SATELLITE COMMUNICATION

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IV Year - II Semester	L	T	P	C
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SATELLITE COMMUNICATIONS

OBJECTIVES

The student will be introduced to:

1. Understand the basic concepts, applications, frequencies used and types of satellite communications.
2. Understand the concept of look angles, launches and launch vehicles and orbital effects in satellite communications.
3. Understand the various satellite subsystems and its functionality.
4. Understand the concepts of satellite link design and calculation of C/N ratio.
5. Understand the concepts of multiple access and various types of multiple access techniques in satellite systems.
6. Understand the concepts of satellite navigation, architecture and applications of GPS.

UNIT I

INTRODUCTION [2] : Origin of Satellite Communications, Historical Back-ground, Basic Concepts of Satellite Communications, Frequency allocations for Satellite Services, Applications, Future Trends of Satellite Communications.

ORBITAL MECHANICS AND LAUNCHERS[1] : Orbital Mechanics, Look Angle determination, Orbital perturbations, Orbit determination, launches and launch vehicles, Orbital effects in communication systems performance.

UNIT II

SATELLITE SUBSYSTEMS[1] : Attitude and orbit control system, telemetry, tracking, Command and monitoring, power systems, communication subsystems, Satellite antenna Equipment reliability and Space qualification.

UNIT III

SATELLITE LINK DESIGN[1] : Basic transmission theory, system noise temperature and G/T ratio, Design of down links, up link design, Design of satellite links for specified C/N, System design example.

UNIT IV

MULTIPLE ACCESS[1][2] : Frequency division multiple access (FDMA) Intermodulation, Calculation of C/N. Time division Multiple Access (TDMA) Frame structure, Examples. Satellite Switched TDMA Onboard processing, DAMA, Code Division Multiple access (CDMA),Spread spectrum transmission and reception.

UNIT V

EARTH STATION TECHNOLOGY[3] : Introduction, Transmitters, Receivers, Antennas, Tracking systems, Terrestrial interface, Primary power test methods.

LOW EARTH ORBIT AND GEO-STATIONARY SATELLITE SYSTEMS[1] : Orbit consideration, coverage and frequency considerations, Delay & Throughput considerations, System considerations, Operational NGSO constellation Designs

UNIT VI

SATELLITE NAVIGATION & THE GLOBAL POSITIONING SYSTEM [1] : Radio and Satellite Navigation, GPS Position Location principles, GPS Receivers and codes, Satellite signal acquisition, GPS Navigation Message, GPS signal levels, GPS receiver operation, GPS C/A code accuracy, Differential GPS.

TEXT BOOKS:

1. Satellite Communications – Timothy Pratt, Charles Bostian and Jeremy Allnutt, WSE, Wiley Publications, 2nd Edition, 2003.
2. Satellite Communications Engineering – Wilbur L. Pritchard, Robert A Nelson and Henri G.Suyderhoud, 2nd Edition, Pearson Publications, 2003.

REFERENCES :

1. Satellite Communications : Design Principles – M. Richharia, BS Publications, 2nd Edition, 2003.
2. Satellite Communication - D.C Agarwal, Khanna Publications, 5th Ed.
3. Fundamentals of Satellite Communications – K.N. Raja Rao, PHI, 2004
4. Satellite Communications – Dennis Roddy, McGraw Hill, 2nd Edition, 1996.

Outcomes:

At the end of this course the student can able to:

1. Understand the concepts, applications and subsystems of Satellite communications.
2. Derive the expression for G/T ratio and to solve some analytical problems on satellite link design.
3. Understand the various types of multiple access techniques and architecture of earth station design.
4. Understand the concepts of GPS and its architecture.

UNIT-I

Introduction and orbital Mechanics and launchers: A brief history of satellite communications, Orbital mechanics, look angle determination, Orbital perturbations, Orbit determination, launch and launch vehicles, Orbital effects in communication system performance

UNIT-II

Satellites:- Satellite sub systems, Attitude and Orbit Control system (AOCS), Telemetry, Tracking, Command & Monitoring, Power systems, communication subsystems, satellite antennas.

Multiple access techniques:- Introduction, FDMA, TDMA, DAMA, Random Access.

UNIT-III

Satellite link Design: Basic transmission theory, System noise temperature and G/T ratio. Design of down links, Satellite systems using small earth stations, Uplink design, Design for specified c/N: Combining c/N and c/I values in satellite links.

VSAT systems: Introduction, overview of VSAT systems, Network Architectures, Access control Protocols, Basic techniques, VSAT earth station engineering.

UNIT-IV

Satellite Navigation and Global positioning system: Introduction Radio and satellite Navigation, GPS position location Principles, GPS receivers and codes, Satellite signal Acquisition, GPS

Navigation message, GPS signal levels, Timing Accuracy, GPS receiver operation, GPS c/A code accuracy, Differential GPS.

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UNIT-I

→ 1945. Arthur c clarke provide an article

Satellite communication began in October, 1957, with the launch by the U.S.S.R of a small satellite called <u>spurnik 1</u>. spurnik 1 carry only a Txer and didn't have communication capabilities.

The first satellite successfully launched by the USA was ~~EXPLORER 1~~ SCORE (35 days) on January 31, 1958. → first communication satellite ECHO I & II were launched as floating balloons. They are passive satellites.

The true communication satellites <u>TELSTAR I & II</u> were launched in <u>1962</u>. and 1963. These satellites were built by BELL Telephone laboratories. → In 1963 first geostationary satellite SYNCOM was launched by Nasa and US Dept of Defense.

The orbit choosen for The TELSTAR satellities caused early failure of the electronics on board.

The most critical step was in August 1962, when the U.S congress passed the communication satellite Act. This set the stage for commercial investment in an international satellite organisation, on July 19, 1964; first 12 countries, to investing <u>Intelsat</u> (International Telecommunication satellite Organisation).

The first 'INTELSAT' satellite was launched on April 16, 1965. The satellite weighed <u>36 kg</u> and incorporated two <u>6/4</u> GHz, transponder.

<u>CANADA</u> was the first country to build a national telecommunication system using '<u>GEO</u>' SATELLITE.

<u>ANIK 1A</u> was launched in May, 1974.

The commercial success of 'INTELSAT' let many nations to invest in satellite systems, within the 25 years, INTELSAT has 145 countries as members.

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In 1970's and 1960's, there was rapid development of 'GEO' satellite systems for international region and domestic region, telephon traffic and video distribution.

Types of satellites:-

1) Natural satellites Eg:- Moon.

~~2) Artificial satellites.~~

Based on orbit of earth, satellites are classified as:-

1. Geostationary satellite (GEO)
2. Medium earth orbiting satellite (MEO)
3. Low earth orbiting satellite (LEO)
4. Highly elliptical orbiting satellite (HEO)
5. Polar orbiting satellite.

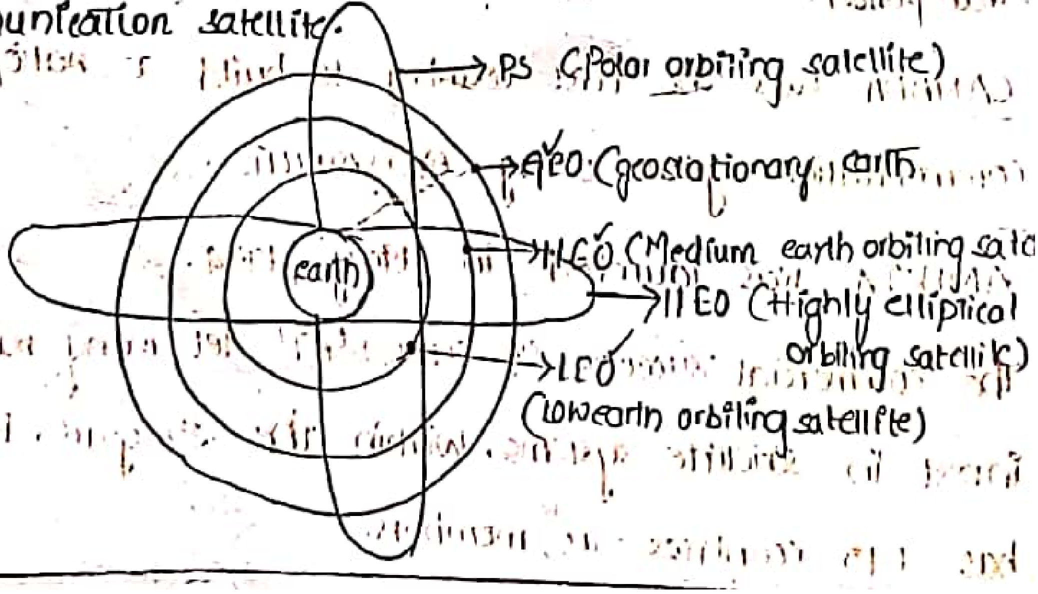
Based on applications, they are classified as:-

1. Remote sensing satellite.
2. Meteorological satellite.
3. Navigation satellite.
4. Scientific & Military satellite.
5. Communication satellite.

C-band

1. Planes of orbit

1. Equitorial plane
2. Inclined plane.
3. Polar plane.



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The geostationary satellites are placed above equator at a distance of 36,000 kms.

The 'MEO' satellites operate at a distance of about 5000 to 12000 kms.

The 'LEO' satellites placed at an altitude of 500 to 1500 kms and it uses advanced compression schemes with a transfer rate of 2400 bits/second.

The 'HEO' comprises with a relatively low altitude perigy (nearest) and extremely high altitude apeogy (farest).

The polar satellites orbit from Northern hemisphere to southern hemisphere, inclined about 86° with an orbital period of 18hrs.

3 ORBITAL MECHANICS:-

The fundamental newton equation describe the motion of a satellite. We will give some co-ordinate axis within which the orbit of the satellite can be set and determine various forces on earth's satellite.

Newton's law of equations are

$$s = ut + \tfrac{1}{2}at^2 \quad \text{①}$$

$$v^2 = u^2 + 2as \quad \text{②}$$

$$v = u + at \quad \text{③}$$

$$F = ma \quad \text{④}$$

where s : distance travelled from t=0

u : initial velocity at time t=0.

v : final velocity at time t = T.

a : acceleration

F : force acting on the object.

m : mass of the object:

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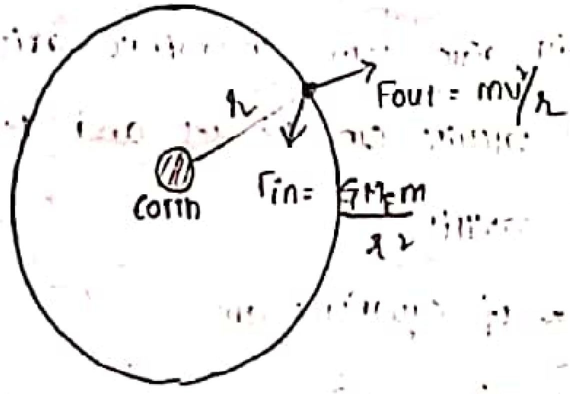
The last equation ④ describes the motion of the satellite in a stable orbit. It states that force acting on a body is equal to mass of the body multiplied by the resulting acceleration of the body.

In a stable orbit, there are two main forces acting on a satellite. A centrifugal force due to kinetic energy of the satellite and a centripetal force due to gravitational attraction which attempts to pull the satellite down towards the planet. If these two forces are equal, the satellite will remain in a stable orbit.

The satellite has a mass of 'm' and is travelling with the velocity 'v' in the plane of the orbit is shown below.



The acceleration by the kinetic energy of a satellite is

$$a = v^2/r \quad \text{⑤}$$

∴ the centrifugal force $(F_{out}) = ma = \frac{mv^2}{r}$ ⑥

The acceleration due to gravity is $a = \mu/r^2$, where

μ is the product of universal gravitational constant (G) and mass of the earth.

∴ The centripetal force $(F_{in}) = ma = \frac{mGM_E}{r^2}$ ⑦

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If the forces of the satellite are balanced,

$$F_{in} = F_{out}$$

$$\Rightarrow \frac{mGM_E}{r^2} = \frac{mv^2}{r}$$

$$\boxed{v = \sqrt{\frac{GM_E}{r}}}$$

If the orbit is circular, the distance travelled by the satellite in one orbit is '$2\pi r$'.

$\therefore$ The orbital timeperiod of the satellite $(T) = \frac{2\pi r}{v}$

$$T = \frac{2\pi r}{\sqrt{\mu/r}} = \frac{2\pi (r)^{3/2}}{\mu^{1/2}}$$

$$\boxed{T = \frac{2\pi (r)^{3/2}}{(\mu)^{1/2}}}$$

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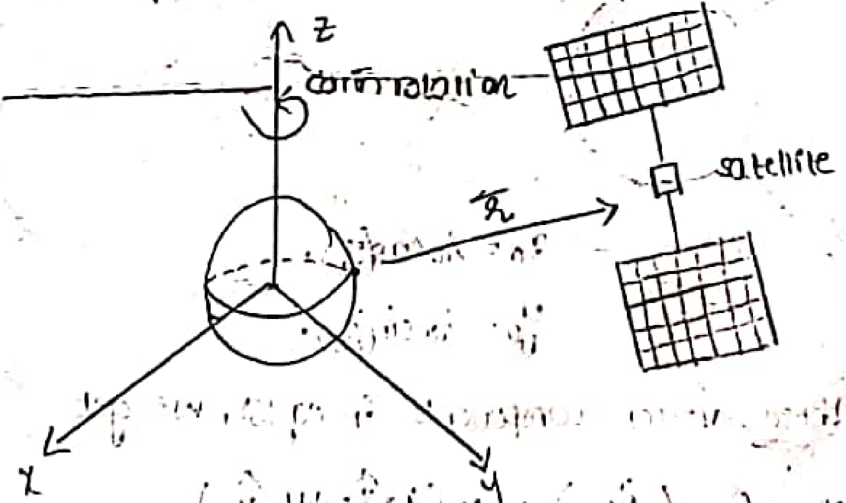
* Equation for the Radius of satellite:-

The initial coordinate system that could be used to describe the relationship b/w the earth and the satellite is the cartesian coordinate system. A cartesian coordinate system with geographical axis of of the earth as principle axis is shown below.



If the satellite of mass 'm' located at a vector distance r from the centre of the earth.

The gravitational force "F" on the satellite is given by

$$\bar{F} = \frac{-GM_E m \bar{r}}{r^3} \quad \text{——(1)}$$

But the force due to kinetic energy of the satellite is

$$\bar{F} = \frac{m d^2(\bar{r})}{dt^2} \quad \text{——(2)}$$

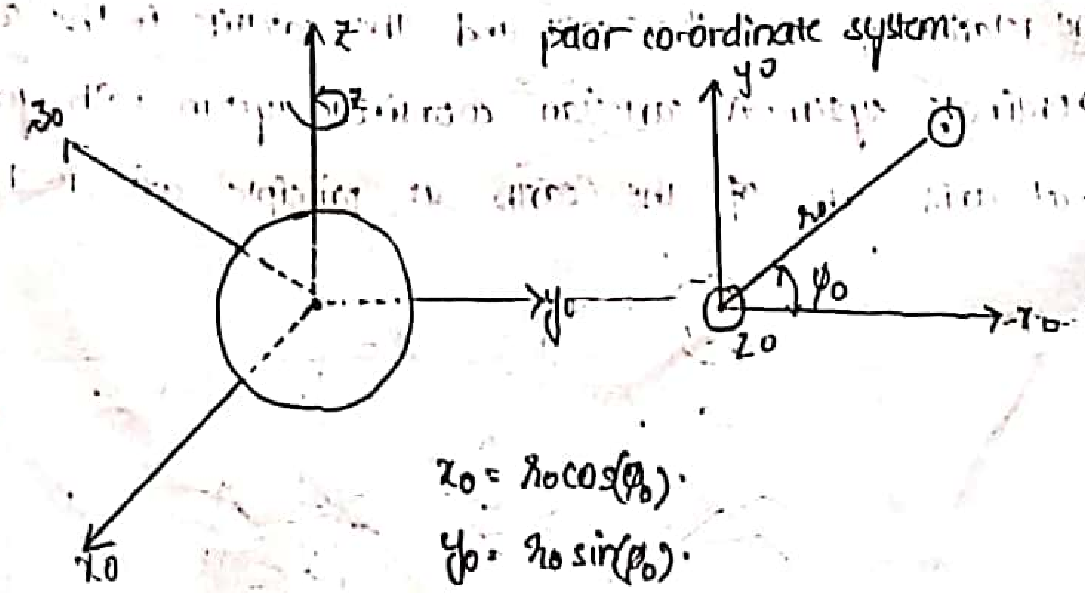
∴ From the eq ① & ②, we have,

$$\frac{-GM_E m\bar{r}}{r^3} = \frac{m d^2\bar{r}}{dt^2}$$

$$-\frac{\bar{r}}{r^3}\mu = \frac{d^2\bar{r}}{dt^2} \quad [\text{where: } GM_E = \mu]$$

$$\frac{d^2\bar{r}}{dt^2} + \frac{\bar{r}}{r^3}\mu = 0 \quad \text{——(3)}$$

This is the 2nd order linear differential eq and its solution will involve six undeterminant constants called orbital elements. The solution to eq 3 is difficult. In order to solve this eq, a different set of co-ordinates can be chosen, which is known as polar co-ordinate system.



$$x_0 = r_0\cos(\phi_0)$$

$$y_0 = r_0\sin(\phi_0)$$

Substituting these vector components in eq(3), we get

$$\hat{x}_0\left(\frac{d^2x_0}{dt^2}\right) + \hat{y}_0\left(\frac{d^2y_0}{dt^2}\right) + \frac{\mu(x_0\hat{x}_0 + y_0\hat{y}_0)}{(x_0^2+y_0^2)^{3/2}} = 0 \quad \text{——(4)}$$

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The solution for the above equation will give the equation for the radius of the satellite 'r_0', as

$$\boxed{r_0 = \frac{p}{1+e\cos(\phi_0-\theta_0)}}$$

where θ_0 is a constant

• e is the eccentricity of ellipse, whose semiletus rectum p is given by

$$\boxed{p = h^2/\mu}$$

where h is the magnitude of the orbital angular momentum of the satellite.

Kepler's laws of planetary motion:-

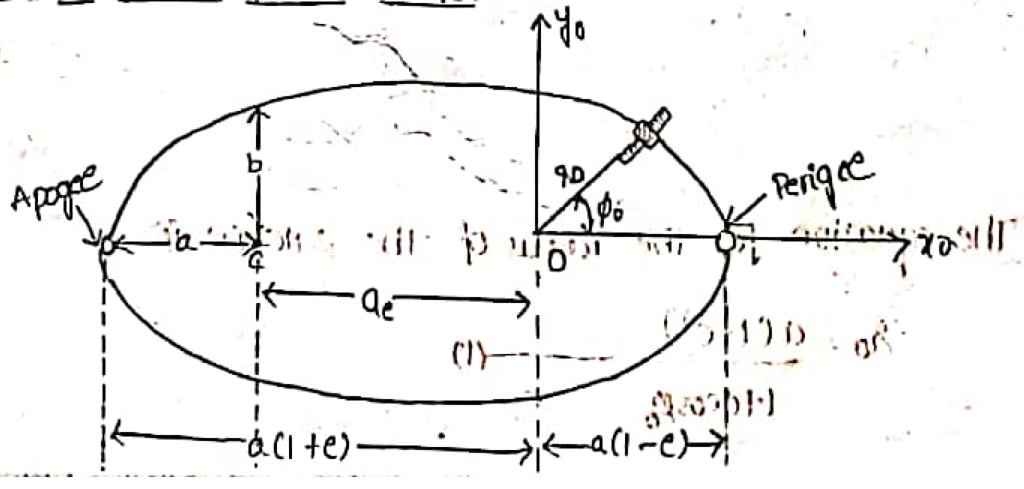
Law1: The orbit of any smaller body about a larger body is always an ellipse, with the centre of the larger body as one the two foci.

Law2: The orbit of the smaller body sweeps out equal area in equal time.

Law3: The square of the period of revolution of the smaller body about the larger body equals a constant multiplied by the third power of the semi-major axis of the orbital ellipse i.e,

$$T^2 = \frac{4\pi^2 a^3}{\mu} \qquad a: \text{radius}$$

Describe the orbit of a satellite:-



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The eq. for the radius of the satellite is

$$\boxed{r_0 = \frac{p}{1+e\cos(\phi_0-\theta_0)}}$$

The quantity θ_0 serves to orient the ellipse with respect to the orbital plane axis x_0 and y_0. We always choose x_0 & y_0 plane so that $\theta_0 = 0$. Then the equation of the radius of the orbit becomes

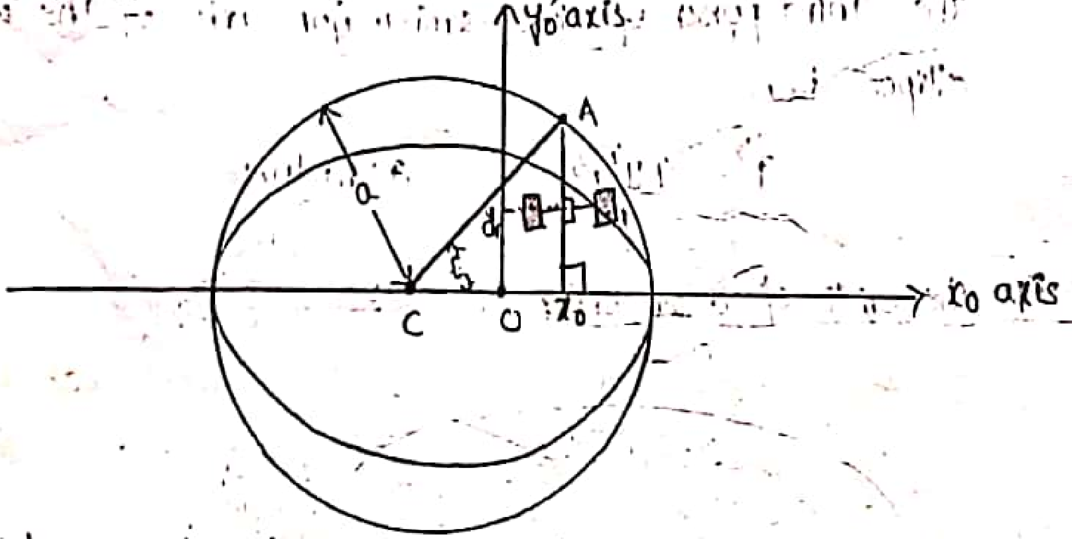
$$\boxed{r_0 = \frac{p}{1+e\cos(\phi_0)}}.$$

The lengths a & b of the semi major and semi minor axis are given by

$$\boxed{a = \frac{p}{1-e^2}} \qquad \boxed{b = \frac{a}{p}(1-e^2)^{1/2}}$$

The point in the orbit where the satellite is closest to the earth is called 'perigee' and the point where the satellite is farthest from the earth is called 'apogee'. The pt 'o' and 'c' is the centre of the earth.

Locating the satellite in the orbit



The equation for the radius of the satellite is

$$\boxed{r_0 = \frac{a(1-e^2)}{1+e\cos\phi_0}} \text{———} (1)$$

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The rectangular co-ordinates are given by

$$\boxed{x_0 = r_0 \cos\phi_0 \; ; \; y_0 = r_0 \sin\phi_0}$$

To be perfectly geostationary orbit, the orbit of a satellite need to have 3 features.

1) It must be exactly circular.
2) It must be in the plane of equator.
3) It must be at a certain altitude.

So, we projected the satellite onto the circumscribed.

A line from the centre of the ellipse to the pt of projection 'A' makes an angle E with x_0 axis, and 'E' is called eccentric anamoly. In order to calculate the eccentric anamoly, 1st we need to calculate mean anamoly, which depends on the angular velocity & time of perigee.

$$\boxed{M = \eta(t - t_p) = E - e\sin E}$$

The average angular velocity $(\eta) = \frac{2\pi}{T}$

where $T = \frac{2\pi a^{3/2}}{\mu^{1/2}}$

$$\eta = \frac{2\pi \mu^{1/2}}{2\pi a^{3/2}}$$

$$\boxed{\eta = \frac{\mu^{1/2}}{a^{3/2}}}$$

If we know the time of perigee (t_p), eccentricity (e) and length of the major axis (a), we determine the co-ordinates (r_0, ϕ_0) and (x_0, y_0).

The process is as follows.

- First of all, calculate angular velocity.

- Calculate Mean anamoly.
- Calculate eccentric anamoly.

