutes.

Generally, Sun outages occur in February, March, september and October, that is, around the time of the equinoxes. At these times, the apparent path of the Sun across the sky takes it directly behind the line of sight between an earth station and a satellite. As the sun radiates strongly at the microwave frequencies used to communicate with satellites (C-band, ka band and ku band) and sun swamps the signal from the satellite.

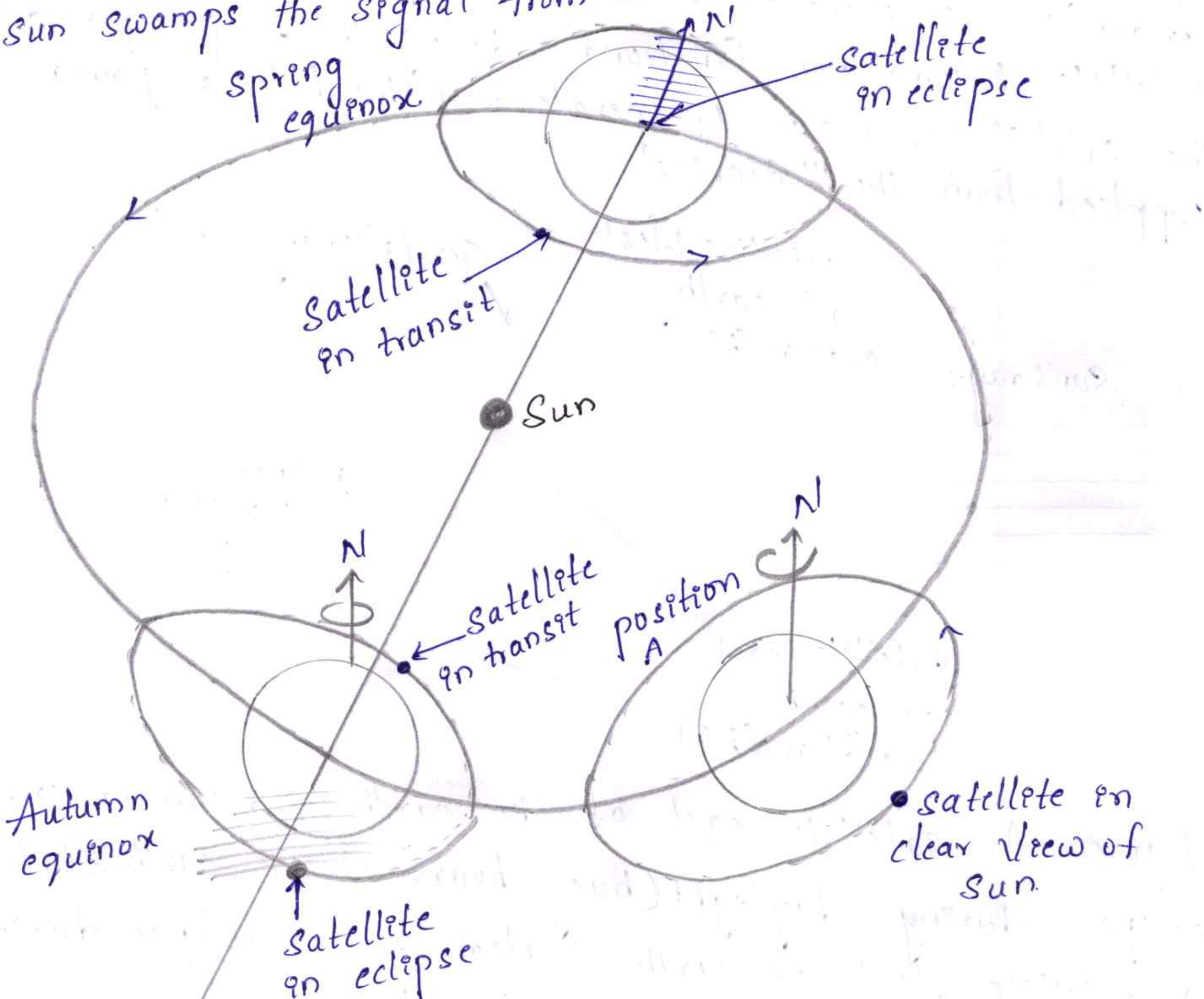


figure: Earth Eclipse of a satellite and sun transit outage

UNIT-2 : SATELLITE SUBSYSTEMS

Space segment :- The space segment of the satellite system consits of the orbiting satellite and the ground satellite control facilities necessary to keep the satellites operational.

Ground segment :- The ground segment, or earth segment, of the satellite system consists of the transmit and receive earth stations and the associated equipment to interface with the user network.

Bus :- The bus refers to the basic satellite structure itself and the subsystems that support satellite. The bus subsystems are : the physical structure, power subsystem, attitude and orbital control subsystem, thermal control subsystem and command and telementary subsystem.

payload :- The payload on a satellite is the equipment that provides the services or services intended of the satellite. A communication satellite payload consists of the communication equipment that provides the relay link between the up- and downlinks from the ground. The early Tracking and Data Relay satellites, for example, had an 'Advanced westar' communications payload in addition to the tracking and data protocol, which was the major mission of the satellite.

Attitude and orbit control system

satellite Bus : The basic characteristics of each of the bus subsystems are described in the following subsections

physical structure : The physical structure of the satellite provides a 'home' for all the components of the satellite.

The basic shape of the satellite depends of the method of stabilization employed to keep the satellite stable and pointing in the desired directions. Two methods are commonly employed: spin stabilization and three axis or body stabilization. Both methods are used for GSO and NGSO satellites.

Spin stabilization :- A spin stabilized satellite is usually cylindrical in shape, because the satellite is required to be mechanically balanced about an axis, so that it can be maintained in orbit by spinning on its axis. For GSO satellites, the spin axis is maintained parallel to the spin axis of the earth, with spin rates in the range of 30 to 100 revolutions per minute.

The spinning satellite will maintain its correct attitude without additional effort, unless disturbance torques are introduced. Extremely forces such as solar radiation, gravitational gradients, and meteorite impacts can generate undesired torques. The entire space craft rotates for spin- stabilized satellites that employ omnidirectional antennas. when directional antennas are used, which is the prevalent case, the antenna subsystem must be despun, so that the antenna is kept properly pointed towards Earth. The antenna is driven by an electric motor in the despun plat-form is driven by an electric motor in the opposite direction of the satellite spin, on the same spin axis and at the same spin rate as the satellite body, to Maintain a fixed orientation for the antennas, relative to earth.

Three-axis stabilization :- A three stabilization satellite is Maintained in space with stabilizing elements for each of three axes, referred to as roll, pitch, and yaw, in conformance with the definitions first used in the aircraft industry. The entire body of the spacecraft remains fixed in space, relative to the earth, which is why the three-axis stabilized satellite is also referred to as a body-satellite.

Fuel is expended for both the control jets and for the reaction wheels, which must periodically be 'unloaded' of momentum energy that builds up in the wheel. The three-axis stabilized satellite does not need to be symmetric or cylindrical, and most tend be box-like, with numerous appendages attached. Typical appendages include antenna systems and solar cell panels, which are often unfurled after placement at the on-orbit location

Attitude control :- The attitude of a satellite refers to its orientation in space with respect to earth. Attitude control is necessary so that the antennas, which usually have narrow directional beams, are pointed correctly towards earth. Several forces can interact to affect the attitude of the space craft, including gravitational forces from the sun, moon, and planets : solar pressures acting on the spacecraft body, antennas or solar panels; and earth's magnetic field.

Orientation is monitored on the spacecraft body, antennas by infrared horizon detectors, which detect the rim of earth against the background of space. Four detectors are used to establish a reference point, usually the center of the earth, and any shift in orientation is detected by one or more of the sensors. A control signal is generated that actives attitude control device to restore proper orientation. Gas jets, ion thrusters, or momentum wheels are used to provide active attitude control on communication satellite

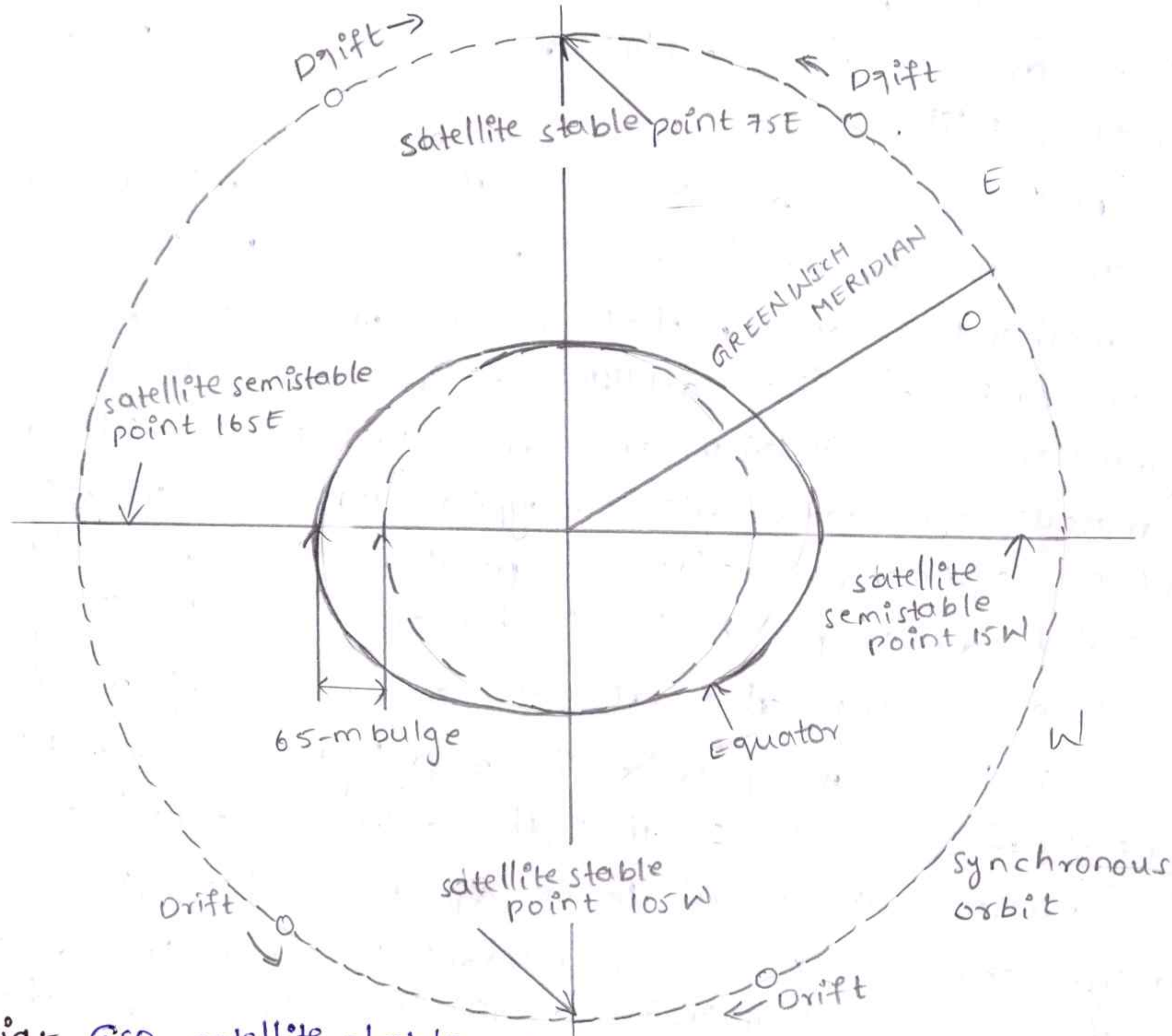


Fig:- GSO satellite stable points

Orbital control :- Orbital control, often called station keeping, is the process required to maintain a satellite in its proper orbit location. It is similar to, although not functionality the same as, attitude control, discussed in the previous section. GSO satellites will undergo forces that would cause the satellite to drift in the east-west and north-south directions, as well as in attitude, if not compensated for with active orbital control jets.

Keeping maneuvers must also be accomplished periodically to maintain the normal satellite orbit location

North south station-keeping tolerance requirements are similar to those for east-west station keeping, 0.1° for c-band, and +} 0.05° for ku-band. satellite altitude will vary about *} 0.1% which is about 72 km for a nominal 36000-km geostationary altitude. Ac-band satellite, therefore must be maintained in a 'box' with longitudinal and latitudinal sides of about 150 km and an altitude side of 72 km. summarizes the maintained in for the c-band and ku-band cases. It is not unusual for a communications satellite to 'run out of fuel' with most of its electronic communications subsystem still functioning.

thermal control :- orbiting satellites will experience large temperature variations, which must be controlled in the harsh environment of outer space. Low orbiting satellites can also be affected by thermal radiation reflected from the earth itself. the satellite thermal control.system is designed to control the large thermal gradients generated in the satellite by removing or relocating the heat to provide as an stable as possible temperature environment for the satellite. several techniques are employed to provide thermal control in a satellite. thermal blankets and thermal shields are placed a critical location to provide insulation. Radiation mirrors are placed around electronic subsystems. particularly for spin-stabilized satellites to protocol critical equipment. Heat pumps are used to alocate heat from devices such as traveling wave power amplifiers to outer walls or heat sinks to provide a more effective thermal path for heat to escape.

The satellite antenna structure is one of the critical components that can be affected by thermal radiation from the sun. Large aperture antennas can be twisted or controlled as the sun moves around the satellite, heating & cooling various portions of the structure. This 'potato chip' effect is most critical for apertures exceeding about 15 m designed to operate at high frequencies, i.e., Ku-band, Ka-band, and above, because the small wavelengths react more severely resulting in antenna beam point distortions and possible gain degradation.

Telementary, Tracking, command and monitoring :-

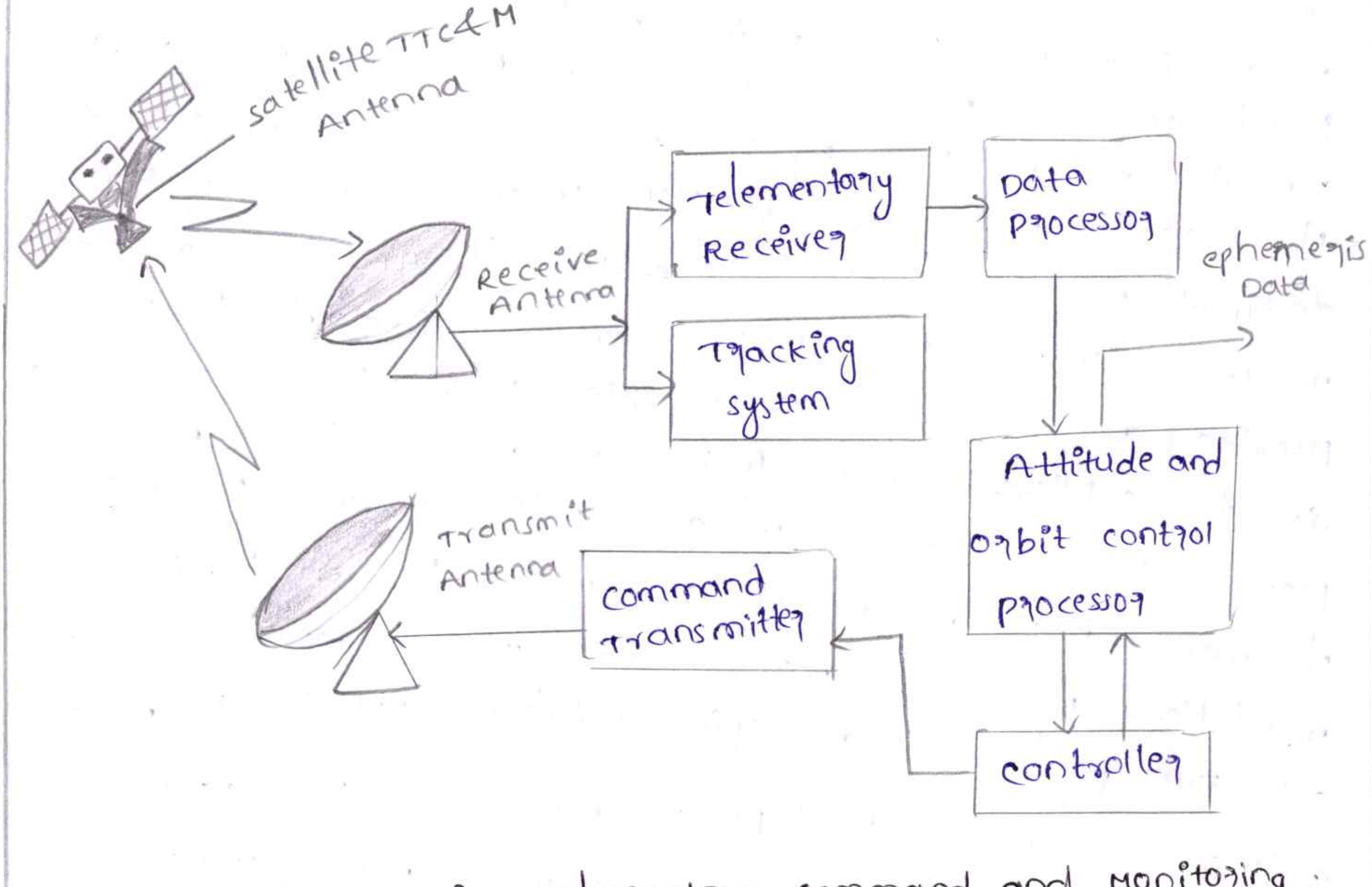


Fig : Tracking, telementary, command and Monitoring.

* Ranging Tones - used for range measurement
* Monitoring system collects data from sensors
* Telemetry monitored data digitized and encoded usually PSK for transmission.
* Command structure heavily encrypted many built in checks.

Tracking :- Tracking refers to the determination of the current orbit, position and movement, of the space craft. The tracking function is accomplished by a number of techniques, usually involving satellite beacon signals, which are received at the satellite TTC&M earth station. The Doppler shift of the beacon is monitored to determine the rate at which the range is changing. The telemetry function involves the collection. Acceleration and velocity sensors on the satellite can be used to monitor orbital location and changes in orbital location.

Telemetry :- The telemetry function involves the collection of data from sensors on-board the spacecraft and the relay of this information to the ground. The telemetered data include such parameters as voltage and current conditions in the power subsystems, temperature of critical subsystems, status of switches and relays in the communications and antenna subsystems, fuel tank pressures, and attitude control sensor status. The telemetry carrier modulation is typically frequency or phase shift keying, with the telemetry channels transmitted in a time division multiplex format. Telemetry channel data rates are low, usually only a few kbps.

Command :- Command is the complementary function to telemetry. The command system relays specific control and operations information from the ground to the space craft, often in response to telemetry information received from the spacecraft. Parameters involved in typical command links include changes and corrections in attitude control and orbit control.

* antenna pointing and controls

* transponder mode of operation;
* battery voltage control.

The command system is used during launch to control the firing of the boost motor; deploy appendages such as solar panels and antenna reflectors, and 'spin-up' a spin-stabilized spacecraft body. security is an important factor in the command system for a communications satellite. the backup system usually operates with an omnidirectional antenna, at UHF or s-band, with sufficient margin to allow operation in the most adverse conditions. the backup system could also be used if the main TTC&M system fails on orbit.

power systems :- the electrical power for operating equipment on a communication satellite is obtained primarily from solar cells, which convert incident sunlight into electrical energy. the radiation on a satellite from the sun has an intensity averaging about 1.4KW/m2. solar cells operate at an efficiency of 20-25% at beginning of life (BOL), and can degrade to 5-10% at end of life (EOL) usually considered to be 15 years. Because of this, large number of cells, connected in serial-parallel arrays, are required to support the communications satellite electronic systems, which often require more than one to two kilowatts of prime power to function. the spin-stabilized satellite usually has cylindrical panels, which may be extended after deployment to provide additional exposure area. A cylindrical spin-stabilized satellite.

the three axis satellite configuration allows for better utilization of solar cell area, because the cells can be arranged in flat panels, or sails, which can be rotated to maintain normal exposure to the sun- levels up to 10 KW are attainable with rotating panels. they have good reliability and long life, and do not outgas when in a charging cycle. Nickel- hydrogen (NiH_2) batteries, which provide a significant improvement in power-to-weight ratio, are also used. A power conditioning unit is also included in the power subsystems, for the control of battery charging and for power regulation and monitoring.

the power generating and control systems on a communications satellite account for a large part of its weight, often 10 to 20% of total dry weight

communication subsystem :-

Satellite payload:- The next two sections discuss the key elements of the payload portion of the space segment, specially for communications satellite systems: the transponder and antenna subsystems.

Transponder :- the transponder in a communication satellite is the series of components that provides the communications channel, or link, between the uplink signal received at the uplink antenna, and the downlink satellite transmitted by the downlink Antenna. A typical communications satellite will contain several transponders, and some of the equipment may be common to more than one transponder.

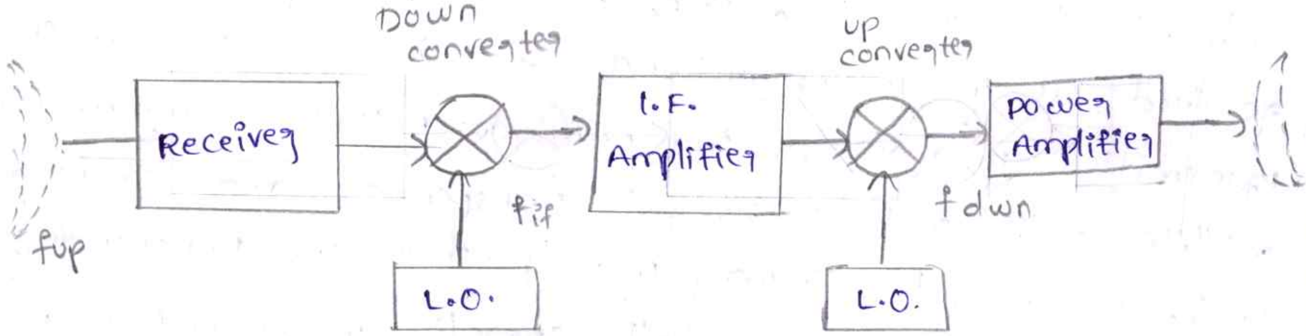
Each transponder generally operates in a different frequency band, with the allocated frequency spectrum band divided into slots, with a specified center frequency and operating bandwidth. the c-band FSS service allocations, the communications satellite transponder is implemented in one of two general types of configurations: the frequency translation transponder and the on-board processing transponder.

Frequency translation transponder :-

the first type, which has been the domain configuration since the inception of satellite communications, is the frequency translation transponder. the frequency translation transponder, also referred to as a non-regenerative repeater, or bent pipe, receives the uplink signal and, after amplification, retransmits it with only a translation in carrier frequency. Figure, shows that the typical implementation of a dual conversion frequency translation transponder, where the uplink radio frequency, fup is converted to an intermediate lower frequency, fif, amplified, and then converted back up to the downlink RF frequency, fdown, for transmission to earth.

the uplinks and downlinks are codependent, meaning that any degradation introduced on the uplink will be transferred to the downlink, affecting the total communication link. this has significant impact on the performance of the end-to-end link.

Fig:- Frequency translation transponder



* Frequency translation transponder, also called
  (1) Repeater
  (2) Non-Regenerative satellite
  (3) 'Bent pipe'
* the dominant type of transponder currently in use.
  (1) FSS, BSS, MSS

* uplinks and downlinks are codependent

On-board processing Transponder :-

Figure shows that the second type of satellite transponder, the on-board processing transponder, also called a regenerative repeater demod/remod transponder, or smart satellite. the uplink signal at fup is demodulated to baseband, fbaseband. the baseband signal is available for processing on-board, including reformatting and error-correction. the baseband information is then remodulated to the downlink carrier at fdwn, possibly in a different modulation format to the uplink and, after amplification, transmitted to the ground. online the frequency translation transponder where uplink degradation are codependent, are discussed earlier.

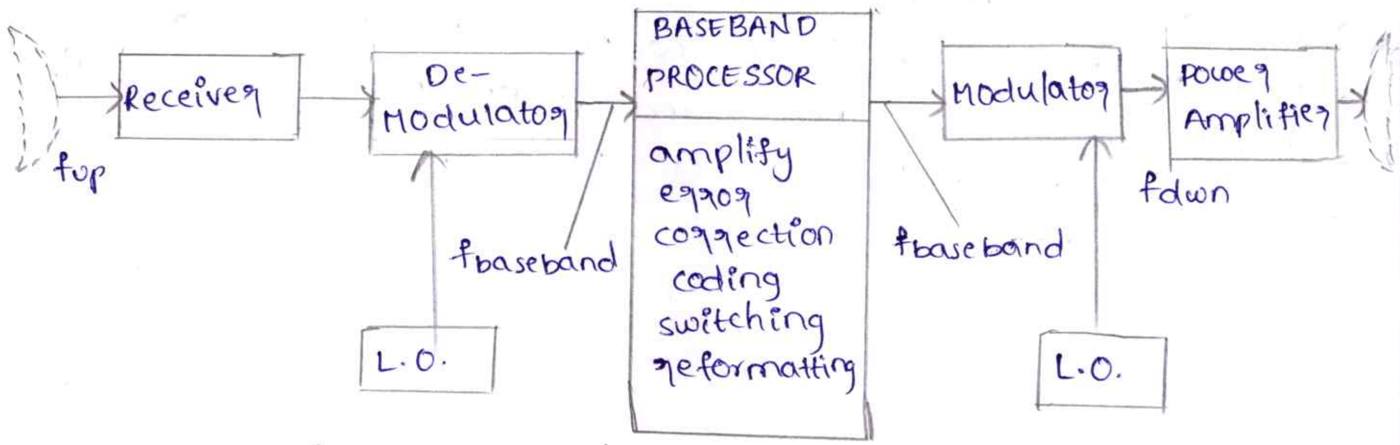


Fig :- on-board processing transponder

* on-Board processing Transponder, also called
  (1) Regenerative Repeater
  (2) Demod/Remod Transponder
  (3) 'smart satellite'
* First generation systems,
  (1) ACTS, MILSTAR, IRIDIUM....
* uplinks and downlinks are independent

onboard processing satellites tend to be more complex and expensive than frequency translation satellites; however, they offer significant performance advantages, particularly for small terminal users or for large diverse networks. the performance of the on-board processing satellite's composite link is discussed. Traveling wave tube amplifiers (TWTAs) or solid state amplifiers (SSPAs) are used to provide the final output power required for each transponder channel. The TWTA is a slow wave structure device, which operates in a vaccum envelope, and requires permanent magnent focusing and high voltage DC power supply support systems. the major advantage of the TWTA is its wide bandwidth capability at microwave frequencies.

other frequencies may be included in the basic transponder configuration of figures, including band pass filters, switches, input multiplexers, switch matrices, and output multiplexers. Each device must be considered when evaluating the signal losses and system performance of the space segment of the satellite network.

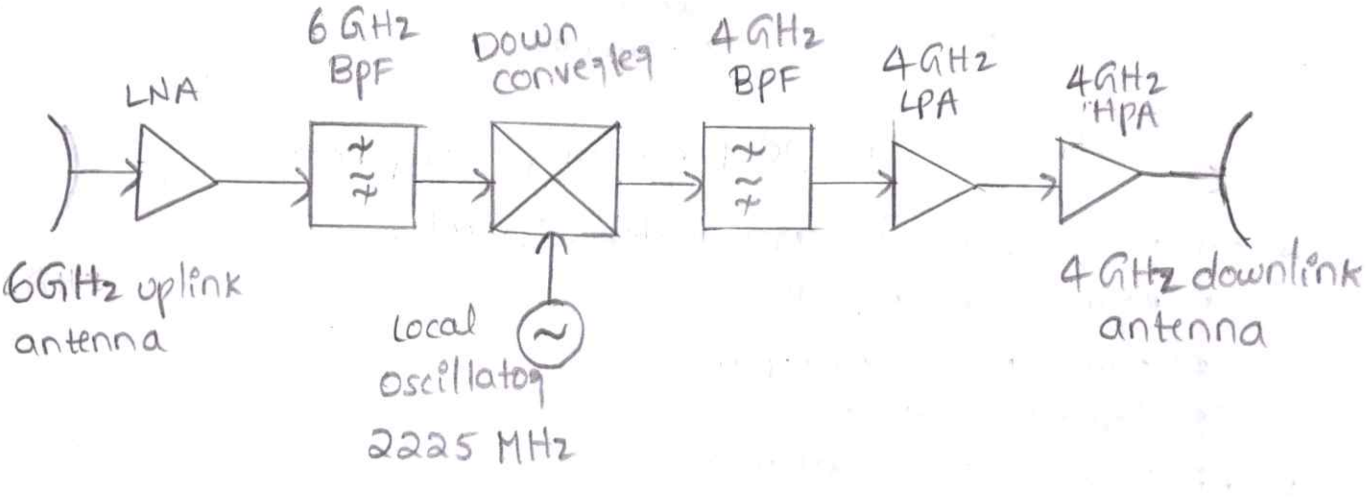


Fig:- simplified single conversion transponder (bent pipe) for 6/4 GHz band

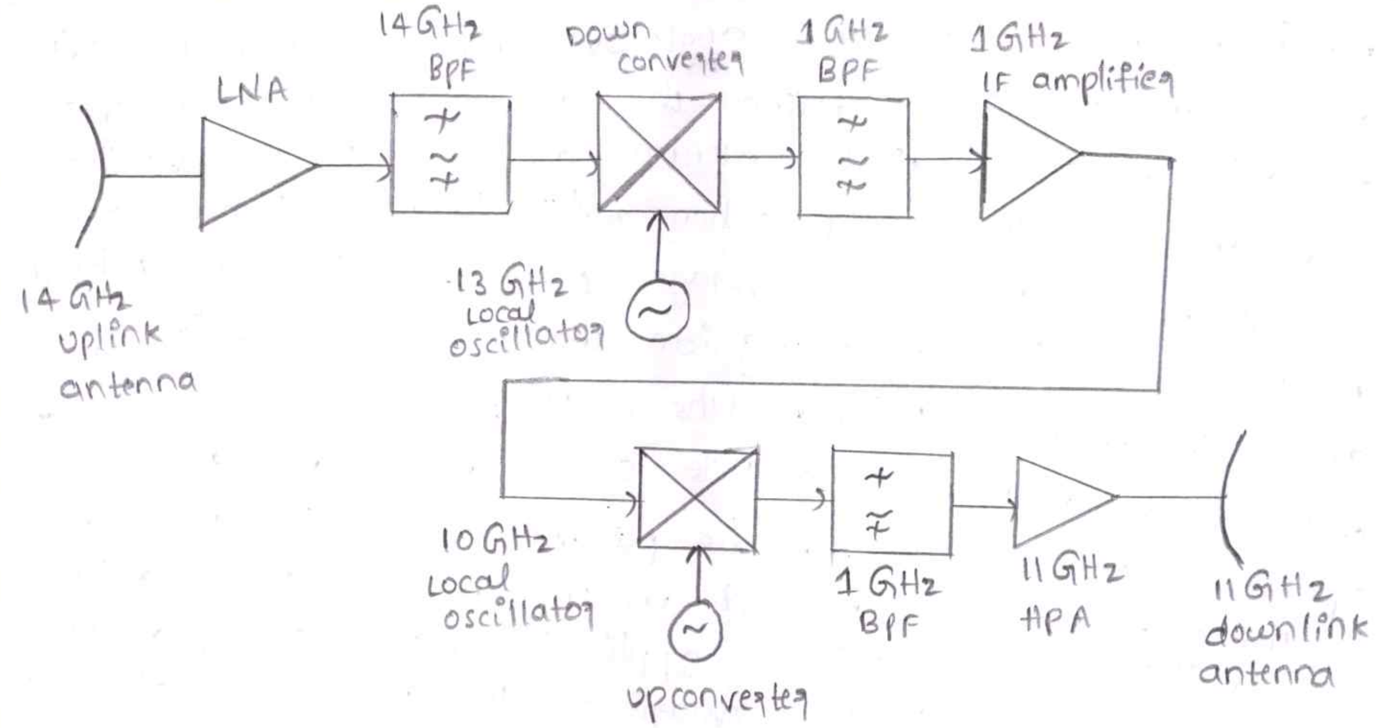


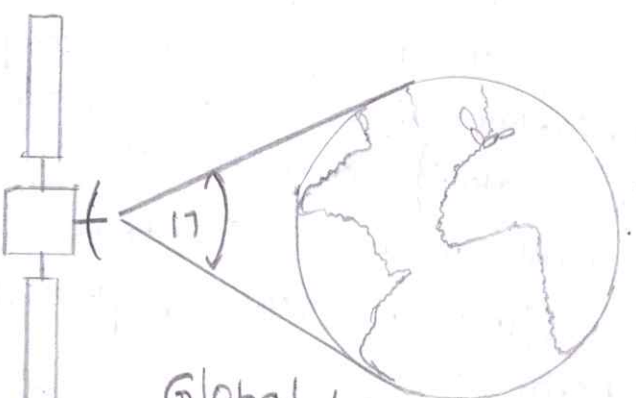
fig:-Simplified double conversion transponder (bent pipe) for 14/11 GHz band

Satellite antenna :-

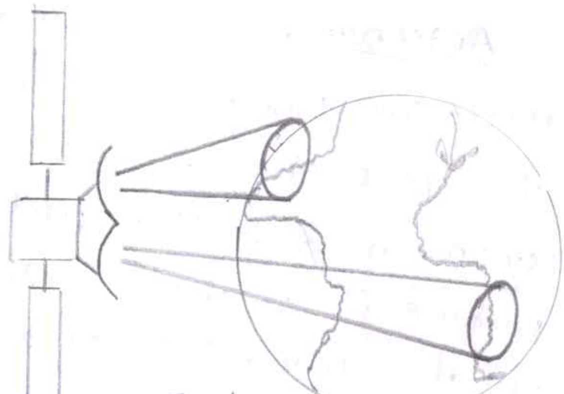
Antennas :- the antenna system on the spacecraft are used for transmitting and receiving the RF signals that comprise the space links of the communication channels. The antenna system is a critical part of the satellite communication system, because it is the essential element in increasing the strength of the transmitted or received signal to allow amplification, processing, and eventual retransmission.

the most important parameters that define the performance of an antenna are antenna gain, antenna beamwidth, and antenna side lobes. the gain defines the increase in strength achieved in concentrating the radio wave energy, either in transmission or reception, by the antenna system. the antenna gain is usually expressed in dBi, decibels above an istropic antenna, which is an antenna that radiates uniformly in all directions. the beamwidth is usually expressed as the half-power beamwidth or the 3-dB beamwidth, which is measure of the angle over which maximum gain occurs. the side lobes define the amount of gain in the off-axis directions. Horn antennas are used at frequencies from about 4 GHz and up, when relatively wide beams are required, such as global coverage from a GSO satellite. A horn is a flared section of waveguide that provides gain of up of about 20dBi, with beam widths of 10° or higher. the most often used antenna for satllite systems, particularly for those operating above 10 GHz, is the parabolic reflector antenna.

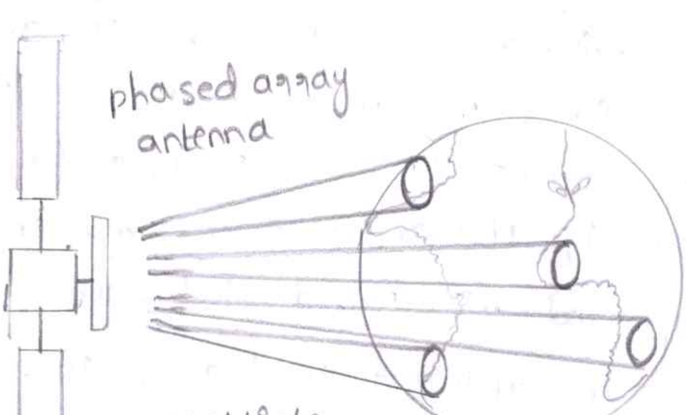
there is increasing interest in the use of array antennas for satellite communications applications. the array antenna gain increases with the square of the number of elements. Gains and beamwidths comparable to those available from parabolic reflector antennas can be achieved with array elements.



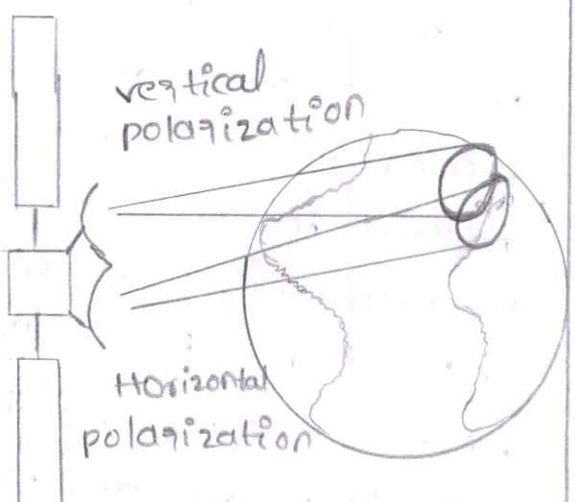
Global beam



spot beams



Multiple spot beams
and scanning beams



Orthogonally
Polarized beams.

Equipment Reliability and space Qualification :-

communication satellites built already have provided operational lifetimes of up to 15 years, once a satellite is in geo stationary orbit, there is little possibility of repairing components that fail or adding more fuel for station keeping. the components that make up the satellite must therefore have very high reliability in the hostile environment of outer space.

space Qualification :- outer space, at geostationary orbit distances is a harsh environment. there is a total vacuum and the sun irradiates the satellite with 1.4KW of heat and light on each square meter of exposed surface. Electronic equipment cannot operate at such extremes of temperature and must be housed with in the satellite and heated or cooled so that its temperature stays within the range 0° to 75°C, this requires a thermal control system that manages heat flow throughout a GEO satellite as the sun moves around once every 24 hr.

Many of the electronic and mechanical components that are used in satellite are known to have limited life times, or a finite probability of failure. If failure of one of these components will jeopardize the mission or reduce the communication capacity of the satellite, a backup, or redunbant, until will provided. the design of the system must be such that when one unit fails, the backup can authomatically take over or be switched into operation by a command from the ground.

Reliability :- Reliability is counted by considering the proper working of satellites critical components. Reliability could be improved by making the critical components redunbant. components with a limited lifetime such as travelling wave tube amplifier etc should be made redundant.

Travelling wave Tube Amplifier (TWTA):- travelling wave tube amplifiers have applications in both receiver and transmitter systems, and come in all shapes and sizes, but they all consist of three basic parts - the tube, the tube mount and the power supply.

Transmitter TWTAs are naturally somewhat bulkier, and often have the power or supplies as a separate unit. Medium-power tubes have outputs of up to about 10W, while high-power tubes deliver several hundred watts. such tubes have grains of the order of 30 or 40 dB, and bandwidth of up to an octave.

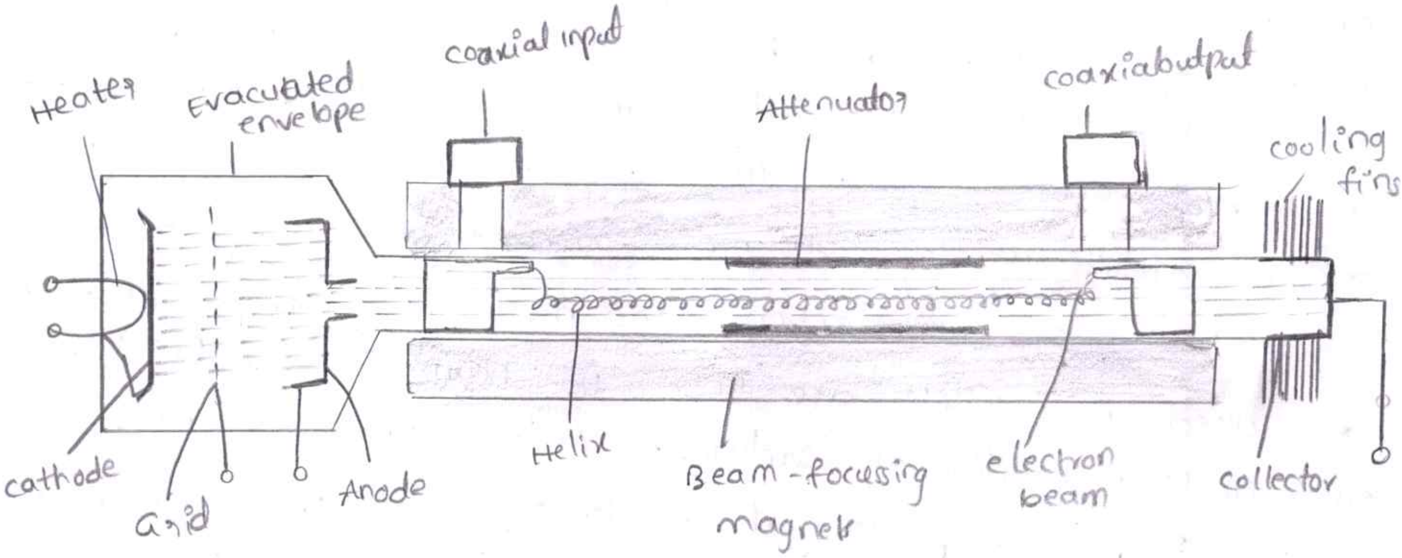


Fig: TWTA

other critical components are antenna reflectors, beaming assemblers etc.

A reliability model is used to calculate the satellite's reliability. It is defined as "the probability that a given component or system performs its functions as desired within a specific time".

the failure rate for all components is calculated and they are categorized into the following three categories:-

* Early high failure rate region: used for manufacturing faults, defects in material etc.
* Low failure: used for random component failure.

* High failure rate : used for components weave-out.

certainly early failures criteria is eliminated as most of the components are tested before used in the satellite. Random failures criteria is eliminated as most of the components are tested before used in the satellite. Random failures are more seen. they could be reduced by using reliable engineering techniques. the life-spam of components could be increased by improving manufacturing techniques and the type of material used to reduce the number of worn out parts and hence reducing the high failure rate criteria.

It is sent that the failure rate is constant over time and is looking at this reliability can be determined. the system is made of several components, connected in a series, then the overall reliability is determined. By duplicating the less reliable and critical components, the overall reliability of the system could be improved. if any failure occurs in operational unit, then the standby unit takes over to develop a system with rebundant components, its redundant elements are considered in parallel. parallel redundancy is useful when the reliability of an individual sub-system is high.

UNIT-3

Satellite Link Design & Multiple Access

Basic Transmission theory:

The RF segment of the satellite communication link is a critical that impacts the design and performance of communications over the satellite.

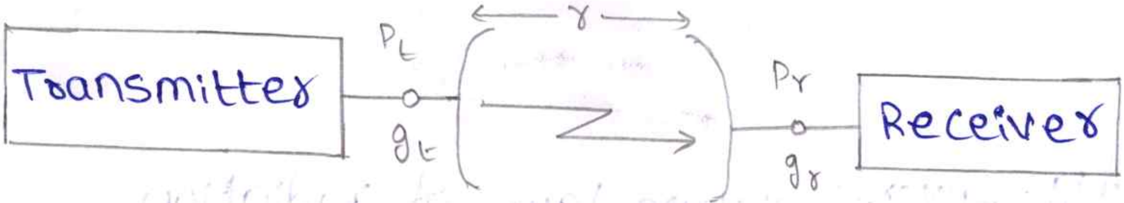


fig: Basic communication link

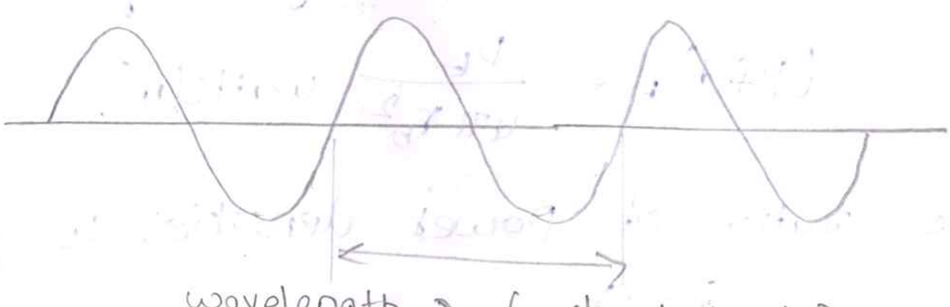
$P_t \rightarrow$ Transmitted power

$P_r \rightarrow$ Received power

$g_t \rightarrow$ Transmit antenna gain

$g_r \rightarrow$ Receive antenna gain

→ The wavelength λ, of the radiowave is the



wavelength, λ, (units of length)

The frequency and wavelength in free space are related by $\lambda = \frac{c}{f}$

$c \rightarrow$ Phase velocity of light in vacuum

$c = 3 \times 10^8$ m/s.

$$\lambda = \frac{30}{f(GHz)} \text{ cm} = \frac{0.3}{f(GHz)} \text{ m}$$

→ consider a radiowave in free space from a point source P of power Pt watts.

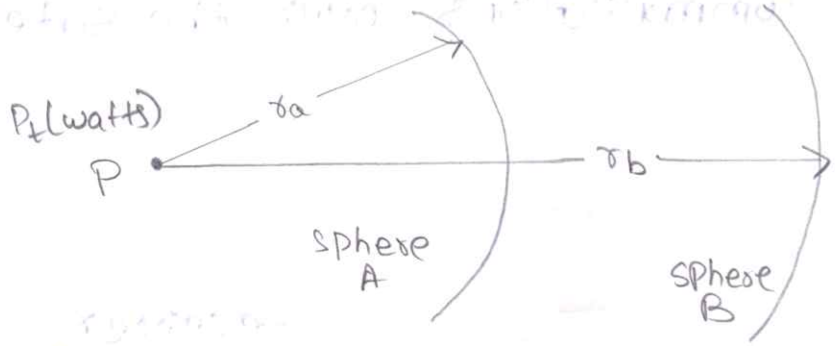


fig: Inverse square law of radiation

→ The power flux density (or power density), over the surface of a sphere of radius r_a from the point P, is given by

$$(Pfd)_A = \frac{P_t}{4\pi r_a^2} \text{ watts/m}^2$$

→ Similarly, at the surface B, the density over a sphere of radius r_b is given by

$$(Pfd)_B = \frac{P_t}{4\pi r_b^2} \text{ watts/m}^2$$

→ The ratio of power densities is given by

$$\frac{(Pfd)_A}{(Pfd)_B} = \frac{r_b^2}{r_a^2}$$

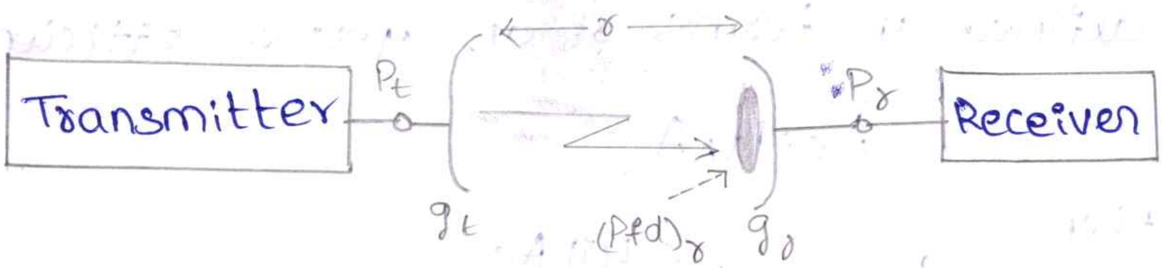
⇒ Effective Isotrophic radiated Power

$$eirp = P_t g_t$$

in dB ⇒ $EIRP = P_t + G_t$

⇒ Power Flux Density

The power density, usually expressed in watt/m², at the distance r from the transmit antenna with a gain g_t, is defined as the power flux density $(pfd)_r$



The $(pfd)_r$ is therefore

$$(pfd)_r = \frac{P_t g_t}{4\pi r^2} \ w/m^2$$

or, in terms of the eirp,

$$(pfd)_r = \frac{eirp}{4\pi r^2} \ w/m^2$$

The power flux density in dB, will be

$$(PFD)_r = 10 \log\left(\frac{P_t g_t}{4\pi r^2}\right)$$

$$= 10\log(P_t) + 10\log(g_t) - 20\log(r) - 10\log(4\pi)$$

with r in meters,

$$(PFD)_r = P_t + G_t - 20\log(r) - 10.99$$

$$(PFD)_r = EIRP - 20\log(r) - 10.99$$

⇒ Antenna gain

Consider first a lossless (ideal) antenna with a physical aperture area of $A(m^2)$. The gain of the ideal antenna with a physical aperture area A is defined as

$$gain = \frac{4\pi A}{\lambda^2}$$

where λ is the wavelength of the radiowave

→ To account for this, an effective aperture A_e, is defined in terms of an aperture efficiency, η_A

$$A_e = \eta_A A$$

then

$$g_{real} = g = \frac{4\pi A_e}{\lambda^2}$$

$$g = \eta_A \frac{4\pi A}{\lambda^2}$$

⇒ g in terms of dB;

$$G = 10 \log\left[\eta_A \frac{4\pi A}{\lambda^2}\right] dB;$$

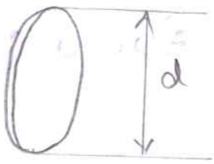
also the effective aperture can be expressed as

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

⇒ Circular Parabolic Reflector Antenna

The circular parabolic reflector is the most common type of antenna used for satellite earth station and spacecraft antennas.

The Physical area of the apertuse of a circular Parabolic aperture is given by. (3)



$$A = \frac{\pi d^2}{4}$$

from the antenna gain equation

$$g = \eta_A \frac{4\pi A}{\lambda^2} = \eta_A \frac{4\pi}{\lambda^2}\left(\frac{\pi d^2}{4}\right)$$

$$g = \eta_A \left(\frac{\pi d}{\lambda}\right)^2$$

Expressed in dB form

$$G = 10 \log\left[\eta_A \left(\frac{\pi d}{\lambda}\right)^2\right] dBi$$

for the antenna diameter d given in meters, and the f in GHz

$$g = \eta_A (10.472 fd)^2 = 109.66 f^2 d^2 \eta_A$$

or, in dB; $G = 10 \log(109.66 f^2 d^2 \eta_A)$

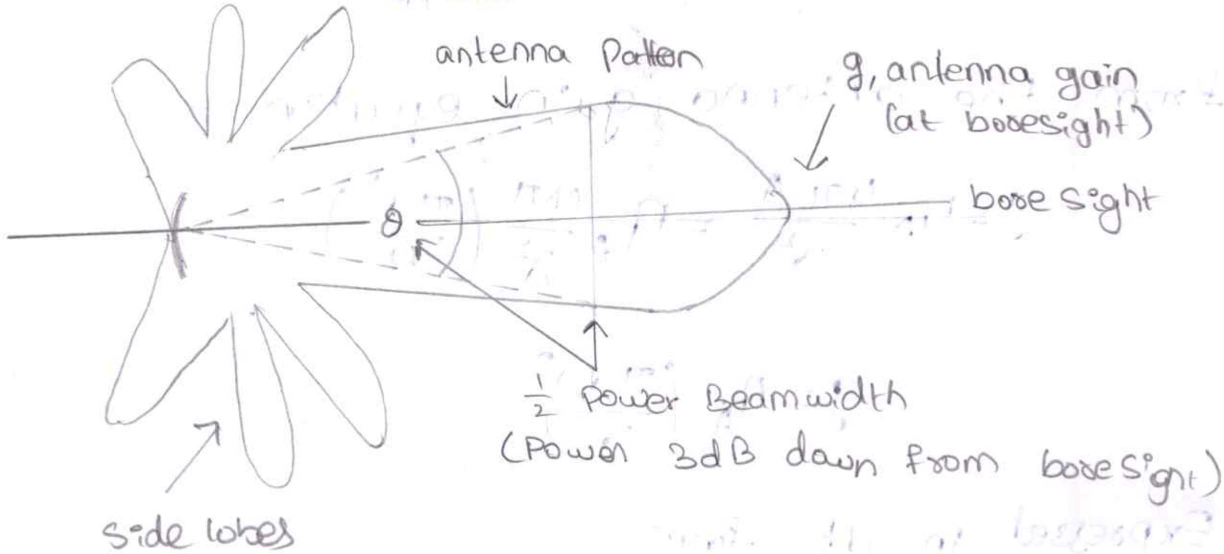
⇒ Beam width:

The boresight direction refers to the direction refers to the direction of maximum gain.

→ The 1/2 Power beamwidth is the contained conical angle θ for which the gain has dropped to 1/2 the value at bore sight.

→ Most antennas have sidelobes, or regions where the gain may increase due to physical structure elements or the characteristics of the antenna design.