The relationship b/w the eccentric anamoly & radius r_0 is

$$\boxed{ae\cos(E) = a - r_0}$$

- Find r_0, using the above relation.
- Solve eq (1) to calculate ϕ_0.
- Calculate x_0 & y_0 using the relations

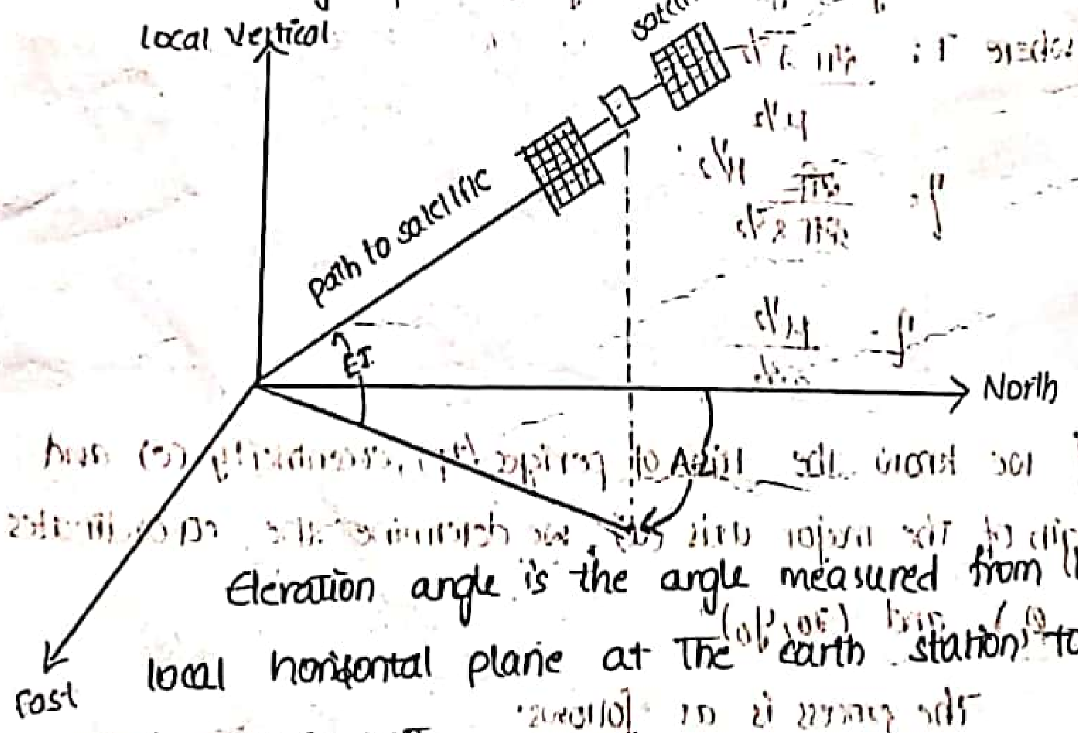
$$\boxed{x_0 = r_0\cos\phi_0; \quad y_0 = r_0\sin\phi_0}$$

LOOK-ANGLE DETERMINATION:

Look-angles:- The co-ordinates at which an earth station antenna must be pointed to communicate with the satellite are called Look angles. They are most commonly expressed as

① Azimuth angle (Az).

② Elevation angle (El).



Elevation angle is the angle measured from the local horizontal plane at the earth station to the satellite path.

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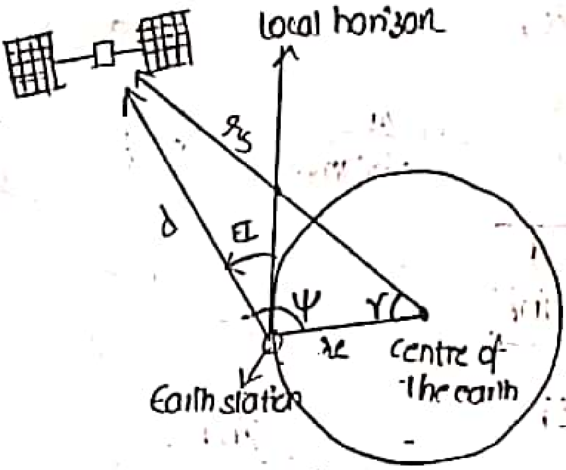
Azimuth angle is the angle measured eastwards (clockwise) from the geographical north to the projection of the satellite on the horizontal plane at earth station.

Elevation angle calculation :-



The above diagram shows the goemetry of the elevation angle calculation. Here, r_s is the vector from the center of the earth to the satellite. 'r_e' is the vector from the center of the earth to the earth station. d is the vector from the earth station to satellite. Here 'El' is the elevation angle & 'ψ' is the angle made b/w the vectors r_e and d. These three vectors lie in the same plane and form a Δle. Thus the central angle 'γ' is measured b/w r_e and r_s is related to the earth station north latitude (L_e) and west longitude (l_e) and subsatellite point north latitude (L_s), and west longitude (l_s) and the relation is given by

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

The law of cosine allows us to the magnitude of the vector joining the satellite and the earth station 'd' is given by

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

From the diagram,

$$\boxed{\psi = 90^\circ + El}$$

By the law of sines,

$$\boxed{\frac{r_s}{\sin\psi} = \frac{d}{\sin\gamma}} \Rightarrow \frac{r_s}{\sin(90+EL)} = \frac{d}{\sin\gamma}$$

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

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

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

AZIMUTH ANGLE PRESENTATION:-

In order to find the azimuthal angle, an intermediate angle α must be first found. The angle α permits the correct 90° quadrant to be found for azimuth calculation. Since the azimuth angle lie anywhere b/w 0° and clockwise through 360°. Therefore the intermediate angle

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

After calculating 'α', the azimuth look angle.

Case 1: Earth station in the northern hemisphere

a) satellite to the SE of earthstation $A_z = 180^\circ - \alpha$.

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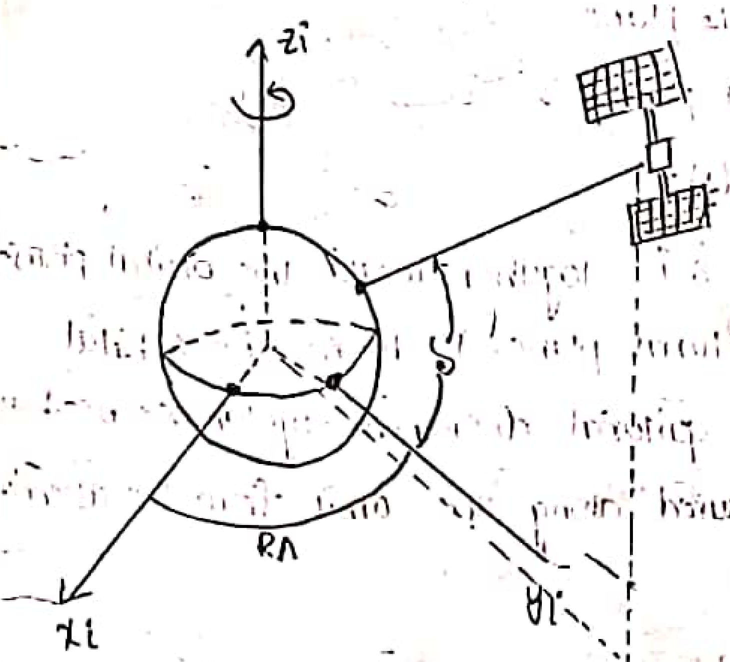
b) satellite to the SW of earth station ; $A_z = 180^\circ + \alpha$

Case 2: Earth station in the southern hemisphere.

a) Satellite is located to the NE of earth station ; $A_z = \alpha$

b) satellite is located to the NW of earth station ; $A_z = 360^\circ - \alpha$

LOCATION OF SATELLITE W.R.T EARTH:-



In order to locate the satellite on the rotating surface of the earth, we will begin with the geocentric equitorial co-ordinate system as shown in the fig beside.

The rotational axis of the earth is zi axis which is through the geographical north pole. The xi axis from the center of the earth towards a fixed location in space is called the first point of Aries. The xi direction is always the same whatever the earth's position around the sun. The xi, yi plane contains the earth's equator and is called equitorial plane. The angular distance measured eastward in the equitorial plane from the x-y axis is called Right Ascension and is given the symbol RA.

The two points at which the orbit penetrates the equitorial plane are called nodes. The fig is shown below indicating the nodes.

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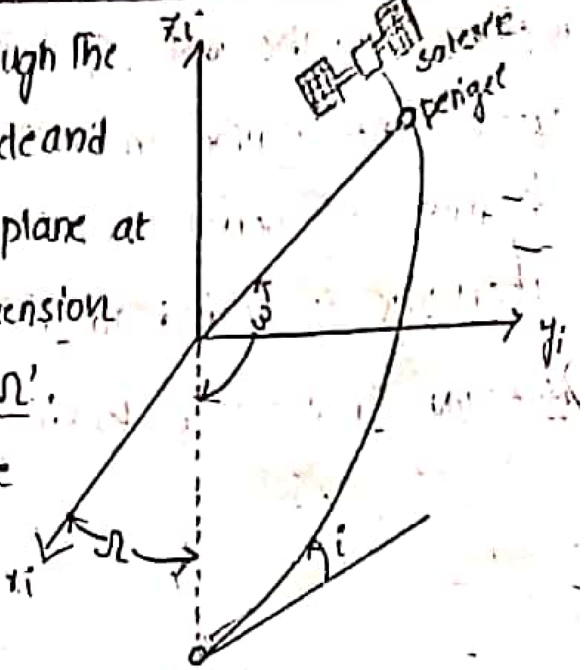
The satellite moves upward through the equitoral plane at the ascending node and downward through the equitoral plane at the descending node. The right ascension of the ascending node is called 'Ω'. The angle that the orbital plane makes with the equitoral plane is called the inclination (i).



The variables Ω & i together locate the orbital plane with respect to the equitoral plane. To locate the orbital co-ordinate system w.r.t equitoral co-ordinate system, we need ω. The ω is the angle measured along the orbit from the ascending node to the perigee.

ORBITAL ELEMENT:-

To specify the absolute co-ordinates of a satellite at time T, we need to know six quantities. This quantities are called orbital elements. They are

a) eccentricity(e) ; semi
b) semi majoraxis (a),
c) Time of perigee (tp).
d) right ascension of ascending node (Ω).
e) Inclination (i).
d) argument of perigee (ω).

These are the six orbital elements.

ORBITAL PERTURBATIONS:

~~The~~ Under ideal conditions, the orbital equations developed b/w the earth and the satellite are influenced only by gravitational attraction. In practical, the satellite & the earth responds to many other influences including assymmetry of earth's gravitational field, the gravitational fields of the sun and the moon, solar radiation pressure and non-symmetry of equitorial radius. For LEO satellites, atmospheric drag can also be important.

The approach normally adopted for communication satellite is first to derive an osculating orbit for some instant time i.e., the keplerian orbit spacecraft could follow if all the perturbing forces were removed: at that time, with orbital elements $(a, e, t_p, \Omega, i, \omega)$. The perturbations are assumed to cause the orbital elements vary with time and the orbit and satellite location at any instant are taken from the osculating orbit.

To visualize this process, the osculating orbital elements at time 't0' are $(a_0, e_0, t_{p_0}, \Omega_0, i_0, \omega_0)$, then assume that orbital elements vary linearly with time at constant rates are given by.

$$a_0 + \delta t\frac{da_0}{dt},\ e_0 + \delta t\frac{de_0}{dt},\ t_{p_0} + \delta t\frac{dt_{p_0}}{dt},\ \Omega_0 + \delta t\frac{d\Omega_0}{dt},\ i_0 + \delta t\frac{di_0}{dt},\ \omega_0 + \delta t\frac{d\omega_0}{dt}$$

13* Position of satellite changes due to i) longitudinal changes &
ii) inclination changes

LONGITUDINAL CHANGES:-

There is longitudinal changes occur in The satellite due to earths oblanterels.

a) the earth is neither a perfect sphere nor a perfect ellipse.

b) the equitorial diameter is not constant.

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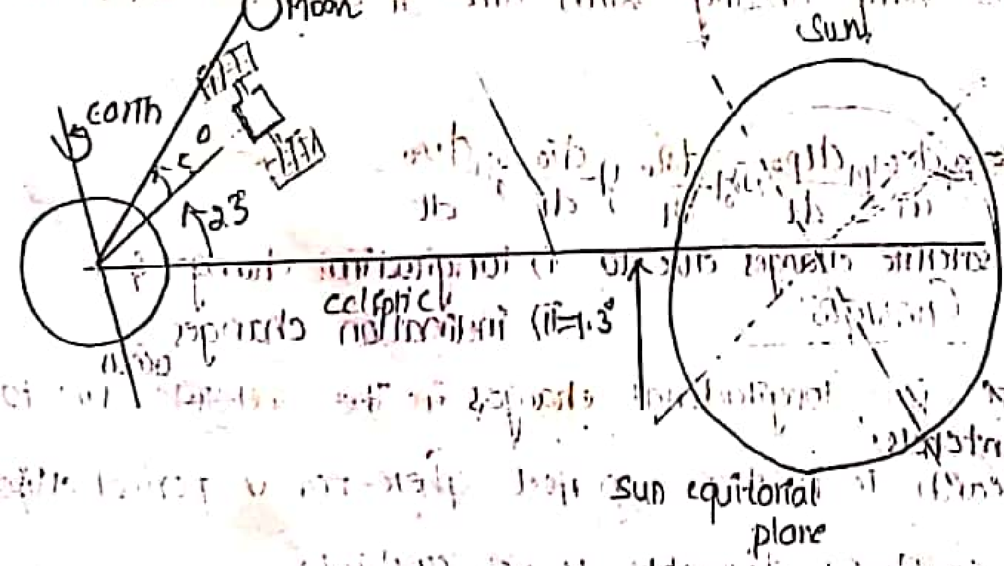
4) In addition to these non regular features of the earth, there are regions where avg density of the earth appear to be high. These are referred as regions of mass concentrati on Masons.

The non sphericity of the earth and non-circularity of the equitorial radius & the mascons lead to non-gravi uniform gravitational field around the earth. Therefore the force on a orbiting satellite vary with the position. This lead to longitudinal changes in the satellite. Due to the position of the mascons and equitoral bulges, there are 4 equilibrium points in the stationary orbit. 2 of them are stable & 2 are unstab points. The stable points are at about 75° east and 252° east, and unstable point are at 162° E and 348° E. If a satellite is perturbated slightly from one of the stable points, it will tend to drift back to the stable point without any cluster requir If a satellite is perturbated slightly from one of the unstab pts, it will oscillate in longitudinal position about this point.

INCLINATION CHANGES:-



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The plane of the earth's orbit around the sun is called as ecclipitic. Now the equitorial plane of the sun, makes an inclination of 7.3° with ecclipitic. The earth makes an inclination of 23° from the ecclipitic.

The moon circles the earth with an inclination of around 5° to the equitorial plane of the earth. Due to this facts of various planes such as the sun's equator, the ecclipitic, the earth's equator and the moon's orbital plane around the earth are all different. Due to this difference, a satellite in an orbit around the earth will subject to variety of out of plane forces i.e., there is an inclination changes in the satellite.

The mass of the sun is slightly larger than that of moon, but the moon is considerably closer to the earth than the sun. For this reason, the acceleration force induced by the moon on the satellite is about twice as large as that of the sun.

Some maneuvers are designed to correct both inclination and longitudinal changes simultaneously.

ORBIT DETERMINATION:

Orbit determination requires

6.3 ORBITAL EFFECTS ON COMMUNICATION SYSTEM PERFORMANCE:

1) Doppler shift:- To a stationary observer, the frequency of a moving radio transmitter varies with ther's velocity relative to the observer. Take the frequency when the transmitter is at rest is (f_T). Then the received frequency f_R is higher than f_T when the transmitter moves towards the receiver and lower than f_T

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when Txer moves away from the Rxer this change in frequency is called <u>Doppler shift</u>. Mathematically the relationship b/w Txed and Rxed frequencies is

$$\boxed{\frac{f_R - f_T}{f_T} = \frac{\Delta f}{f_T} = \frac{V_T}{c}}$$

$$\therefore \boxed{\Delta f = \frac{V_T f_T}{c} \text{ ; Change in freq} \Rightarrow \text{Doppler shift}}$$

where V_T : Velocity component / component of the Txer velocity directed towards the receiver

c : Phase velocity of light.

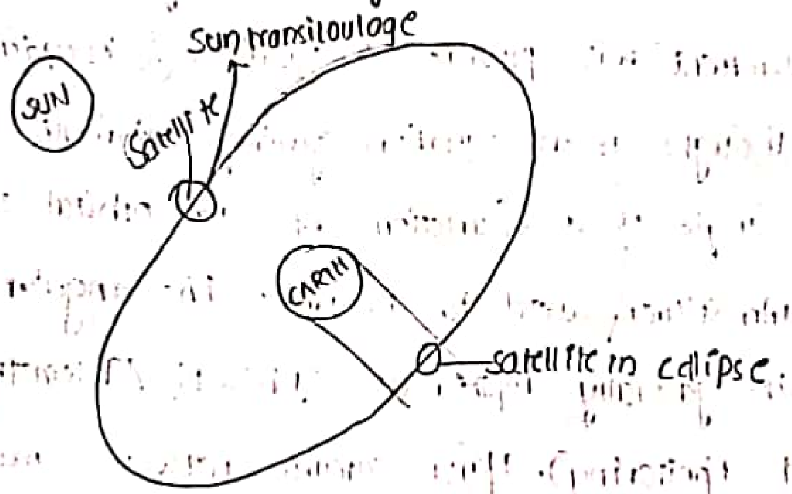
f_T : frequency of the Txer at rest.

ii) <u>Range</u> <u>Variations</u>:-

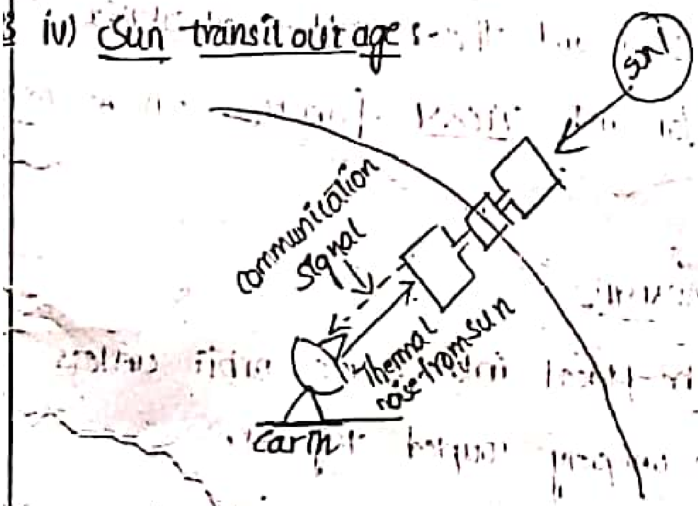
The position of the satellite w.r.t the earth exhibits a cyclic daily variations. The variation in position will lead to variation in range b/w the satellite and user terminals. If, we choose TDMA, careful attention must be paid to the timing of the frames within the TDMA, so that the individual user frames arrive at the satellite in the correct sequence at the correct time.

iii) <u>Solar</u> <u>Eclipse</u>:-

A satellite is said to be in eclipse when the earth prevents sunlight from reaching it i.e., when the satellite is in the shadow of the earth. For geostationary satellites, eclipse occurs during two periods that begin with <u>23 days</u> before the equinox (from about March 21 & about Sep 23). During full eclipse, a satellite receives, no power from the sun and it must operate entirely from its batteries. Batteries are designed to operate with a maximum depth of discharge. The depth of discharge therefore sets the power drain limit during eclipse operations.



iv) Sun transit outage :-



The sun is a hot microwave source with an equivalent temp of about 6000-10,000K depending on the time within the 11 years, sunspot cycle. At this time, the earth station receive not only the signal from the satellite, but also the noise temperature transmitted by the sun. This added noise temperature will cause the noise margin of the receiver to be exceeded, and an out-age occurs which is sun-transit out age.

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* ORBIT DETERMINATION:-

① Orbit determination requires that sufficient measurements to be made, to determine the six orbital elements ② three angular position measurements are needed because they are 6 unknowns and each measurement will provide 2 equations. ③ Conceptually, this can be thought as one equation giving azimuth angle & other elevation angle as a function of six orbital elements. ④ The control earth station used to measure the angular position of satellites are generally refered as TTC&M (Telemetry tracking Command and Monitoring). Major satellite networks maintain their own TTC&M stations around the world. Small satellite systems generally contract for such TTC&M functions from spac craft manufacturer.

* LAUNCH VEHICLES AND LAUNCH:-

A satellite cannot be placed into stable orbit unless two parameters that are uniquely coupled together.

① orbital height

② velocity vector

Eg:- A GEO must be in orbit of height 36,000kms above the surface of earth with an inclination of 0° ellipticity of zero and a velocity of 3074.7 m/s tangential to earth in plane of orbit.

In any earth satellite launch, the largest fraction of energy expended by rocket is to accelerate the vehicle from rest until it is about 32 kms (20 miles).

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To make efficient use of fuel system, it is common to shed excess mass from launcher as it moves upward. It is called **staging**:-

Most launch vehicles have multiple stages and as each stage is completed, that portion of launcher is expended until the final stage places the satellite into desired trajectory. Hence the term **ELV** (Expendable launch Vehicle). The solid rocket booster (SRB) are recovered and refurbished, for future machine mission and space settled itself, will fall back to earth. Hence the term **RLV** (Reusable Launch Vehicle).

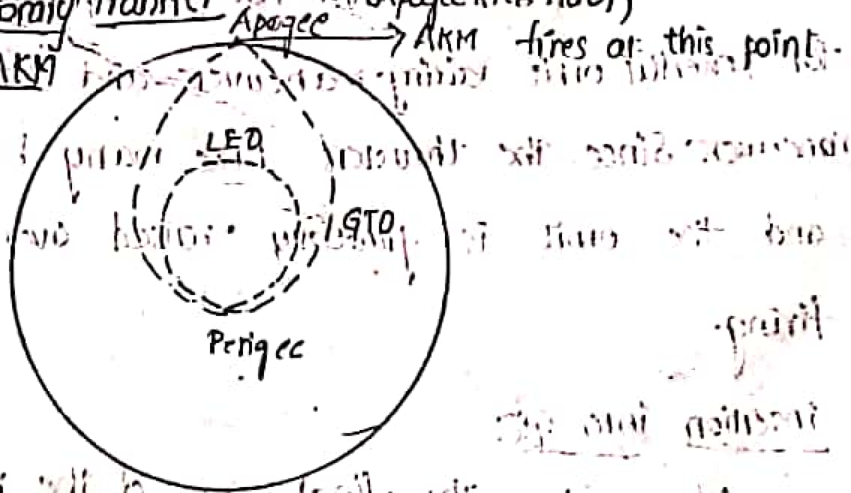
Launch Vehicle Selection Features:-

1) Price / cost.
2) Reliability.
3) Performance.
4) Safety issues.
5) Launch site location.
6) Market conditions i.e., what market will bear.

Placing satellites into GEO stationary orbit:-

1) Geostationary Transfer orbit & AKM

(Apogee kick Motor)



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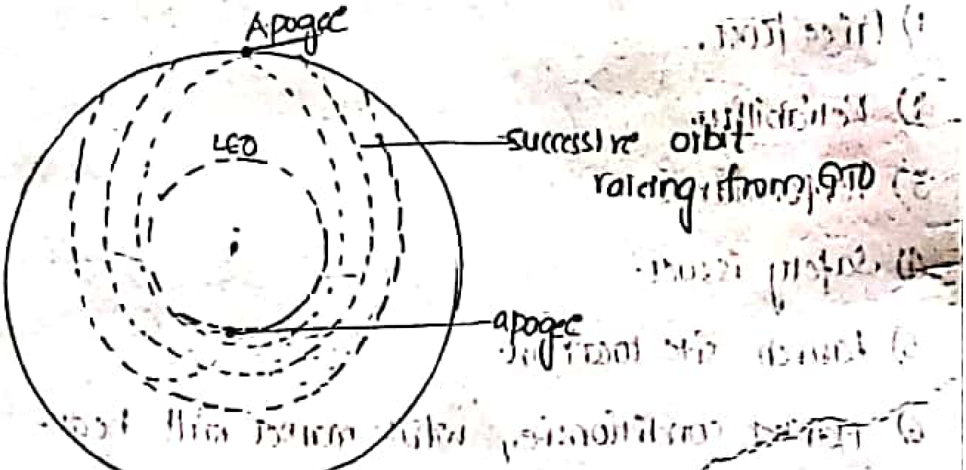
The initial approach for launching geostationary satellites was to place the space craft into low earth orbit. Now after a couple of orbits, orbital elements are measured, then the final stage is reignited and the spacecraft is then launched into geostationary transfer orbit called as GTO. Again, after a few orbits in the GTO, orbital elements are measured; a rocket motor is ignited at apogee and the GTO is raised until it is circular, geostationary earth orbit. Since the rocket motor fires at apogee, it is commonly referred as apogee kick motor(AKM

Geostationary Transfer orbit with slow orbit Raisings:



In this procedure, space craft thrusters are used to raise the orbit from GTO to GEO. The satellite has 2 power levels of thrusters. One for powerful orbit raising maneuvers and other for low thrust maneuvers. Since the thrusters take many hours of operation and the orbit is gradually raised over successive thruster firing.

Direct insertion into GEO:-

In this method the final stage of the rocket places the satellite directly into GEO(geostationary earth orbit

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The spaceshuttle is an example of LEO satellite. Sometimes it orbits at an altitude of 250kms above the earth's surface. The mean earth radius is approximately 6378.14 kms. Calculate the period of the shuttle orbit when the altitude is 250kms and the orbit is circular. Find also the linear velocity of the shuttle along its orbit.

T, v

$T = 2\pi\sqrt{\frac{GM_E}{R}}$ $\quad T^2 = \frac{4\pi^2 a^3}{GM_E} = \frac{4\pi^2 a^3}{\mu}$

$a = 6378.14 + 250 = 6628.14$ kms, $\mu = 3.986004418\times10^{5}\,km^3/s^2$

$T^2 = 28840114.49$

$T = 5370.29$ sec

Velocity $= \frac{2\pi a}{T} = 7.7548$ km/sec

1 sidereal one rotation for one day → 23hr 56min 4sec

Clarcke's orbit → Geostationary orbit

subsatellite point → points on the surface of the earth, by which we can point the satellite

(satellite to earth) up to down → Nadir

down to up → Zenith (earth to satellite)

VSAT → Very Small Aperture terminal antennas.

Input back of a transponder:

To avoid intermodulation distortions, we use input back of transponder.