→ The antenna beamwidth for a parabolic reflector antenna can be



$$\theta \cong 75 \frac{\lambda}{d} = \frac{22.5}{df}$$

⇒ Free space Path loss

$$P_r = (Pfd)_r A_e = \frac{P_t g_t}{4\pi r^2} A_e \text{ watts}$$

where $A_e = \dfrac{g_r \lambda^2}{4\pi}$

then $P_r = \dfrac{P_t g_t}{4\pi d^2} * \dfrac{g_r \lambda^2}{4\pi}$

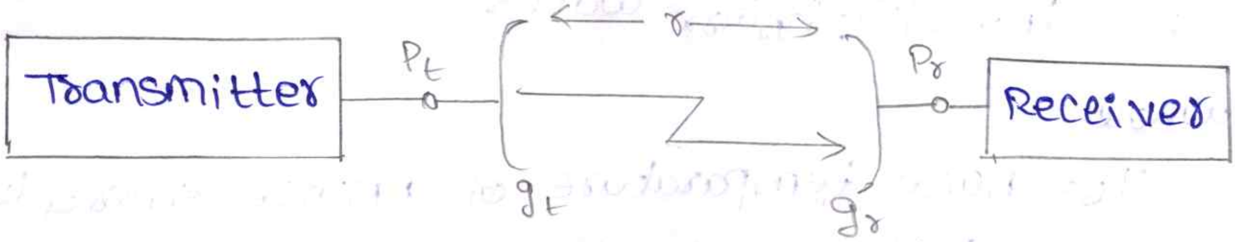
by re-arranging of terms

$$P_r = \left[\frac{P_t g_t}{4\pi r^2}\right] g_r \left(\frac{\lambda^2}{4\pi}\right)$$

↑ Power flux Density (Pfd) in w/m²

↑ spreading loss in m²

⇒ Basic Link equation for Received Power



The receiver Power at the receive antenna terminal P_r, is given by

$$P_r = P_t g_t \left(\frac{1}{L_{FS}}\right) g_r$$

$$= eirp \left(\frac{1}{L_{FS}}\right) g_r$$

or, expressed in dB

$$P_r(dB) = EIRP + G_r - L_{FS}$$

→ This is basic Link equation, sometimes reffered to as the Link power Budget equation.

System noise temparature and G/T ratio:

⇒ Noise tempartute :

At microwave frequencies, a black body with a physical temparature, T_p degrees kelvin, generates electrical noise over a wide bandwidth. The noise Power is given by

$$P_n = K T_p B_n$$

where

K = Boltzman's constant $= 1.39 \times 10^{-23}$ J/k $= -228.6$ dBW/k/Hz

T_p = Physical temparature of source in kelvin degrees

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

The noise power at the demodulator input is

$$P_{no} = kT_s B_n G_{rx} \text{ watts}$$

where

T_s = noise temparature of a noise source, located at the input of a noiseless receiver.

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

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

$$P_{no} = kT_s B_n \text{ watts}$$

⇒ <u>Calculation of system noise temparature:</u>

A superhet is a type of communication receiver that uses an RF amplifier and a single frequency conversion from the RF input to the IF output, and this form is used for almost all radio receivers with few expectations.

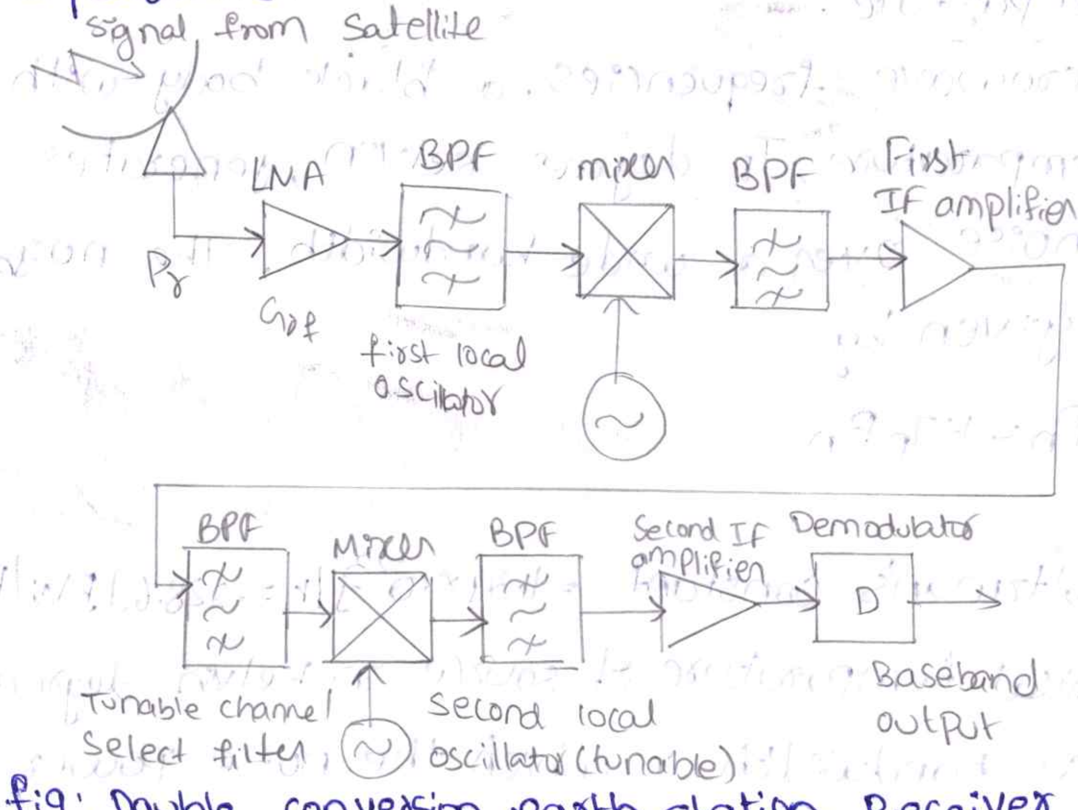


fig: Double conversion earth station Receiver.

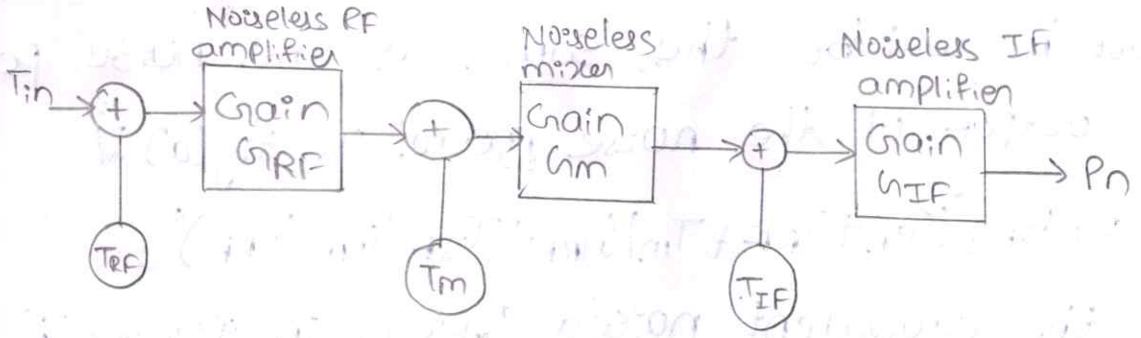
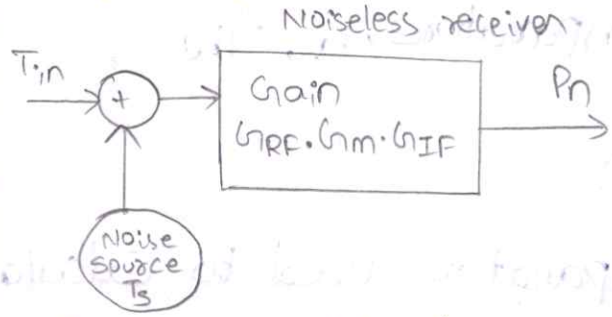


fig: Equivalent noise sources

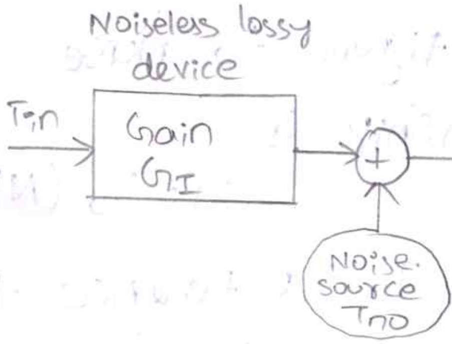
$$P_n = G_{IF} k T_{IF} B_n + G_{IF} G_m k T_m B_n + G_{IF} G_m G_{RF} k B_n (T_{RF} + T_{in})$$

where

G_{RF}, G_m and G_{IF} are the gains of the RF amplifier, mixer and IF amplifier, and T_{RF}, T_m and T_{IF} are their equivalent noise temparatures. T_{in} is the noise temparature of the antenna, measured at its output poot.



b) Noise model of receiver



c) Noise model for a lossy device.

Above equation can be written as

$$P_n = G_{IF} G_m G_{RF} [(k T_{IF} B_n)/(G_{RF} G_m) + (k T_m B_n)/G_{RF} + (T_{RF} + T_{in})].$$

$$G_{IF} G_m G_{RF} k B_n [T_{RF} + T_{in} + T_m / G_{RF} + T_{IF} / (G_{RF} G_m)]$$

→ The single source of noise shown in figure (b) with noise temparature T_s generate the same noise power P_n at its output if

$$P_n = G_{IF} G_m G_{RF} k T_s B_n$$

The noise power at the output of the noise model in figure b will be the same as the noise power at the output of the noise model in fig(a) is

$$kT_s B_n = kB_n [(T_{in} + T_{RF} + T_m / G_{RF} + T_{IF} / G_m G_{RF})]$$

→ Hence the equivalent noised source in figure (b) has a system noise temparature T_s

$$T_s = [T_{in} + T_{RF} + T_m / G_{RF} + T_{IF} / (G_m G_{RF})]$$

With high RF gain

$$T_s = T_{antenna} + T_{LNA}$$

⇒ Noise figure and noise source

Beacuse noise temparature is more useful in satellite communication system, it is best to convent noise figure to noise temparature, T_d. The relationship is

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

where, T_0 ⇒ reference temparature used to calculate the standard noise figure usually 290K.

⇒ G/T Ratio for earth stations

The link equation can be written in terms of (C/N) at the earth station.

$$\frac{C}{N_0} = \frac{EIRP_{sat} \cdot \left(\frac{G_r}{T_s}\right)}{k L_{tot}} , \quad \frac{C}{N} = \frac{EIRP_{sat} \cdot \left(\frac{G_r}{T_s}\right)}{k L_{tot} B}$$

dB form

$$\left(\frac{C}{N_0}\right)_{dB\text{-}Hz} = EIRP_{sat} [dBW] + \frac{G}{T} [dB/K] - L_{tot} - K$$

$$\left(\frac{C}{N}\right)_{dB} = EIRP_{sat} + \frac{G}{T} - L_{tot} - K - 10\log_{10} B$$

Design Of Downlink:

The downlink of a satellite circuit is where the space craft is transmitting the data to the earth station and the earth station is receiving it.

Design of downlink: Link Budgets:

C-band satellite parameters

Transponder saturated output power	20W
Antenna gain, on axis	20dB
Transponder bandwidth	36MHz
Downlink frequency band	3.7-4.2GHz

Signal: FM-TV analog signal

FM-TV signal Bandwidth	30MHz
Minimum permitted overall C/N in receiver	9.5dB

Receiving C-band earth station

Downlink frequency	4.00GHz
Antenna gain, on axis, 4GHz	49.7dB
Receiver IF bandwidth	27MHz
Receiving system noise temparature	75K

Downlink Power budget

P_t = Satellite transponder output power, 20W	13.0dBW
B_o = Transponder output backoff	-2.0dB
G_t = Satellite antenna gain, on axis	20.0dB
G_r = Earth station antenna gain	49.7dB
L_p = free space path loss at 4GHz	-196.5dB
L_{ant} = Edge of beam loss for satellite antenna	-3.0dB
L_a = Clear air atmospheric loss	-0.2dB
L_m = other losses	-0.5dB
P_r = Received power at earth station	-119.5dBW

Downlink noise power budget in clear air

K = Boltzman's constant	$-228.6\ dBW/K/Hz$
T_s = system noise temparature, 75K	$18.8\ dBK$
B_n = Noise Bandwidth, 27MHz	$74.3\ dBHz$
N = Receiver noise power	$-135.5\ dBW$

C/N ratio in receiver in clear air

$$C/N = P_r - N = -119.5\ dBW - (-135.5\ dBW) = 16.0\ dB$$

Satellite Link Design - Downlink Received power:

$$P_r = EIRP + G_r - L_p - L_a - L_{ta} - L_{ra}\ dBW$$

where

$$EIRP = 10\log_{10}(P_t G_t)\ dBW$$

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

path loss $\Rightarrow L_p = 10\log_{10}[(4\pi R/\lambda)^2] = 20\log_{10}(4\pi R/\lambda)\ dB$

Satellite Link Design: Down link Noise Power:

$$P_n = K T_s B_n$$

$$N = K + T_s + B_n\ dBW$$

Uplink Design:

The uplink of a satellite circuit is where the earth station is transmitting the data to the space craft and the space craft is receiving it.

→ Analysis of the uplink requires calculation of the power level at the input to the transponder so that uplink C/N ratio can be found.

→ with small-diameter earth stations, a higher power earth station transmitter is required to achieve a similar satellite EIRP.

→ uplink power reffered to the transponder.

→ The noise power reffered to the transponder input is N_{xp} w

$$N_{xp} = K + T_{xp} + B_n \text{ dBw}$$

→ The power received at the input of the transponder is P_{rxp}

$$P_{rxp} = P_t + G_t + G_r - L_p - L_{up} \text{ dBW}$$

→ The value of $(C/N)_{up}$ at the LNA input of the satellite receiver is given

by $\frac{C}{N} = 10 \log_{10} [P_r/(kT_sB_n)] = P_{rxp} - N_{xp}$ dB

→ The received power at the transponder input is also given by

$$P_{rxp} = N + \frac{C}{N} \text{ dBw}$$

Design of satellite links for specified C/N:

→ when more than one $\frac{C}{N}$ ratio is present in the link, we can add the individual C/N ratios reciprocally to obtain overall C/N ratio, which we will denote here as $(C/N)_o$

$$(C/N)_o = 1/[1/(C/N)_1 + 1/(C/N)_2 + 1/(C/N)_3 + \cdots]$$

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

There are three different transponder types or operating modes:

Linear transponder: $P_{out} = P_{in} + G_{xp}$ dBW

Non linear transponder: $P_{out} = P_{in} + G_{xp} - \Delta G$ dBW

Regenerative transponder: P_{out} = Constant

Multiple Access

Multiple access divides resources (bandwidth/time) into nonoverlaping segments for many earth stations, using

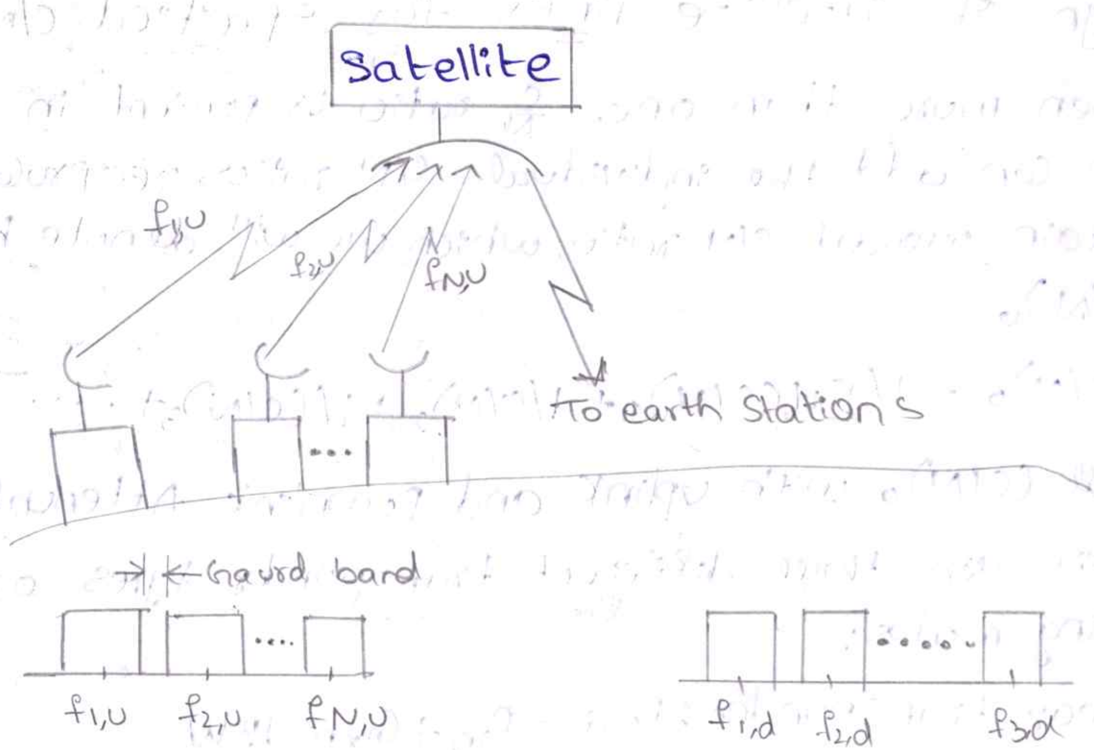
i) Frequency Division multiple Access (FDMA)

ii) Time Division multiple Access (TDMA)

iii) Code Division Multiple Access (CDMA)

Frequency Division Multiple Access (FDMA):

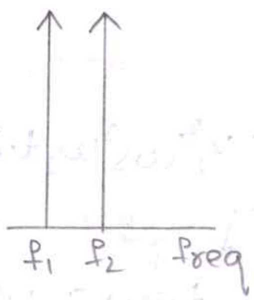
In FDMA, the available satellite bandwidth is divided into portions of non-overlapping frequency slots which are assigned exclusively to individual earth stations.

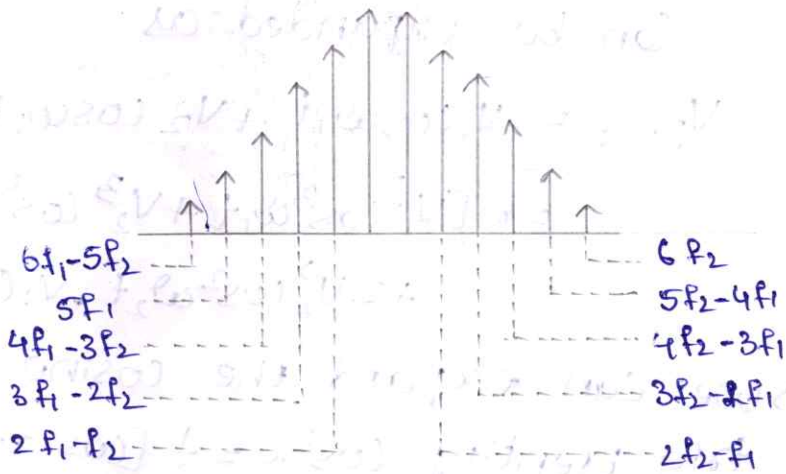


→ Examples of these techniques are FDMA/FM/FDMA used in INTELSAT II & III and SCPC satellite systems.

→ SPACE (single-channel-per-carrier PCM multiple access demand assign equipment) used in

INTELSAT IV is considered as a FDMA system. (8)





Intermodulation:

Intermodulation products are generated whenever morethan one signal is carried by nonlinear device.

→ FDMA signals interact with each other causing intermodulation products.

→ The other major disadvantage of the FDMA system is the need for accurate uplink power control among network stations.

→ The other m, Third-order IM is important beacuse third-order products often have frequencies close to the signals that generate the intermodulation, and are thereforelikely to be within the transponder bandwidth.

$$V_{out} = AV_{in} + b(V_{in})^3 \rightarrow (1)$$

where $A >> b$

The amplifier input signal is

$$V_1 \cos\omega_1 t + V_2 \cos\omega_2 t \rightarrow ②$$

The amplifier output signal is

$$V_{out} = AV_{in} + b(V_{in})^3$$

$$= AV_1 \cos\omega_1 t + AV_2 \cos\omega_2 t + b(V_1 \cos\omega_1 t + V_2 \cos\omega_2 t)^3$$

→ The cubic term, which will be denoted as V_{3out}, can be expanded as

$$V_{3out} = (V_1 \cos\omega_1 t + V_2 \cos\omega_2 t)^3$$

$$= b[V_1^3 \cos^3\omega_1 t + V_2^3 \cos^3\omega_2 t + 2V_2^2 \cos^2\omega_2 t \cdot V_2 \cos\omega_2 t$$
$$+ 2V_2^2 \cos^2\omega_2 t \cdot V_1 \cos\omega_1 t]$$

→ We can expand the cosine squared terms using the trig identity $\cos^2 x = \frac{1}{2}[\cos 2x + 1]$. Hence the IM terms of interest become

$$V_{IM} = bV_1^2 \times V_2[\cos\omega_2 t \times (\cos 2\omega_1 t + 1)] +$$
$$bV_2^2 \times V_1[\cos\omega_1 t \times (\cos 2\omega_2 t + 1)]$$
$$= bV_1^2 \times V_2[\cos\omega_2 t \cos 2\omega_1 t + \cos\omega_2 t] +$$
$$bV_2^2 \times V_1[\cos\omega_1 t \cos 2\omega_2 t + \cos\omega_1 t]$$

$$\Rightarrow \cos x \cos y = \cos(x+y) + \cos(x-y)$$

The output of the amplifier contains IM frequency components given by

$$V'_{IM} = bV_1^2 \times V_2[\cos(2\omega_1 t + \omega_2 t) + \cos(2\omega_1 t - \omega_2 t)]$$
$$+ bV_2^2 \times V_1[\cos(2\omega_2 t + \omega_1 t) + \cos(2\omega_2 t - \omega_1 t)]$$

→ The third-order intermodulation products that are of concern are given by V_{3IM} where

$$V_{3IM} = bV_1^2 V_2 \cos(2\omega_1 t - \omega_2 t) + bV_2^2 V_1 \cos(2\omega_2 t - \omega_1 t)$$

→ The wanted output from the amplifier is

$$V_{out} = AV_1 \cos\omega_1 t + AV_2 \cos\omega_2 t$$

→ The total power of the wanted output from the HPA, refered to a 1 Ohm load, is therefore (9)

$$P_{out} = \frac{1}{2}A^2V_1^2 + \frac{1}{2}A^2V_2^2 = A^2(P_1+P_2)\,W$$

→ where P_1 and P_2 are the power levels of the wanted signals. The power of the IM products at the output of the HPA is

$$P_{IM} = 2\times\left(\frac{1}{2}b^2V_1^6 + \frac{1}{2}b^2V_2^6\right) = b^2(P_1^3+P_2^3)\,W$$

⇒ Intermodulation Example:

The transponder carries two unmodulated carriers at 3718 and 3728 MHz with equal magnitudes

$$f_{31} = (2\times3718 - 3728) = 3708\text{ MHz}$$

$$f_{32} = (2\times3728 - 3718) = 3738\text{ MHz}$$

→ Both of the IM frequencies are within the transponder bandwidth and will be there present in an earth station receiver that is set to the frequency of this transponder

→ Carrier 1 has frequencies 3714 to 3722 MHz and Carrier 2 has frequencies 3726 to 3734 MHz.

$(2f_{1lo} - f_{2hi})$ to $(2f_{1hi} - 2f_{2lo})$ and

$(2f_{2lo} - f_{1hi})$ to $(2f_{2hi} - f_{1lo})$

→ The IM products are spread over bandwidths $(2B1+B2)$ and $(2B2+B1)$. Hence the third-order IM products for this example cover these: 3706-3730 MHz and 3716-3740 MHz with bandwidths of 24 MHz.

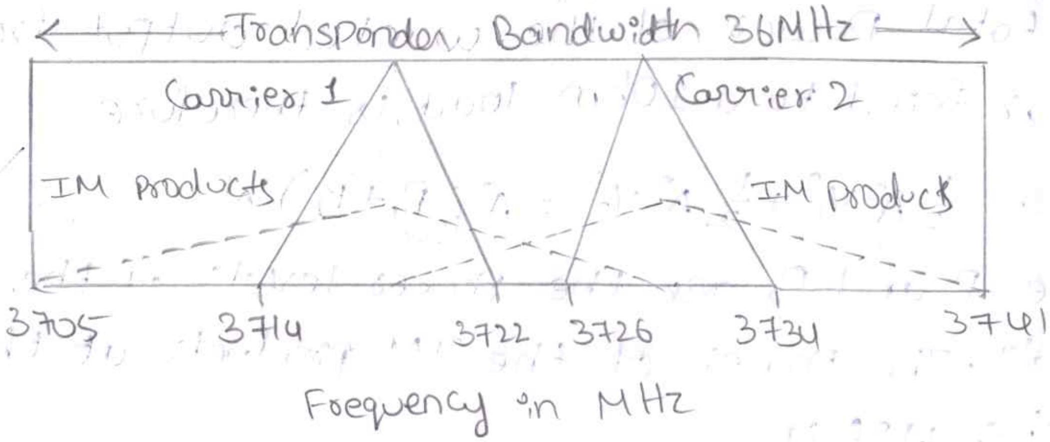


fig: Intermodulation between two C-band carriers in a transponder with third-order nonlinearity.

→ Third-order IM products grow rapidly as the output of the transponder increases toward saturation.

→ Intermodulation products are reduced by 9dB when 3dB backoff is applied.

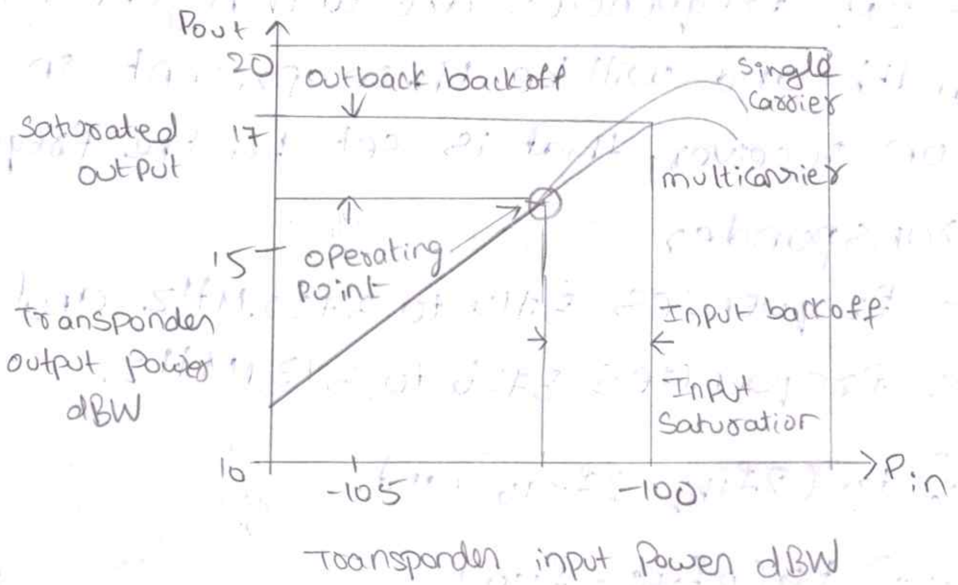


fig: Typical input-output characteristics of a transponder using a travelling wave tube amplifier (TWTA).

→ If the powers are unequal, the weaker signal may be swamped by intermodulation products from the stronger carrier.