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IN THIS TWO DIFFERENT MATERIALS AVAILABLE

UNIT-II SATELLITE SUBSYSTEMS

* Satellite subsystems:-

In order to support the communication system, the satellite must provide a stable platform onto which we mount the antenna, electric power for the communication system and also provide a controlled temperature environment.

The major satellite subsystems required on the satellite are:

1) Altitude & orbit control system (AOCS):- This subsystem consists of rocket motors that are used to move the satellite back to the correct orbit, when external forces acting on it and gasjets are used to control the altitude of the satellite.

2). Telemetry tracking Command & Monitoring (TTC&M):- This systems are partly on the satellite and partly on the controlling earth station. The telemetry system sense data derived from many sensors on the satellite via a telemetry link to the controlling earth station. The tracking system is located at earth station, and provides information on the range, elevation and azimuthal angles of the satellite. Based on the telemetry data, received from the satellite and orbital data obtained from tracking system, the control system used to correct the position and altitude of the satellite.

3) Power Systems:- All communications subsystem derive their electric power from solarcells. This power is mainly used in the transmitters, receivers, and other electrical systems on the satellite.

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4) Communication subsystem:- The communication subsystem usually composed of set of transmitters and receivers and one or more antennas. Here the set of Txers & Rxers are known as transponders.

5) Satellite Antennas:- The satellite antenna system is very complex and produce beams with shapes to match the areas on the earth's surface. Most satellite antennas operate in a single frequency band. In order to use multiple frequency bands, we need four or more antennas.

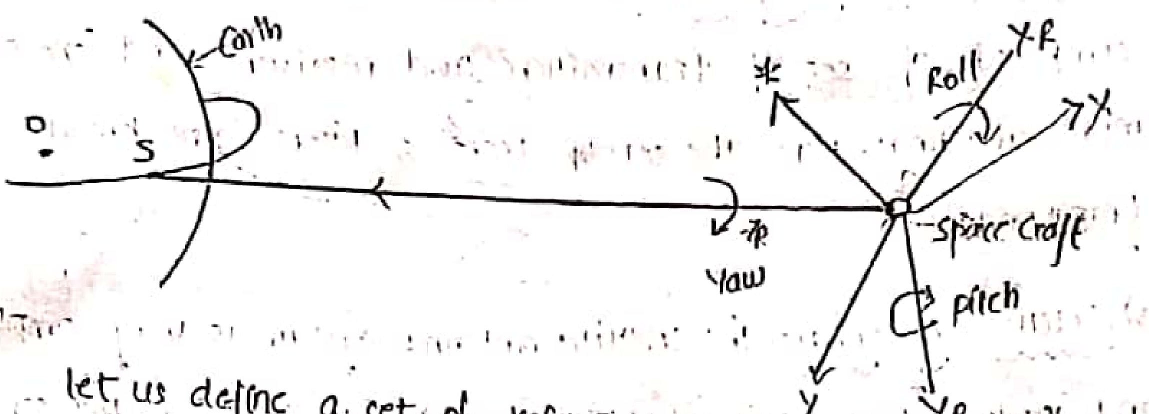
1.3 ATTITUDE AND ORBIT CONTROL SYSTEM (AOCS):-

There are several forces acting on a orbiting satellite that tend to change its attitude and orbit. The most important are the gravitational fields of the sun and the moon, irregularities in the earth's gravitational field, solar pressure from the sun and variations in the earth's magnetic field.

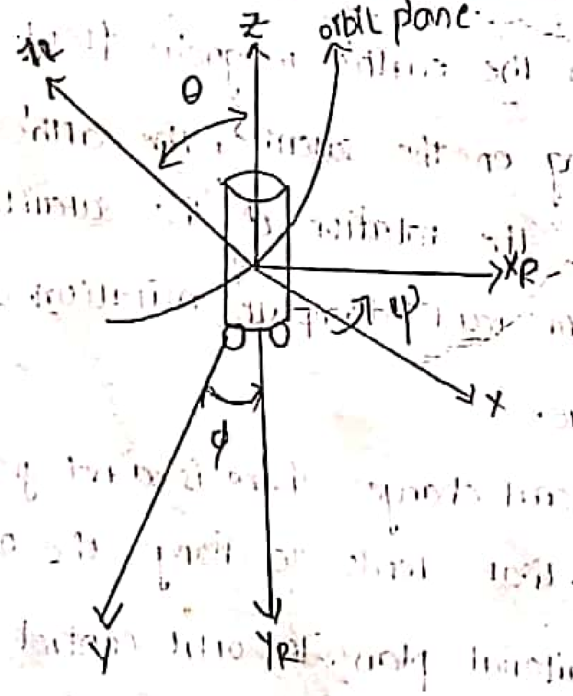
Solar pressure acting on the satellite, the earth's magnetic field tend to change the rotation of the satellite body. Now, the attitude control system must dampout this nutation and counter any rotational torque.

Due to the inclinational changes, there is a net gravitational pull on the satellite that tends to change the orbit of the satellite from its equitorial plane. The orbit control system of a satellite must be able to move the satellite back into the equitorial plane, before the orbital inclination becomes excessive.

ATTITUDE CONTROL SYSTEM :-



let us define a set of reference co-ordinate system i.e., X_R, Y_R, Z_R with the satellite at the origin as shown in the diag The Z_R axis is directed towards the center of the earth and X_R axis is tangent to the orbital plane. Y_R axis is perpendicul to the orbital plane. The rotation about the X_R, Y_R and Z_R axis is defined as roll about X-axis, pitch about Y-axis, Yaw about Z-axis. The satellite must be stabilised with respect to the reference axis to maintain accurate pointings of its antenna beams.



changes in the satellite attitudes cause the angles θ, φ & ψ. The location of Z-axis intercept defines the pointings of satellite antenna, due to this rotation, the Z-axis intercept point may be moved to repoint all the antenna beams, the attitude control system is used.

There are 2 ways to make a satellite stable in the orbit.

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① The body of the satellite is rotated typically at the rate of 30-100 rotations per minute, to create a gyroscopic force that provides stability of the spin axis, such satellites are known as spinner satellites.

② The satellite can be stabilised by one or more momentum of wheels. This type of satellites ~~are~~ are known as three-axis stabilized satellites.

12-7-13

* SPINNER SATELLITES:-

In this spinner satellites, satellite consists of cylindrical drum which is covered with solar cells, power systems and rocket motors. Usually for spinner satellite, the axis of rotation is in Y-axis, which is perpendicular to the orbital plane. Pitch correction is required only in 'Despun' antenna system and this can be done by varying the speed of the despun motors. Yaw & Roll are controlled by radially mounted jets.

* 3-AXIS STABILIZED SATELLITES:-

Attitude control of 3-axis stabilized satellites requires an increase or decrease in the speed of the momentum of wheels. If a constant torque exists about one axis of the satellite, a continuous increase or decrease in momentum of wheelspeed is necessary to maintain correct attitude.

13-7-13

* ORBIT CONTROL SYSTEM:-

For the satellite to be in truly geo-synchronous earth orbit, the orbit must be: ① in the equitorial plane.

② It should be circular.

③ It must be at a correct altitude.

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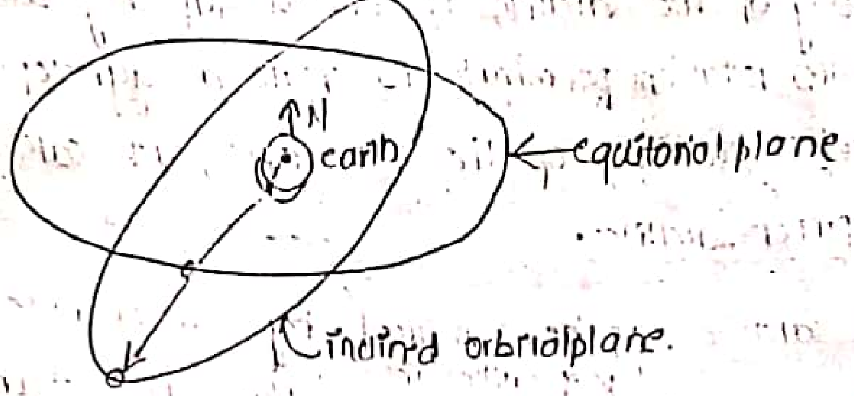

This cannot be done with momentum of wheels. So we need linear acceleration, to correct the orbit of the satellite. For this purpose, we use gasjets.

If the orbit is not circular, the velocity increase or decrease will have to be made along the x-axis. For spinning satellite, this is acheived by pulsing radially jets, along the x-axis direction. For a 3-axis stabilised satellites, we use two pairs of radially jets which are acting in opposite direction.

The inclination of the orbit of the satellite increases at an average rate of 0.85° peryear, withan initial rate of change of inclination In an equitorial orbit between 0.75° to 0.94° peryear.

For practically, the corrections are made using N-S mo station keeping maneuvers & E-W station keeping maneuvers. It has become normal to split E-W and N-S maneuvers, so that at intervals of 2 weeks, the E-W corrections are made west first and after 2 more weeks, N-S corrections are made. Correcting the inclination of the satellite requires more fuel than any other orbital correction.

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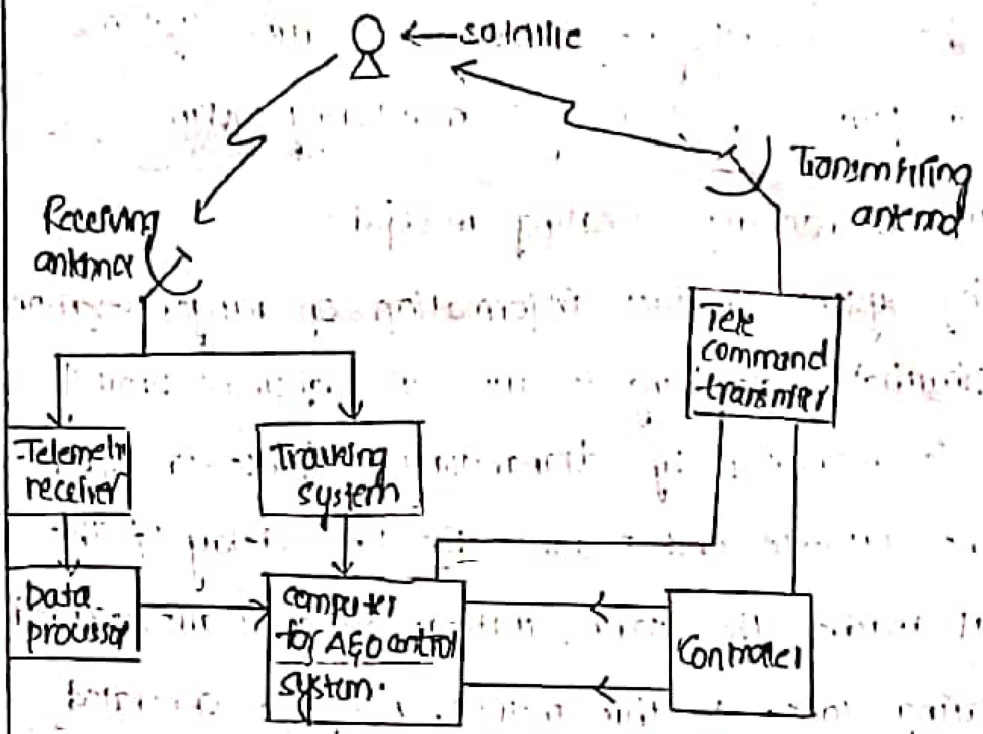
TELEMETRY TRACKING COMMAND & MONITORING SYSTEMS:-



TTC&M are used for is essential for the successful operation of the communication satellite. It is the part of the satellite management task. Satellite management used to control altitude & orbit of the satellite, monitor all the sensors of the satellite and control ON and OFF sections of communication satellite. TTC&M are owned and operated by the satellite owners or it gets from the third party on contract basis.

Telemetry & Monitoring system:-

It collects the data from the sensors of the satellite and sends to the earth station via telemetry link. This monitors

1) pressure in the fuel tanks &
2) voltages & currents in the power conditioning unit.
3) currents drawn from each subsystem.
4) critical currents & voltages in communication satellites.

This data is digitalized by PSK using TDM technique.

Computer at the earth station decode this information to determine the status of the sensors, subsystems and communication systems. This is the main purpose of telemetry & monitoring system.

Tracking systems:- Tracking → locating an object.

Tracking system provides information on range, elevation angle and azimuthal angle. Range is used to determine orbital elements. Range is measured by transmitting a pulse or sequence of pulses to the satellite and measure the time delay of the pulse before it reaches the earth station. Range is also measured by using ranging tones. In this method, a carrier generated at the satellite is modulated with series of sine waves and it is compared at the earth station.

Command System:-

A command system used to make changes in attitude and correction to the orbit, and also it controls the communication system. During launch, it is used to control the firing of the apogee kick motor.

The command structure contains safeguards against unauthorised attempts to make changes to the satellite operation. Encryption of commands & responses are used to provide security in the communication system. The control ~~word~~ code is converted into command word, which is sent to the satellite. After checking the validity in the satellite, the word is sent back to the control station via telemetry link, where it is checked again in the computer. If it is found the data received correctly and, execute instruction will be sent to the satellite, so that the command word is executive.

18-11

* **Power systems:-**

All the communication satellites obtain their electrical power from solar cells, which convert sunlight into electrical energy. Previously, space planetary research satellites used thermonuclear generators, to supply electrical power to the satellites. But, because of the danger to the people on the earth, if the launch shou fail and nuclear fuel to spread over a inhabitated area.

Most of the power comes from the sun. In geostationary attitude, the radiation falling on the satellite has an intensity of $1.39\ kW/m^2$. All the power from the incident energy is not converted into the electrical energy. Their efficiency is typically 20-25% at beginning of life, and their efficiency increases by 15% at the end of life.

For spinner stabilised satellite, as it is in cylindrical body covered in solar cells, only half of the cells are illuminated and the edges of the illum other half of is illuminated. Because of this low angle of incidence to the other half, little electrical power is generated.

For 3-axis stabilised satellite, this satellite can make better use of its solar cells area since, the cells are arranged on flat panels, that can be rotated to maintain normal incidence of the sunlight. Therefore more power is generated in 3-axis stabilised satellite when compared to spinner stabilised satellite.

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the satellite must carry batteries to power the subsystem during the eclipse, and during launch. Eclipse occurs twice an year, around the spring & fall equinox i.e., at March 21 and September 21. The duration of the eclipse is 70min. To avoid the need for the large and heavy batteries, most of the communication system may be shutdown for voice and data communication. For TV broadcasting, we use batteries, usually of the Ni-Hydrogen type with good reliability and good lifetime and can be safely discharged to 70% of their capacity. Sensors on the batteries, power conditioning unit and solar cells monitor temperature, voltage and current and supply this data to the controlling earth station via the telemetry link.

Communication sub-system:-

→ A communication satellite exists a provides a platform in geostationary orbit for the relaying of voice, video and data communications. All other subsystems on the satellite exist solely to support the communication system.

→ Since it is the communication system that earns the revenue for the system operator, communications satellite are designed to provide the largest traffic capacity possible.

→ The satellite transponders have limited output power and the earth stations are atleast 36,000 kms away from a GEO satellite, so the received power level, even with large aperture, earth station antennas are very small.

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→ For the system to perform satisfactorily, the signal power must exceed the power of the noise generated in the receiver by b/w 5 and 25db, depending on the bandwidth of the transmitted signal and modulation scheme used.

→ Early communication satellites were fitted with transponders of 250 or 500MHz bandwidth, but had low gain antennas and transmitters of 1 or 2W o/p.

→ Later generations of communication satellites have transponders with greatly increased o/p power, upto 200w for DBS-TV satellites and have steadily improved in bandwidth utilisation efficiency.

→ The total channel capacity of a satellite that uses a 500MHz band at 6/4 GHz can be increased only if the bandwidth can be increased or reused.

→ The trend in high capacity satellites has been to reuse the available bands by employing several beams at the same frequency (spatial frequency reuse) and orthognal polarizations at the same frequency (polarization frequency reuse). Large GEO satellites also use both 6/4 GHz & 14/11 GHz bands to obtain more bandwidth.

Eg: Some GEO satellites have acheived an effective bandwidth of 2250MHz within a 500MHz band at 6/4 GHz and a 250MHz band at 14/11 GHz by a combination of spatial & polarization frequency reuse.

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→ The designer of a satellite communication system is not free to select any frequency and bandwidth. International agreements restrict the frequencies that may be used for particular services, and regulations are administered by the appropriate agency in each country.

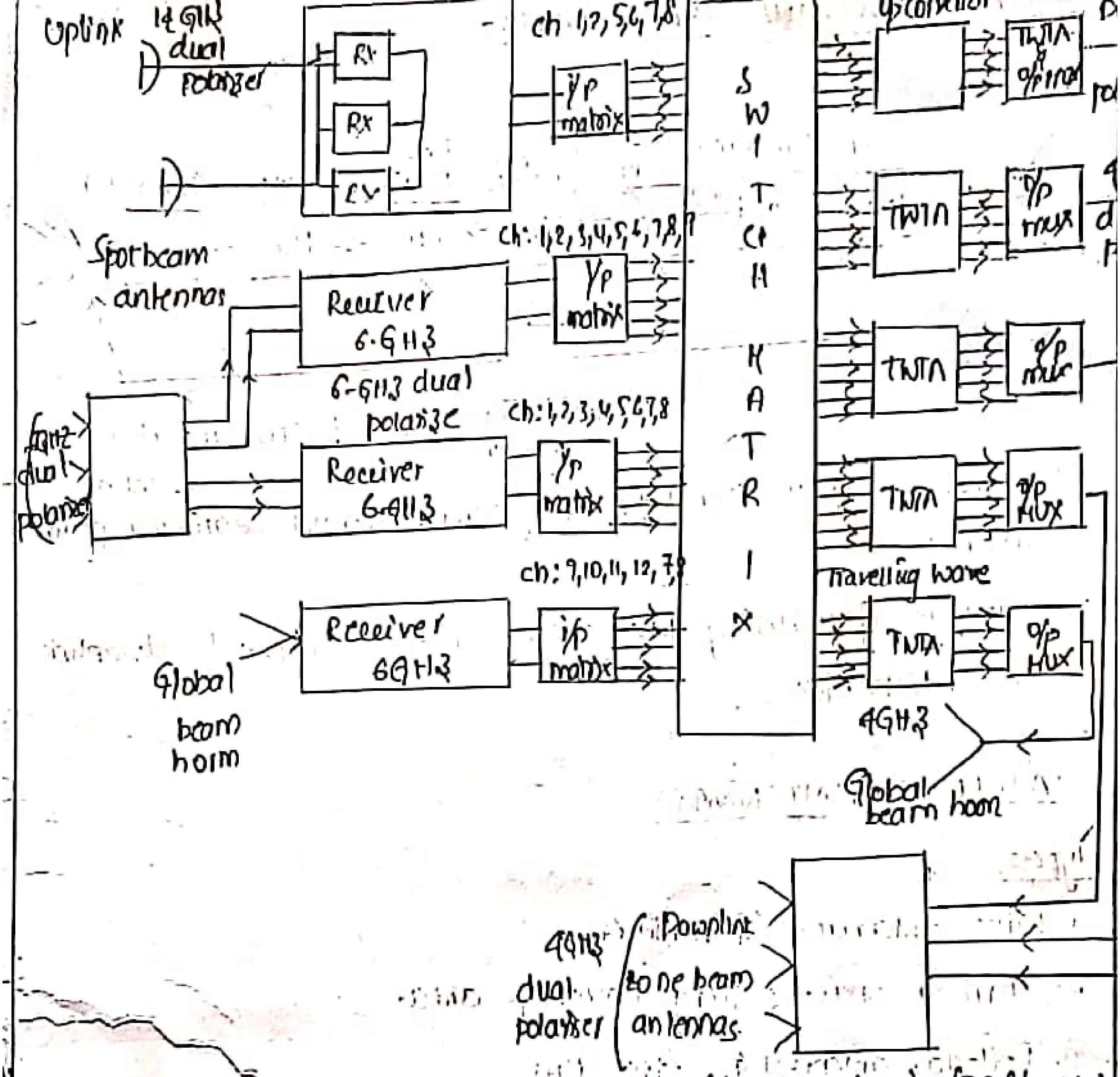
- The federal communication commission (FCC) in the united states.

→ The bands currently used for the majority of services are 6/4 GHz, 14/11 GHz & 30/20 GHz.

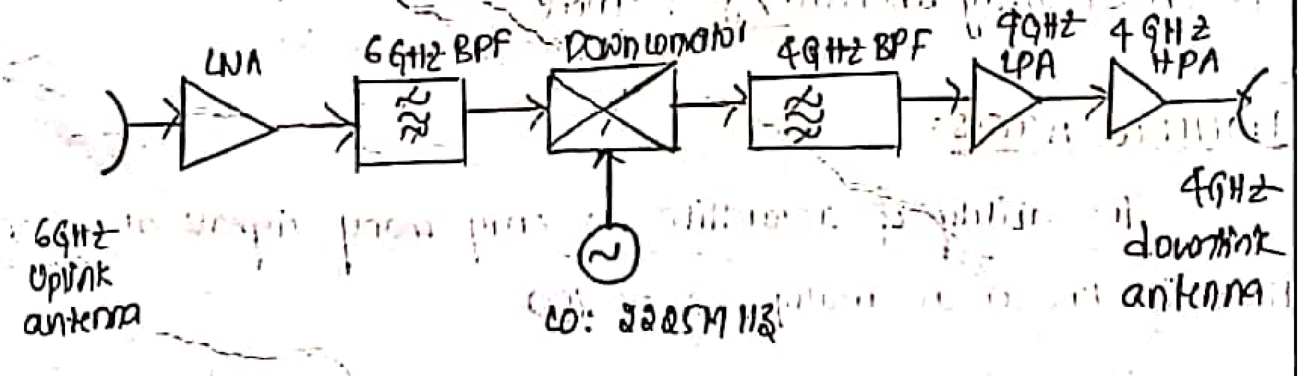
→ The 500MHz bands originally allocated for 6/4 and 14/11 GHz, satellite communication have become very congested. Extension of the bands to 1000MHz will eventually provide greater capacity as the new frequencies come into use. Many systems now use 14/11 GHz for TV broadcast & distribution and 30/20 GHz systems are introducing internet-like services from GEO

→ Satellite systems designed for ku band (14/11 GHz) & Ka band (30/20 GHz) have narrow antenna beams and better control of coverage patterns than satellites using Cband (6/4 GHz).

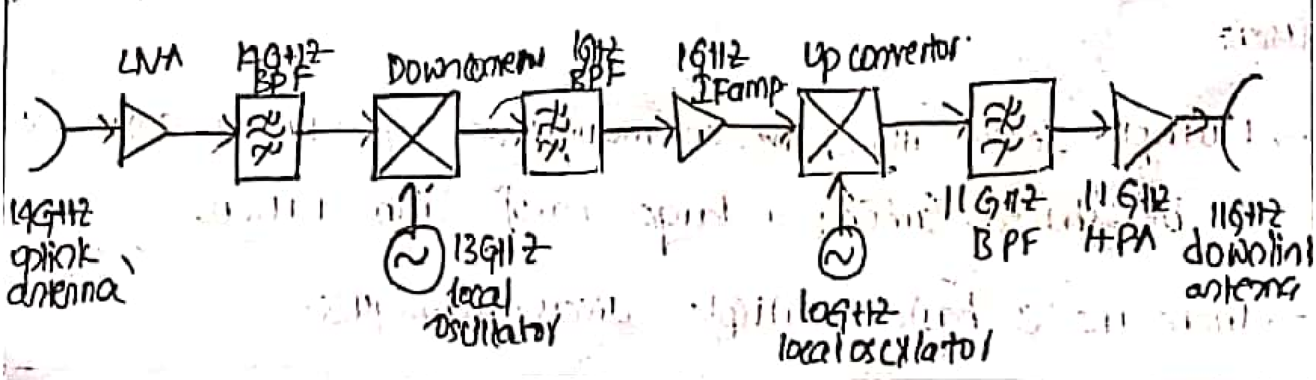
TRANSPONDER :-



Simplified single conversion transponder (bent pipe) for 6/4 GHz



Double conversion transponder:-



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on board controller → reduces error in uplink & downlink

- Uses switched beam technology, to generate narrow beam for earth station.

- advantage of switching b/w uplink access technique to downlink access technique.

SATELLITE ANTENNAS:-

Types:-

1. Wire antennas :- Transmitter...
2. Horn antennas :- large coverage area.
3. Reflector antennas :- App:- DTH
4. Phased array antennas. App:- Telephone.

13

MULTIPLE ACCESS:-

The ability of a satellite to carry many signals at a same time is known as multiple access. (or)

The ability of a service to be accessable by different users

→ Multiple access allow the communication capacity of a satellite to be shared among a large no. of earth stations.

→ There are 3 basic multiple access techniques.

1. FDMA :- All users share the satellite at same time and each user transmit at unique allocated frequency.

2. TDMA :- Each user is allocated a unique timeslot at satellite.

3. CDMA :- All users transmit to satellite on same frequency & at same time.

→ The assigning of a transponder depends on many factors:

1) Percentage of utilisation,
2) Type of information and
3) Economy in terms of users.