⇒ **Calculation of C/N with intermodulation:**

Intermodulation between carriers in a nonlinear transponder adds unwanted products into the transponder bandwidth that are treated as though the interface were Gaussian noise.

→ The output backoff of a transponder reduces the output power level of all carriers, which therefore reduces the (C/N) ratio in the transponder.

→ IM noise in the transponder is defined by another C/N ratio, (C/Ni), which enters the overall $(C/N)_o$ ratio through the reciprocal formula.

$$(C/N)_o = 1/[1/(C/N)_{up} + 1/(C/N)_{down} + 1/(C/N)_{IM}]$$

→ There is an optimum output backoff for any nonlinear transponder operating in FDMA mode.

→ Intermodulation products increase in power at three times the rate at which the input power to the transponder is increases, causing (C/N) IM to decrease rapidly as saturation is approached.

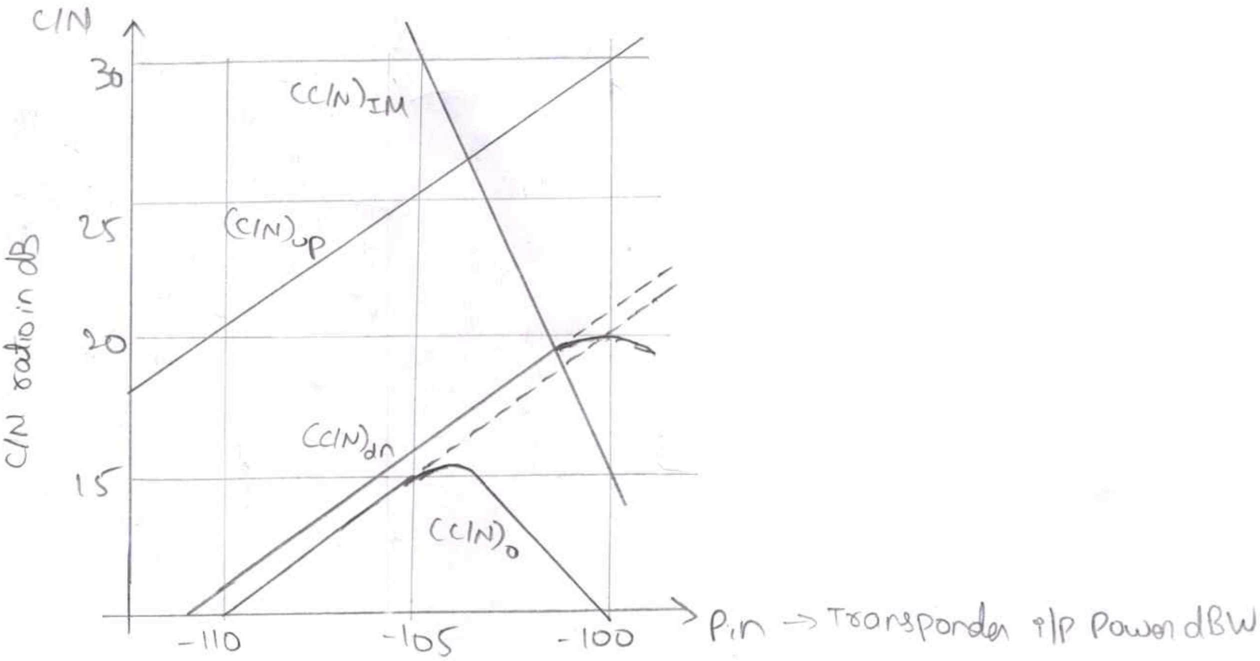


fig: C/N ratios for a link using the nonlinear transponder

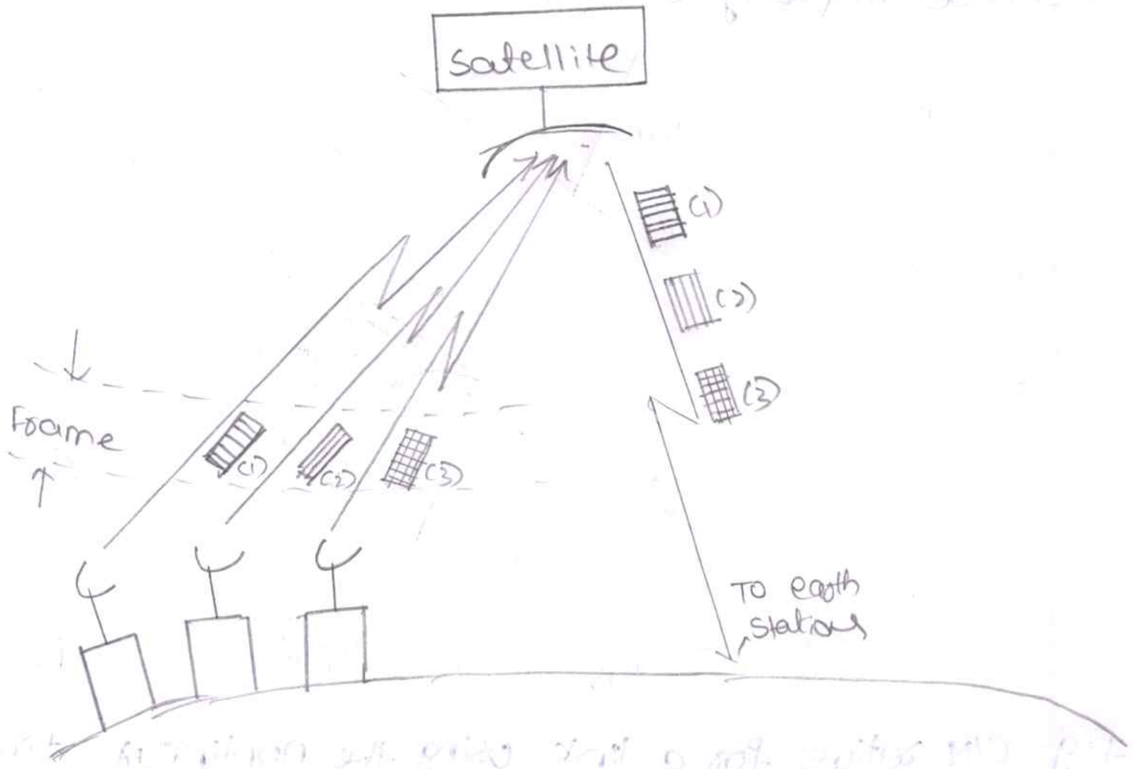
→ The overall $(C/N)_0$ ratio in the receiving earth station receiver has a maximum value at an input power level of −104dBW.

→ The optimum operating point may be many decibels below the saturated output level of the transponder under some conditions.

→ VSAT networks and mobile satellite telephones often use SCPC FDMA, requiring the transponder to operate in a linear mode, either by using a linear transponder or by applying large output backoff.

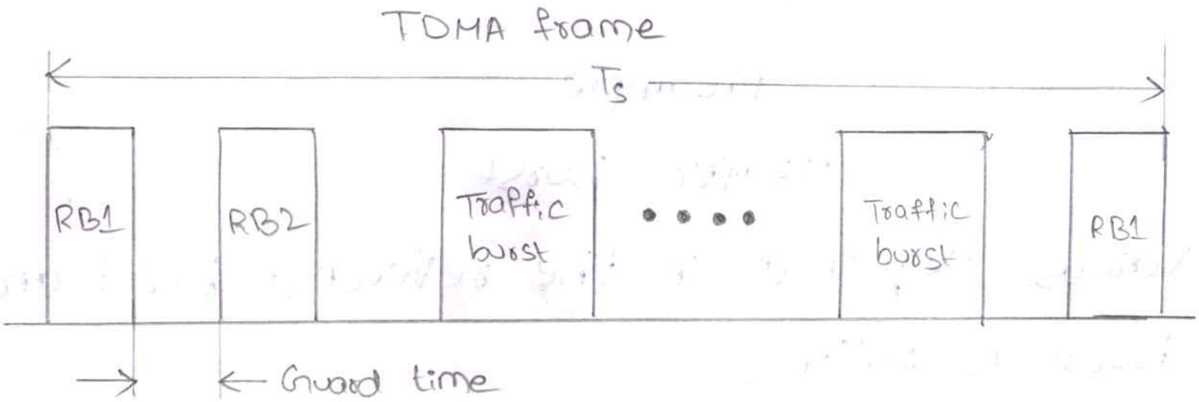
Time Division Multiple Access (TDMA):

In TDMA, the sharing of the communication resources by several earth stations is performed by assining a short time to each earth station in which they have exclusive use of the entire transponder bandwidth and communicate with each other by means of non-overlapping burst of signals.



→ In TDMA, the transmit timing of the bursts is accurately synchronized so that the transponder receives one burst at a time. Each earth station receives an entire burst stream and extracts the bursts intended for it.

→ A frame consists of a number of bursts orginating from a Community of earth stations in a network.



→ It consits of two reference burts RB1 and RB2, traffic burts and the guard time between bursts.

→ The traffic bursts carry information from the traffic earth station.

→ Each earth station accessing anywhere in the frame as a transponder may transmit one or two traffic bursts per TDMA frame and may position them anywhere in the frame according to a burst time plan that coordinates traffic between earth stations in the network.

→ The Guard time between bursts ensure that the bursts never overlap at the input to the transponder.

→ The TDMA bursts structure of the reference and traffic burst are given below.

Carrier and bit timing recovery	UW	TTY	Service channel	VOW	Control and delay Channel

Reference burst

Carrier and bit timing recovery	UW	TTY	Service channel	VOW	Traffic data

←————— preample —————→

Traffic burst

Varias sequences in the reference burst and traffic burst as follows:

⇒ Carrier and bit timing recovery (CBTR)

The CBTR pattern provides information for Carrier and timing recovery circuits of the earth station demodulator.

The length of the CBTR sequence depends on the Carrier-to-noise ratio at the input of the demodulator and the acquisition range.

⇒ Unique word (UW)

The unique word in the reference burst provides frame timing, while the UW in the traffic burst marks its begining and identifies bursts intended for an earth station

The unique word is a sequence of ones and zeros with good correlation properties, in the INTELSAT V TDMA system, it has length of 24 symbols.

⇒ Teletyp (TTY) and voice order wire (VOW):

Teletype and voice order wire patterns carry instructions to and from earth stations. The number of symbols for each of the pattern is 8 symbols for the INTELSAT V TDMA.

⇒ Service channel (SC)

The service channel of the reference burst carries management instructions such as burst time plan and also monitoring and control information to the traffic stations.

The service channel of the traffic burst carries the traffic station's status to the reference station and contains information such as the high bit error rate and UW loss alarms.

⇒ Control and delay channel (CDC)

The control and delay channel pattern carries acquisition and synchronization information to the traffic earth stations to enable them to adjust their transmit delays.

It also carries the reference station status code which enables them to identify the primary and secondary reference bursts.

⇒ Traffic data

This portion contains the information from a source traffic station to a destination traffic

Station. The informats can be voice, data, video or facsimile signals. The traffic data pattern is divided into blocks of data.

→ The size of each data block is given by:

subburst size(symbols) = symbol rate (symbols/sec) X frame length (sec)

→ The INTELSAT TDMA with a frame length of T f=2 msec for PCM voice data has a subburst size of 64 symbols long.

Satellite-Switched TDMA (SS-TDMA)

→ A satellite-switched TDMA system is an efficient TDMA system with multiple spot beam operation for the uplink and downlink transmissions.

→ The interconnections between the uplink and downlink beams is performed by a high-speed switch matrix located at the heart of the satellite.

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

→ The switch matrix is configured in a crossbar design in which only a single row is connected to a single column at a time.

→ An SS-TDMA scheme has been planned for INTELSAT VI and olympus satellites.

⇒ Satellite switched TDMA

One advantage that TDMA has when used with a baseband processing transponder is satellite switched TDMA.

A narrow antenna beam has a gain than a broad beam, which increases the satellite EIRP and therfore increase the capacity of the downlink.

Onboard processing:

→ The advantagy of bent pipe transponder is flexibility, it can be used for any combination of signals that fit within its bandwidth.

→ The disadvan of the bent pipe transponder is that is not well suitable to uplinks from small earth stations, especially uplinks operated in Ka band.

→ The overall C/N ratio in the hub station receiver cannot be greater than C/N ratio in the transponder, so the bit error rate increase quickly as rains effects the upline.

→ Onboard processing or a baseband processing transponder can overcome this problem by separating the uplink and downlink signals and their C/N ratios.

→ The baseband processing transponder can have different modulation schemes on the uplink and downlink to improve spectral efficiency, and can dynamically apply forward error control to only those links affected by rain attenuation.

→ All LEO satellites providing mobile phone telephone service use onboard processing.

→ Ka band satellites providing internet access to individual users also use onboard processing.

⇒ satellite switched TDMA with onboard processing.

Baseband processing is essential in satellites using satellite switched TDMA, beacuse data packets must be routed to different antenna beams based on the destination earth station.

→ switched beam operation of an uplink from a small earth station requires synchronization of the earth station transmit time with the satellite beam pointing sequence.

→ A satellite with switched beam capability can have much narrower beams with higher gain than a satellite with a single fixed beam.

→ The Astrolink satellites have 105 spot beams for links to small user terminals.

→ The satellite must generate at least 170 beams to cover the united states with 0.32° beams.

→ A steerable beam antenna allows the geographical capacity of the satellite to be reconfigured throughout its lifetime.

Demand Access Multiple Access (DAMA)

→ Demand access can be used in any satellite communication link where traffic from an earth station is intermittent.

→ Demand access allows a satellite channel to be allocated to a user on demand, rather than continously, which greatly increases the number of simultaneous users who can be served by the system.

→ The two-way telephone channel may be a pair of frequency slots in a DA-SCPC system, a pair of time slots in a TDM or TDMA system, or any combination or FDMA, TDM and TDMA.

→ Most SCPC-FDMA system use demand access to ensure that the available bandwidth in a transponder is used as fully as possible.

→ The growth of cellular telephone systems has led to the development of low cost, highly integrated controllers and frequency synthesizers that make demand access feasible.

→ The major difference between a cellular system and a satellite system in that in a cellular system the controller is at the base station to which the user is connected by a single hop radio link.

→ In a satellite communication system, there is always a two hop link via the satellite to a controller at the hub earth station.

→ All connections pass through a controlling earth station that can determine wether to permit the requested connection to be made, and who should be charged.

→ The presence of the signals from all destinations at a central earth station also allows security agencies the option of monitoring any traffic deemed to be contrary to the national interest.

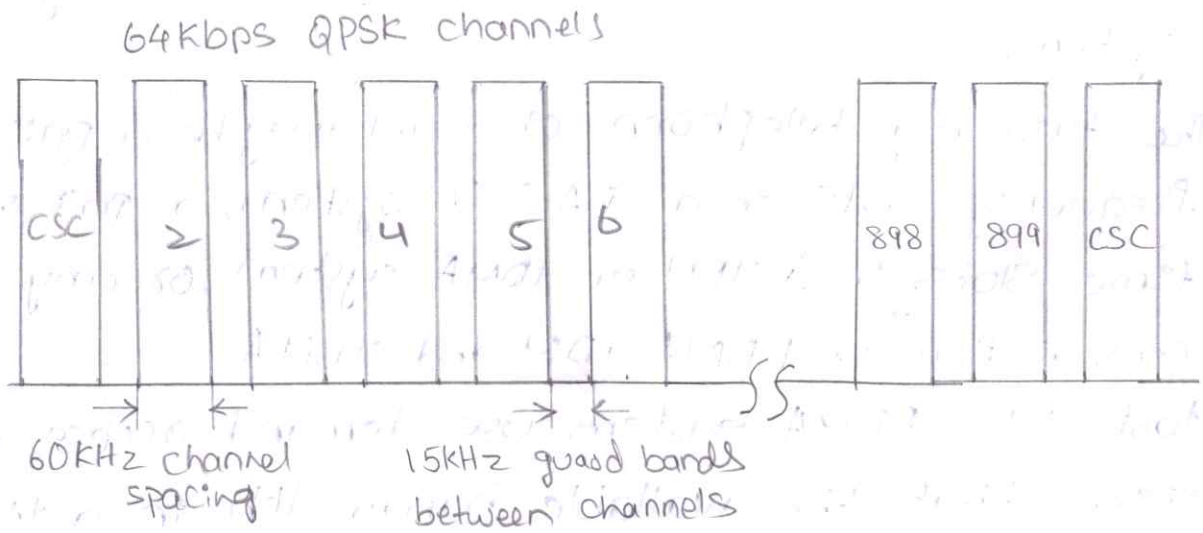


fig: Frequency plan for a 54-MHz transponder carrying 900 demand access channels.

→ Demand access system require two different types of channel : a common signalling channel (csc) and a communication channel.

→ The CSC is usually operated in random access mode beacuse the demand for use of the CSC is relatively low, messages are short, and the CSC is therefore lightly loaded.

→ Packet transmission techniques are widely used in demand access system beacuse of the need for addresses to determine the source & destination signals.

→ Bent pipe transponders are often used in demand access mode, allowing any configuration of FDMA channels to be adopted.

→ There seem to be few standards for demand access systems in the satellite communication industry, with each network using a different proprietary configuration.

→ A 54MHz bandwidth transponder can acommodate 900 of these 60kHz, channels, but it is unlikely that all are used at the same time.

→ many VSAT systems are power limited, preventing the full use of the transponder bandwidth.

→ considerable backoff is required in a bent pipe transponder with large number of FDMA channels.

CODE DIVISON MULTIPLE ACCESS (CDMA):

→ In CDMA satellite systems, each uplink earth station is identified by a unique address code imposed on its carrier, allowing it to use the entire bandwidth and transmit through the satellite whenever desired without bandwidth or time sharing.

→ Signal identification is achieved at the receiver earth station by recognizing the corresponding address code, and three CDMA techniques are used.

→ Three CDMA techniques are

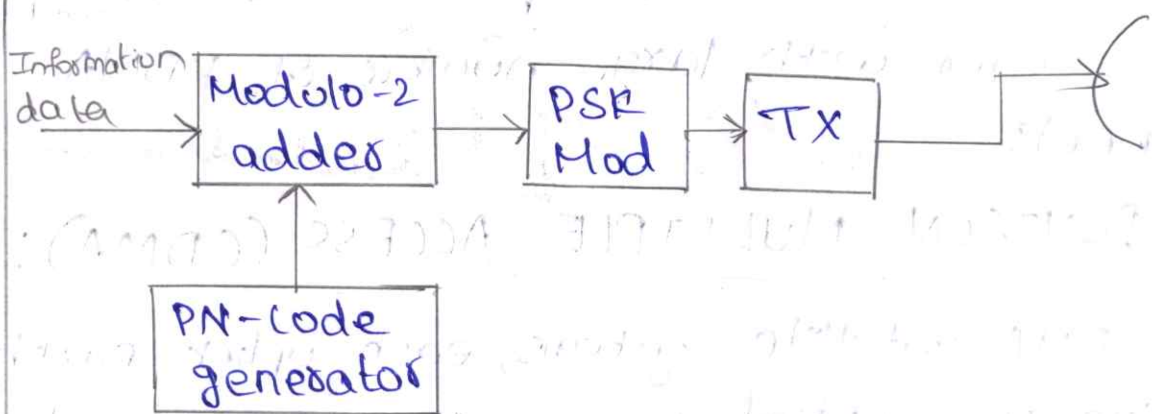
i) Direct sequence CDMA (DS-CDMA)

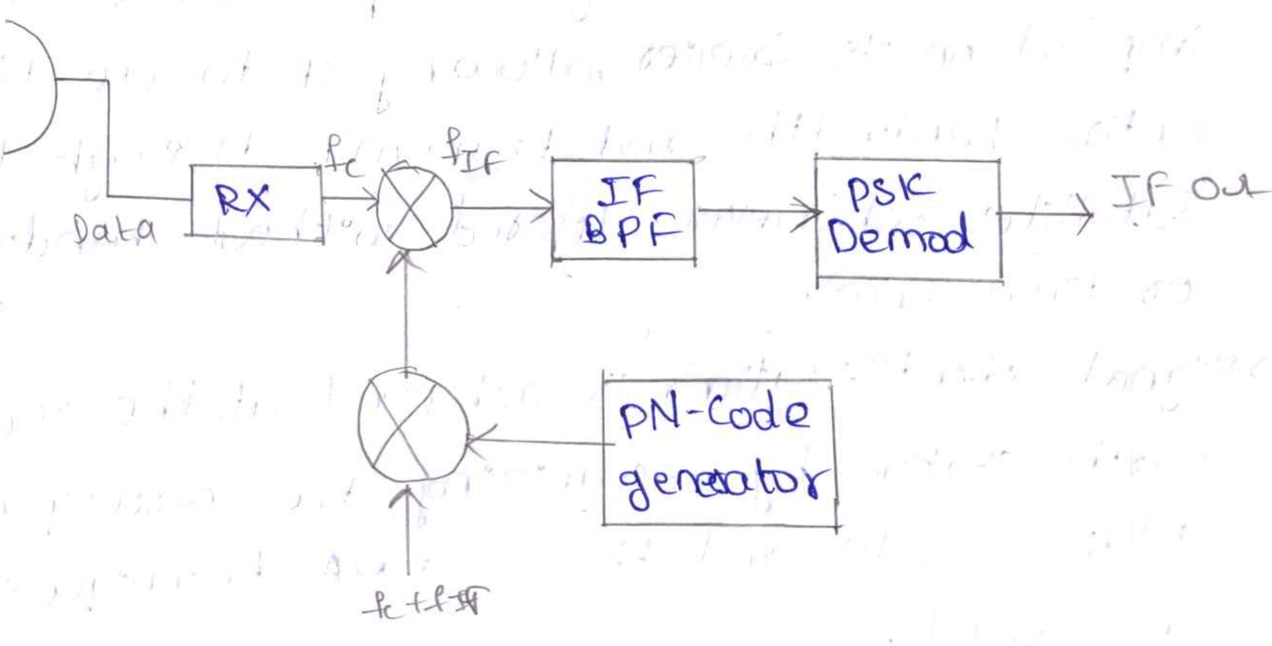
ii) Frequency hopping CDMA (FH-CDMA)

iii) Hybrid CDMA

1) Direct Sequence CDMA (DS-CDMA)

In this technique, an addressed pseudo-noise (PN) sequence with information data is directly modulated on the carrier at the uplink earth station, and the same PN sequence is used synchronously at the receiver station to despread the signal and recover the original data.





→ The bits of the PN sequence are reffered to as chips.

→ The ratio between the chiprate and information rate is called the spreading factor.

→ phase-shift-keying modulation schemes are commonly used for these systems.

→ The most widely used binary PN sequences is the maximum length linear feedback shift register sequence (m-sequences) which is generated by an m-stage shift register.

→ In a synchronous system, the entire system is synchronized in such a way that the PN sequence period or bit duration of all the uplink carriers in the system are in time alignment at the satellite.

→ A synchronous DS-CDMA must have the type of network synchronized used in a TDMA system but in a much simpler form.

→ In an asynchronous DS-CDMA satellite no time alignment of the PN sequence period at the satellite is required and each uplink carrier operates independently with no overall network synchronization.

2. Frequency Hopping CDMA (FH-CDMA)

The block Diagram of an FH-CDMA transmitter / receiver is showing

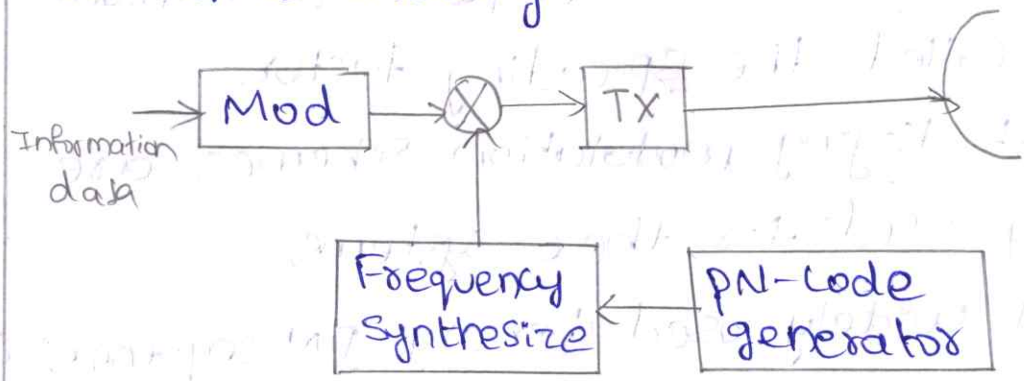


fig: Transmitter

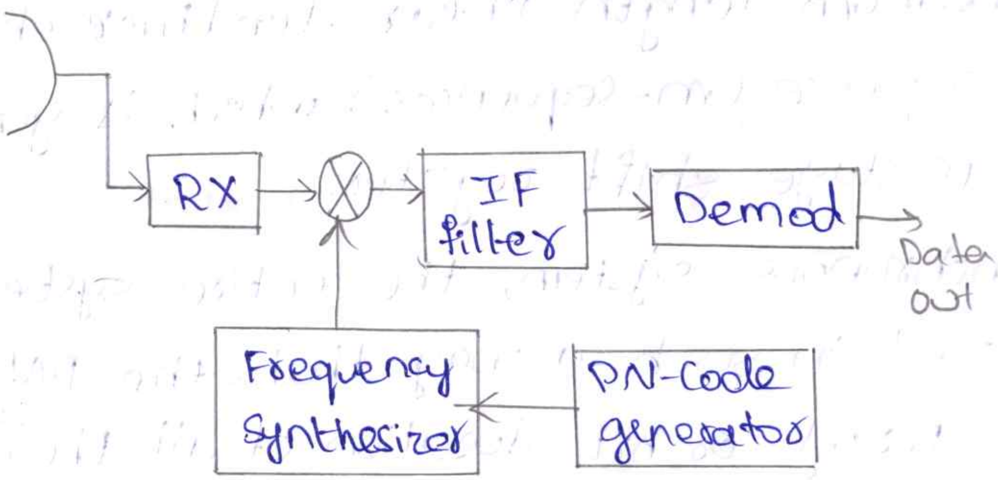


fig: Receiver

- → The addressed PN sequence is used continually change the frequency of the carrier at the uplink earth station.
- → The local PN code generator produces a synchronized replica of the transmitted PN code which changes the synthesizer frequency in order to remove the frequency hops on the received signal.
- → Non-coherent M-ary FSK modulation schemes are commonly used for the system.

3. Hybrid CDMA

→ A hybrid CDMA system employs a combination of DS-CDMA and FH-CDMA techniques.

→ CDMA systems are also refered to as spread to as spread spectrum multiple access (SSMA) system.

→ Spreading the spectrum of the transmitted signal has important application in military satellite systems since it produces inherent anti jam advantages.

→ Another important feature of these systems is their low probability of interception (LPI).

⇒ Spread spectrum Transmition and Reception:

CDMA for satellite communications will be restricted to direct sequence systems, since that is the only form of spread spectrum that has been used by commercial satellite systems to date.

→ The spreading codes used in DS-SS CDMA systems are designed to have good auto correlation properties and low cross-correlation.

→ Various codes have been developed specifically for this purpose, such as Gold and Kasami codes.

→ The DS-SS codes will be treated as Pseudo Noise (PN) sequence in this discussion.

→ PseudoNoise refers to the spectrum of code which appears to be a random sequence of bits with a flat, noise like spectrum.

→ Most DS-SS systems generate spread spectrum signals using BPSK modulated versions of the data stream.

→ Each data bit results in the transmission of complete PN sequence of length M chips.

→ Recovery of the original data stream of bits from the DS-SS signal is achieved by multiplying the received signal by the same PN code that used to generate it.

Unit-IV

Earth Station Technology, LEO and Geostationary satellite systems

Introduction:-

Earth station is a vital element in any satellite communication network. The function of an earth station is to receive information from or transmit informing to the satellite network in the most cost-effective and reliable manner while retaining the desired signal quality. The design of earth station configuration depends upon many factors and its location. But it is fundamentally governed by its location which are listed below.

- In Land
- on a ship at sea
- on board aircraft.

The factors are

- ~~Type~~ of services
- Frequency bands used
- Function of the transmitter
- Function of the receiver
- Antenna characteristics

Earth station configuration:-

Any earth station consists of four major subsystems

- Transmitter
- Receiver
- Antenna
- Tracking equipment

Two other important subsystems are

(*) Terrestrial interface equipment.

(*) Power supply.

The earth station depends on the following parameters

(*) Transmitter power
(*) choice of frequency
(*) Gain of antenna
(*) Antenna efficiency.
(*) Antenna pointing accuracy.
(*) Noise temperature.
(*) Local conditions such as wind, weather etc,
(*) Polarization
(*) Propagation losses.

The functional elements of a basic digital earth station are shown in the below figure.

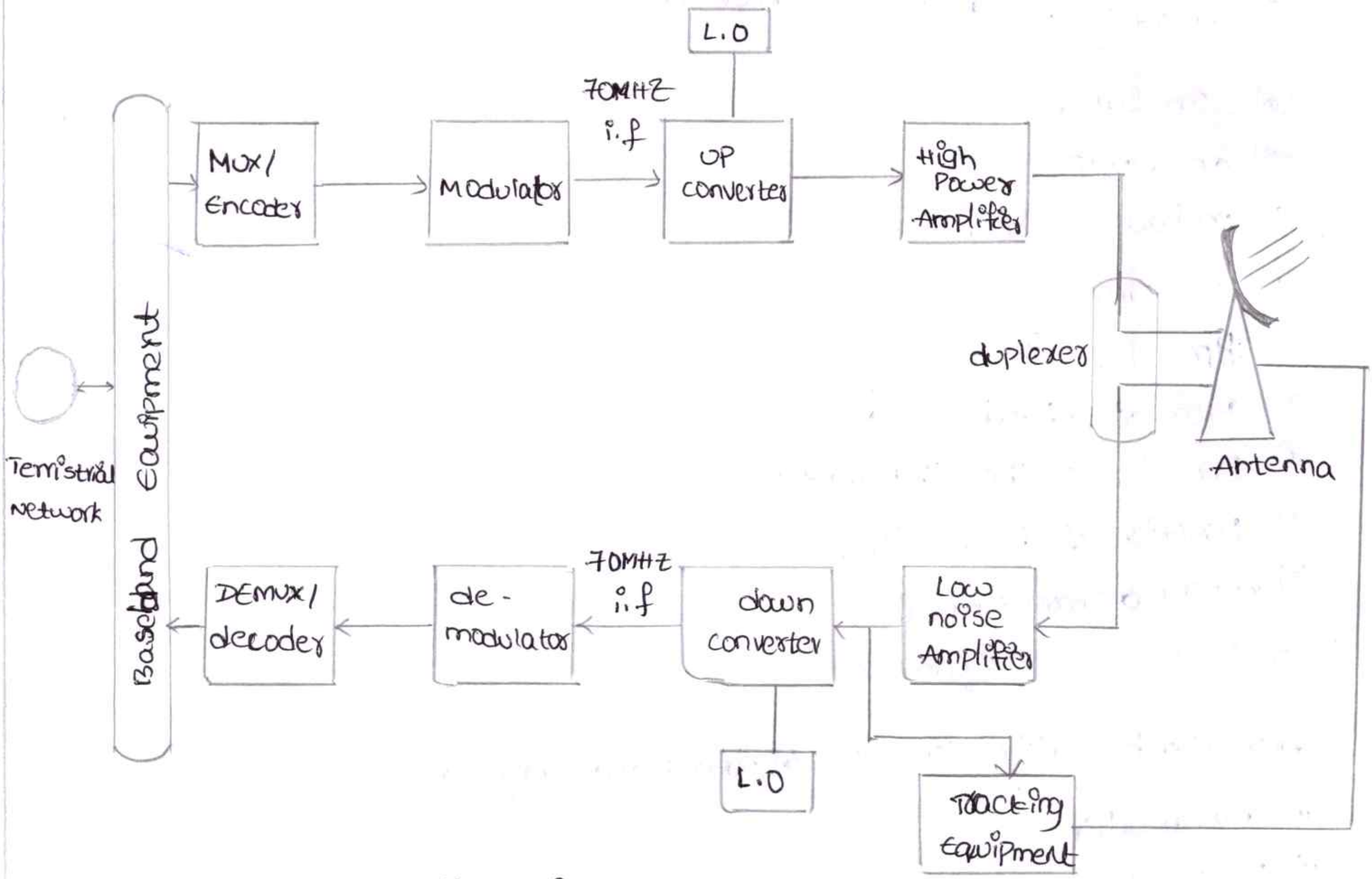


fig:- General configuration of an earth station.

→ Digital information in the form of binary from terristrial networks enters earth station and is then processed by the base band equipment.

→ The encoder performs error correcting coding . to reduce the error rate, by introducing extra digits into digital stream generated by the base band equipment

(i) Modulation and Intermediate frequency (I.F) :-

The modulator converts the encoded symbol stream into an I.F carrier typically (70 MHZ or 140 MHZ) , which is easier to handle then direct modulation at high uplink frequencies like 6GHZ or 14GHZ.

(ii) Upconversion and transmission :-

The modulated I.F signal is up-converted to the uplink R.F frequency, amplified by a High Power amplifier (HPA), and transmitted via the antenna to the satellite.

(iii) Reception and signal Amplification :-

The Earth station Receives the downlink R.F signal, which is weak and noisy. A low noise Amplifier (LNA) boosts the signal strength and improves the signal-to-noise Ratio (SNR).

(iv) Demodulation and Decoding :-

The R.F signal is down-converted back to I.F for easier demodulation . the demodulator identifies transmitted symbols . and the decoder corrects errors using redundancy added during encoding.

(v). Baseband processing and satellite tracking :-

The recovered information stream is processed at baseband and delivered to the terrestrial network . tracking equipment ensures the antenna beam remains aligned with the satellite for continuous communication.

Antenna subsystem :-

The antenna system consist of

- Feed system
- Antenna Reflector
- Mount
- Antenna tracking system.

Feed system :- The feed along with the reflector is the radiating / receiving elements of Electromagnetic waves.

→ The feed system, along with the reflector, is responsible for both transmitting and receiving electromagnetic waves. Its reciprocity allows it to work in both directions.

Axi-symmetric configuration:-

→ The feed is placed symmetrically with respect to the reflector. It includes:

(i) Primary feed:- Located at the focal point of the dish

(ii) Cassegrain:- uses a convex sub-reflector to bounce waves back to a central feed.

(iii) Gregorian:- uses a concave sub-reflector placed beyond the primary focus.

Asymmetric configuration (offset feed):-

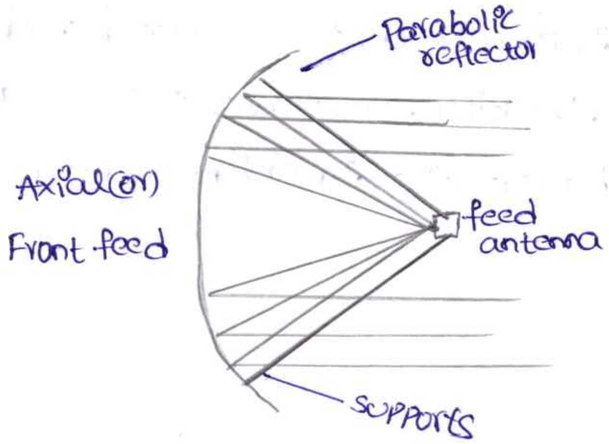
→ The feed is placed off-center to avoid blocking the main beam, improving effeciency and reducing side lobe levels.

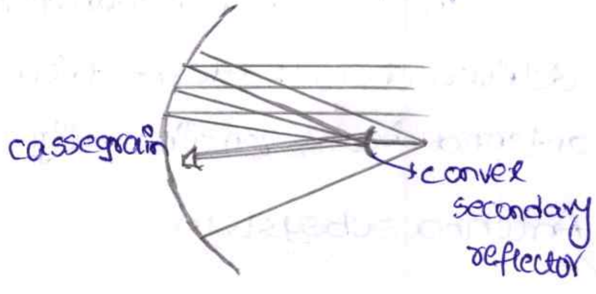
Folded systems for compactness:-

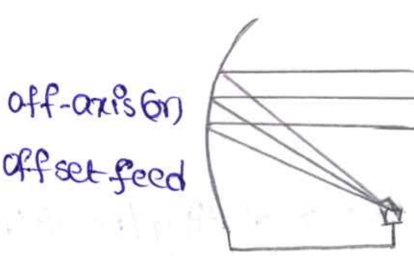
→ Designs like Cassegrain and Gregorian use multiple reflections to make the antenna system more compact and convenient.

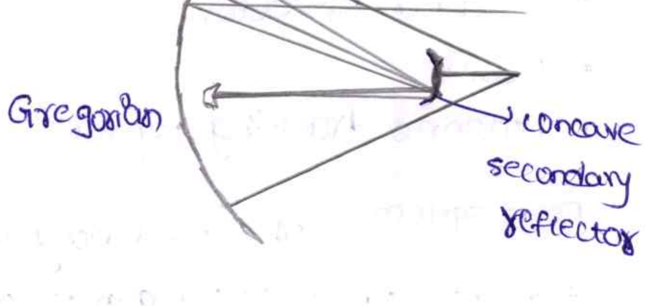
Feed configuration purpose:-

The way electromagnetic waves enter and exists the antenna system defines the feed configuration, which directly affects performance and design complexity.









Antenna Reflector:-

→ Parabolic reflectors are used in Earth stations because they provide strong signal gain and can focus incoming waves to a single point for efficient transmission and reception.

→ Large antennas may use multiple reflectors - like in the cassegrain systems - to make the setup more compact and improve performance.

Earth stations are also classified on the basis of services for example:

1) Two way TV, Telephony and data.
2) Two way TV.
3) TV receive only and two way telephone and data.
4) Two way data.

For mechanical design of parabolic reflector the following parameters are required to be considered:

→ size of the reflector
→ Focal length / diameter ratio
→ Rms error of main and sub reflector.
→ Pointing and tracking accuracies.
→ Speed and acceleration.
→ Type of mount
→ Coverage Requirement
→ wind speed.

The gain of the Antenna is given by.

$$\text{Gain} = (\eta\, 4\pi A_{eff}) / \lambda^2$$

with circular aperature diameter D.

$$\text{Gain} = (\eta \cdot 4\pi/\lambda^2)(\pi D^2/4)$$

$$= \eta(\pi D/\lambda)^2$$

The overall efficieny of the Antenna is the product of various factors such as:

1) Cross Polarization
2) Spill over
3) Diffraction
4) Blockage
5) surface accuracy
6) phase Error
7) Illumination.

Antenna Mount:-

Antenna mounts and i/p back-off in there are 3 types.

they are:

Azimuth - elevation mount:- contrals direction using verticle (azimuth) and horizontal (elevation) axes.

X-Y mount:- uses two perpendicular axes (x and y) for precise antenna steering.

Mount selection:- The choice of mount depends on coverage area and tracking needs of the earth station Antenna.

input Back-off (IBO):- To reduce signal distortion. the i/p power to the travelling wave Tube (TWT) is lowered from saturation level: this shift is called i/p back-off, measured in decibels.

Earth station Tracking system:-

Tracking is essential when the satellite drift, as seen by an earth station antenna is a significant fraction of an an earth station's antenna beam width.

(i) Tracking Necessity:- Tracking is crucial when satellite drift affects the antenna's beam alignment. it ensures continuous and accurate communication with the satellite.

(ii) Tracking Modes:-

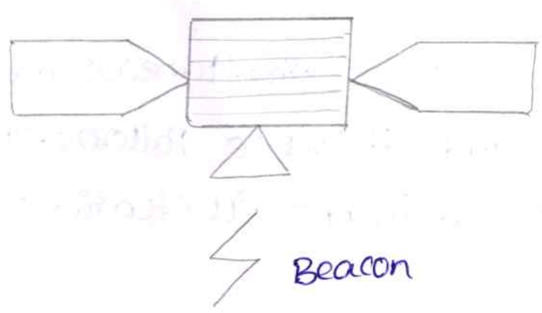
a) satellite Acquisition:- scans Predicted satellite positions and locks onto the signal.

b) Automatic tracking:- uses a closed - loop systems for precise real-time adjustments.

c) Manual & Program tracking:- Manual allows human control; Program tracking uses Predicted satellite data from operators.

(iii) system Reliability:-

Manual tracking acts as a backup in case of system failure while program tracking depends on accurate satellite position data for effective operation.



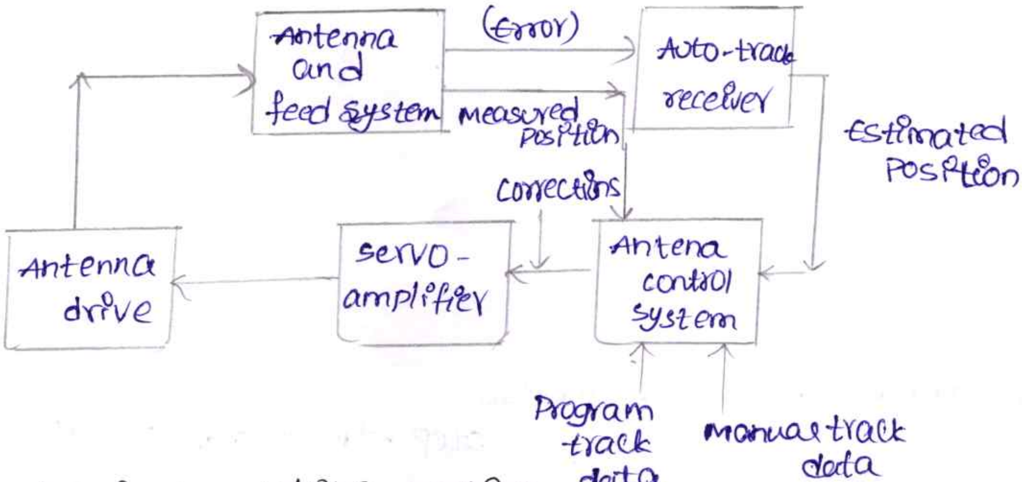


fig:- Main elements of A satellite tracking system.

-> communication satellites transmit a becon signal that is used by auto-track receivers to calculate satellite position and adjust the antenna automatically for accurate allignment.

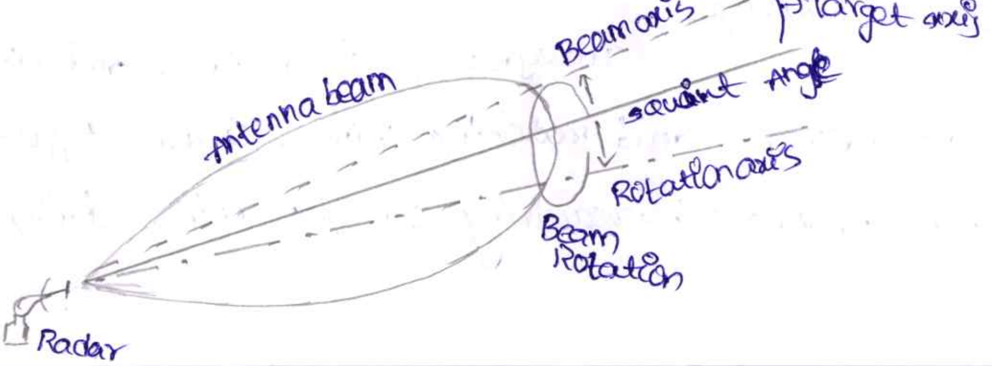
-> In mannual mode, operators adjust antenna angles manually in program-track mode, a computer predicts satellite positions and drives the antenna based on calculated errors.

Auto track system:-

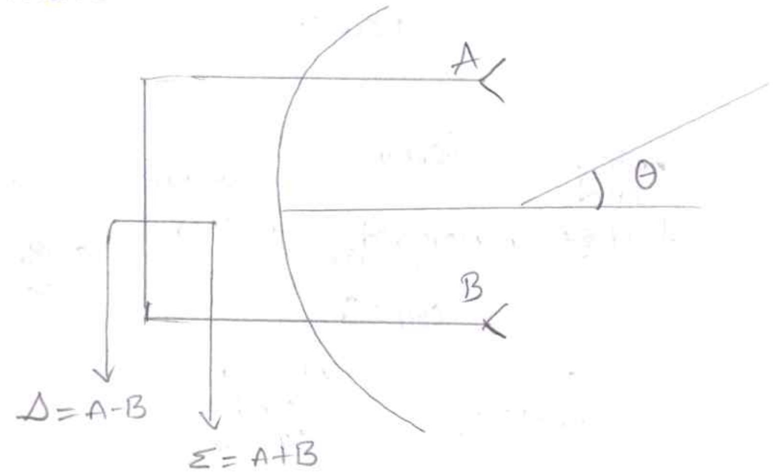
There are three main types of auto-track system which have been commonly used for satellite tracking;

1. conical scan:-

Rotates the antenna beam around a small offset (squint angle) to detect tracking errors based on signal modulation. it uses full received power but suffers from reduced accuracy due to amplitude disturbances.



2. Monopulse Technique:-
uses simultaneous measurements from offset horns to generate sum and difference patterns. this method is highly accurate and immune to amplitude fluctuations, making it ideal for precise tracking.



3. step-track & Recent Advances:-
step-track adjusts antenna positions in small steps to maximize signal strength. New techniques like electronic beam switching use fast switching of a single beam to mimic simultaneous lobing, offering high accuracy with simpler.

TERRESTRIAL Interface:- The terrestrial interface comprises a wide variety of equipment.

1. Range of Equipment:-
Terristrial interfaces vary widely from no equipment in mobile or receive-only stations to complex setups in large commercial systems handling TV, data, and hundrends of phone channels.

2. signal formatting:-
signals from terrestrial systems (using frequency or time-division multiplexing) often need to be reformatted for satellite transmission, especially when combining multiple carriers or handling return paths.

3. system integration challenges:-
Integrating terrestrial and satellite systems involves seperating and matching various signal types (e.g., video, audio, control channels), requiring careful planning during system design.

Primary Power:-

Earth stations use various Power setups - from solar or battery - operated units to large commercial Power with diesel backup. most reauire no-break systems to ensure uninterrupted operation during outages.

Test methods:-

Noise Power Ratio (NPR) :-

NPR is a test method used to measure inter-modulation noise in FDM systems, it involves filling the baseband spectrum with noise except for one channel, then measuring the noise that leaks into that empty slot.

$$P = -15 + 10\log N \text{ dBm0}, \quad N \geq 240$$
$$P = -1 + 4\log N \text{ dBm0}, \quad N < 240$$

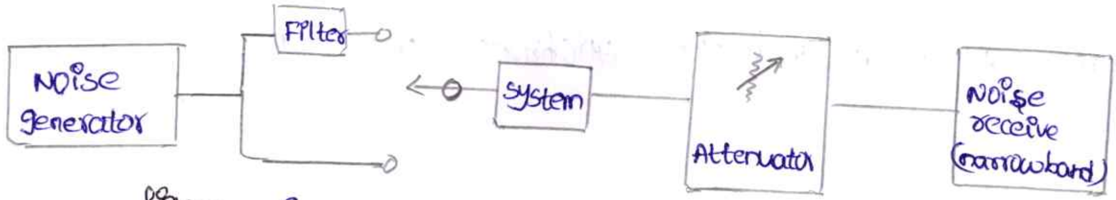


fig:- Noise Power ratio test setup.

G/T Measurement:-

→ The G/T ratio (antenna gain to system noise temperature) is a key Performance metric. smaller antennas can be tested directly, while larger ones often reply on "calibrated satellite signals" for accurate measurement.

Orbit consideration:-

orbit considerations in satellite communications focus on altitude, which affets coverage and signal delay, and inclination, which determines the regions a satellite can serve. these factors shape how effictively, satellites meet communication needs.

(i) Equatorial orbits:- Equatorial orbits lie directly above Earth's equator, with zero inclination, allowing satellites to circle the planet in sync with its rotation. these orbits are ideal for geostationary satellites, Providing continuous coverage over equatorial regions.

$$P = \frac{24T}{24-T} \text{ hours}$$

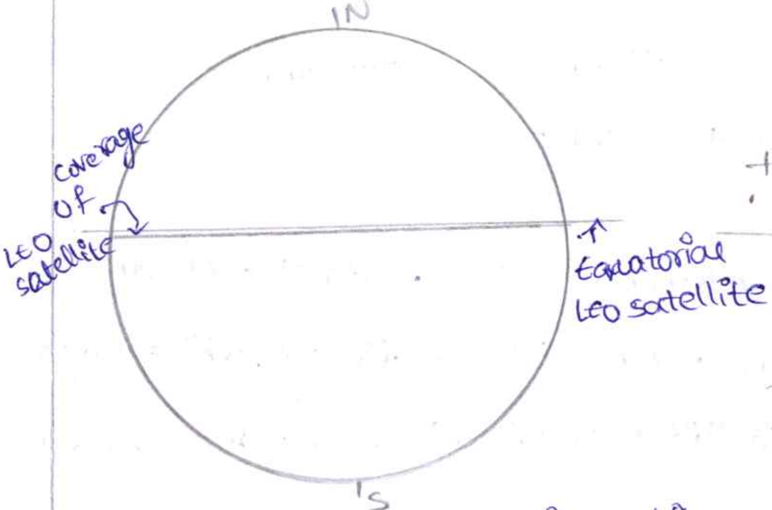
where $T^2 = \frac{4\pi^2 r^3}{\mu}$

Orbital Periods and observing Time.

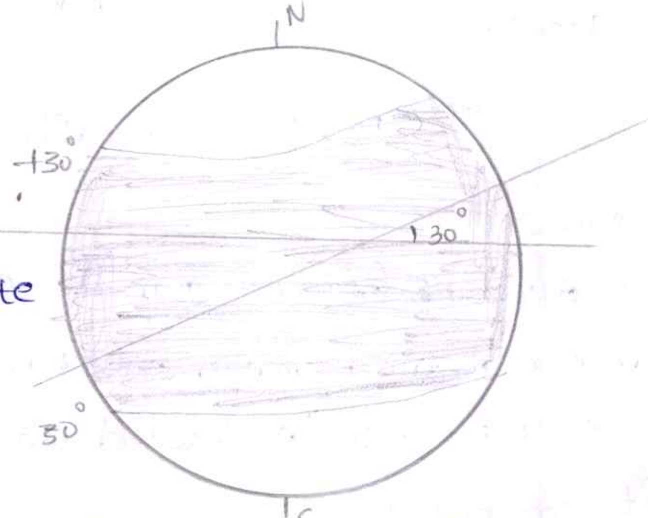
orbital height (km)	True (hours) (T)	Apperent (hours) (P)	observing Time (hours) P-T
500	1.408	1.496	0.183
1000	1.577	1.688	0.283
5000	1.752	1.890	0.587
10,000	5.794	7.645	2.894
35786	23.934	∞	∞

(2) Inclined orbits:-

Inclined orbits have a tilt greater than 0° relative to earth's Equator, allowing satellites to cover regions beyond the Equatorial zone, they're useful for reaching higher latitudes and are common in polar and sun-synchronous missions.



(a) coverage of an equatorial orbit LEO satellite



(b) coverage of an inclined orbit LEO satellite.

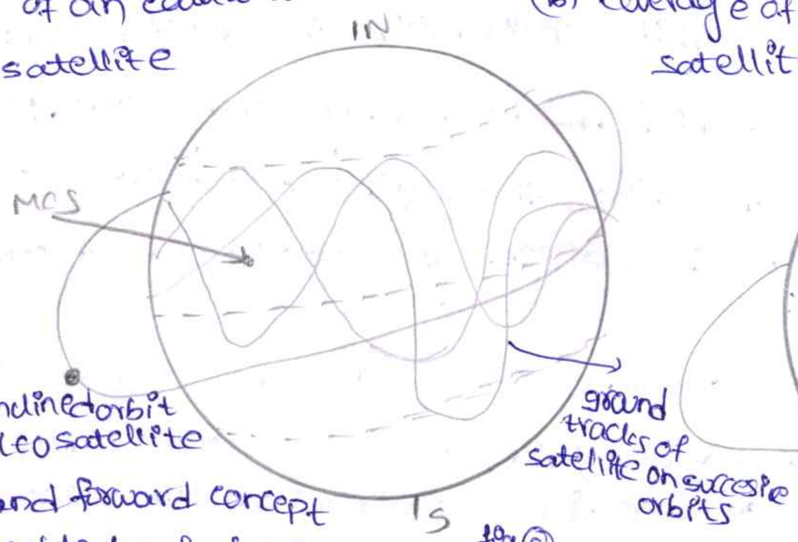


fig ©

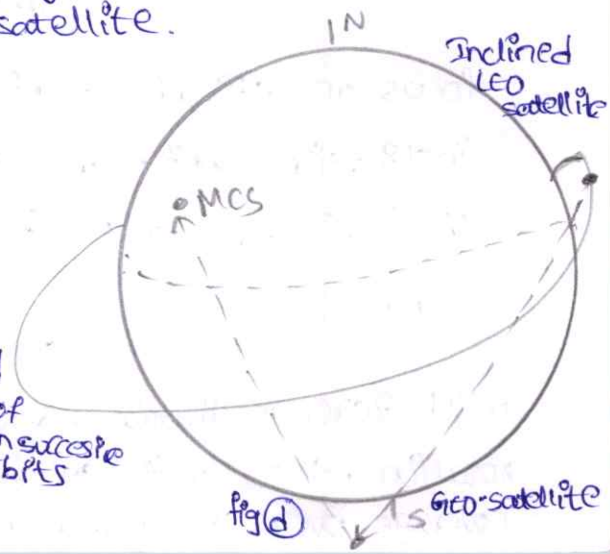
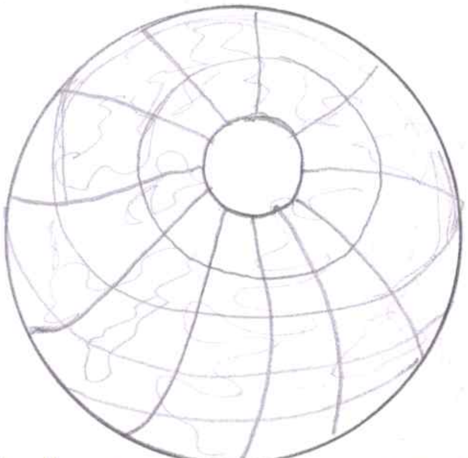


fig ⓓ

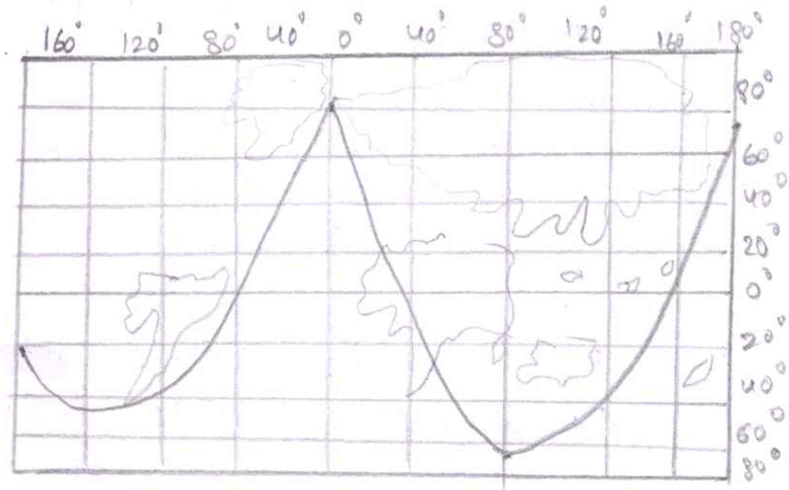
fig ©:- Store and forward concept

fig ⓓ:- Real-time data transfer in a Geo satellite.