~~PAMA~~ Pre-assigned Multiple Access / Fixed-assigned Multiple Access (PAMA/FAMA)

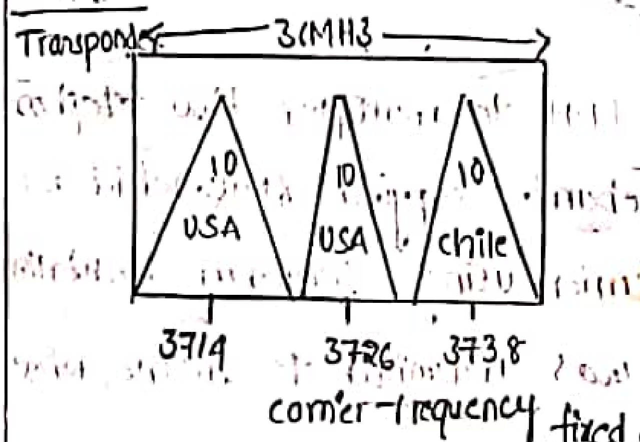
:- The transponder leased out permenently either for lifetime of satellite. No other earth stations can use this.

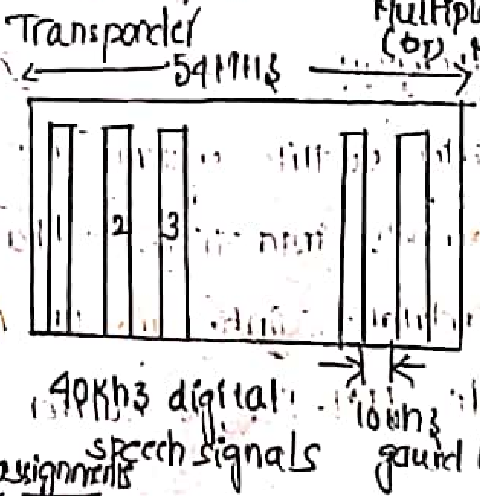
(DAMA) Demand Access Multiple Access :- It resource is allocated as needed depending on changing traffic conditions. Efficiency is quite high.

Random Multiple Access :- Any earth station will can try to occupy a transponder and use it for short durations. It requires different level of control signals and a special equipment.

- Some satellite systems will have both TDMA & FDMA that is called hybrid Multiple Access (or) MFTDMA (Multiple frequency TDMA).

FDMA :-





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frequency range - 300 to 3400hz.

12 channels - 60 to 108 khz (basic group), 60 channels - 60 to 300khz (supergroup)

Types of FDMA:- FDMA are defined with baseband and the type of modulation

1) FDM - FM - FDMA.

2) PCM - PSK - FDMA.

3) PCM - TDM - FDMA.

4) PCM - SCPC - MAD. - FDMA (SPADE).

SCPC : single channel per carrier.

MAD: Multiple access for demand.

- FDMA is the first multiple access used in satellite in 1960's for telephony.
- All the signals are analog and a analog multiplexing is used to combine large no of channels to a single baseband that could modulated on single RF carrier.
- The process begins by limiting individual telephone channels to a frequency range of 300-3400 hz and then frequency shifting 12 channels to a freq. range of 60-108 khz. These 12 channels are called as basic group. 5 basic groups can be shifted to a range of 60-300khz to make a 60 channel supergroup.
- Early satellite systems use FDM to multiplex 1800 telephon channels into a wide baseband, occupying 8MHz, which wa modulated onto an RF carrier using frequency modulati
- The FDM-FM, RF carrier was transmitted to satellite wher

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It share a transponder with other carriers using FDMA.

- The fixed assignment FDM-FM-FDMA also makes inefficient use of transponder bandwidth. The estimate of average utilization in INTELSAT using fixed assignment was 15%, By demand assignment and single channel per carrier allows higher utilization. Gaurd bands are essential in FDMA system to allow the filters to select individual channels, without excessive interference from adjacent channels.
- These gaurd bands of 10-25% of channel bandwidth are needed to minimize adjacent channel interference.
- "Most satellite transponders use high power amplifiers, which are driven close to saturation, causing non-linear operation. & a transponders using travelling wave tube amplifiers, is more prone to non-linearity than high power amplifiers."

III (TDMA cont---)

- At receiving earth station, the highspeed bitstream must first be recovered which requires a demodulation of RF carrier, generation of a bitclock.
- The synchronization bits in packets or frames must be found so that highspeed bitstream can split into original lower speed signals.
- The framelength is usually constant and the clock frequency for bitstream is fixed The packet lengths can vary. The entire process requires considerable storage of bits, so that original signal can be rebuild and leading to delay in transmission.

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as a burst at specific time. At satellite, the burst from

earth stations arrive sequentially.

- The TDMA transmission, the burst is assembled at transmitting earthstation, so that it will correctly fit in a TDMA frame. The TDMA frame has a length from $125\mu s$ to many milliseconds.

- A time overlap of two RF signals is called collision & it results in data, and in both signals being lost. Collision must not be allowed to occur in TDMA system.

(FDMA cont....)

Voice Band channel:- A channel that is suitable for transmission of speech or analog data and it has the maximum usable frequency range of 300-3400 hz is called voice band channel.

* FDMA can be performed in two ways:-

1. Fixed Demand Multiple Access (FAMA):- The subchannels assignments are of fixed allotment. Ideal for broadcast satellite communication.

2. Demand-assignment Multiple Access (DAMA):- The sub-channel allotment changes based on demand. Ideal for point to point communication (centralised control and distributed control).

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* SPADE - DAMA system (single channel per carrier PCM multiple Access Demand assignment equipment).

- SPADE is an example for DAMA (uses distributed control).

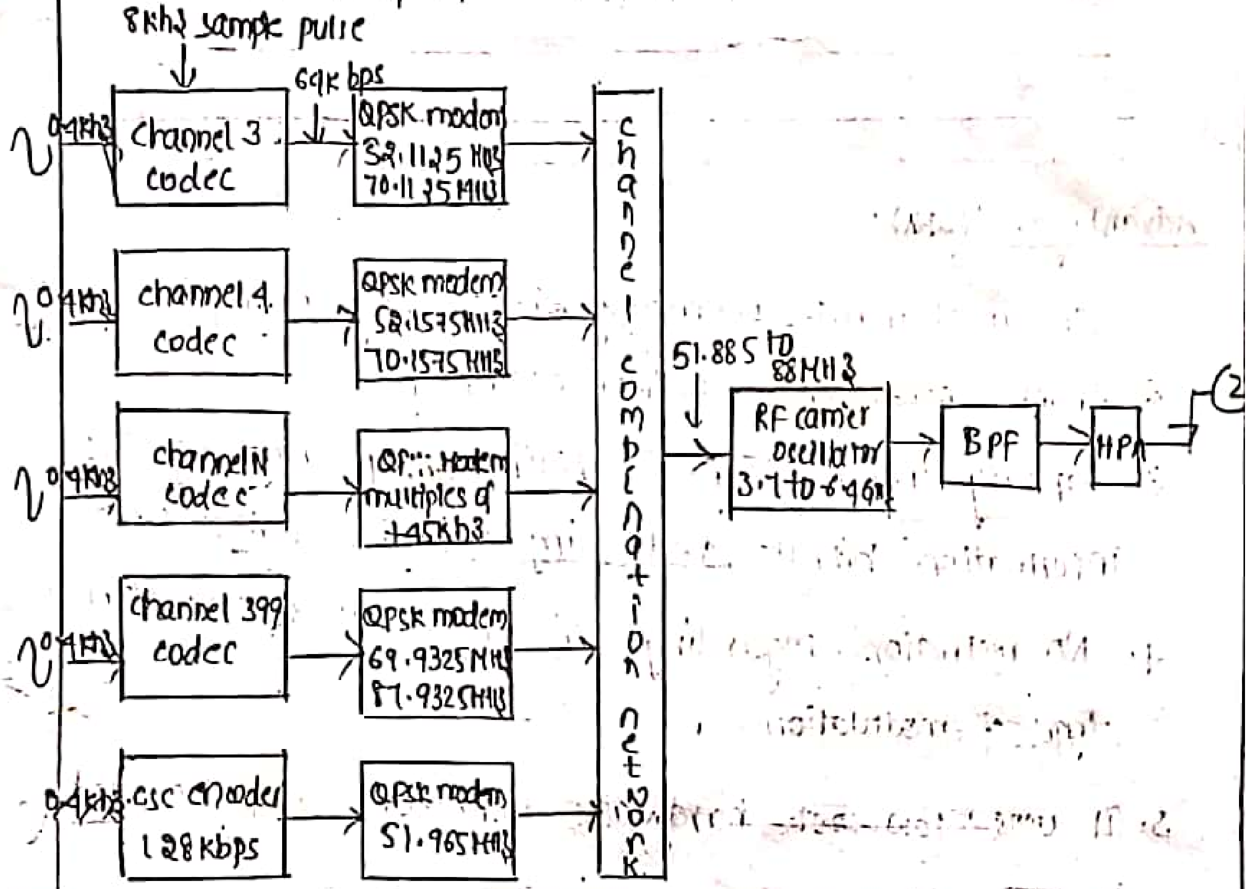
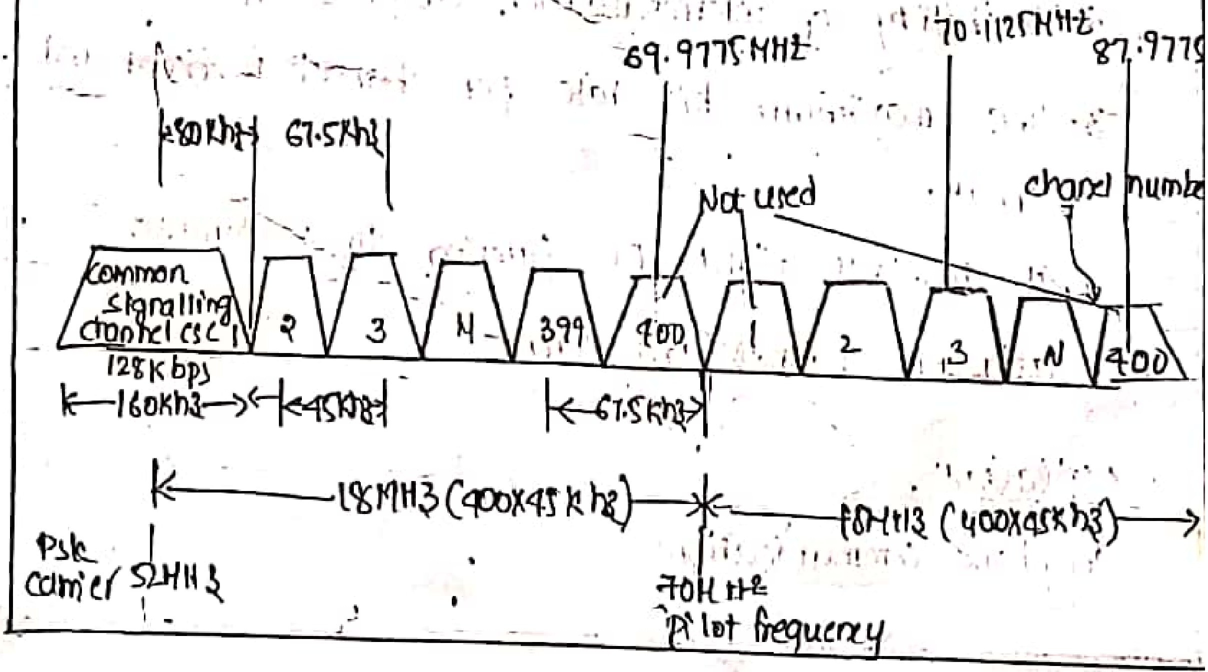


fig FDMA, SPADE EARTH STATION TRANSMITTER

* Carrier-frequency assignments for the INTELSAT single channel per carrier-per multiple access demand-assignment equipment [SPADE]



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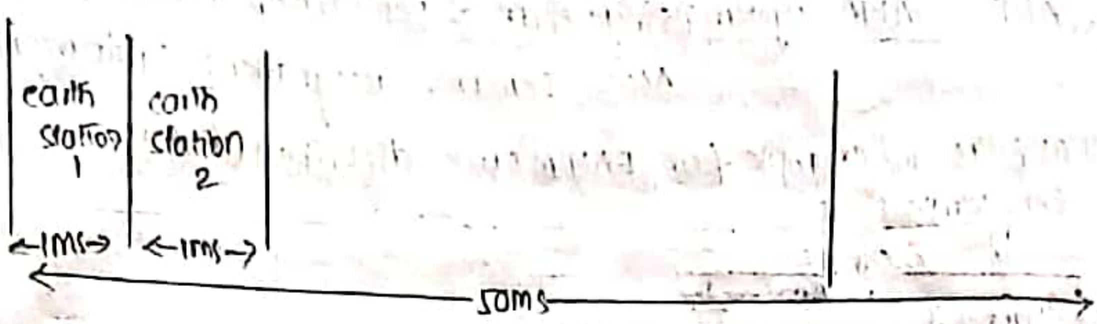

Advantages:- (FDMA):-

1. Users can transmit continuously without any interruption.
2. Channel bandwidth is utilized efficiently.
3. Capacity increase can be obtained by reducing the information bitrate and using efficient digital codes.
4. No restriction regarding the type of baseband (or) type of modulation.
5. It uses low cost hardware technology and no need for N/W timing.

Disadvantages:-

1. extra gaurd bands are required to avoid inter channel.
2. Possibility of intermodulation distortion of transponder
3. The maximum bit rate per channel is fixed and small.
4. It requires right RF filtering to minimize adjacent channel interference.

Applications:-

Telephone communications.

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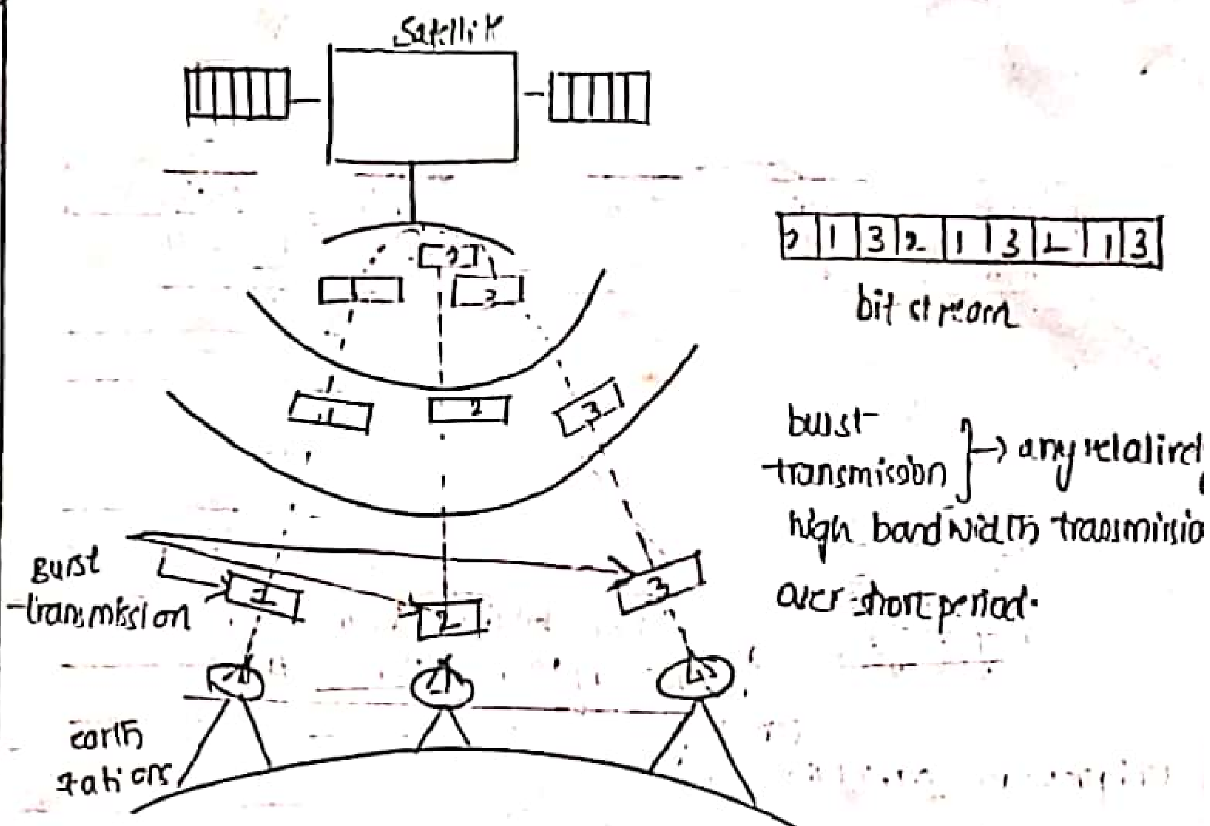
* TDMA (Time division Multiple Access):-



burst transmission → any relatively high bandwidth transmission over short period.

- In TDMA, no. of earth stations takes turns transmitting burst of RF signals, through a transponder.
- All practical TDMA systems are digital and can easily reconfigure for changing traffic demands.
- The major advantage of TDMA is when using the entire bandwidth of transponder, is that only one signal is present in transponder at one time.
- However using all of transponder bandwidth requires every earth station to transmit high bitrate, which requires high transmission power.
- Group of bits taken from each bitstream taken from and formed in baseband packets or frames, that also contains synchronous bits and identification bits.

← Prev page

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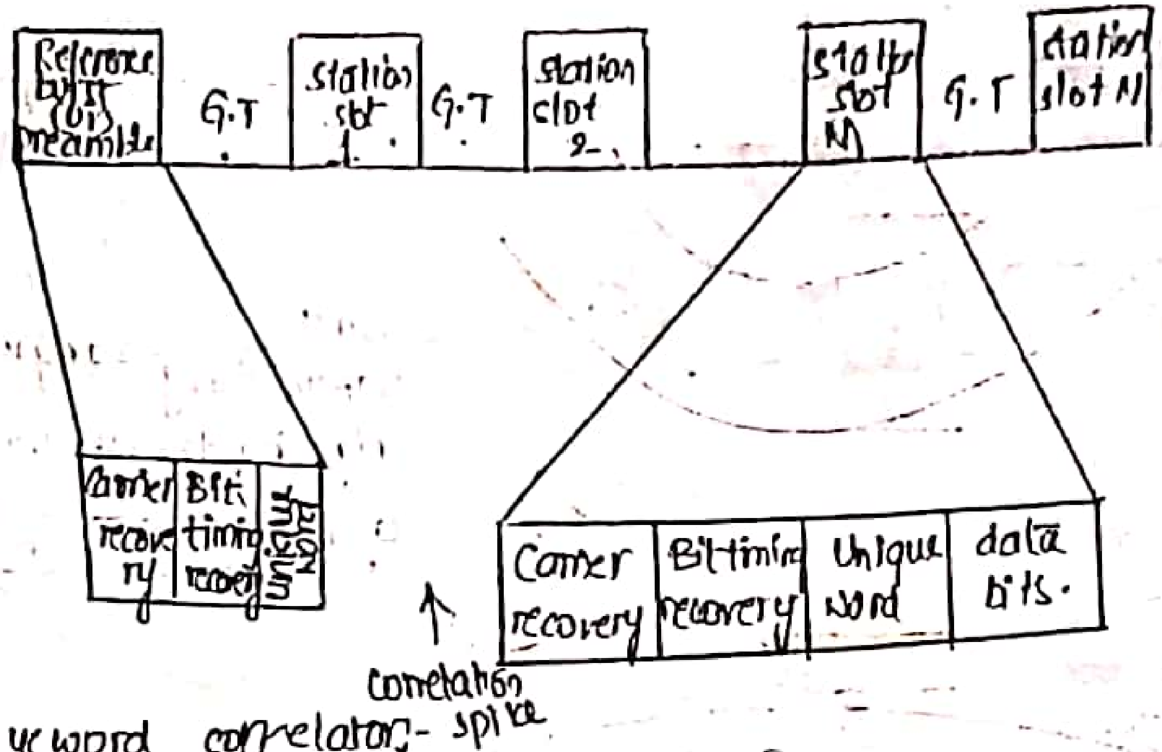
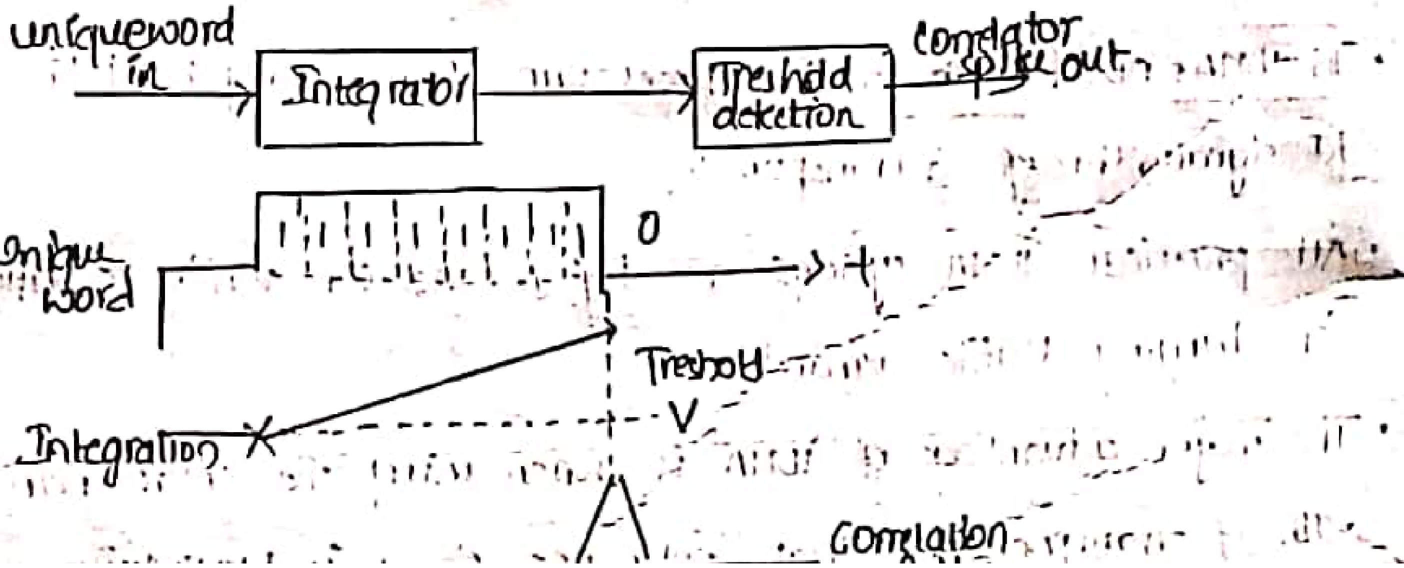
- TDMA - frame structure:



Uniqueword correlator -



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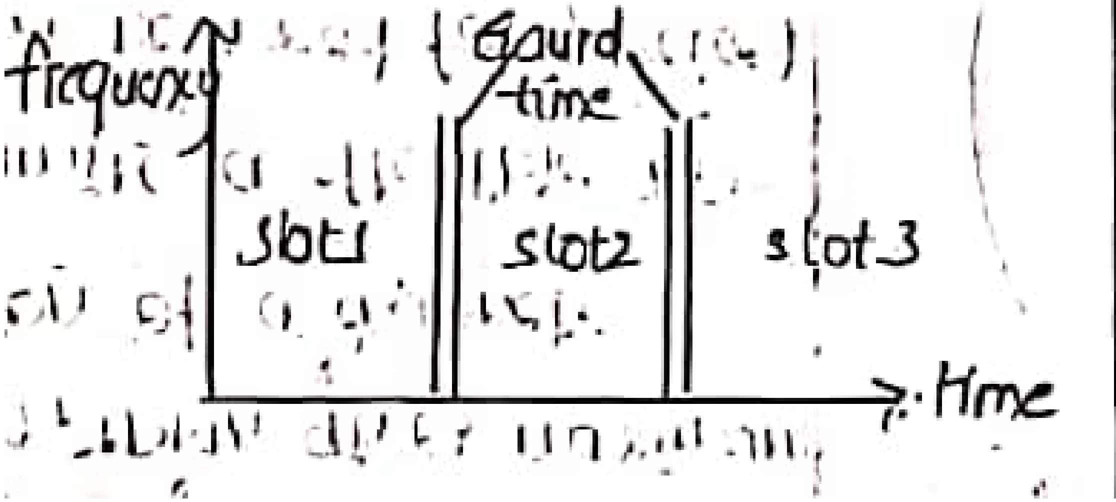
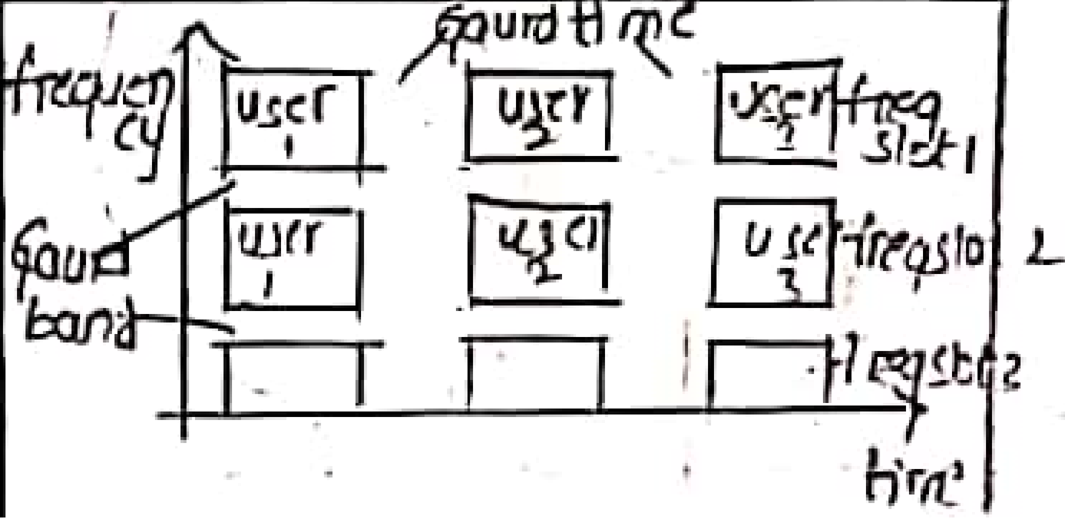
TDMA (Time division multiple acces)	CDMA (code division multiple acess) (spread spectrum)
1. In this, the time of the channel is shared by multiple users	1. In this, the time as well as bandwidth of a channel is shared by multiple users.
	