Two molniya orbits with the planes of the orbits seperated by 180°. (6)



fig(a) view from the apogee point of a Molniya orbit positioned at almost 0° when at apogee.



fig(b) Ground track of the Molniya a orbit shown in fig (a)

Drawbacks:-

(i) The first is the reawirement to track the spaceicraft.

(ii) The second in the need to switch communications. to other molniya satellite - rather like a mobile radio hand off situation when the first goes out of coverage as the other comes into coverage.

(5) ~~singl~~ Radiation Effects:- The effects of radiation on electronics in space is generally separated out into two main aspects total dose and single-event upsets.

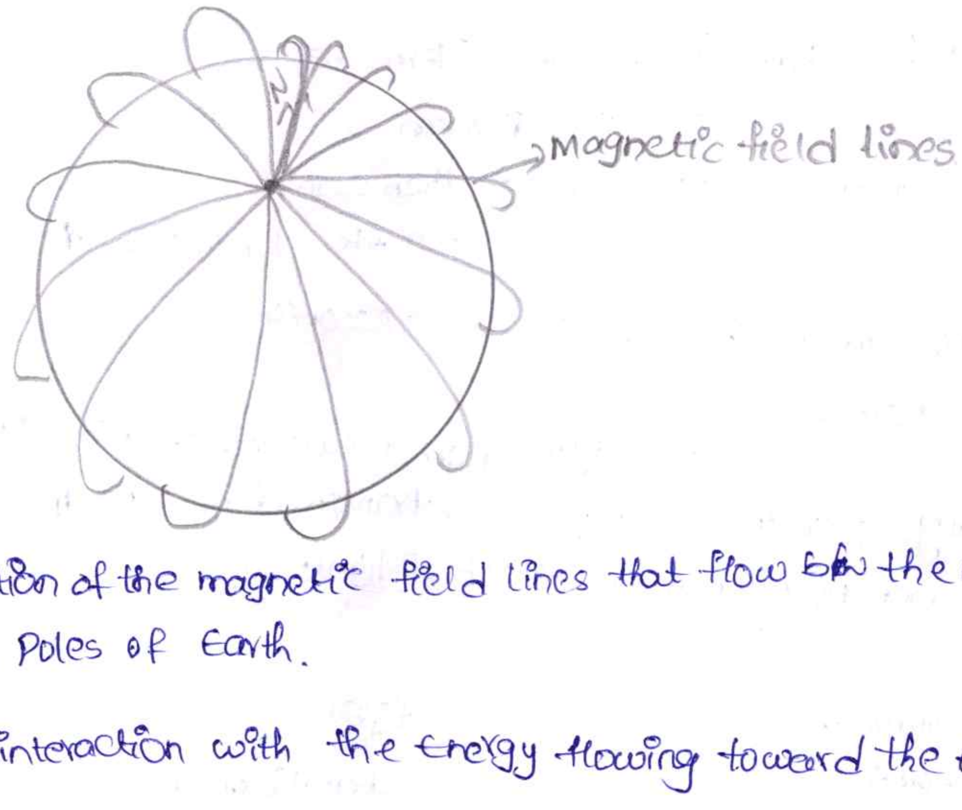


fig:- Representation of the magnetic field lines that flow b/w the north and south magnetic poles of Earth.

The earth due to interaction with the energy flowing toward the earth from the sun.

③ Eliptical orbits:-

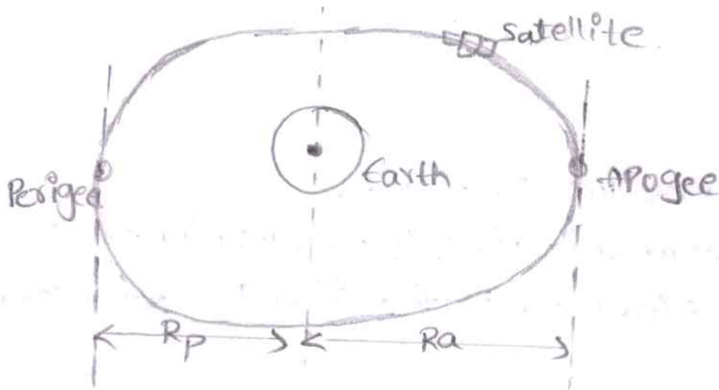
An elliptical orbit will have a non zero eccentricity the orbit eccentricity. e. is determined by the lengths of semi major axis a, and semi minor axis b.

$$e^2 = 1 - \frac{b^2}{a^2}$$

$$e = \frac{Ra - Rp}{Ra + Rp}$$

Ra = distance b/w center of earth and apogee point

Rp = distance b/w center of earth and perigee point.



$\Delta R = \pm e R_{av}$

for GEO, $R_{av} = 42164.17 km$, $e = 10^{-4}$

then $\Delta R = \pm 4.2 km$

* For LEO, $R_{av} = (800 + 3578.03) km$, $e = 10^{-4}$

$\Delta R = \pm 0.7178 km$

If orbit becomes less circular then $e = 10^{-3}$

then $\Delta R = \pm 7.178 km$ (↑es)

famous orbits has an eccentricity ≃ 0.74

(4) Molniya orbit:-

A new type of orbit was required to provide good communications coverage over the former USSR, transpired was Molniya system. The word Molniya means "flash of lightning."

fig@:- schematic of a molniya orbit

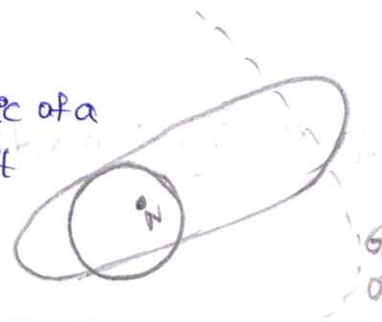
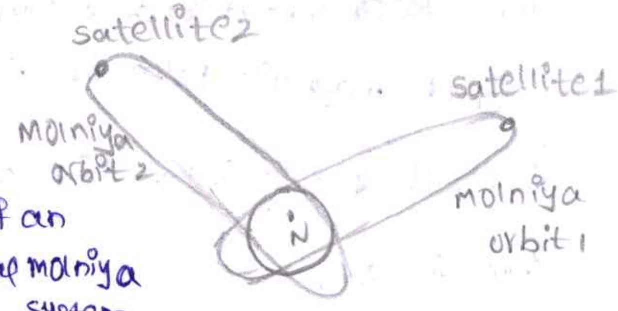


fig ⓑ:- schematic of an operational molniya system



$$\phi = \sin^{-1}\left[\sin\alpha \sin 78.5^\circ + \cos\alpha \cos(.69^\circ+\beta)\right]$$

α is geographic latitude
β is geographic longitude.

North & East coordinates are +ve
South & West " " -ve

Sunspots:- Sunspots are disturbances on the surface of the sunspots appear to generate huge outflows of energy from sun and amount of energy closely follows the number of sunspots (or) rather groups of sunspots.

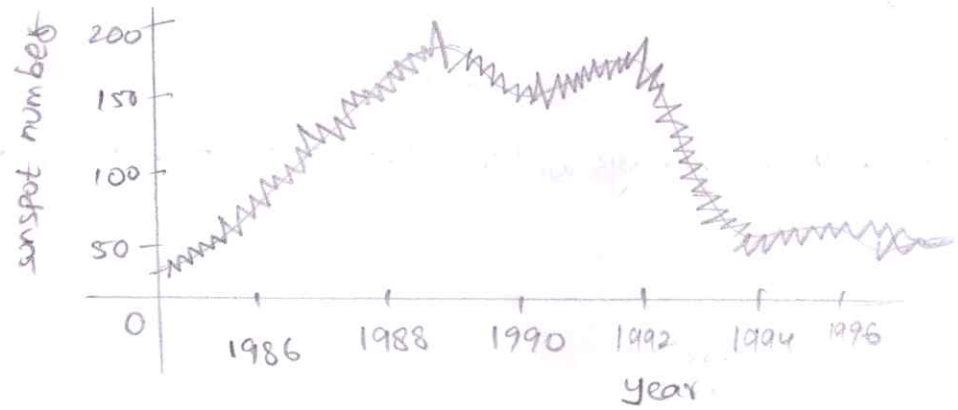


fig:- General variation of sunspot number over solar cycle 22

Van Allen radiation belts:-

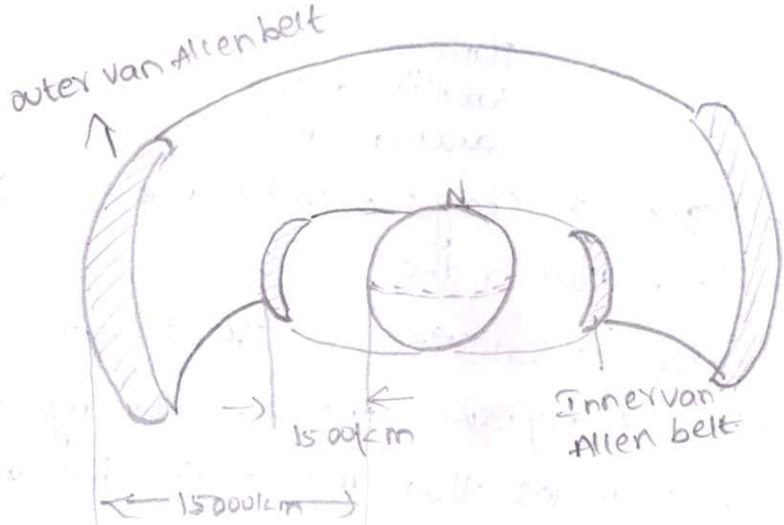


fig:- Pictorial representation of two van Allen belts.

(6) Sun synchronous orbit:- A sun synchronous orbit is a special form of LEO where the plane of the orbit maintains a contant aspect angle with the direction to the sun.

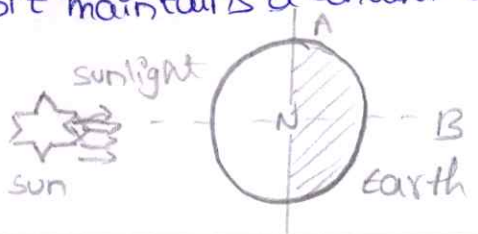
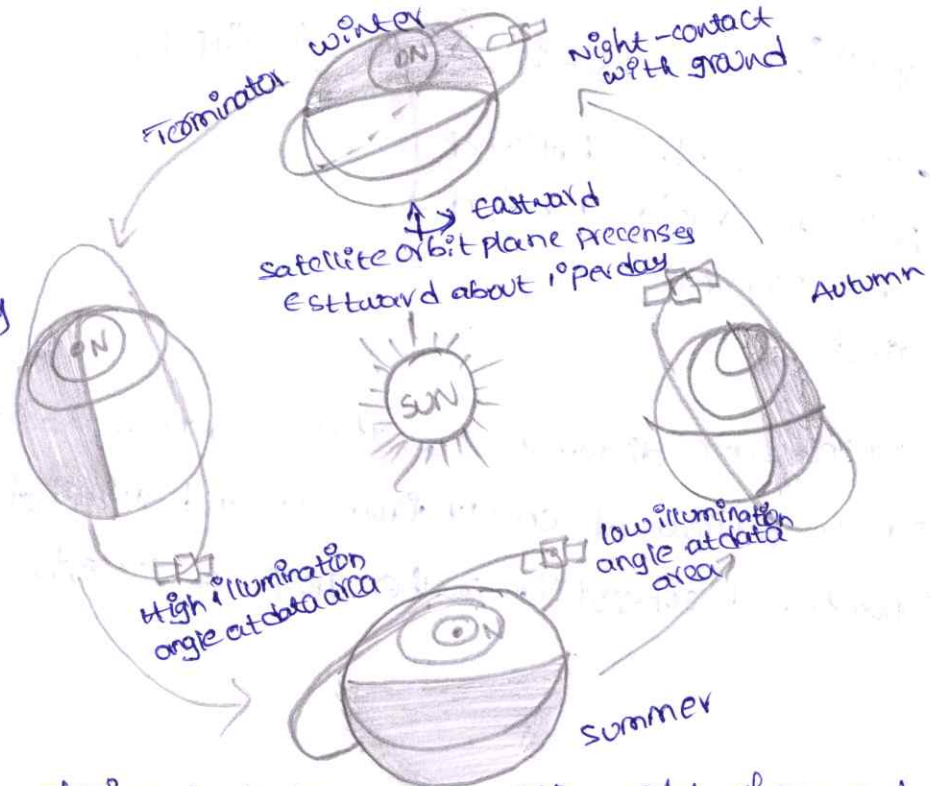


fig:- Examples of two sun synchronous orbits.



orbit A is designed to be always within sight of sun and so called sunset-sunrise orbit.

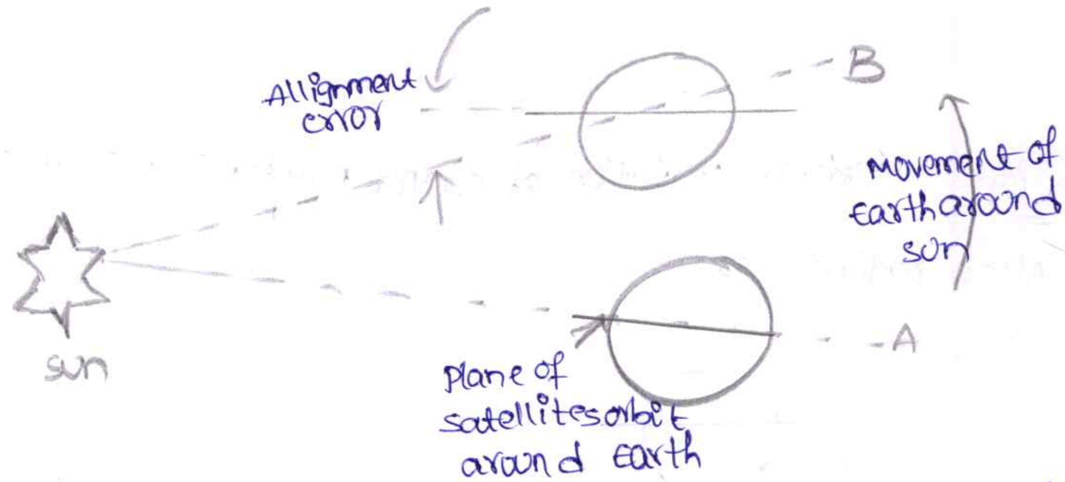


fig - Illusteation of allignment changes of orbital plane of a satellite due to the movement of earth around the sun.

→ sun synchronous orbit allows a satellite to pass over a section of the earth at the same time of day. since there are 365 days in a year and 360° in a circle. it means that the satellite has to shift its orbital plane by approximately one degree per day.

→ The orbit is designed to ensure that the angle b/w the orbital plane and the sun remains constant resulting in consistent lighting conditions.

Coverage and frequency considerations:-

$$\frac{r_s}{\sin(90+\theta)} = \frac{d}{\sin(\gamma)}$$

$$\cos\theta = \frac{r_s \sin(\gamma)}{d}$$

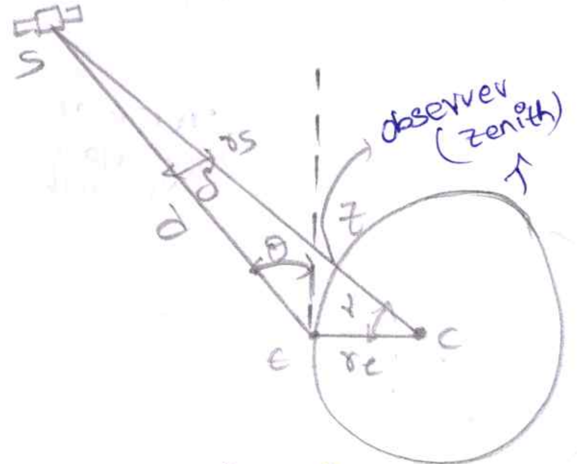


fig:- Geometry for calculating coverage area

frequency band:-

consider a LEO satellite with a coverage zone on the Earth's surface that has $A\,m^2$ output power P_t watts.

$G_t \rightarrow$ Gain of tx'ter (sat)

$$EIRP = G_t \cdot P_t$$

Avg flux density $F = \dfrac{P_t G_t}{A}$

$\downarrow$ independent of frequency

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

→ The received power at the mobile earth station is given by $P_r = F \times A$

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

Elevation angle considerations:-

INTELSAT requires that all earth stations uses C-band (6/4) GHz and elevation angle of 5°

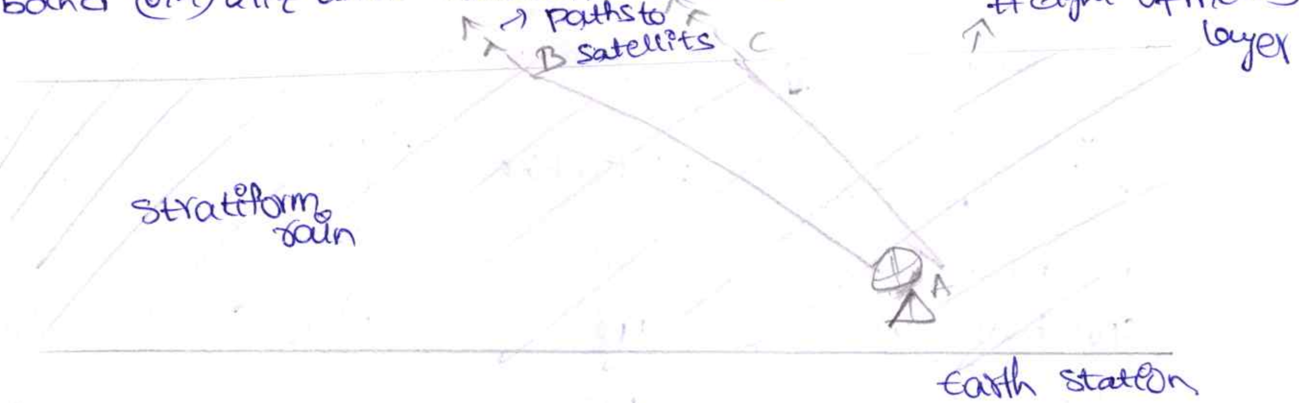


fig:- Illustration of the decrease in the path through rain as the elevation angle to the satellite increases.

The higher elevation angle path (AC) will therefore suffer less attenuation than the lower elevation angle path (AB).

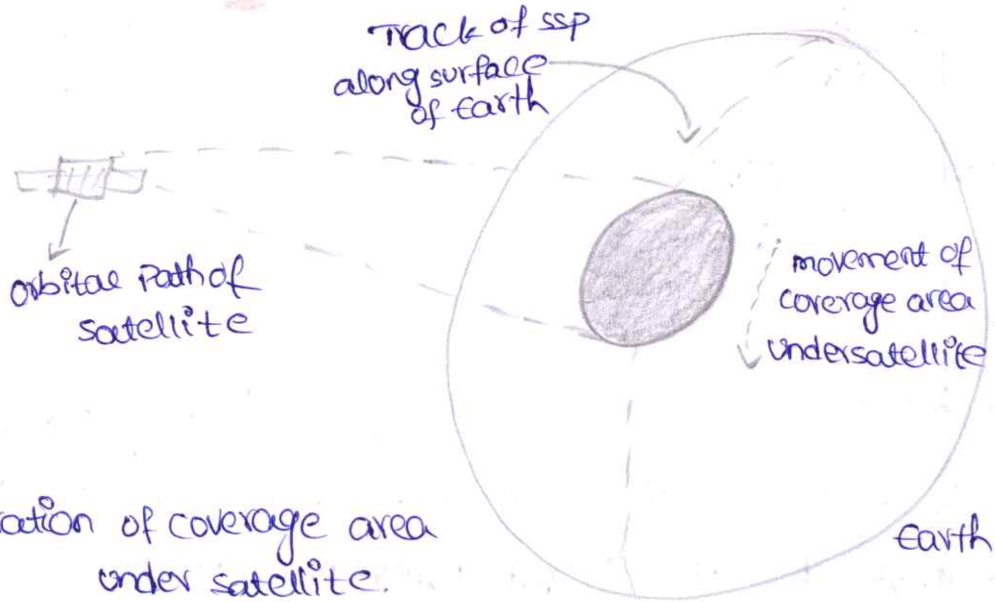


fig:- Illustration of coverage area under satellite.

Increasing the altitude of the satellites orbit will increases the coverage.

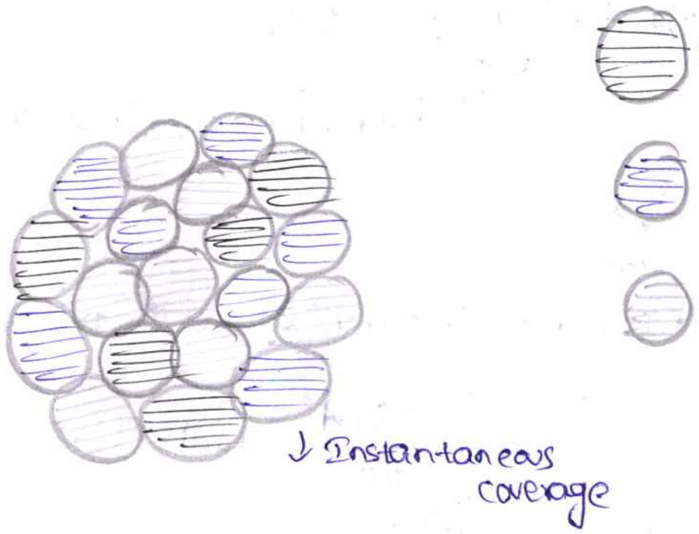


fig:- Illustration of a three cell reuse pattern

Number of Beams per coverage :-

Parameters	Iridium	Globalstar	New ICO.
mobile user link Freq (up/down) GHz	1.62135-1.6265	1.619-1.6215 2.4835-2.49985	1.980-2.010/ 2.170-2.200
max BW (MHZ)	5.15	11.35	30
spot beams per satellite	48	16	163
nominal capacity per sat (voice ckt)	1110	2400	4500
orbital altitude (km)	780	1414	10355

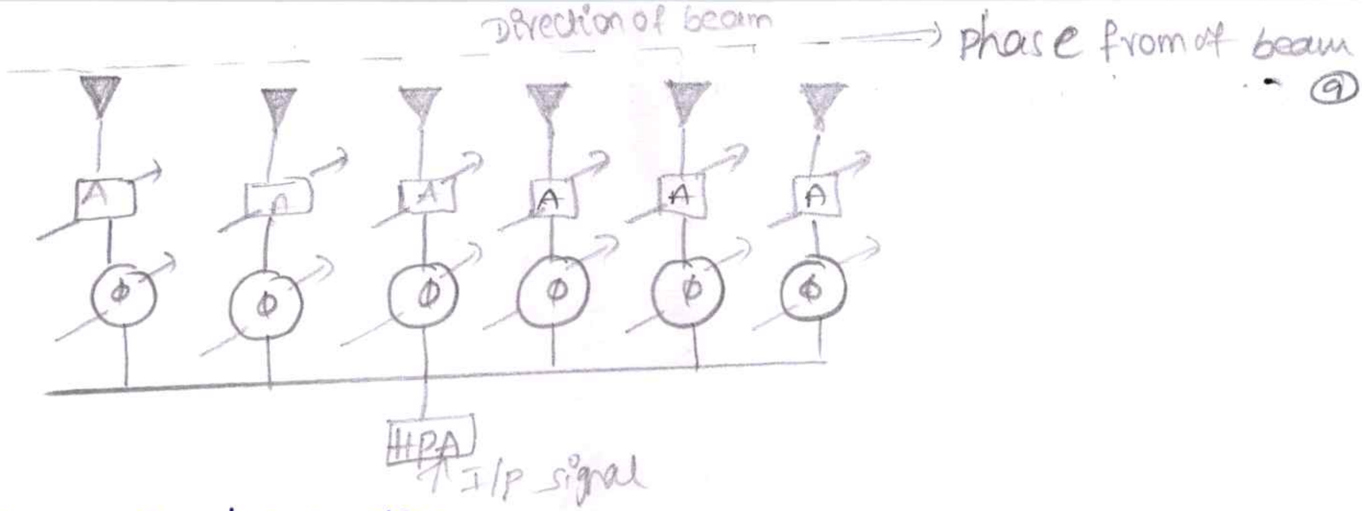


fig (a):- Passive phased array

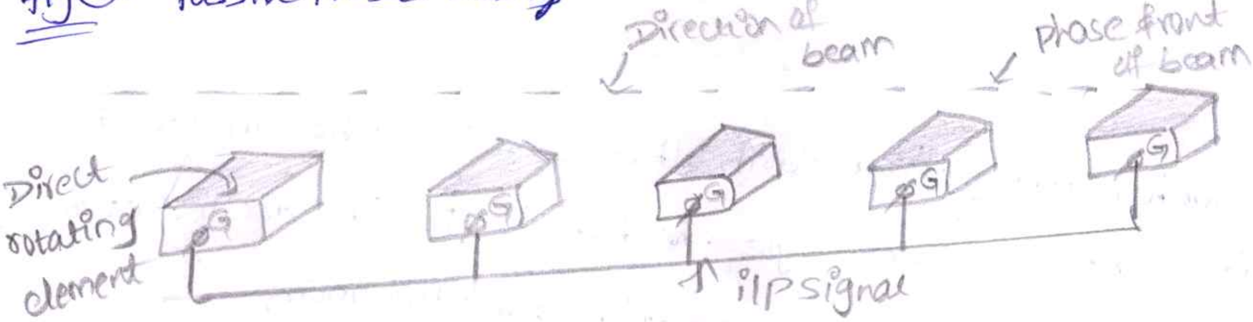
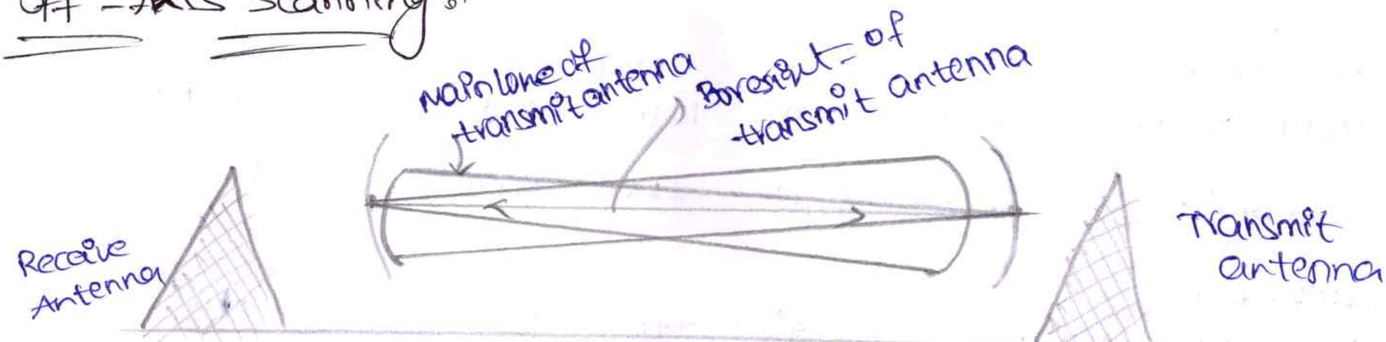
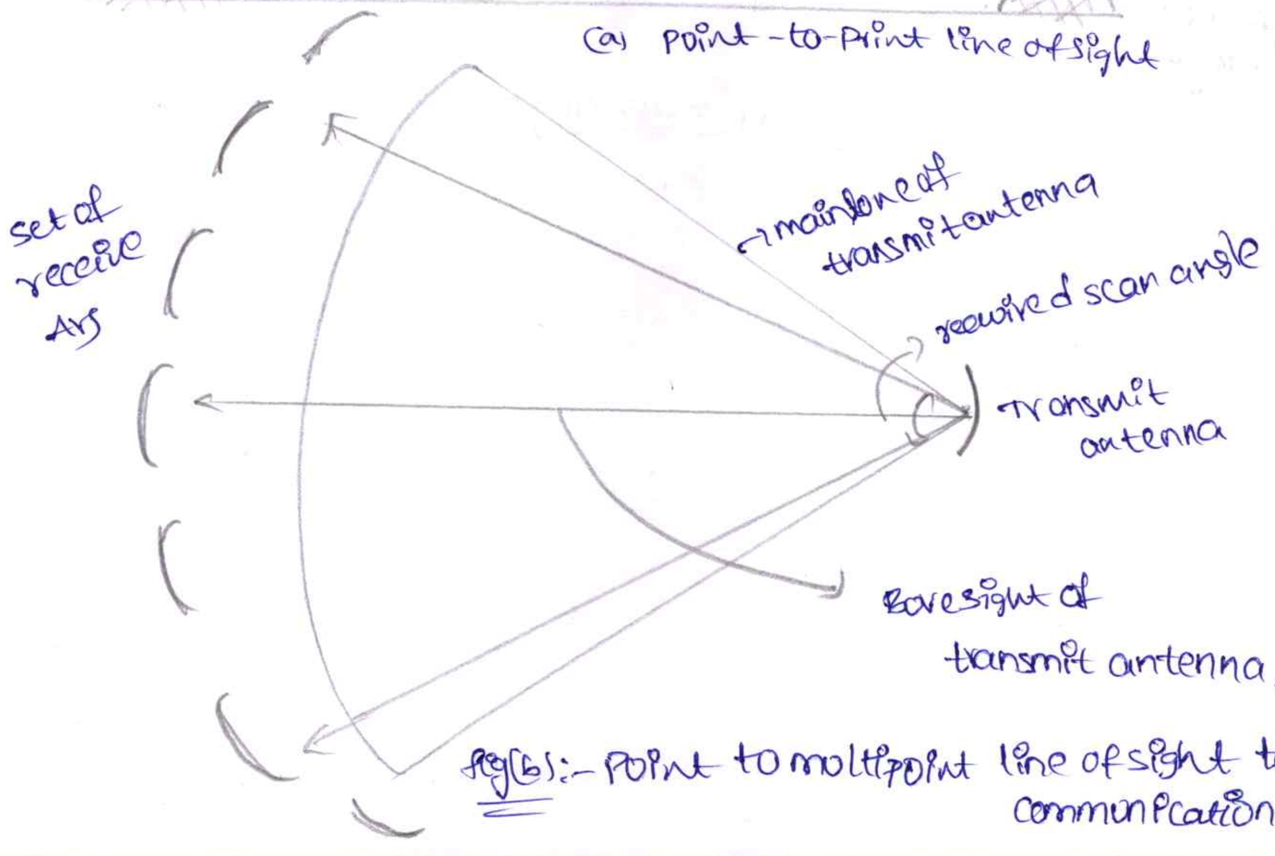


fig (b):- Direct radiating array.

Off-axis scanning:-

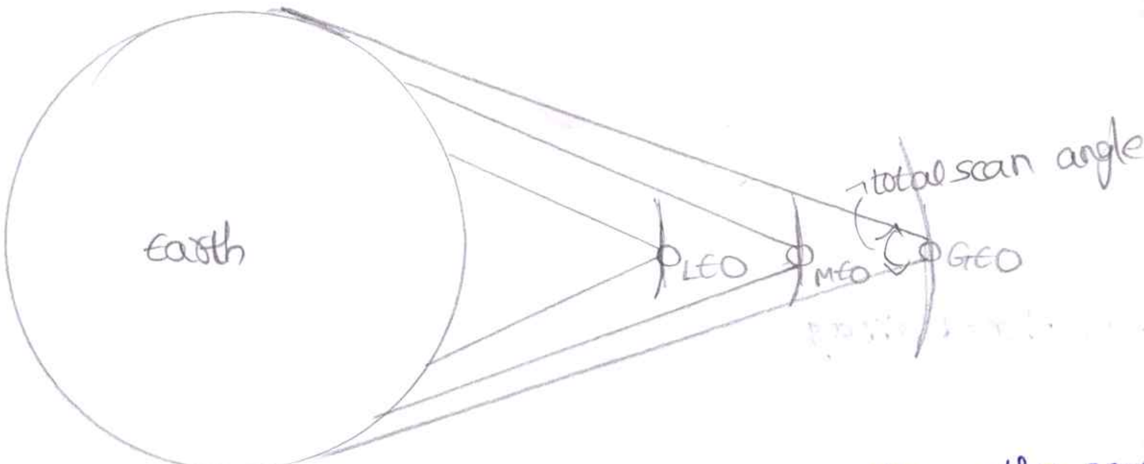


(a) Point-to-Print line of sight



fig(b):- Point to multipoint line of sight terrestrial communication link.

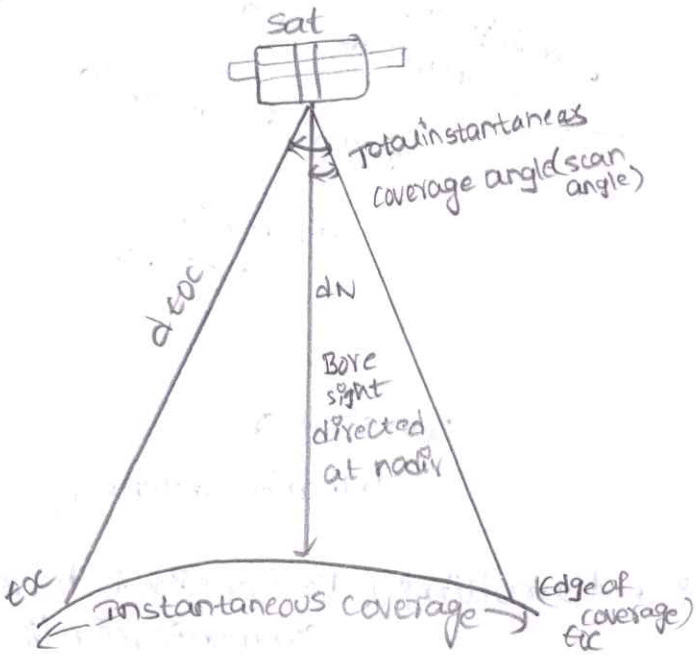
Schematic of total scan angle:-

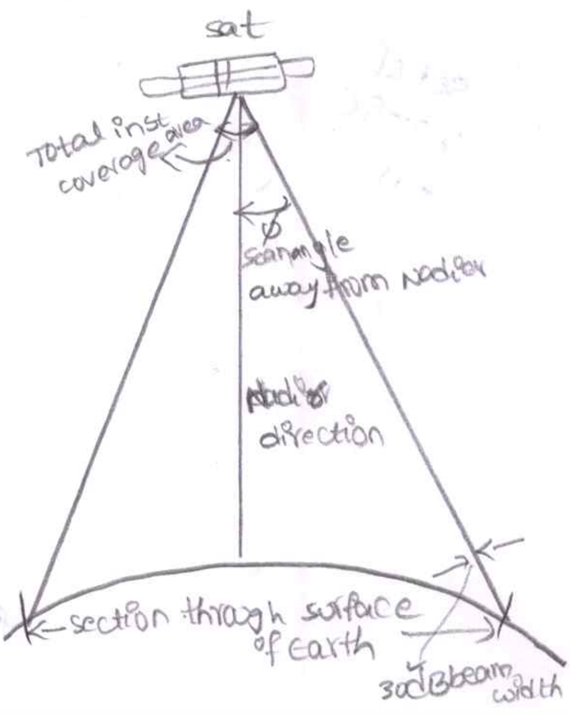


The further away from Earth the satellite the smaller the satellite antenna scan angle. needed to provide an instantaneous coverage out to a given user elevation angle minimum. scan angle and lattitude/longitude Ranges for Different satellite altitudes.

orbit and orbital height	LEO 750km	LEO 1800km	MEO 1000km	MEO 14000km	GEO 35786 km
scan angle	±57.2°	±47.1°	±21.5°	±17.1°	±8.25°
lattitude / longitude range	±12.8°	±22.9°	±48.5°	±52.9°	±61.8°

Illustration of Pathloss and scan angle loss:-





the instantaneous coverage. there are two factors to the considered.

(1) the gain loss due to not being at the center of the individual beam.

(2) the scan loss due to not being at the nadir point of the instantaneous coverage region.

- scanloss $= (\text{cosine}(\phi))^k$

ϕ is the scan angle off boresight for LEO

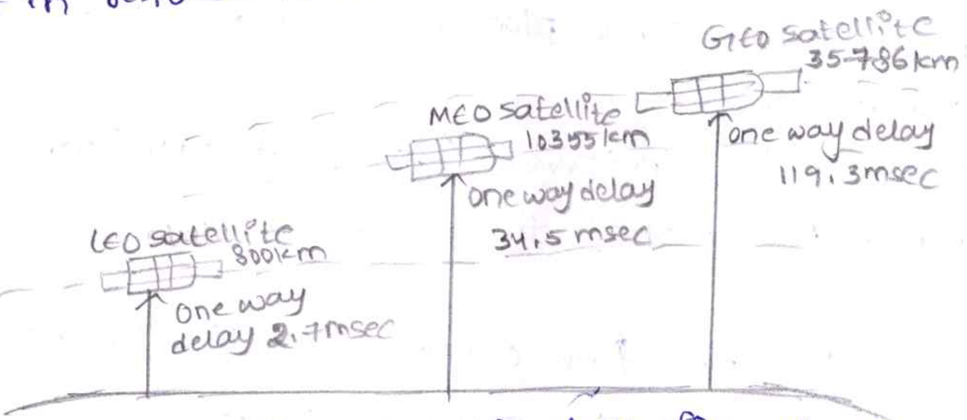
k is the Empirical number b/w 1.2 & 1.5 1.3

for example, a LEO system that needs to scan 57.2° away from boresight will have a scan loss.

- scan loss $= (\text{cosine}\, 57.2)^{1.3} = 0.4507 = -3.5\,dB$.

Delay and throughput considerations :-

Delay in a communications link is not normally a problem unless the interaction b/w the users are very rapid - a few milliseconds apart in response time.



Based on calculations shown in above fig, the time delay for a signal passing b/w LEO User 1 and LEO user 2 in the same instantaneous coverage is 5.4msec (2.7msec up and 2.7msec down) and go and return (round-trip) delay b/w two users is twice this i.e 10.8msec.

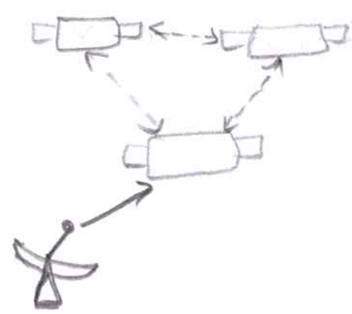
System throughput considerations :-

(*) Delay must be minimized.

(*) Proper communication protocol must be used to minimize loss of throughput.

(*) If ISL is to be used then proper matching across seam of links must be considered

ISL (Inter satellite link)



System considerations:-

There are four important factors that influence the design of any satellite communication system.

(1) Incremental growth
(2) Interim operations
(3) Replenishment options
(4) End-to-End system implementation

(1) Incremental growth :- INTELSAT organisation selected GEO satellite system rather then a 12 satellite MEO system ~~that was~~ supported by many cantories, that was driven by incremental growth plans as well as launcher technologes.

(2) Interiom operations :-

These operation serve two functions.

(1) They can bring a service online gradually introducing technology to the market while teething problems are sorted out.
(2) They can acts as a fall back plans, should multiple satellite failures occurs over a short period.

when a satellite fails in service there is an additional satellites must be launched to replenish the system.

Replenishment options:-

launching fine or more satellite to replace one failed satellite makes little economic ~~sensor~~.

End-to-end system implementations:-

AT&T and INTELSAT first didn't provide end-to-end mobile satellite services to users later NGSO satellites like Globalstar and Iridium dilute that.

Satellite Navigation & The Global Positioning System

Radio and Satellite navigation

① Navigation before Radio & GPS:

on land → compass and landmarks were used, but accuracy was low

At sea → sailors relied on the sun and starts for direction

Problems:

* shipwrecks due to poor accuracy.
* People lost in wilderness areas.
* Pilots of small aircraft relying only on maps and landmarks often got lost and ran out of fuel

② Military Need for Navigation System:

* 1930s Aircraft flying above the clouds they required radio-based navigation (compass/visual cues useless above clouds)
* WWII (world war II): Military strategy relied heavily on bomber aircraft to destroy enemy industries
* post-WWII: New weapons (nuclear bombs, ICBMS, cruise missiles) depend precise navigation to hit targets.

High military demand → accelerated devolpment of radio and later satellite navigation systems

③ civilian use of GPS:

* Although developed for military, majority of GPS users today are civilian.
* Applications: aviation, marine, vehicles, mobile devices
* worldwide GPS equipment market projected at $25 billion by 2005

④ Radio Navigation:

VOR (VHF omni Range):

* Defined "airways" for commercial aircraft
* still widely used in the U.S as a backup to GPS

GPS advantages:

* More accurate and reliable than VOR
* Direct point-to-point navigation
* Provide exact latitude/longitude

⑤ Differential GPS (DGPS):

* Enhances GPS accuracy by using reference station
* Replaces ILS (Instrument Landing system) for runway approaches
* Enables automatic landings in zero visibility
* Safe docking of ships in bad weather

⑥ Transit - predecessor satellite Navigation system:

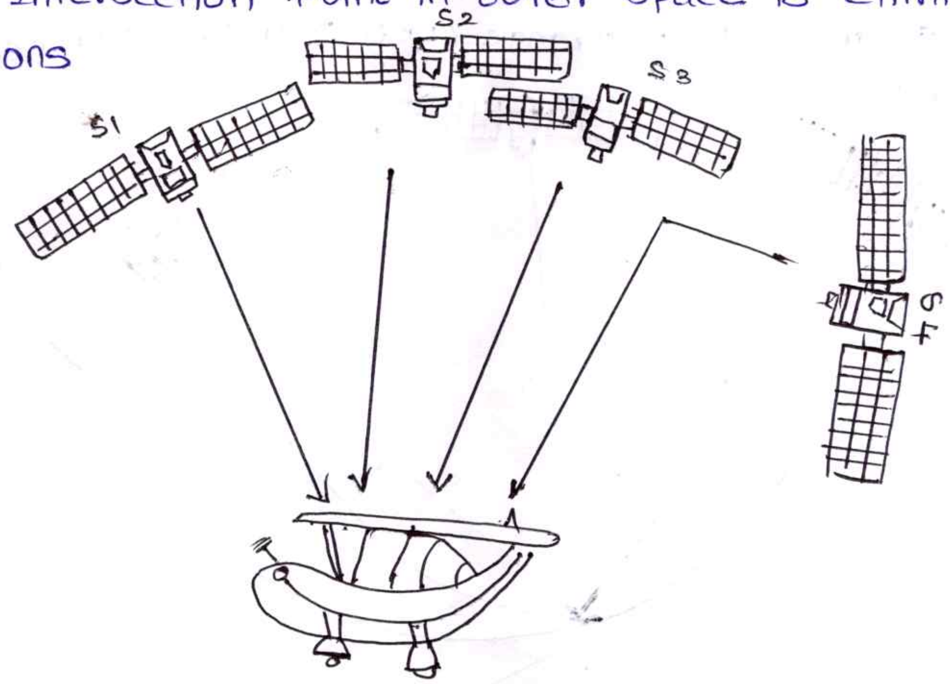
* Built for U.S. Navy ship navigation
* Used LEO satellites + Doppler shift to determine position
* Accuracy much lower than GPS
* Satellite velocity ~7.5 km/s → large frequency shift observed.
* Position calculated from Doppler shift over ~10 minutes + satellite orbit data
* Became obsolete when GPS introduced.

⑦ SARSAT (Search and Rescue Satellite):

* Designed to locate Emergency Locator Transmitters (ELTs) carried by aircraft
* LEO satellites pick up signal and send to rescue coordination centers
* 97% false alarms due to accidental activation / dropped devices
* Likely future: GPS + mobile/satellite phones expected to replace SARSAT.

GPS Position Location principles

* GPS require 4 Satellites : 3 for range, 1 for clock error correction.
* each distance R_i = radius of a sphere centered at a GPS satellite
* Receiver position = intersection of three spheres
* Locally, large-radius spheres appear as planes near earth.
* Intersection of three planes defines a unique point on earth
* Extra Intersection point in outer space is eliminated in calculations



* GPS range = time delay x velocity of EM waves
* Requires knowing signal transmit the time and having a synchronized reciver clock
* Each GPS satellite has four atomic clocks (accuracy ~1 in 10^5 - 10^6)
* GPS receivers use cheaper crystal oscillators
* Receivers clock offset introduces large range (10ms → 3000km).
* C/A code receivers sync to GPS time within 170ns
* Repeated measurments reduce error further below 50m
* clock error removed using a 4th satellite measurment

Three satellites → solve for position (x, y, z)

Fourth satellite → solves for receiver clock offset (τ)

Position Location in GPS.

* GPS uses the earth - centered Earth - Fixed (ECEF) cooridinate system
* origin of ECEF = center of Earth.
* z-axis passes through North pole
* x-axis passes through Greenwhich meridian (0° longitude)
* y-axis passes through 90° East ~~Medi~~ Meridian
* GPS receiver cooridinates = (U_X, U_Y, U_Z)
* GPS satellite coordinates = (x_i, y_i, z_i), $i = 1, 2, 3, 4$
* Measured distance = Pseudorange (PR_i) ? includes receiver clock offset error

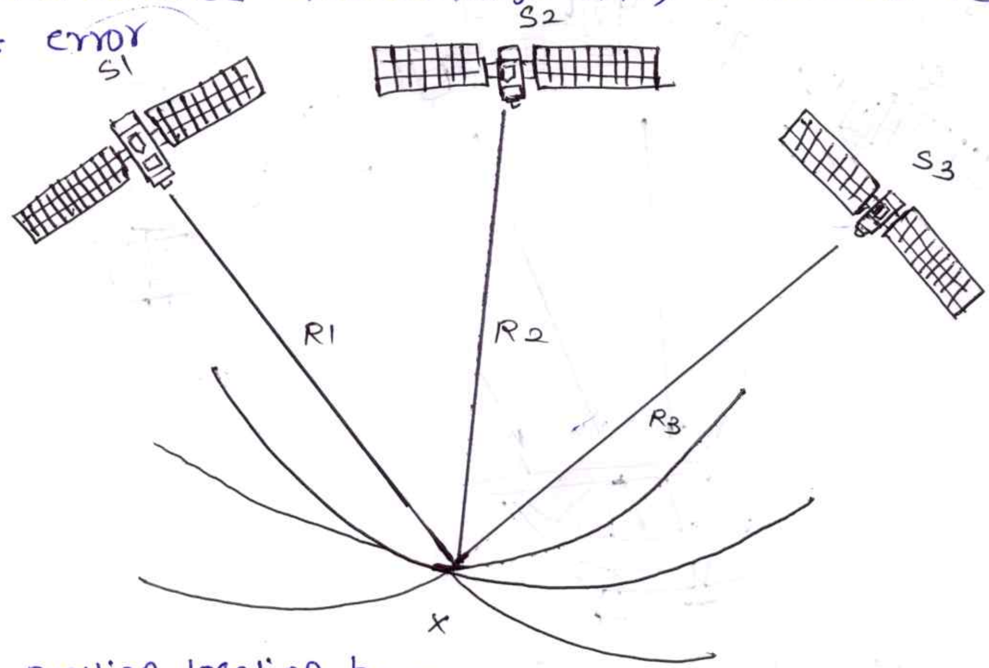


Fig:- Position location by measurment of the distance to three satellites.

Psuedorange, denoted as PR_i, is measured from the propagation time delay T_i between the satellite. GPS receiver, that EMI waves travel with velocity c.

$$PR_i = T_i \times c$$

The distance R between two points A and B in a rectangular coordinate system is given

$$R^2 = (x_A - x_B)^2 + (y_A - y_B)^2 + (z_A - z_B)^2$$

The equations which relate pseudorange to time delay are called ranging equations

$$(x_1 - U_x)^2 + (y_1 - U_y)^2 + (z_1 - U_z)^2 = (PR_1 - Jc)^2$$

$$(x_2 - U_x)^2 + (y_2 - U_y)^2 + (z_2 - U_z)^2 = (PR_2 - Jc)^2$$

$$(x_3 - U_x)^2 + (y_3 - U_y)^2 + (z_3 - U_z)^2 = (PR_3 - Jc)^2$$

$$(x_4 - U_x)^2 + (y_4 - U_y)^2 + (z_4 - U_z)^2 = (PR_4 - Jc)^2$$

GPS Time:-

* clock bias(T) from position calculation is added to receiver clock → syncs with GPS time
* GPS receiver crystal oscillators are stable short-term but drift with temparature and aging
* clock bias correlation updates the receiver clock every 1-2 seconds
* All GPS receivers are synchronized globally act as super clocks
* GPS time accuracy ≃ better than 40ns
* Atomic clocks use molecular resonance to stabilize crystal oscillators
* Satellite clocks updated by ground stations to within 1μs of UTC
* Navigation message includes satellite clock error info relative to GPS time.
* UTC = GMT, the global time standard

GPS Navigation Message

* Navigation message Key Feature of GPS C/A code, sent at 50 bps using BPSK.
* Structure 1500 bits = 30-s frame with 5 subframes
* Full data Needs 12.5 minutes to transmit, but key info repeats in each frame
* contents satellite clock data, orbital ephemeris, correction factors, neighbor satellite info
* Acquisition helps GPS receivers acquire signals and calculate accurate position.
* error reduction → Narrow bandwidth → high SNR (>17 dB above 10° elevation) → low bit errors
* Accuracy need: pseudorange accurate to 2.4m requires even more accurate satellite orbit calculation
* orbit model. Based on WGS-84 data
* stored data. All these parameters and corrections are stored in GPS receivers for position calculation

GPS Navigation Message: Subframe Details

Header	Telementary. message: health of Satellite, handover word
subframe 1	Satellite clock correction data. Age of transmitted data
subframe 2 and 3	Ephemeris for this satellite
subframe 4	Almanac data for Satellites 25 and higher. Isnospheric model data
subframe 5	Almanac data for Satellites 1-24. Health data for satellite 1-24

GPS Receivers and codes

1. Carrier Frequency (L1):

- All GPS satelites transmit on the L1 frequency: 1575.42MHz
- This frequency is 154 times the master clock frequency (10.23 MHZ)

2. Modulation scheme:

- GPS signals use Binary phase shift Keying (BPSK) modulation

3. C/A code (coarse/Acquisition code):

- Transmitted on the L1 frequency
- Each satelite uses a unique pseudorandom Noise (PN) code.

4. Relativistic correction:

- Frequencies ~ 0.005 Hz lower to offset satelite motion (3.865 km/s)

5. P code:

- Transmitted on L2 (1227.6 MHZ = 120×10.23 MHZ)
- Also on L1, in quadrature with C/A code.

6. Multiple Access:

* Uses different PN codes for each satelite.

7. spread spectrum:-

* DS-SS systems - signals overlaid in L1 and L2 bands.