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Parameters	FDMA(freq division multiple access)	TDMA.(Time division multiple access)	CDMA(code division multiple acc
6. Gaurd band and Gaurd time	6. Gaurd band is required.	6. Gaurd times are required.	6. Gaurd bands & times are required.
7. Synchronisation	7. No synchronisation is required	7. Time synchronisation is essential	7. No synchronization is required.
8. Advantages	a. The users can transmit continu-ously without any interruption b. The channel bandwidth is utilized more efficiently. c. A capacity increase can be obtained by reducing the information bit rate & using efficient digital codes. d. No restriction regarding the type of baseband or the type of modulation e. Uses low cost H/W technology	a. Users get full bandwidth of channel in a particular timeslot. b. For burst signals, such as voice or speech, TDMA gives maximum utilization of a channel. c. It permits a flexible bit rate and no need for precised narrowband filters, and it permits utilization of all advantages of digital techniques. d. Gaurd time b/w timeslots allows to reduce the impact of	a. Maximum utilization of a channel takes place. b. Synchronization is not necessary e.

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	and no need for network timing.	g. Users get full band width of clock instability, transmission time delay.	
9. Disadvantages	a. Extra gaurd bands are required to avoid interchannel interference. b. Possibility of intermodulation distortion at transponder. c. The maximum bit rate per channel is fixed and small. d. It requires right RF filtering to minimize adjacent channel interference	a. It is not much suitable for continuous signals. b. extra gaurdtimes are necessary. c. It requires signal processing for matched filtering & correlation detection. d. It demands high peak power on uplink, in transmit mode.	a. chances of data collision because of overlap. b Protocalls are necessary to avoid collisions.
0. Application	a- Telephone communications	It is used for voice and data transmission.	Cellular mobile communications.

Random Access:-

Random Access is widely used in satellite multiple access technique where the traffic density from individual users is low.

The users can share the transponder space without any control (or) allocation of time or frequency, provided the average activity level is sufficiently low.

In a true Random Access network, a user can transmit packets whenever they are available and the packet has a destination address and source address. All stations receive the packet and the station with correct address only store the data contained in packet. All other earth stations ignore the packet, until it is designated as a broadcast packet with information for all stations. Earlywork on Random Access technique for radio channels are done at university of HAWAII. The system is called ALOHA and was known by a generic term, Packet Radios.

"Random Access cannot be used when traffic density exceeds 18% and therefore makes inefficient use of bandwidth available in transponder."

DEMAND ACCESS MULTIPLE ACCESS:-

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

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Telephone voice users communication at Random times for a period ranging from less than a minute to several minutes, as a percentage of total time, the individual user uses telephone, may be as little one person. Demand access allow a satellite channel to be allocated to user on a demand rather than continuously, which greatly increases the no. of simultaneous users, who can be served by the system. Most SCPC – FDMA systems, use demand access to ensure that available bandwidth in a transponder is used as fully as possible.

Demand access system requires two different types of channels. 1) common signalling channel and 2) communication channel. The user wishing to communication network first calls the controller earth station using communication signal channel (csc). Packet transmission techniques are widely used in demand access systems because of need for address to determine the source & destination of signals. Bent pipe transponders are often used in Demand Access technique.

Ch Srini

Unit-2 SATELLITE SUBSYSTEM

Attitude and orbit control system telemetry, tracking, Command and monitoring, power systems, Communication subsystems, Satellite antenna Eqipment reliabity and Space qualification.

The major subsystems required on the satellite are given below

Attitude and orbit Control System :-

This subsystem consists of rocket motors that are are used to move satellite back to the correct orbit when the external forces cause it to drift off station and gas jets (or) internal devices that control the attitude of the Satellite

Telemetry, Tracking, Command and monitoring

These systems are partly on the satellite and partly at controlling earth station. The telemetry system sends data derived from many sensors on the satellite, which monitor the satellites health via a telemetry link to the controlling earth station

The tracking system is located at this earth station and provides information on the range and the elevation and azimuth angles of the satellite.

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-> ④ ...ased on telemetry data received from the satellite at orbital data obtained from the tracking system, the contr system is used to correct the position and attitude of satellite.

* It is also used to control the antenna pointing and commu system configuration to suit current traffic requirements, an to operate switches on the satellite

Power System

All communications satellite derive their electrical power from sol cel's. The power is used by the communications system, mainly in th transmitters and also by all other electrical systems on the satelli

Communications subsystem :-

* The communications subsystem is the major component c a communications satellite, the communications equipment is on a small part of the weight and volume of the whole satellite. It usually composed of one or more antennas, which receive and tr over wide bandwidths at microwave frequencies, and a set of receivers and transmitters that amplify and retransmit the incoming signals.

* The receiver-transmitter units are known as transponder There are two types of transponder in use on satellites the linear (or) bent pipe transponders that amplifies the received and retransmits it at a different, usually lower, frequency and the baseband processing transponder which is used only with digita signals, that converts the received signal to baseband process it and then retransmits a digital signal.

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Satellite Antennas :-

②

* Although these form part of the Complete Communication System, they can be Considered Seperately from the transponders. On large GEO Satellites the antenna Systems are Very Complex and produce beams with shapes carefully tailered to match the areas on the earth's Surface Served by the Satellite.

* Most Satellite antennas are designed to operate in a Single frequency bands for example, C band (or) ku-band. A Satellite which uses multiple frequency bands usually has fair (or) more antennas.

(1)

Attitude and orbit Control System (AOCS) :- 3(a)

* The earth is not quite a perfect sphere. At the equator, there are bulges of about 65m at longitudes 162°E and 348°E, with the result that a Satellite is accelerated toward one of two stable Points in the GEO orbit at longitude 75°E and 252°E, To maintain accurate station keeping, the satellite must be periodically accelerated in the opposite direction to the forces acting on it.

* There are two ways to make a satellite stable in orbit, When it weightless. The body of the Satellite can be rotated, typically at a rate between 30 and 100rpm, to create a gyroscopic force that provides Stability are known as Spinners

* Alternatively, the Satellite Can be Stabilized by one or more wheels momentum wheels.

* The momentum wheel is usually a solid metal disk driven by an electric motor.

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* The momentum wheel is usually a solid metaldisk driven By an electric motor. Either there must be one momentum wheel for each of the three axes of the satellite (or) single momentum wheel can be mounted on gimbals and to provide a rotational force about any of the three axis.

* Increasing the speed of the momentum wheel causes the satellit to process in the opposite direction, according the principle of conservation of angular momentum.

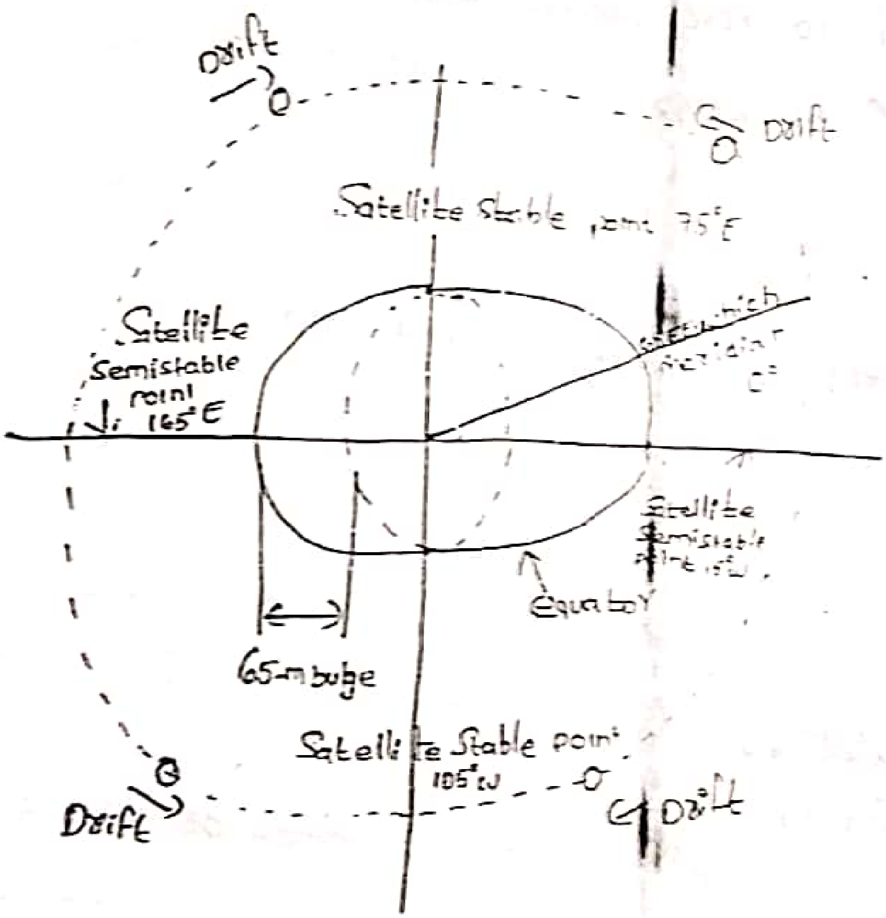

Figure: forces on a Synchronous Satellite

* The spinner design of satellite is typified by many built by the Hughes Aircraft Corporation for domestic Communication systems

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* there are two types of rocket motors used on Satellites. The traditional bio propellent thruster described above, and arc jets (or) ion thrusters. The fuel that is stored on a GEO Satellite is used for to purposes. to fire the apogee kick Motor that injects the Satellite into its final orbit.

* If the launch is highly accurate, a minimum amount of fuel is used to attain the final orbit. If the launch is less accurate ~~more accurate~~ ~~more~~ minimum more fuel must be used to attain the final orbit.

3(a) (2

II

* Arc jets or ion thrusters are mainly used for north-South station keeping, which is where the greatest use of fuel is required for Station Keeping maneuvers, and become operational on the Hughes 600 Series of Satellite buses. Arc jets or ion thrusters lack the total thrust required to move Satellites quickly but a Small Continous thrust is adequate to maintain N-S and E-W position keeping.

* In a three-axis stabilized, one pair of gas jets is needed for each axis to provide for rotation in both directions of pitch, roll and yaw.

* An additional set of controls allowing only one jet on a given axis is to be operated, provides for velocity increments in the x, y, and z-directions

* Let us define a set of reference Cartesian axes (x_R, y_R, z_R) with the Satellite at the origin as shown in figure. The z_R axis is directed toward the center of the earth and is in the plane of the Satellite orbit. The x_R axis is tangent to the orbital plane and lies in the orbital plane.

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Serving the Northern Hemisphere, the directions of X_R and Y_R are nominally east and south.

* Rotation about the X_R, Y_R and Z_R axes is defined as roll about X_R axis, pitch about Y_R axis and yaw about the Z_R in exactly the same ways as for an aircraft (or) ship travel in the x-direction.

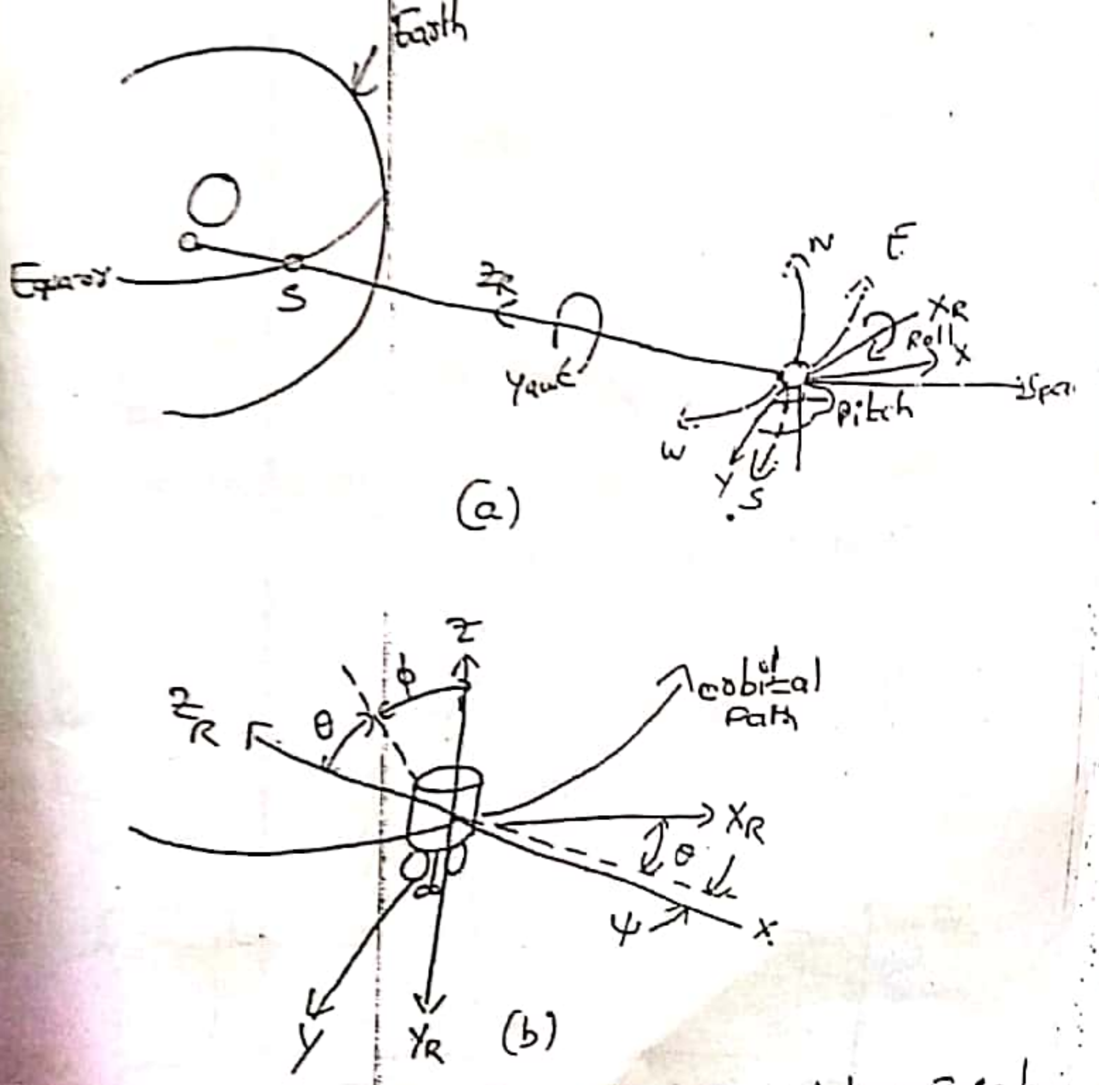

Figure : (a) forces on a Satellite (b) Relationship b axes of satellite

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④

* In a Spinner-type Satellite, the axis of rotation is usually the y-axis, which is maintained close to the Y_R axis, Perpendicolar to the orbital plane.

* Pitch correction is required only on the despun antenna system can be obtained by varying the speed of the despin motor.

* yaw and roll are controlled by pulsing radially mounted jets at the appropriate instant as the body of satellite rotates.

* Attitude control of a three-axis stabilized satellite requires an increase (or) decrease in the speed of the interia wheel. If a constant torque exist about on axis of satellite, a continual increase (or) decrease in momentum wheel speed is necessary to maintain the correct attitude

3(

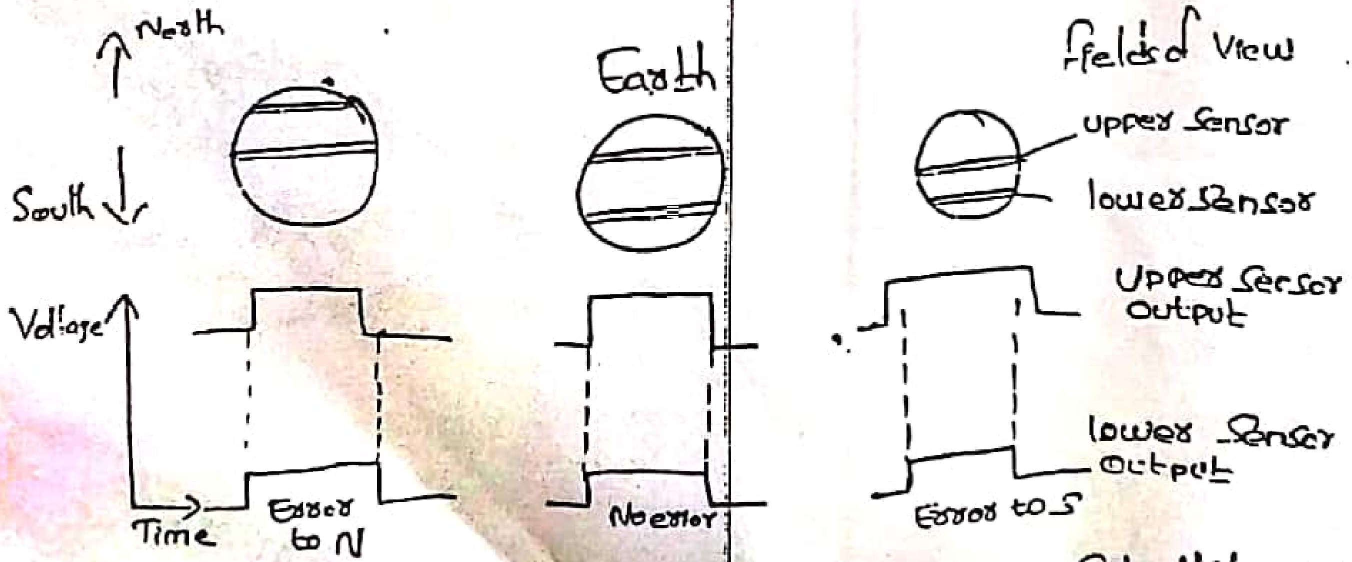

Figure: Principle of N-S Control of a Spinner Satellite using infrared Earth station.

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figure illustrates how an infrared sensor on the spinning of a satellite can be used to control pointing toward the earth.

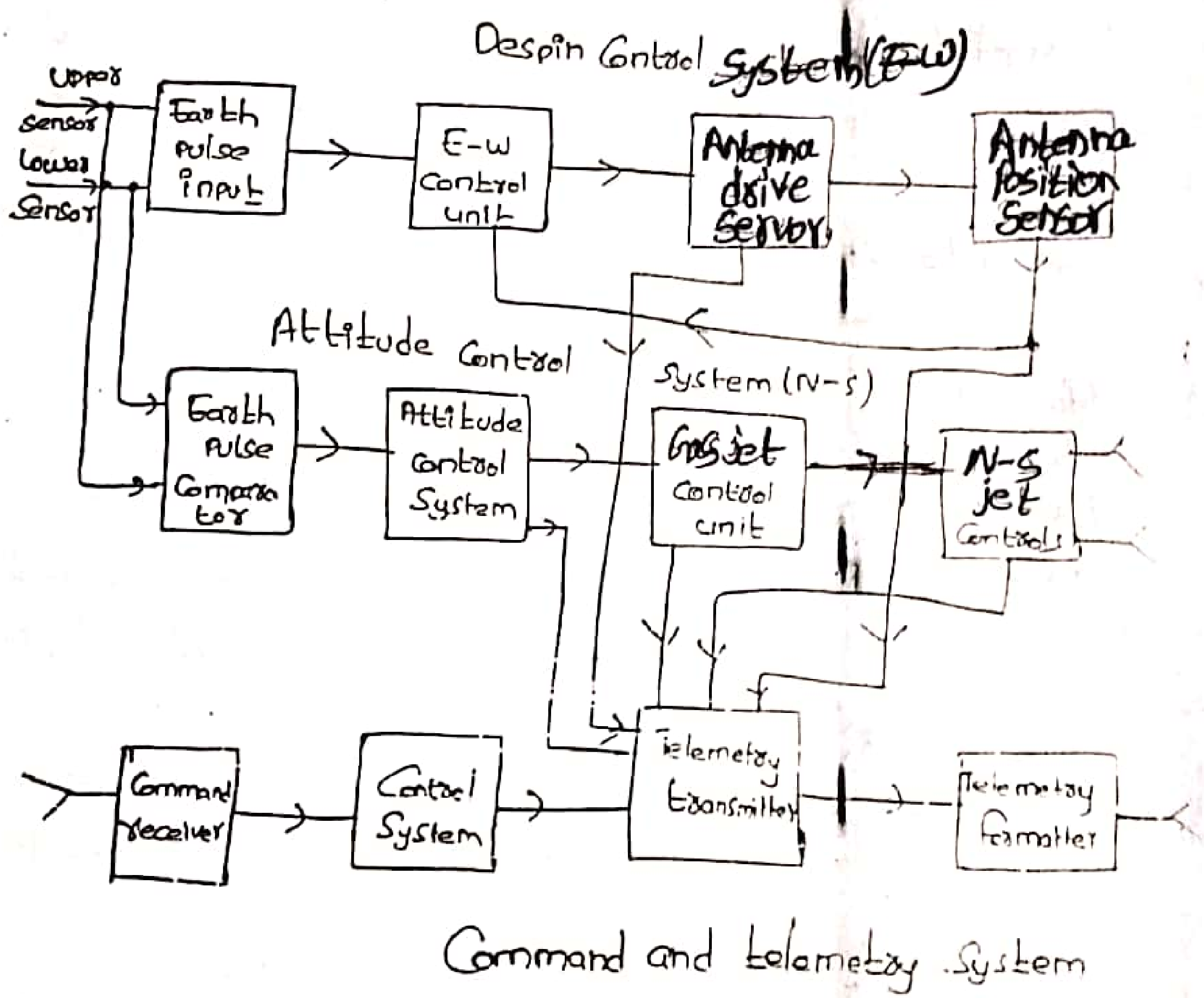

figure : Typical onboard Control system for spinner Satellite.

Above figure shows a typical Control System using the technique. The Control System will be complex for a three axes stabilized Satellite and may on computer to process the sensor data and commands.

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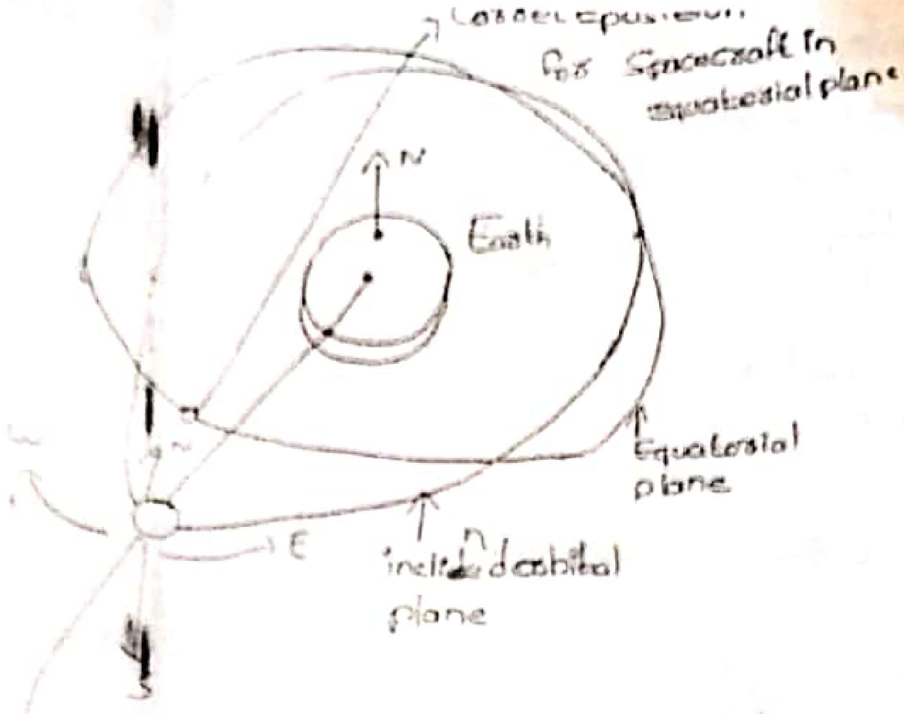

3(a)(4)

Spacecraft position in inclined orbital plane

Above figure shows a diagram of an inclined orbital plane close to the geostationary orbit. for the orbit to be truly geostationary it must lie in the equatorial plane, be circular and have the correct altitude

If the orbit is not circular, a velocity increase or decrease will have to be made along the orbit, in the x-axis direction

The orbit of a geostationary satellite remains approximately circular for long periods of time and does not need frequent velocity corrections to maintain circularity.

The inclination of orbit of a satellite that starts out in a geostationary orbit increases at an average rate of about 0.85° per year, with an inclination for satellite in an

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* Most GEO Satellites are Specified to remain w
box of ±0.05° and so, in pactice Corrections, Called
South station keeping maneuver are made every
to keep the error Small.

* East-west station keeping is effected by the use o
jets of satellite. for a satellite located away from the
at 75°E and 252°E, a slow drift toward these point

* low earth orbit and medium earth orbit Satellite
AOC Systems to maintain the Correct orbit and atti
Continous Communication.

* Because of much stronger gravitational force of
in LEO orbit, attitude stabilization is often accompl
rigid gravity gradient boom.

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Telemetry, Tracking Command and monitoring :-

⑥

5(b) (i)

* On large geostationary Satellites, Some repointing of individual antennas may be possible, under the Command of TTC & M System.

Telemetry and Monitoring System :-

* The monitoring system collects data from many Sensors with in the Satellite and sends these data to the Controlling earth station.
* There may Several hundreds sensors located on the Satellite to monitor Pressure in the fuel tanks, Voltage and Current in the power Conditioning unit, current drawn by each system Subsystem, and critical Voltages and Currents in the Communications electronics.
* Telemetry data are usually digitized and transmitted a phase shift keying of low power telemetry Carrier using time divison techniques.
* A low data rate is normally used to allow the receiver at the earth station to have a narrow bandwidth and thus maintain a high Carrier to noise ratio.
* The entire TDM frame may Contain thousands of bits of data and take Several seconds to transmit. At the controlling earth Station a Computer Can be used to monitor, store, and decode the telemetry data so that the status of any System or Sensor on the Satellite Can be determined immediately by the Controller on the earth.

Tracking :-

* A number of techniques can be used to determine the correct orbit of a satellite. Velocity and acceleration sensors on th satellite can be used to establish the change in orbit from the last known position, by integration of the data

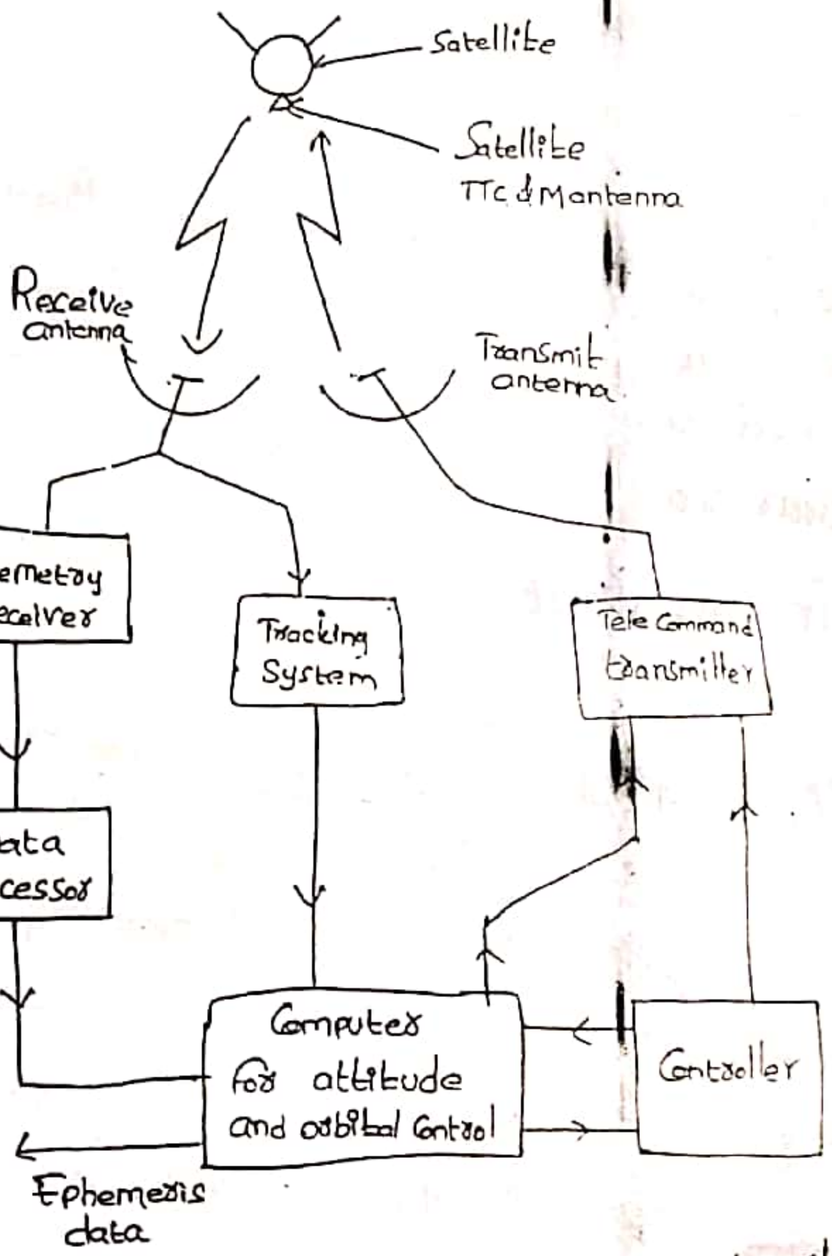

Figure : Typical tracking, telemetry Comman and monitoring System

The earth station controlling the satellite can observe the Doppler shift of the telemetry carrier or beacon transmitter carrier to determine the rate at which range is changing. 3(b

Ranging tones are also used for range measurement. A carrier generated on board the satellite is modulated with a series of sine wave frequency, usually harmonically related.

The phase of the sine wave modulation components is compared at an earth station, and the number of wavelengths of each frequency is calculated

Ambiguities in the numbers are resolved by reference to lower frequencies and prior knowledge of approximate range of the satellite.

If sufficiently high frequencies are used, perhaps even the carrier frequency, range can be measured to millimeter accuracy

ommand :-

The command system is used to make changes in attitude and corrections to the orbit and to control the communication system. During launch, it is used to control the firing of the apogee kick motor and to spin up a spinner or extend the solar sails and antennas of a three-axis stabilized satellite

* The Command Structure must possess Safeguards agains
2) unauthorized attempts to make changes to the Satellites operat and also against inadvertent operation of a control due to errors in a received Command.

* The Control Code is Converted into a Command word which is se in a TDM frame to the Satellite. After checking for validi in the satellite, the word is sent back to the Control statio Via the telemetry link where it is checked again in the Computer.

* If it is found to have been received Correctly, an executi instruction will be sent to the satellite so that the Com is executed. The entire process may take 5 or 10s, but minimiz risk of erroneous Commands Causing a satellite malfunction.

* The Command and telemetry links are usually Seperate from Communication System, although they may operate in the Sa frequency band (6 and 4 GHz). Two levels of Command Sys are used in the Intelsat Satellite: the main System oper in the 6GHz band, in a gap between the Communication c frequencies

* The main telemetry system uses a similar gap in th 4GHz band. These are earth-coverage horns, so the mai System Can be used only after Correct attitude of th Satellite is achieved.

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Power Systems :-

* The Sun is a powerful Source of an energy. In the total vaccum of outer space, at geostationary altitude, the radiation failing on a Satellite has intensity of 1.39kw/m². Solar cells do not convert all this incident energy into electrical power; their efficiency is typically 20 to 25% at beginning of life (BOL) but falls with time because of aging of cells and etching of the surface by micrometer impacts.

* A Spin-stabilized Satellite usually has a cylindrical body covered in solar cells. Becuase the solar cells are on a cylindrical surface, half of the cells are not illuminated at all, and at the edges of the illuminated half, the low angle of incidenbce results in little electrical power being generated

* A three axis stabilized Satellite Can make better use of its cells area, Since the cells can be arraged on flat panels that can be rotated to maintain normal incidente of the Sun light. only one third of the total area of Solar cells is needed relative to a spinner with Some Saving in weight.

* Solar Sails must be rotated by an electric motor once per 24h to keep the cells in full sunlight. This causes the cells to heat up, typically to 50°C to 80°C, which causes a drop in output voltage.

* The Satellite must carry batteries to power the Subsystems during launch and during eclipse. Eclipses occur twice per year, around the Spring and fall equinoxes, when the earth's

Satellite.

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3(b) (3)

* TV broadcast Satellites may not Carry Sufficient Capacity to Supply their high power transmitters during eclipse and may shut down. By locating the Satellite west of the longitude of Service area, the eclipse will occur after 1 am local time for the Service area when the shut down is more acceptable.

*

Communications Subsystem :

Description of the Communications system

* A Communications Satellite exists to provide a platform geostationary orbit for the relaying of Voice, Video and data unications.

* All other Subsystems on the Satellite exist Solely to Support the Communications System, although this may represent only small part of the Volume, weight and cost of Satellite in orbit

* Since it is the Communications System that earns the real for the System operator, Communications Satellites are designed to provide the largest traffic Capacity possible

* Successive Satellites have become larger heavier and more but rate at which traffic Capacity has increased has been resulting in a lower Cost per telephone circuit (or) bit with each succeeding generation of Satellite

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* The Satellite transponders have limited output power and earth S are atleast 36,000km away from a GEO Satellite, So the received level even with large aperture earth station antennas, is very Sm and rarely exceeds 10^{-10} W.

* For the System to perform Satisfactorily, the Signal power mu exceeds the power of the noise generated in the receiver b between 5 and 25 dB, depending on the bandwidth of transmitti Signal and modulation scheme used

* Early Communications Satellites were fitted with transponde 250 (or) 500 MHz band width but had low gain antennas and tran of 1 or 2 W output power.

* The earth station receiver could not achieve an adequa signal to noise ratio when the full bandwidth was used with result the System was power limited.

* The 500-MHz bands originally allocated for 6/4 and 14/1 Satellite Communications have become Very Congested and are n Completely filled for Some Segments of geostationary orbit.

* Many Systems now use 14/11 GHz for TV broadcast and dist and 30/20 GHz Systems are introducing Internet-like Services f GEO.

* The standard Spacing between GEO Satellites was originally se 3°, but under regulations covering North America and much of rest of the world, the Spacing has been reduced to 2°.

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Transponders :-

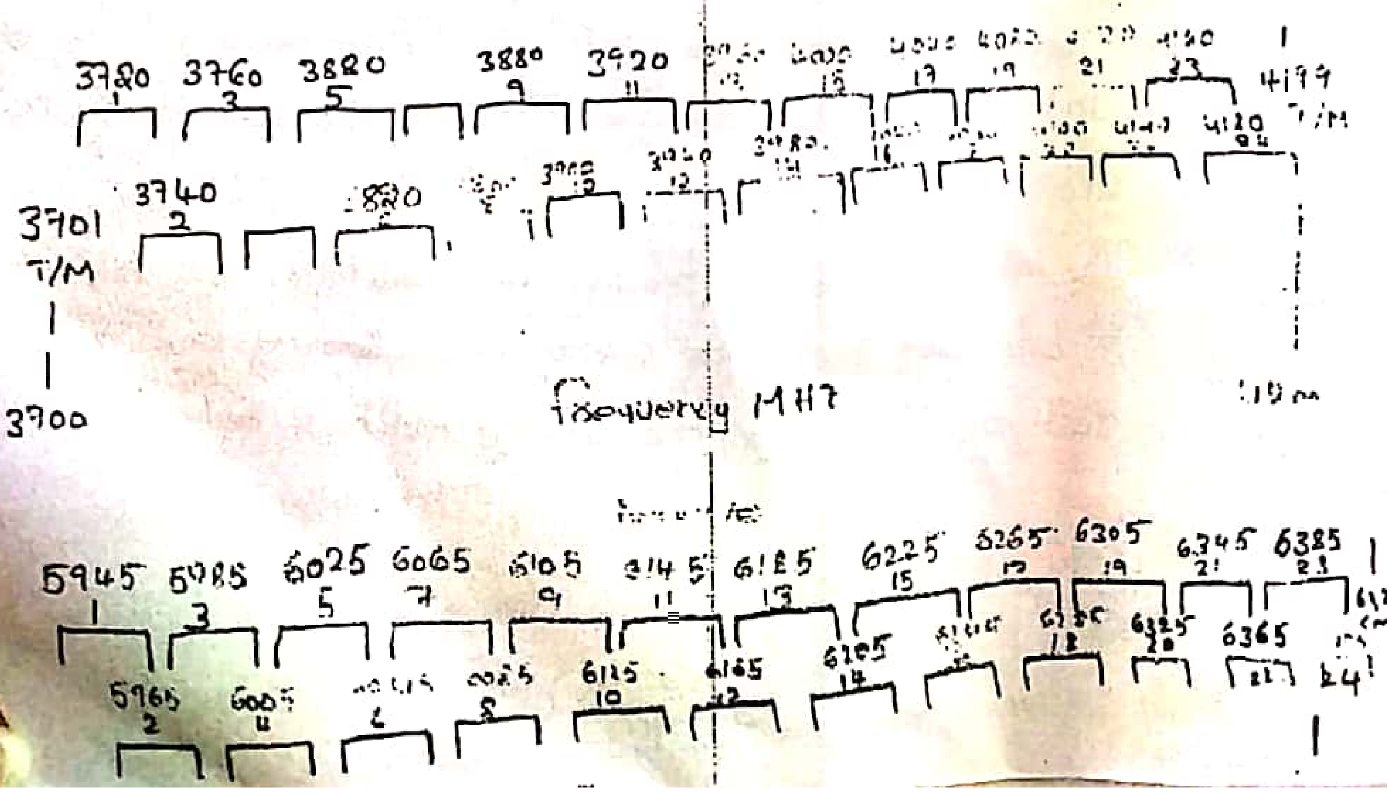
(10)

Signals transmitted by an earth station are received at the satellite by either a zone beam (or) a spot beam antenna. Zone beams can receive from transmitters any where with in the coverage zone, where as spot beams have limited coverage.

The recieved Signal is often taken to two low noise amplifiers and is recombined at their output to provide redundancy. If either amplifier fails, the other one can still carry all the traffic.

Since all carriers from one antenna must pass through a low noise amplifier, a failure at that point is catastrophic. Redundancy is provided wherever failure of one component will cause the loss of significant part of satellite's communication capacity.

Transmit



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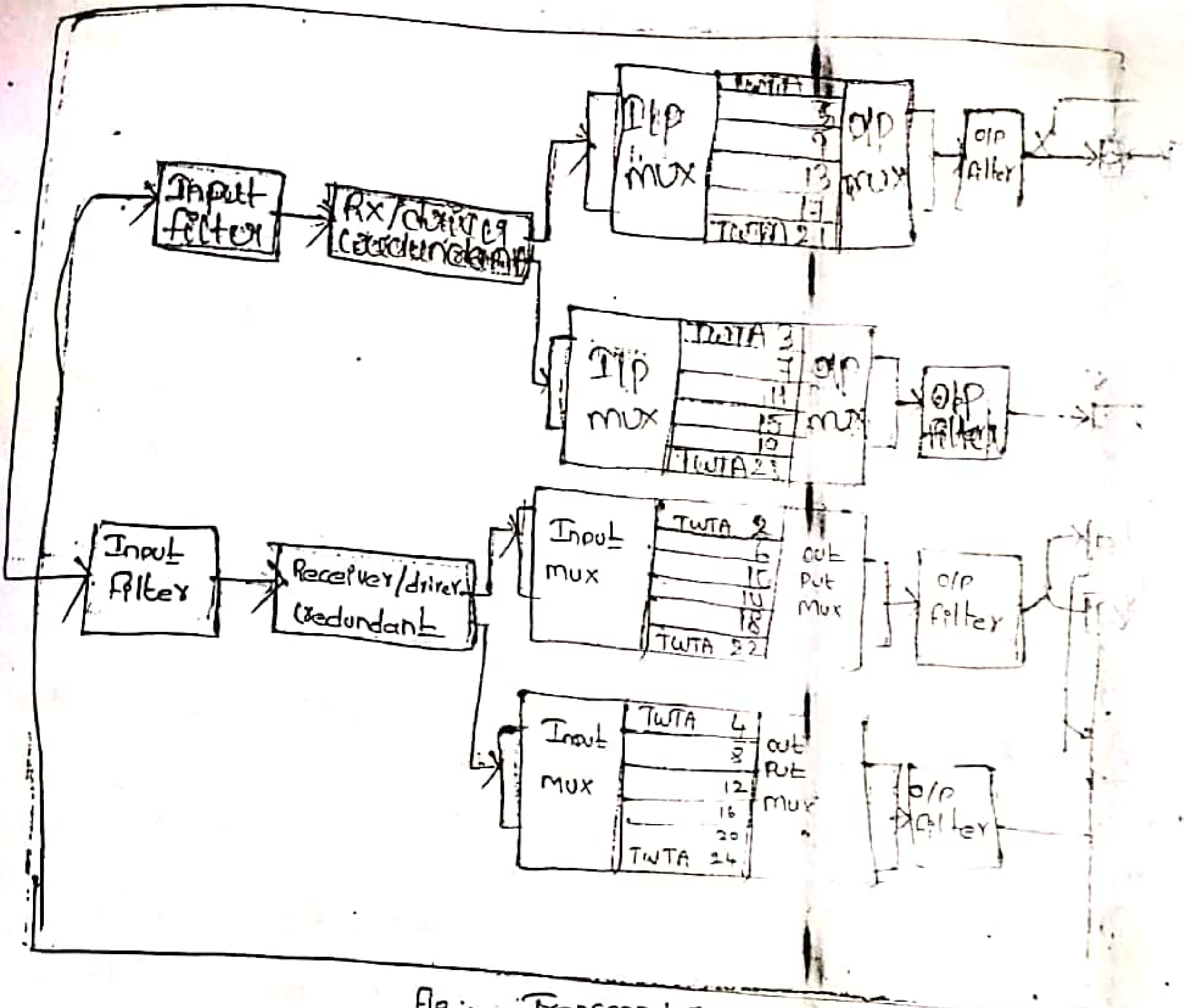

Fig :- Transponder

* Above figure shows a simplified block diagram of a Satellite communication subsystem for the 6/4 GHz band The 500 MHz band width is divided up into channels, often 36 MHz wide, which is each handled by a seperate transponder.

A transponder consists of a band-pass filter to select the channels band of frequencies, a down converter to change and from 6GHz at the input to 4GHz at the output, and one amplifier.

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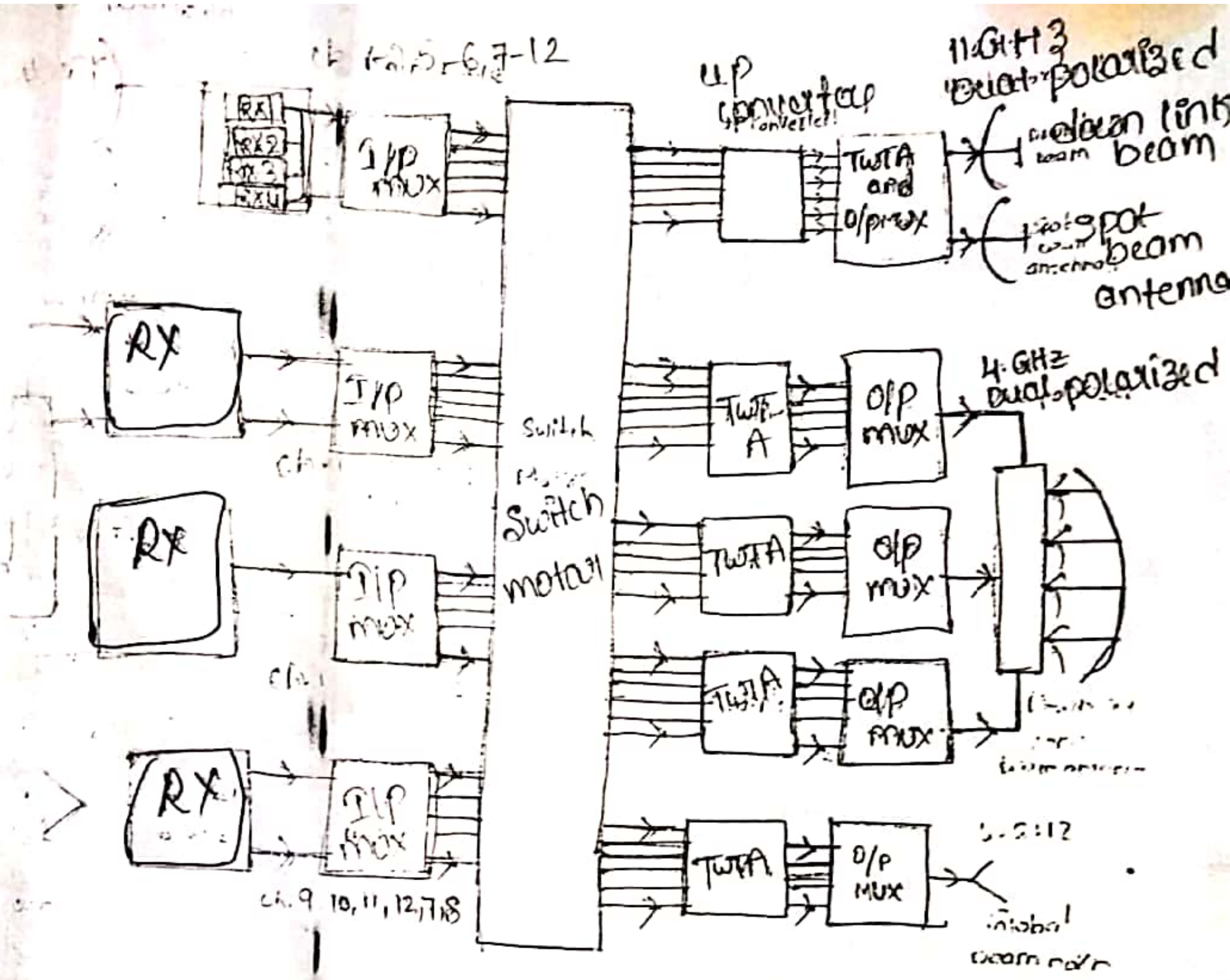

Fig - Simplified block diagram of an INTELSAT V Communication System

Above figure shows a simplified diagram of the Communication System carried by INTELSAT V Satellites. The later Series of Intelsat Satellite use a similar arrangement.

The bulk of the traffic is carried by 6/4 GHz Section, With total bandwidth of 2000 MHz available in frequency reuse. The Switch matrix allows a very large no. of Variations in connecting 6GHz receivers to the 4GHz transmitters.

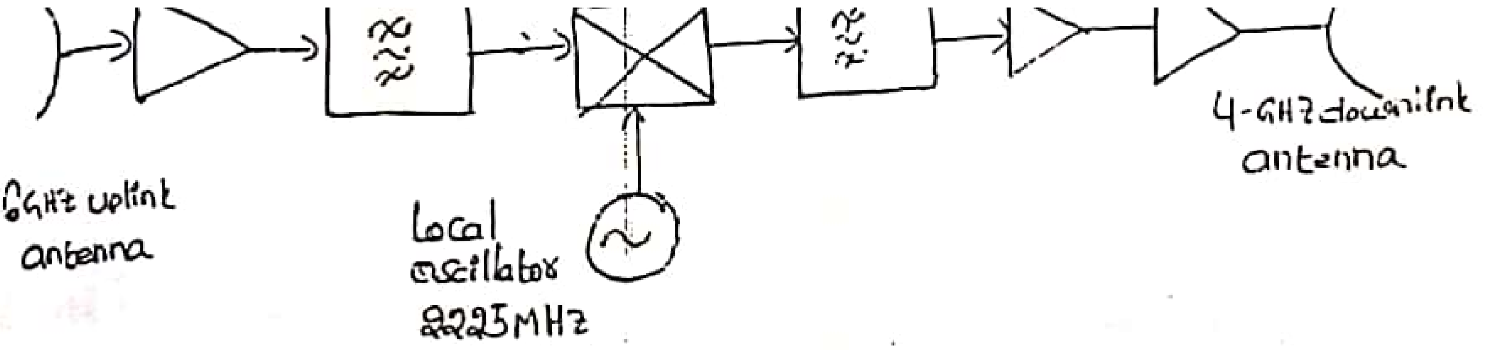

figure: Simplified Single Conversion transpond (bent pipe) for 6/4 GH

* Above figure shows a typical single conversion bent pipe transponder of type used on many satellites for the 6/4 GHz band. The output po amplifier is usually a solid state power amplifier (SSPA) unless a very output power is required, when a traveling wave tube amplifier would

* The local oscillator is at 2225 MHz to provide the appropriate shi frequency from the 6-GHz uplink frequency to the 4-GHz down link uency, and band-pass filter after the mixer removes unwanted f ncies resulting from down Conversion operation.