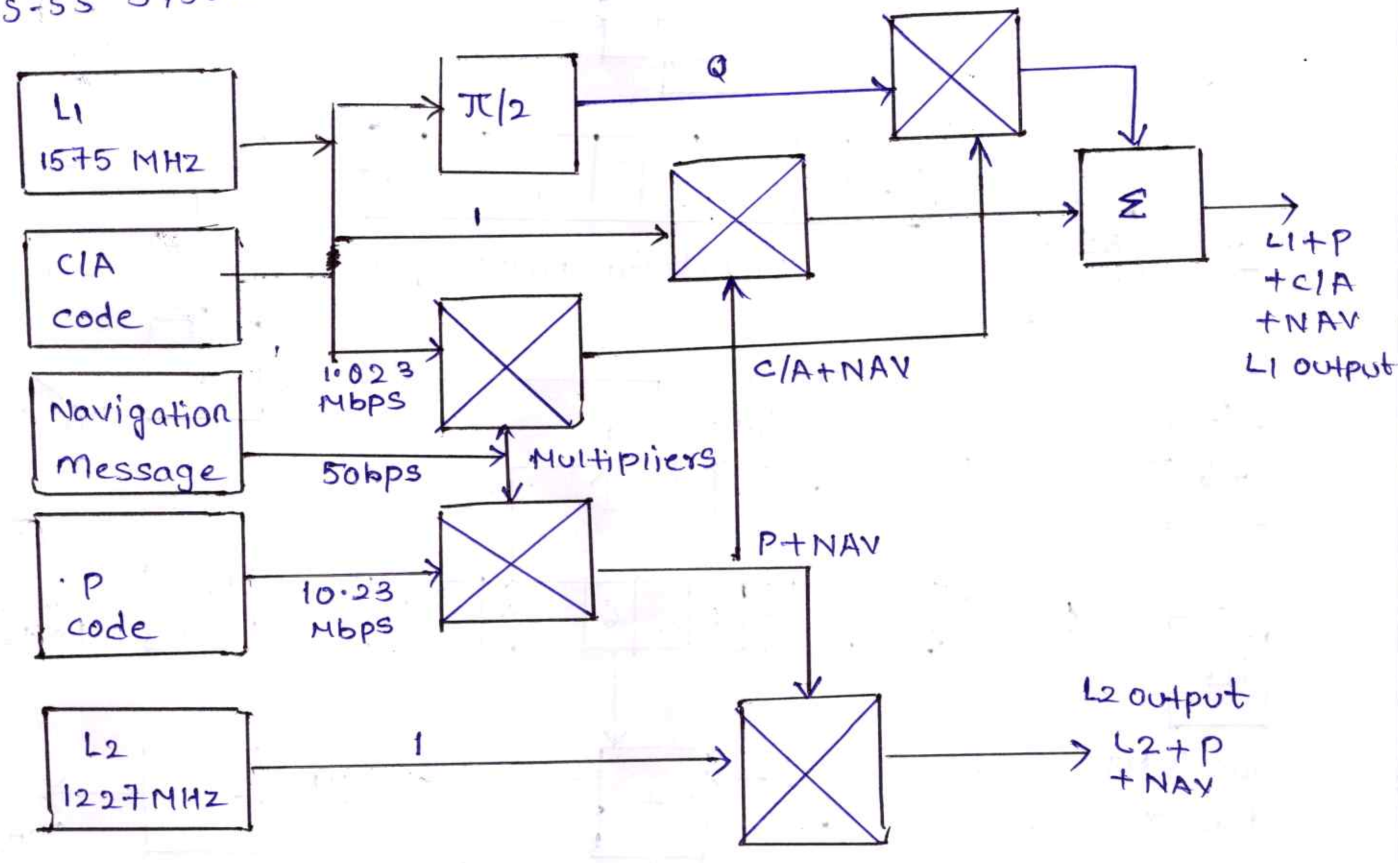


Fig: Signal generation in a GPS Satellite

The C/A code :-

* The coarse / Acquisition (C/A) code is a pseudorandom noise (PRN) code transmitted by each GPS satellite.
* It helps the receiver identify which satellite is sending the signal.
* All GPS C/A codes are 1023-bit Gold codes.
* A Gold code is formed by combining two maximum-length sequences (m-sequences)
* m-sequence = maximum-length pseudorandom (PN) sequence
* Generated using a shift register with feedback taps.
* A shift register with n stages produces a sequence of length $2^n - 1$.
* GPS C/A codes are formed using two 10-bit shift registers, generating sequences G1 and G2.
* Both G1 and G2 are 1023 bits along (since $2^{10} - 1 = 1023$)
* The C/A code is created by multiplying G1 and G2 sequences with different time offsets..
* C/A code = G1 × G2 (with time offsets).

Each satellite gets a unique code based on its PRN ID.

$c_i(t) = G1(t) \times G2(t + 10 i T_C)$

where T_c = clock period for the C/A code.

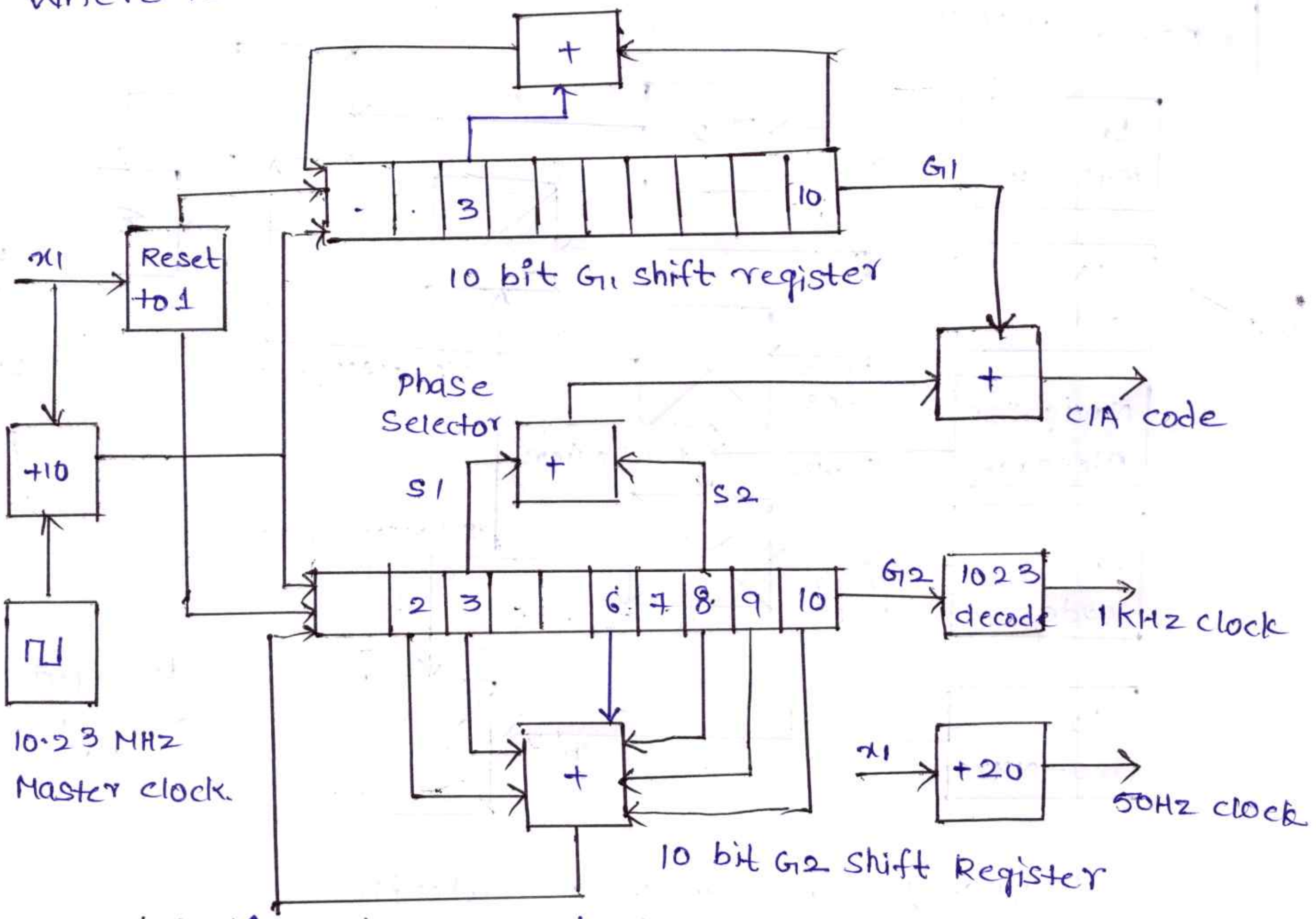


Fig: C/A code generator

* Orrelator function searches for the desired C/A code ⑤ sequence, reject others.
* zero cross-correlation ideal would give rejection ratio of 1023.
* practical case 64 available sequences, 37 selected with lowest cross-correlation.
* Low auto correlation sidelobes important for spread-spectrum systems.
* C/A code length = 1ms corresponds to 300 km range in space.
* code repetition repeats every 300 km causes ambiguity only in outer space.
* Ambiguity resolution aproximate reciever location removes confusion.
* User input entering rough location helps resolve ambiguities faster.
* Receiver antenna usually a circularly polarized patch antenna with LNA
* Receiver architecture conventional superhet, down convert to IF.
* Band width IF signal in about 2MHz range.
* Sampling uses I/Q sampling techinques for digital processing.
* Digital section includes C/A code generator, correlator, and microprocessor.
* Microprocessor role - makes timing measurement and computes position.
* commercial receivers typically 12-channel IC chip sets, cost about $25 (in 2000)

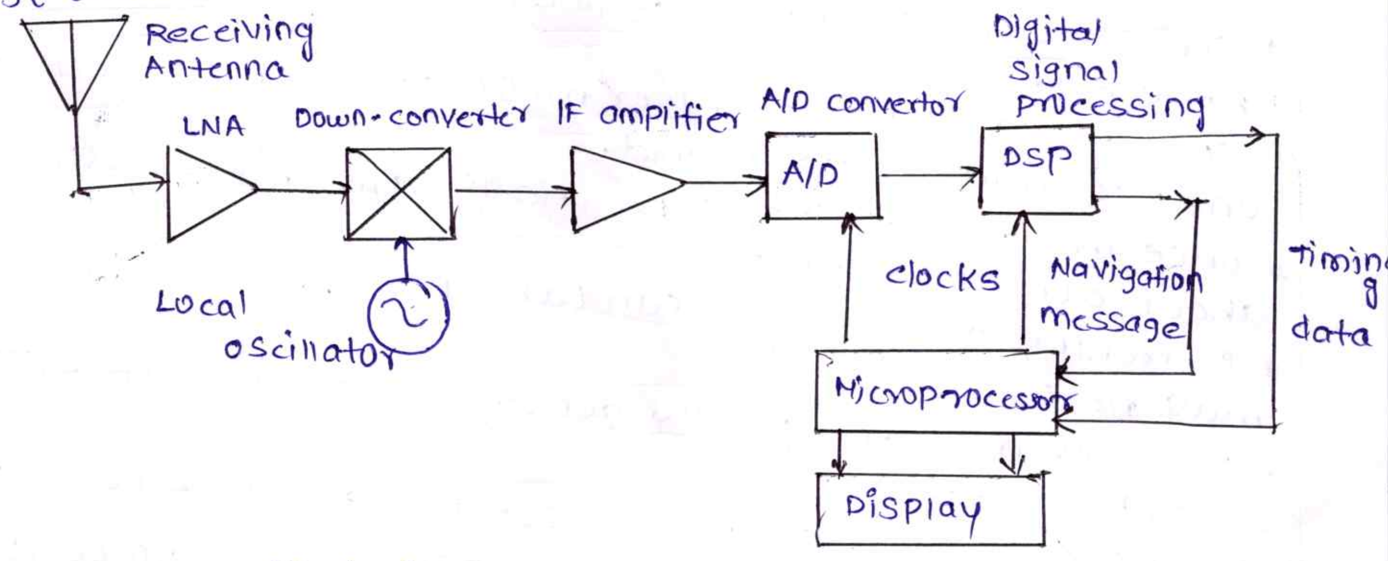


Figure: Simplified GPS receiver

Satelite Signal Acquisition:-

* GPS receiver must find the starting time of the unique C/A code for atleast 4 satelites.
* This is done by correlating received signals with stored C/A codes.
* Receiver usually select the 4 strongest signals for correlation.
* Low-cost receivers sequential acquistion and timing (one satelite at a time)
* Advanced receivers parallel correlators (e.g..12) acquire multiple satelites at once.

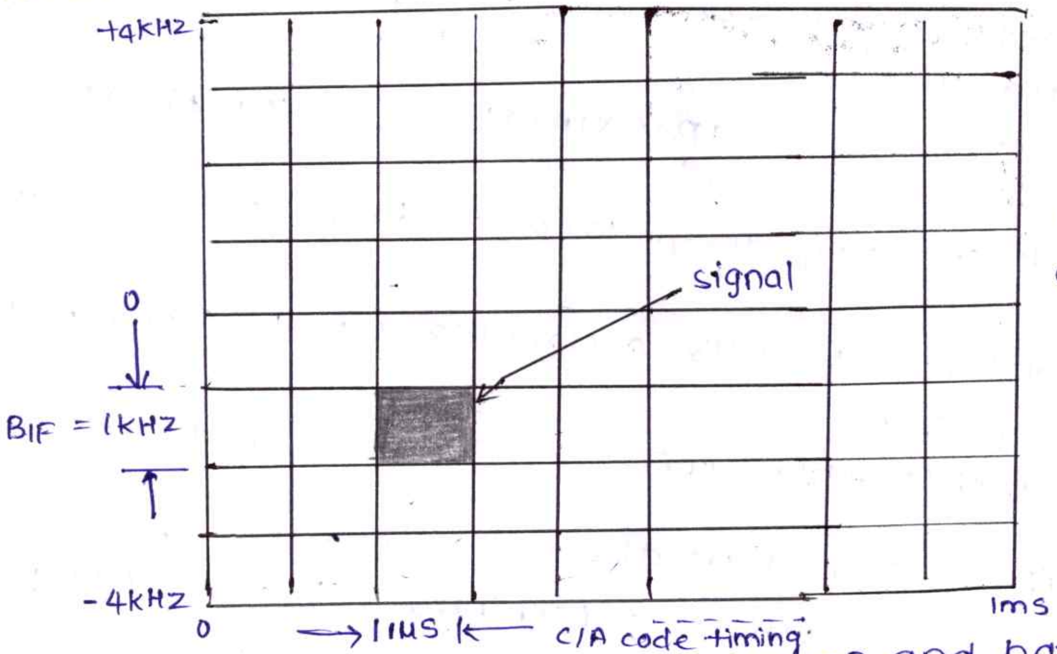


Fig: code synchronization and doppler tracking matrix

up and battery accuracy.
* parallel acquisition faster start
* Integrity monitoring uses a 5th satelite to verify position consistency.
* If one measurement disagree, it is eliminated; if multiple disagree, integrity is compromised.
* Aircraft navigation in IMC requires integrity monitoring.
* P-code generated similarly to C/A code.
* If satelite geometry is poor, weaker signals may also be used.
* In a cold start, receiver must search all 37 C/A codes until correlation is found.
* once the code is acquired, navigation message reveals info about other satelites.
* searching all 36 codes can take time; on average, 16 codes may be tried.
* Receiver matches locally generated code with received code (bit-by-bit)
* unknown code start time must try all 1023 code positions.
* If wrong start code shifted one bit, retried up to 1023 times.

* If no correlation that satelite not visible.
* searching 1023 bits takes 1 second; first satelite may take ~15 seconds to acquire.
* some receivers retry codes multiple times acquisition may takes minutes.
* After first lock, other satelites acquired quickly using navigation data.
* Average lock time per satelite ≈ 20 seconds.
* must also correct for Doppler frequency shift before correlation.
* Theoretical noise bandwidth of C/A receiver = 1.023 MHz
* GPS satelite velocity = 3.865 km/s
* max velocity component toward receiver ≈ 928 m/s at horizon
* max Doppler shift on L1 = ±4.872 KHz (ignoring Earth rotation).
* practical use: limit satelites to elevation > 5°, Doppler ≈ ±4KHZ
* From cold start receiver must try 8 Doppler frequency bins in ±4 KHZ range.
* Doppler search step ≈ ±500Hz (13 Hz resolution per step in tracking.)
* Total search space = 1023 code phases x 8 Doppler bins = 8184 states.
* Acquisition of first satelite may take several minutes.
* once one satelite acquired navmessage gives data of neighbours speeds up acquisition.
* Receiver may still search Doppler shift for other satelites, but C/A codes already known.
* GPS receivers retain last known position and nav message when powered off.
* on restart assumes position near last known, searches expected satelites first.
* If moved far while off requires cold start again (longer acquisition.)

$$\boxed{p_i(t) = X_1(t) + X_2(t + iT_C)}$$

* T_C = periods of X_1 sequence = 15,345,000 bits, repeats every 1.5 sec.
* X_2 sequence = 37 bits longer than X_1.
* P-code repeats after 266.4 days, but is changed every 7

days for security.

* Long p-code length makes distance measurements unambiguous.
* p-code cannot be easily acquired does not repeat (anti-unauthorized use.)
* C/A code gives authorized users info on p-code start time.
* This info is in the navigation message as an encrypted handover word.
* with decrypted handover word + feedback taps receiver alligns x-code generators.
* This enables rapid p-code acquisition.
* Name "C/A code" = coarse Acquisition code (assists p-code lock.)

GPS Receiver operation

* Accurate timing of Gold code arrivals is key to precise positioning.
* All GPS receivers use a microprocessor for calculations and display contool.
* Most GPS receivers use IC chipsets with 12 parallel correlators can track 12 satelites simultaneously.
* parallel correlators keep signals synchronized and improve accuracy.
* Simpler receivers may use a single correlator process satelites sequentially, with lower accuracy.
* Received GPS signals are down-converted to IF frequency in the front end.
* The IF signal in the GPS receiver will consist of the sum of a number (up to 12) of signals from visible GPS satelites.
* The IF carrier signal has several BPSK modulations applied to it by the satelite, and when received on earth has been Doppler shifted by satelite and earth motion.
* The IF signal from N GPS satelites in view is

$$s(t) = \sum_{i=1}^{N} \{A_i C_i(t) D_i(t) \sin[(\omega_i + \omega_d)t - \phi_i(l_i) + \phi_i]\}$$

where A_i is the amplitude of the received signal.

$C_i(t)$ is the Gold code modulation

$D_i(t)$ is the navigation message modulation

$\omega_i(t)$ is the frequency of the received carrier.

ω_d is the doppler shift of the received signal

$\phi_i(l_i)$ is the phase shift along the path.

ϕ_i is the phase angle of the transmitted signal. (7)

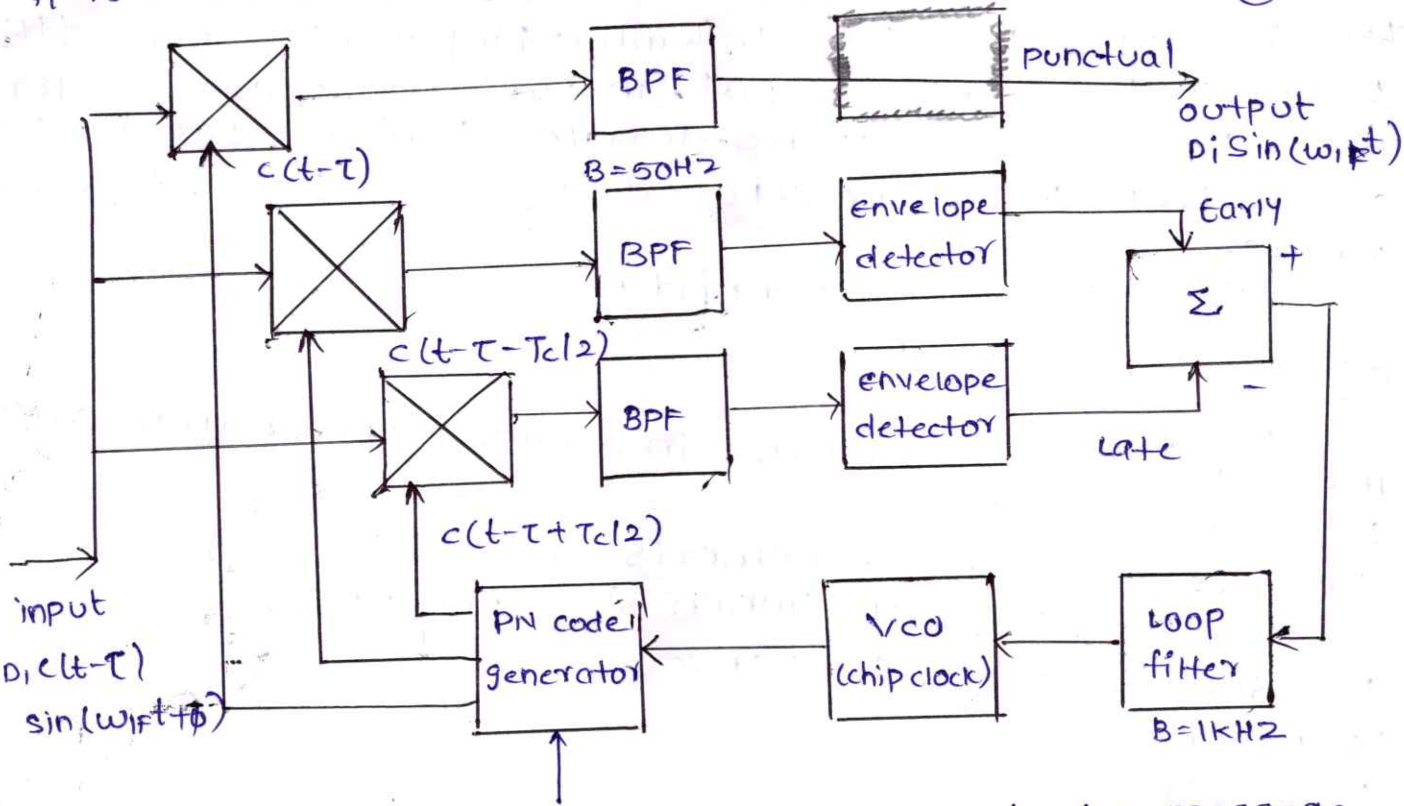


Figure: Noncoherent code lock loop and navigation message recovery. VCO, Voltage controlled. oscillator.

* The logically generated carrier must match the doppler shift, C/A code, and start time of the received signal.
* At startup, these parameters are unknown and must be searched.
* GPS signals are below noise level, so direct analysis is not possible.
* Receiver searches all Doppler shifts, code sequences, and code phases until correlation occurs.
* once one satelite is acquired, its navigation message helps acquires others.
* on restart, the receiver uses stored satelites configuration and elapsed time to predict parameters.

The output of the C/A code correlator with Doppler corrected IF frequency for the satelite signal with code number m is

$x(t) = A_m R(\tau_m - \tau) D_m(t) \sin[\omega_m(t) - \phi_m(t_m) + \phi_m] + n(t)$

The despread IF carrier is BPSK modulated by the navigation message $D_m(t)$

$y(t) = A_m R(\tau_m - \tau) D_m(t) \sin[\omega_m(t) - \phi_m(t_m) + \phi_m] + n(t)$

The IF carrier signal is limited to remove any amplitude variations, which sets $A_1 = 1$. Then

$y'(t) = R(\tau_m - \tau) D_m(t) \sin[\omega_m(t) - \phi'_m] + n(t)$

The navigation message D(t) is recovered by multiplying the IF signal $y'(t)$ by $\sin[\omega_m(t) - \phi'_m]$ and low pass filtering to obtain the 50 bps signal. The reference carrier for the BPSK demodulator can be derived from the output of the costas loop. The demodulated message signal is $z(t)$ where

$$z(t) = R(T_m - \tau) D_m(t) + n'(t)$$

GPS code Accuracy:-
C/A

The major sources of error in a GPS receiver that calculates its position are:

Satelite clock and ephemeris errors.
Selective availability (when switched on)
Ionospheric delay (aduance)
Tropospheric delay
Receiver noise
Multipath.

Range Error for C/A code measurement.

Satelite clock error	3.5
Ephemeris errors	4.3
Selective availability	32.0
Ionospheric delay	6.4
Troposheric delay	2.0
Receiver noise	2.4
Multipath	3.0
Rms range error	33.4 with SA
[Rms range error	9.5m without SA].

Dilution of Precision: HDOP, VDOP, and GDOP

*HDOP → Horizontal accuracy (X-Y plane) typical Value ≈ 1.5, smallest error factor

* VDOP → vertical accuracy (Z-axis), degrades when satellites are near horizon

*GDOP → overall geomentry effect; poor sky view increases all DOPs.

*PDOP = Position accuracy (3D), TDOP = Time accuracy.

*Aircraft need good VDOP

*GPS Satellite orbits are designed to minimize high DOP probability

GPS Signal Levels

* Antenna gain low gain, must be omnidirectional; assume worst case $G = 0\,dB$
* Antenna noise → omnidirectional pickup → temp ≈ 273K
* LNA very low temp (~25K), mounted close to antenna to avoid cable losses
* Antenna types → circularly polarized patches / quadrafilar helices, cutoff below 10° elevation to reduce ground noise
* Processing gain → From despreading:
    * C/A code : 1.023 Mbps → 30.1 dB gain
    * P code : 40.1 dB gain
* Interference from satellites signals from other satellites act like noise due to low cross-correlation of Gold codes
* Worst case → weak low-elevation satellite signal vs strong high-elevation signals.
* Receiver strategy → selects strongest visible to avoid worst case errors.

Timing Accuracy

~~Time~~ The position location process requires an accurate measurement of the of arrival of the code sequence at the receiver. The accuracy with which a timing measurment can be made on a single pulse is given by the

$$\delta t \simeq \frac{1}{[B_n \sqrt{S/N}]} \text{ seconds}$$

The S/N ratio after the correlator is

$$S/N = C/N + G_p - \text{losses}$$

where G_p is the correlator processing gain. For the C/A code $G_p = 1023 = 30.1\,dB$ and

$$S/N = -19.3 + 30.1\,dB - \text{losses}$$

$$= 11.7\,dB - \text{losses}$$

If we assume the specification value for S/N of 11.7 dB and losses of 1.7dB, S/N = 10dB, a power ratio of 10. The theoretical noise bandwidth of the correlator is = 1MHZ

$$\delta t = 1/[10^6 \sqrt{10}]s = 0.316 \mu s.$$

Differential GPS

* Differential GPS improves GPS accuracy and removes selective Availability (SA)
* Needs a reference station at a known position plus user receiver
* Simple DGPS: station sends x, y, z corrections accuracy ~~improve~~ improves from 100m to ~10m
* Advanced DGPS: station sends pseudorange errors → accuracy 5m
* Phase (kinematic) DGPS: uses carrier phase comparison. Accuracy to cm level
* Ambiguity issue solved using P code and C/A code
* Used in land surveying and aircraft precision approach paths
* WAAS (Wide Area Augementation system, FAA):
  * 24 reference stations compute pseudorange errors
  * Data uplinked to GEO satellites
* WAAS signals similar to L1 GPS signals → standard GPS receivers can use them
* DGPS autoland tested on Boeing 737/757 in late 1990s
* Cargo aircraft expected to adopt DGPS autoland first
* Autoland with DGPS often gives better landings than pilots
* Future: DGPS likely to make blind landings in zero visibility common