* The attenuator can be controlled via the uplink command system t set the gain of the transponder. Redundancy is provided for high power amplifiers (HPA) in each transponder by including a spare TWT (or) solidstate amplifier (~~HPA~~) (SSPA) that can be switched into primary circuit if the power amplifier fails

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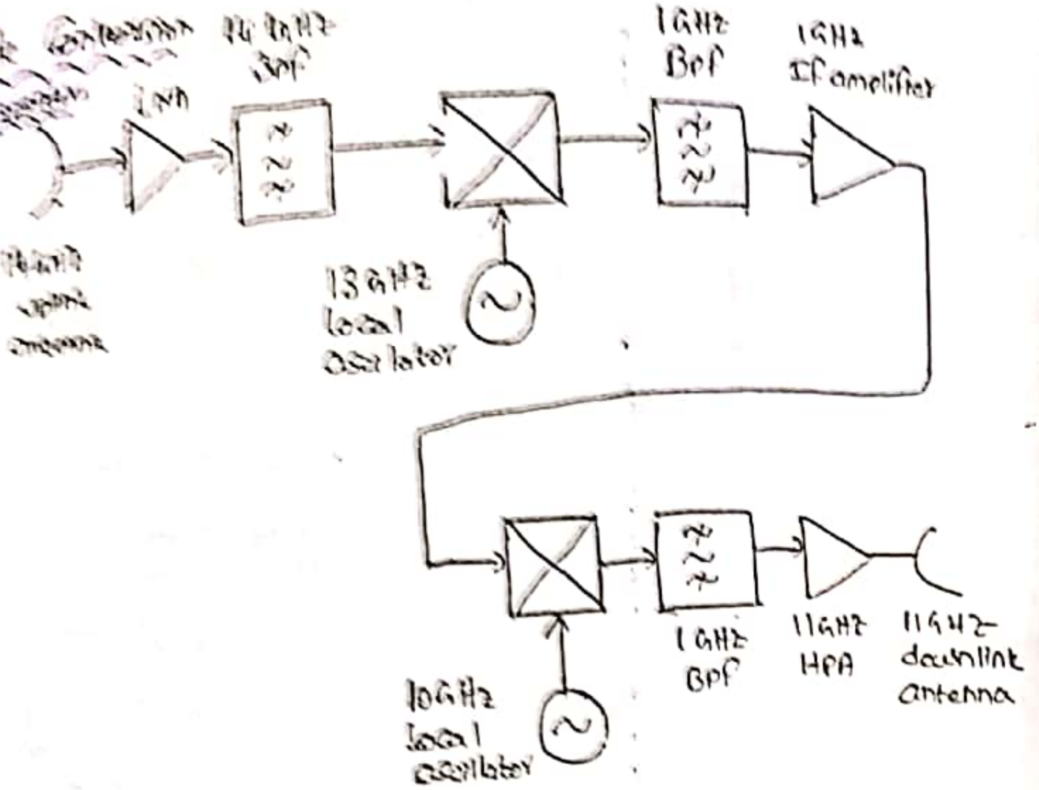
Double Conversion transponder



Simplified double Conversion transponder for 14/11 GHz band.

- * Transponders for use in the 14/11 GHz bands normally employ a double frequency conversion scheme. is shown in above figure.

- * It is easier to make filters, amplifiers and equalizers at an intermediate frequency (IF) such as 1100MHz than at 14 or 11GHz, so the incoming 14-GHz carrier is translated to an IF of around 1GHz. The amplification and filtering are performed at 1GHz and relatively high-level carrier is translated back to 11GHz for amplification by the HPA.

On board processing transponder :-

On board processing may also be used to advantage. to switch between the uplink access technique (eg MF-TDMA) and downlink access technique (eg TDM) so that small earth stations may access each other directly via the satellite.

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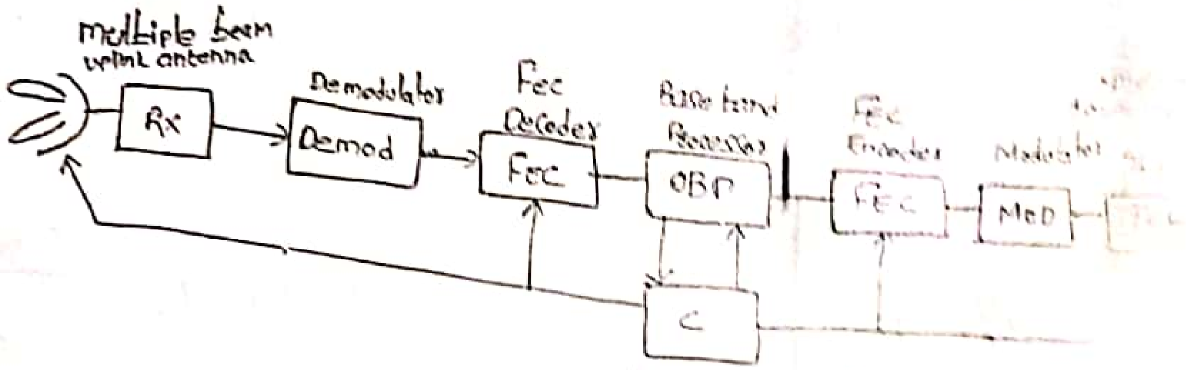

* The processor can provide the data storage needed for Switcher· beam system and also can perform error correction independently on Uplink and downlink.

Satellite ANTENNAS :-

Basic antenna types are Relationships:

Four main types of antennas are used on satellites These are

1. Wire antennas ; monopoles and dipoles
2. Horn antennas
3. Reflector antennas
4. Array antennas.

Wire antenna.s

Wire antennas are used primarily at VHF and UHF to provide action for the TTC&M systems. They are positioned with great on the body of the satellite in attempt to provide omni direct coverage. Most satellites measure only a few wave lengths are frequencies, which makes it difficult to get the required antenna and there~~fore~~ trend to some orientations of the satellite in which antenna sensitivity of the TTC &M system reduced by nulls in antenna

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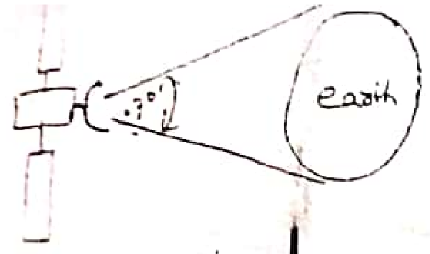
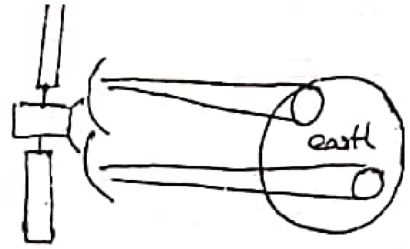
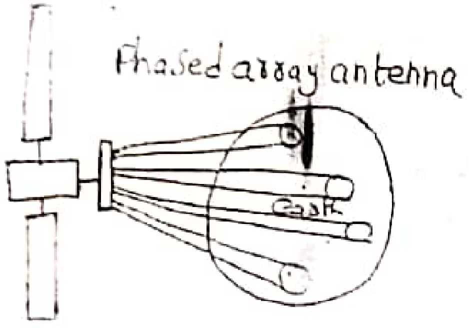


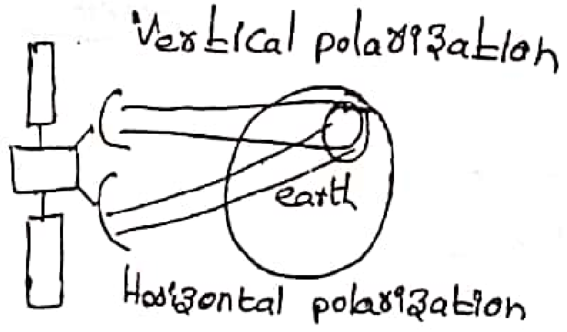
Global beam



Spot beams



multiple spot beams and scanning beams



orthogonally polarized beams

Typical Satellite antenna patterns and coverage zones.

Horn antennas :

Horn antennas are used at microwave frequencies when relatively wide beams are required, as for global coverage. A horn is flared section of waveguide that provides an aperture several wave lengths wide and a good match between the waveguide impedence and free space.

Horns are also used feeds for reflectors, either ~~slightly~~ singly or in clusters. Horns and reflectors are examples of aperture antennas that launch a wave into free space from wave guide.

It is difficult to obtain gains much greater than 23 dB or beam widths narrower than about 10° with horn antennas. for higher gains or narrow beamwidths a reflector antenna (or) array must be used.

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* Reflector antennas are usually illuminated by one or m horns and provide a large aperture than can be achieved horn alone. For maximum gain, it is necessary to generat a plane wave in the aperture of the reflector.

* This is achieved by choosing a reflector profile that has e Path lengths from the feed to aperture, so that all the radiated by the feed and reflected by the reflector reac the aperture with the same phase angle and creates a uni phase front.

The following approximate relationships will be used here t guide the selection of antennas for communications satellite

An aperture antenna has a gain G given by

$$G = \eta_A 4\pi A/\lambda^2 \quad — ①$$

where A is the area of the antenna in meters

λ is the operating wavelength in meters.

η_A is the aperture efficiency of the antenna.

Horn antennas tend to have higher efficiencies than reflec antennas, typically range 65 to 80%. If the aperture is circu Can be written as $G = \eta_A (\pi D/\lambda)^2$ — ②

Where D is the diameter of the circular aperture in mete

The 3dB beam width in a given plane for an antenna with di mension 'D' in that plane is

$$\theta_{3dB} \simeq 75\lambda/D \text{ degrees.} \quad — ③$$

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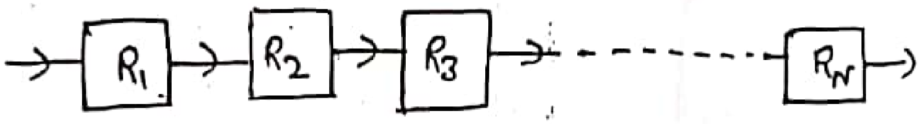
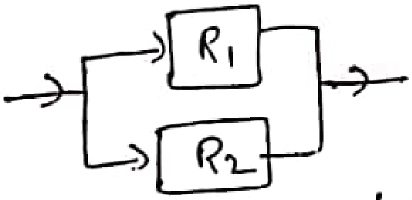
Redundancy:-

In a satellite, many devices are used, each with a different MTBF, and failure of one device may cause catastrophic failure of complete subsystem. If we incorporate redundant devices, the subsystem can continue to function correctly.



(a)

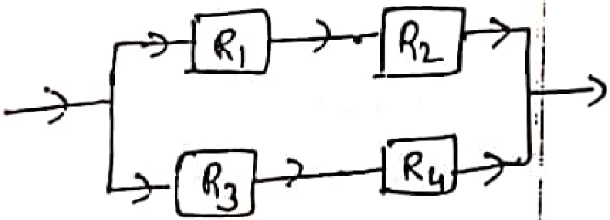
Series Connection



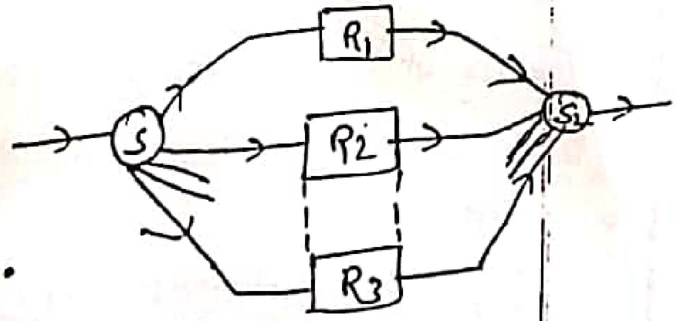
(b)

Parallel connection

(c)



Series/parallel Connection



Switch connection.

(d)

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(16)

The average failure rate λ, is the reciprocal of the MTBF, m. If we assume that λ is constant, then

$$\lambda = \frac{\text{Number of failures in given time}}{\text{Number of surviving Components}}$$

$$\lambda = \frac{1}{N_s}\frac{\Delta N_t}{\Delta t} = \frac{1}{N_s}\frac{dN_t}{dt} = \frac{1}{MTBF}$$

failure rate λ is often given as the average failure rate per 10^9h. The rate of failure, dN_f/dt is the negative of the rate survival dN_s/dt, So we Can ~~defined~~ redefined λ as

$$\lambda = -\frac{1}{N_s}\frac{dN_s}{dt}$$

The Reliability R is N_s/N_o so

$$\lambda = \frac{-1}{N_o R}\frac{d}{dt}(N_o R)$$

$$= -\frac{1}{R}\frac{dR}{dt}$$

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

~~Thus the reliabil~~

However, end of useful life is usually taken the time t_1 at which R falls to 0.37 (1/e)

$$t_1 = 1/\lambda = m$$

The probability of a device failing, therefore has a relationship to the MTBF and is represented by the

Series Connection, used in Solar cells arrays, parallel connection used to provide redundancy of the high power amplifiers in satell transponders, and switched connection often used to provide parallel paths with multiple transponders.

- The Switched Connection arrangment shown in figure is also referred to as ring redundancy since any component can be switched in for any other.
- The important point to note is that the active devices (R₁, R₂ --- Rₙ) have sufficient bandwidth, power output range etc to be able to handle any of channels that might be switched through to them.

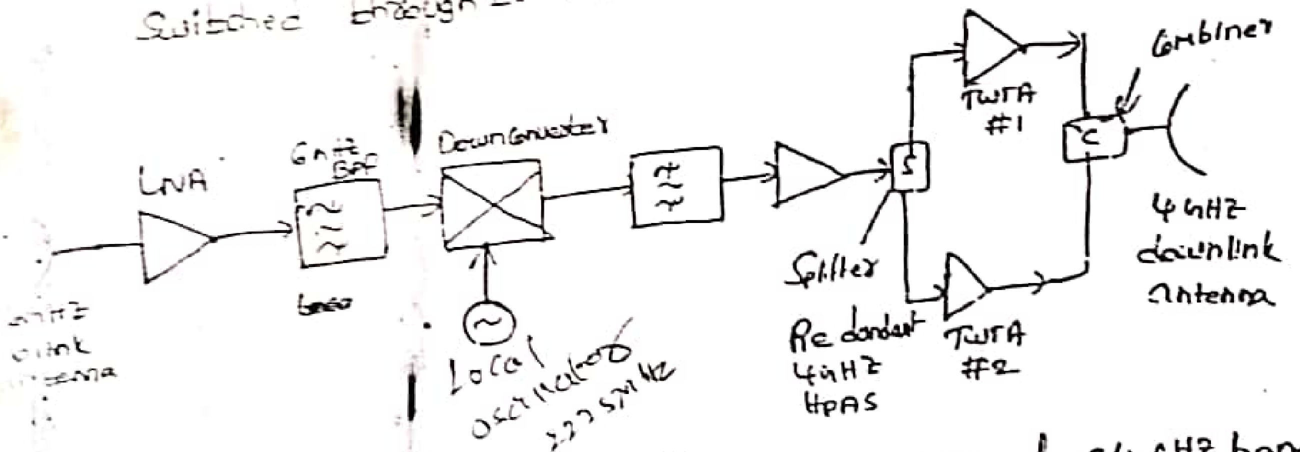

Figure : Redundant TWTA Configuration in HPA of 6/4GHz band

- The parallel Connection of two TWTs as shown in figure raises the reliability of amplifier stage to 0.60 at the MTBF period, assuming zero probability of a short circuit.

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SATELLITE LINK DESIGN

The satellite communication system design is a complex process, involved comprimises between many factors, in order to obtain maximum performance. The factors are:

1. The weight of the satellite.
2. The dc power that can be generated onboard.
3. The maximum dimensions of satellite and ground station antennas.
4. The multiple access technique used to share communication capacity between many earth stations.
5. The frequency bands of a satellite.

The weight of the satellite is limited by high cost of launching a spacecraft into geostationary orbit.

The weight of the satellite is driven by two factors.

a) The number and output power of transponders on satellites.

b) Weight of station keeping fuel.

High power transponders require lots of electrical power which can only be generated by solarcells. If increasing the total output power of transponders raises the demand for electrical power and also dimensions of solarcells.

A communication system must be designed to meet certain minimum performance standard like minimum txing power and RF bandwidth. SNR is an important parameter.

While designing a satellite system, we must try to gaurantee a minimum SNR in the receiver's baseband channel. Increasing total o/p power of transponders raises the demand for

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"SNR in a channel depends on

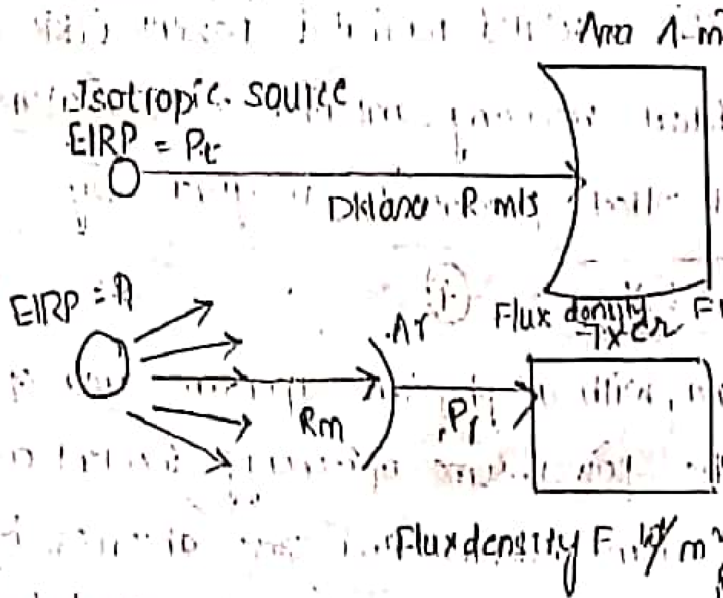
a) C/N of RF signal in receiver.

b) type of modulation used.

c) The IF and channel bandwidth in receiver."

The C/N is calculated at input of receiver and at output terminals of receiving antenna. Designing a satellite system therefore requires knowledge of required performance of uplink & downlink.

BASIC TRANSMISSION THEORY :-



The calc of power received by an earth station with a satellite Txer is fundamental for understanding satellite communication.

Consider a transmitting source in a free space radiating in all directions (uniformly) with total power 'P_t', such a source is called isotropic source. At a distance 'R' mts from hypothetical isotropic source transmitting RF power 'P_t' watts, the flux density crossing the surface of sphere with a radius 'R' is given by

$$\boxed{F = \frac{P_t}{4\pi R^2}} \quad ①$$

All real antennas are directional. Any real antenna has a gain $g(\theta)$ is defined as the ratio of power per unit solid angle radiated in a direction θ to average power radiated per unit solid angle.

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$$\boxed{G(\theta) = \frac{P(\theta)}{(P_0/4\pi)}}$$ —— ②

For a transmitter ~~of~~ Pt for a driving lossless antenna, with a gain ~~gt~~ 'Gt', the flux density in a direction of antenna at a distance R is

~~F x A~~ $$\boxed{F = \frac{P_t G_t}{4\pi R^2}}$$ —— ③

$\boxed{P_t G_t : \text{effective isolated radiated power} = \text{EIRP}}$

If we have an ideal receiving antenna with aperture area of 'A', we would collect power 'P_r' is given by

$$\boxed{P_r = F \times A}$$ —— ④

A practical antenna, with a physical aperture area of 'A_r', will not deliver the power. Some of the energy incident on aperture is reflected away from antenna and some absorbed by lossy components. This reduction in efficiency is described by using an effective aperture A_e.

$$\boxed{A_e = \eta_A \times A_r}$$ —— ⑤

η_A : efficiency ; $\left\{\begin{array}{l} 50 \text{ to } 75\% \text{ for paraboloid} \\ 90\% \text{ for horn} \end{array}\right\}$

The power received by a real antenna with physical receiving area 'A_r' and effective aperture 'A_e' is given as

$$\boxed{P_r = \frac{P_t G_t A_e}{4\pi R^2}}$$ —— ⑥

The fundamental of an antenna theory is gain and

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area of antenna is related by

$$\boxed{G_r = \left(\frac{4\pi}{\lambda^2}\right) A_e} \quad \text{— ⑦}$$

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

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

$$\boxed{P_r = \underbrace{\left(\frac{\lambda}{4\pi R}\right)^2}_{\text{Path loss}} P_t G_t G_r}$$

Collecting various factors, we can write

$$\boxed{P_r = \frac{(EIRP) \times \text{Received antenna gain}}{\text{Path loss } (L_p)}}$$

$$\boxed{P_r|_{db} = [EIRP + G_r - L_p]\ db} \quad \text{— ⑧}$$

The equation 8 represents in ideal condition. But in practise we need to consider

1) Atmospheric loss - due to signal attenuation by rain, water water.

2) Losses due to antenna at the each end of the link.

3) Possible loss of gain due to antenna mispointing

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

L_a : atmospheric loss

L_{ta} : loss associated with txing antenna,

L_{ra} : Loss associated with Rxing antenna.

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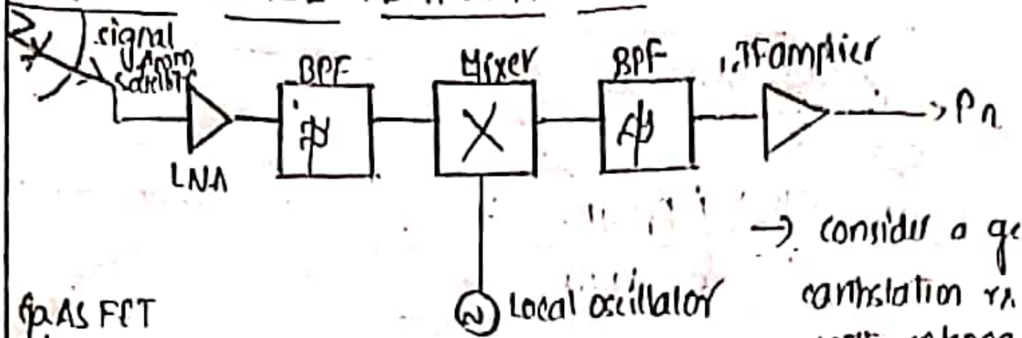
~~SIGNAL~~ SYSTEM NOISE TEMPERATURE :-



→ consider a general earthstation rx er with antenna, RF amp, freq converter, lo & IF amplifier

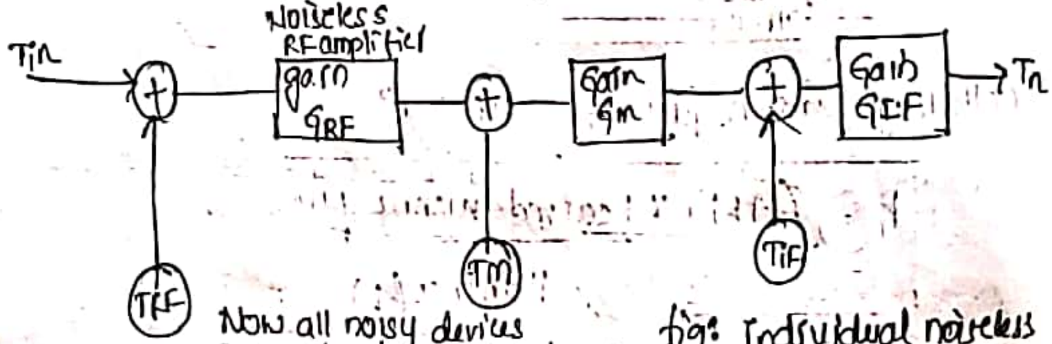
G_{aAS} FET tmp → 30K – 200K

30Kelvin for 4Ghz,

100 kelvin for 11Ghz

→ Now above ckt can be represented by an equi noise generators.

Equivalent ckt for above design



Now all noisy devices are replaced by a simple noise sources

fig: Individual noiseless devices with T_g + noiseless amp & freq converter.

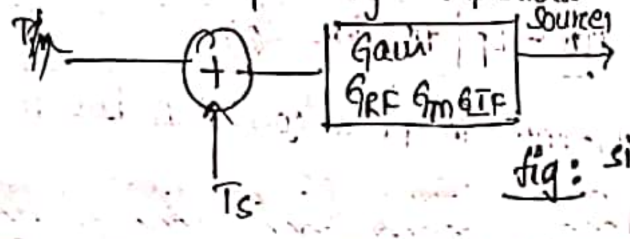


fig: single noise source

from fig1 $P_n = KT_{IF}G_{IF}B + KT_mG_{IF}G_mB + KT_{in}G_{IF}G_mG_{RF}\,[T_{RF}+T$ — ①

from fig2 $P_n = KG_{RF}G_mG_{IF}T_sB$ ——— ②

From equation ①

$$P_n = KG_{RF}G_{IF}G_mB\left[\frac{T_{IF}}{G_mG_{RF}} + \frac{T_m}{G_{RF}} + T_{RF} + T_{in}\right]$$

from eq's ② & ③

$$\boxed{T_s = \frac{T_{if}}{G_mG_{RF}} + \frac{T_m}{G_{RF}} + T_{RF} + T_{in}} \text{ ——— ④}$$

Noise figure is used frequently used to specify the noise generated within a device.

$$\boxed{\text{Noise figure} = \frac{(S/N)\,i/p}{(S/N)\,o/p}}$$

Because noise temperature is more useful in satellite communication systems. It is best to convert noise figure to noise temperature.

$$\boxed{T_d = T_0\,[NF-1]}$$

T_0: reference tmp = 290K

T_d: noise tmp

NF: Noise figure.

G/T ratio for earth station:-

The link equation can be rewritten in terms of C/N is

$$C/N = \frac{P_t\,G_t\,G_r}{K T_s B}\left[\frac{\lambda}{4\pi R}\right]^2$$

$$\boxed{C/N = \left[\frac{P_t G_t}{KB}\right]\left[\frac{\lambda}{4\pi R}\right]^2\left[\frac{G_r}{T_s}\right]}$$

$$(C/N) \propto \left(\frac{G_r}{T_s}\right)$$ → for determining quality in system.

$$\boxed{\frac{G_r}{T_s}\ \text{also called as figure of merit}}$$

If you want to calculate carrier to noise ratio, (downlink)

$$\boxed{C/N = \frac{\text{Power input}}{\text{Noise power}}}$$

P_r: received power of downlink

$$C/N = \frac{P_r G_r}{K T_s B G_r}$$

→ A standard A earth station used in Intelsat N/w is required to have a G/T ratio of 40.7 dB/K at 4GHz & 5° elevation angle:

$$\boxed{C/N = \frac{P_r}{KT_sB}}$$

Satellite systems using small earthstations :-

Direct Broadcast TV (DBS-TV or DTH)

Europe – Analog - FM tx'on
USA – digital tx'on

-Hughes company } — 200 television and audio channels.

Typical mass of domestic satellite — 6800 kg

4khz → 4° spotbeam → 1.4m ↓ diameter of satellite antenna.

DIRECT BROADCAST SERVICE :-

C/N calculation is simplified by use of "LINK BUDGET". A link budget is a tabular form method for evaluating received power and noise power in a radio links.

LINK BUDGET FOR KU BAND DBS-TV Rx'er :-

DBS-TV terminal rxed signal power :

Transponder o/p power 160W	22.0dBW
Antenna beam on axis	34.3 db
Rxing antenna gain on axis	33.5db
Pathloss at 12.2Ghz, 38,000m path	−205.7db

Above values belongs to united states DBS TV

Edge of beam loss	− 3.0db
clearsky atmosphere	−0.4db
Rx'ed power C	−119.7dbw

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DBS-TV terminal Rxed noise power

Boltzmann's constant : −228.6 dbw/K/hz:

clearsky noise temperature : 21.6 dbK.

Rxer noise bandwidth : 73.0 dbhz.

noise power : −134.0 dbW

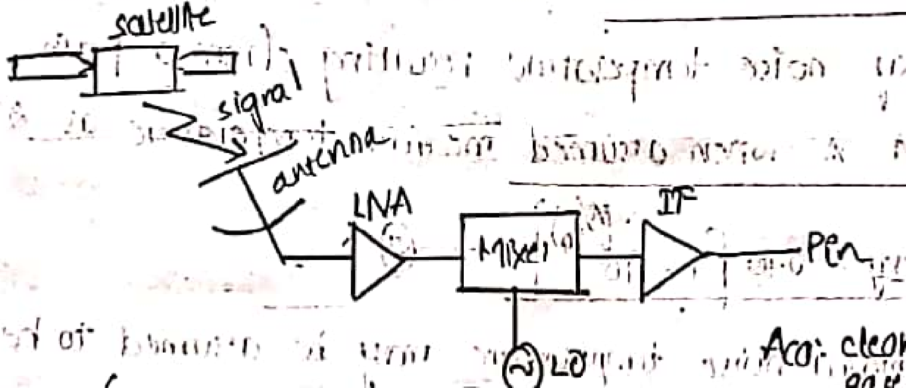
DBS-TV terminal C/N in clearsky

clearsky overall C/N : 14.3 db.

link margin over 8.6 db treshold is 5.7 db.

link availability throughout us better than 99.7%.

Calculations:-



Aca: clearsky atmospheric gases gain atten

$A = (A_{ca} + A_{rain})\,db$ —①

T_{sky} = sky Noise temperature = $270\left[1 - 10^{\left(\frac{-A}{10}\right)}\right]$ —②

$T_S = T_{LNA} + T_A$ —③

T_A: Antenna noise temperature.

T_{LNA}: low noise amplifier.

$T_A = T_{sky} \times \eta_c$ —④

η_c: coupling coefficient.

$$\Delta N_{rain} = \left[\frac{k\,T_{s\,rain}\,B_n}{K\,T_{sca}\,B_n}\right]$$

$\left(C/N\right)_{\underbrace{\text{dn rain}}}$?

downlink when rain attenuation is present.

Theory:-

The C/N ratio in home receiver will fall when rain is present in a path between satellite & receiver antenna. Much of reduction in C/N ratio is caused by sky noise temperature. The total attenuation is given as

A_a : attenuation due to clear sky atmospheric gases + attenuation due to rain

$$\boxed{A_a = A_{ca} + A_{rain}} \text{ ——— ①}$$

The sky noise temperature resulting from a path attenuation A when assumed medium temperature as 270K, then

$$\boxed{T_{sky} = 270\left[1 - 10^{-(A/10)}\right]} \text{ ——— ②}$$

The antenna noise temperature may be assumed to be equal to sky noise temperature. The coupling coefficient η_c of 90-95% is often used when calculating antenna's noise temperature.

$$\boxed{T_A = \eta_c \times T_{sky}} \text{ ——— ③}$$

The system noise temperature when a satellite receiver using high gain lownoise amplifier is given as

$$\boxed{T_S = T_{LNA} + T_A} \text{ ——— ④}$$

T_A : Antenna's noise temperature.

We will assume there are no feed losses. The increase in noise power ΔN_{rain} caused by increase in sky noise temperature,

$$\boxed{\Delta N_{rain} = 10\log_{10}\left[\frac{K T_{s\,rain} B_n}{K T_{sca} B_n}\right] db} \text{———} ⑤$$

The total received power is reduced by attenuation caused by rain, so in rain the carrier power value is

$$\boxed{C_{rain} = [C_{ca} - A_{rain}]\, db} \text{———} ⑥$$

The resulting C/N downlink rain gives

$$\boxed{\left(\frac{C}{N}\right)_{dn\,rain} = \left(\frac{C}{N}\right)_{dn\,ca} - A_{rain} - \Delta N_{rain}} \text{———} ⑦$$

3

<u>Design for uplink and downlink</u>:-

① The primary objective is to gaurantee continuity of link

② To provide many channels in a minimum capital cost

LINK BUDGET :-

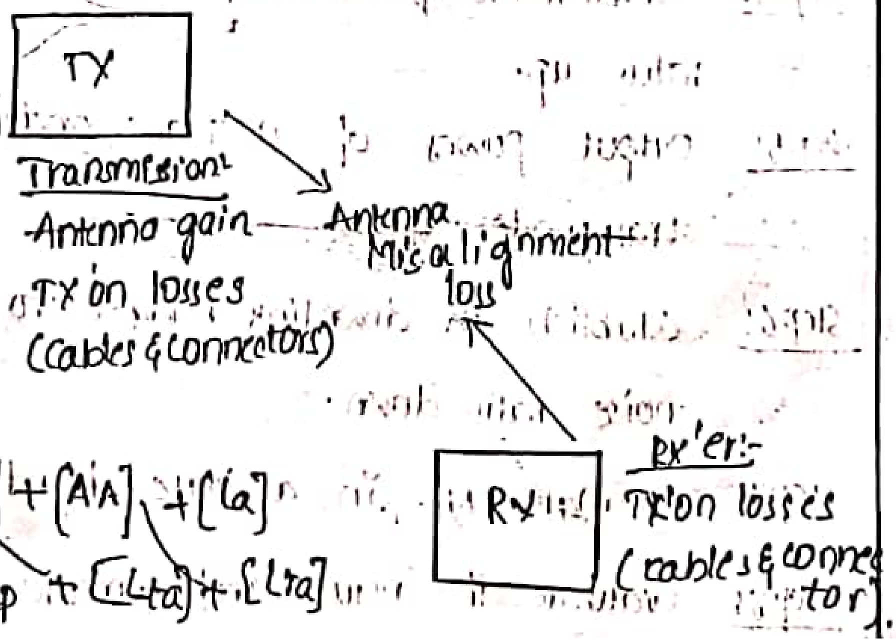
$$\left(\frac{C}{N}\right)_{uplink} = [EIRP] + [G_r] + [L_A] - [losses] \quad \left(\frac{C}{N_0}\right) = \left(\frac{C}{N_0}\right)_{up} + \left(\frac{C}{N_0}\right)_{down} \rightarrow \text{bent pipe}$$

$$\left(\frac{C}{N_0}\right)_{downlink} = [EIRP]_{dn} + [G_i]_{dn} - [L_A] - [K] - [B_0]_{I}$$

BOI :- input back of

LINK POWER BUDGET :-

$$\boxed{\frac{C}{N} = EIRP + \left[\frac{G_r}{T_S}\right] - [losses]}$$



$$losses = [RFL] + [AA] + [La] + L_p + [L_{ta}] + [L_{ra}]$$

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$P_r = [EIRP] + [G_r] - [losses]$

$losses = [FSL] + [RFL] + [AML] + [AA] + [PL]$

FSL : free space tx'on loss in db

RFL : Receiver feeder loss in db.

AA : Atmospheric absorption loss in db.

AML : antenna misalignment loss

PL : Depolarisation loss.

System Noise tmp:- Thermal noise due to active & passive components.

Noise tmp of Rxer: Thermal noise due to RF amplifier, mixer and IF amplifier.

20-9-13.

* Sattelite communication link design procedure

Step1: choose the frequency band for your system.

Step2: Determining the parameters of communication.

Step3: Determine the parameters of rxing & txing earth stations (antenna gain, temperature, efficiency etc).

Step4:- Establish an uplink budget to find carrier to noise ratio up.

Step5: output power of a transponder based on transponder gains.

Step6: Establish an downlink budget to find carrier to noise ratio down.

Step7: calculate SNR in a base band channel.

Step8: Evaluate the result and compare with specific requirements.

Step 9: Choose the propagation.

Step 10: Re-design the system with modified parameters.

Design of specified C/N:

1) Hypothetical reference circuit.

2) C/N & C/I addition.

3) Reciprocal method.

Reciprocal method:-

$$\left(\frac{C}{N}\right)_0 = 1 \Big/ \left[\frac{1}{(C/N)_1} + \frac{1}{(C/N)_2} + \frac{1}{(C/N)_3} + \cdots\cdots\right] \quad \text{—— ①}$$

$$\left(\frac{C}{N}\right)_0 = \frac{C}{[N_1 + N_2 + N_3 + \cdots\cdots]}$$

In decibels

$$\left(\frac{C}{N}\right)_0 = C\,dBW - 10\log(N_1 + N_2 + N_3 + \cdots)\ dB.$$

C: single carrier power 'C'.

Specific thumbrules:-

1) If both (C/N) values are equal, $(C/N)_0$ is 3dB of either value.

20dB

$10\log_{10} x = 20$

$x = 10^2$

$x = \underline{100}$

2)
$(C/N)_{up} = 20db$

$(C/N)_{dn} = 20db$

$(C/N)_{out} = ?$

$$\left(\frac{C}{N}\right)_0 = \frac{1}{1/(C/N)_{up} + 1/(C/N)_{down}} = \frac{1}{1/100 + 1/100} = 50$$

$$\left.\left(\frac{C}{N}\right)_{out}\right|_{db} = 10\log(50) = 16.98\,db.$$

$(C/N)_{out} = 17db.$

4) If one $_{\alpha}$ C/N value is 10db smaller than other (C/N) value, $(C/N)_o$ is 0.4db smaller than smaller of C/N value.
lower

5) If one C/N value is 20db (or more) greater than other (C/N) value, the overall (C/N) is equal to smaller of 2 (C/N) values within accuracy of decibels calculations.

Eg:- $(C/N)_{up} = 40db = 10^4$ $\qquad 10\log x = 40$, $x = 10^4$

$(C/N)_{dn} = 20db = 10^2$ $\qquad 10\log_{10} x = 20$

① $$(C/N)_o = \frac{1}{1/10^4 + 1/10^2} = 99.0099$$

$$(C/N)_o\big|_{db} = 10\log(99.0099)$$
$$= 19.95678$$
$$\approx 20db.$$

* Rain attenuation in uplink and downlink:-

$$(C/N)_{o,rain} = \frac{1}{\left[\frac{1}{(C/N)_{uplink\ rain}} + \frac{1}{(C/N)_{downlink\ rain}}\right]}$$

$$(C/N)_{o,uplink\ rain} = \left[(C/N)_{clearair} - A_{rain}\right] db$$

$$(C/N)_{o,downlink\ rain} = \left[(C/N)_{dnclearair} - A_{rain}\right] db$$

22-9-13

* VSAT :- [Very Small Aperture terminal]

architecture of VSAT network:-

1) One way implementation
2) Split two way implementation (split IP).
3) Two way implementation — Star.
   - Mesh.

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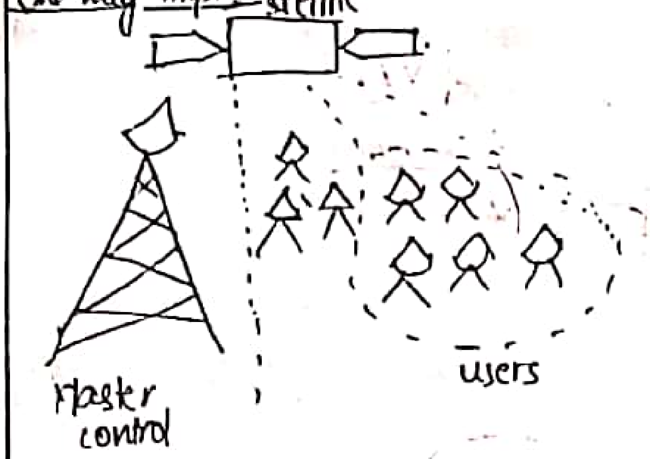
One-way implementation

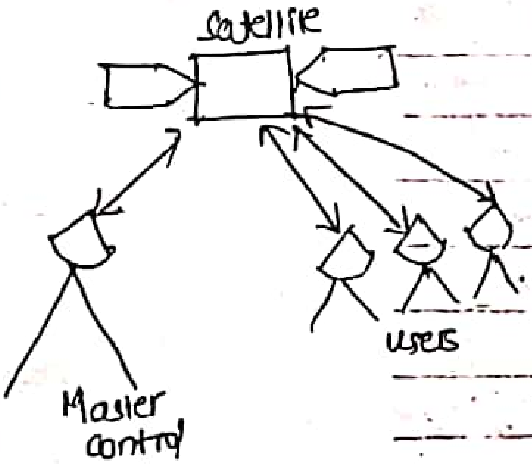


TCP/IP → N/W layer

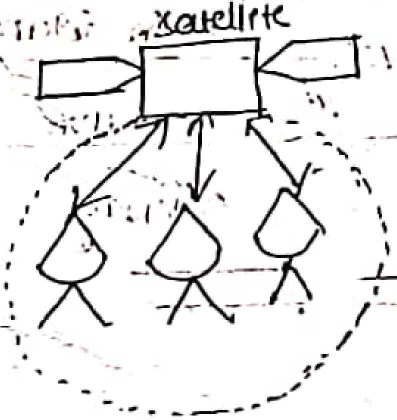
layers

1. Physical layer
2. Datalink layer
3. N/w ing layer
4. Transport layer.
6. Presentation layer
5. Session layer.
7. Application layer.

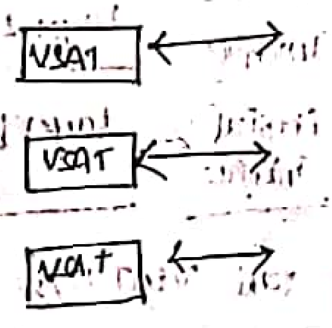
→ Star architecture



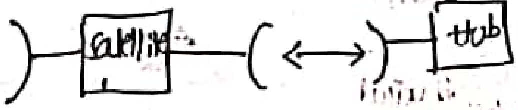
In Mesh, without design of hub station, any user can connect with another user.



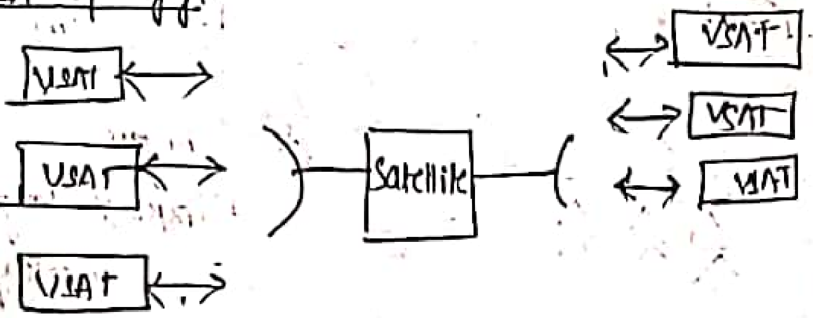
Satellite topology view:



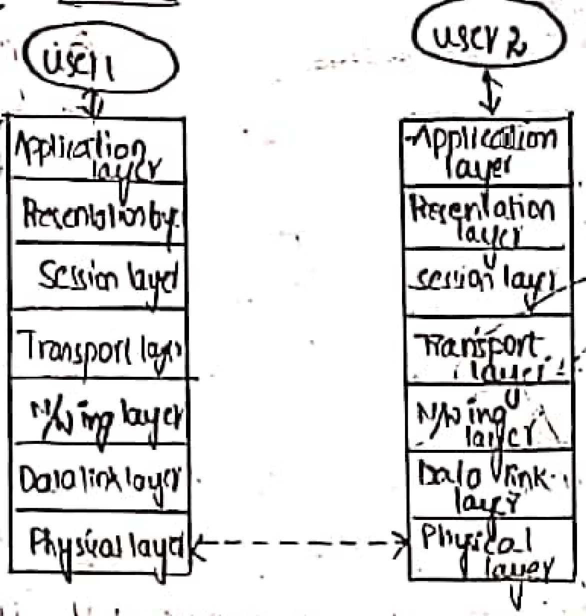
Star topology



Mesh topology:



Access Control Protocols:-



① Acknowledgement (ACK)

② Not Acknowledgement (NAK)

→ Automatic Repeat request (ARQ)
↓
used in internet protocols.

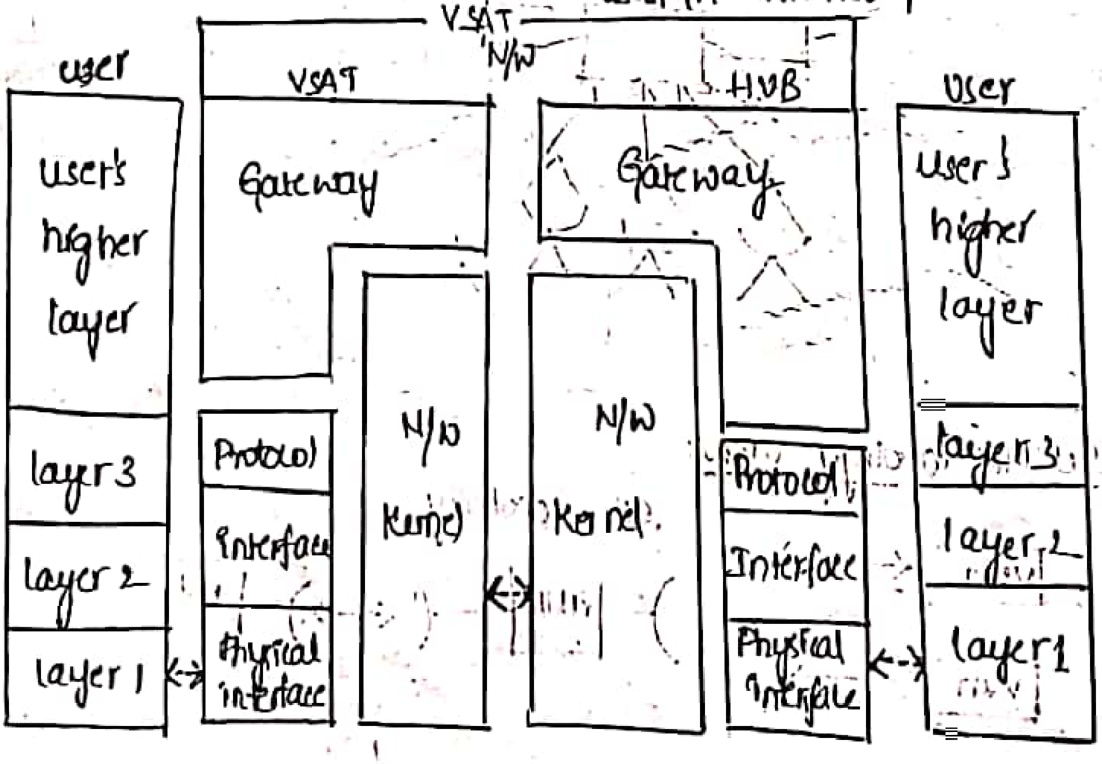


fig: Protocol architecture of ~~stat~~ VSAT N/W "spoofing" – separating the satellite link and terrestrial link.

1. modulo-8
2. modulo-128 } operations made by users while forming a link.

modulo-8 : user can transmit 7 packets at a time. A modulo-128 : user can transmit 127 packets at a time. Most VSAT uses this modulo-128 operation.

VSAT EARTH STATION ENGINEERING:

1. outdoor unit (ODU):
2. Inter-facility link (IFL):
3. Indoor Unit (IDU):

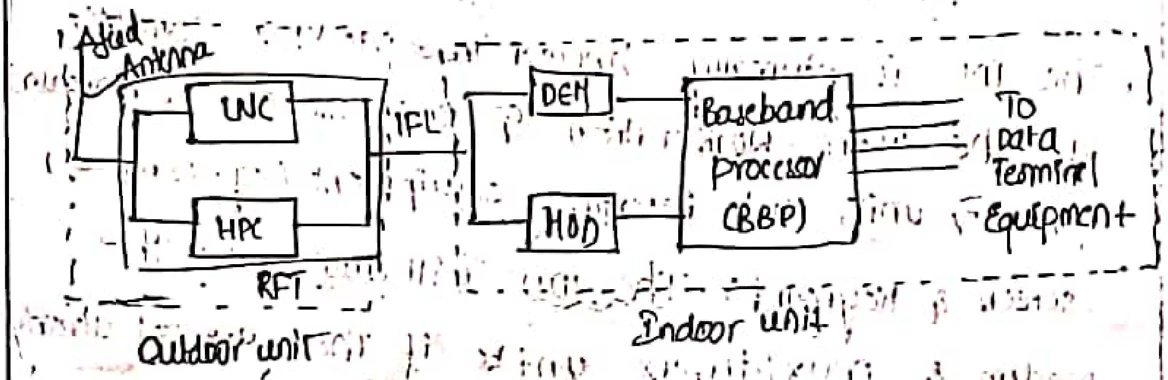
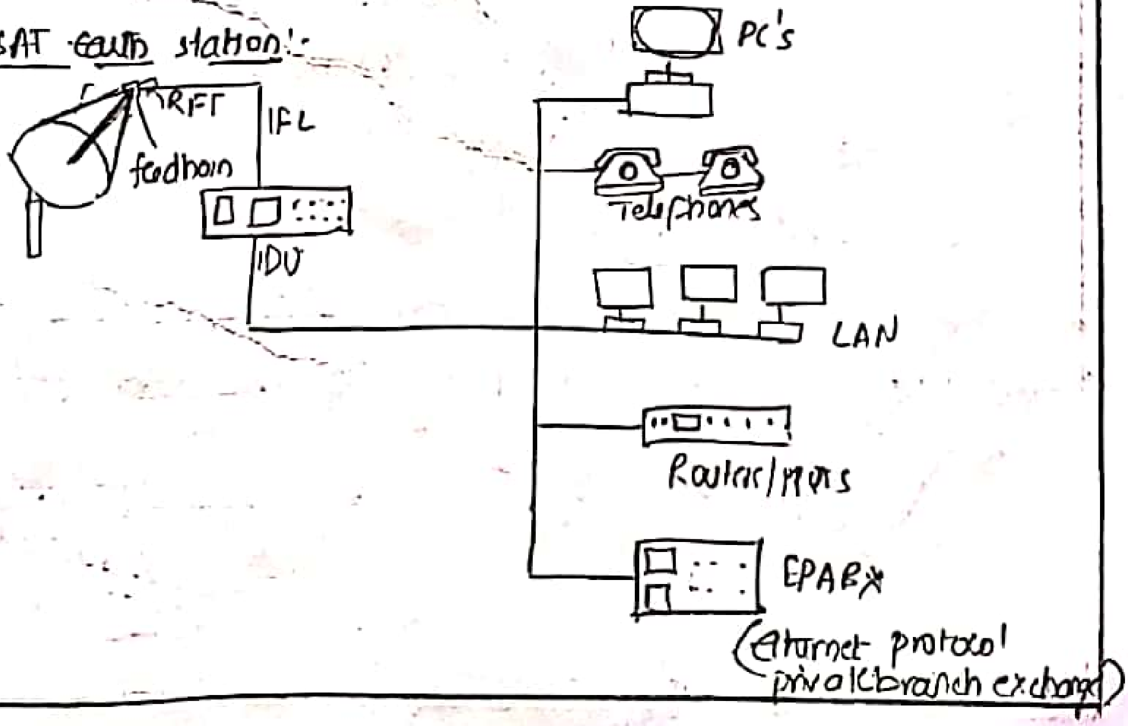


fig: VSAT earth station block dgm.

VSAT earth station:



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Horn → more coverage antenna

DTH → antenna → cassegrain-feed system.

phased array antenna → Telephone conversation

* VSAT earth station:-

- The VSAT outdoor unit is located where it will have a clear line of sight to the satellite & is free from casual blockage by people and/or equipment moving infront of it. It includes the Radio freq. transreceiver (RFT).

- The interfacility link (IFL) carries the electronic signal b/w the ODU and the indoor unit as well as power cables for the ODU & control signals from the IDU.

- The IDU is normally housed in a desktop computer at the user's workstation & consists of the baseband processor units and interface equipment (eg. computer screen & keyboard). The IDU will also house the modem & mux/demux units if these are not already housed in the ODU.

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6-12

UNIT-III : GLOBAL POSITIONING SYSTEM

Navigation satellite timing & Ranging.
NAVSTAR → first GPS satellite – 1978 – U.S

Later it is converted into GPS satellite.

24 GPS satellites are launched by US.

4 satellite } → constellation
together }

Placed at 12,000 kms away from the surface of earth.

L2 : precise code (public use) } ← L band
L1 : military code }

GPS is a space-based satellite navigation system

Galileo – European

Glonass – Russia

Navstar – USA

GPS satellite Vehicle

- 4 atomic clocks
- 3 Ni-Cd battery
- Two solar panels
  → battery charging

[illegible] → 1136 W
  → power generation
- S band → satellite control

GPS signals:- [illegible] →

- signals driven by an atomic clock.
  → fundamental freq) at 10.23 MHz.
- 2 carrier signals (sine waves)

→ L1 : $f = 1575.43$ MHz ($\lambda = 19$ cm)
→ L2 : $f = 1227.60$ MHz ($\lambda \approx 24$ cm)

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→ ephemeris → stores information in a tabular form.
⇒ almanacs → status of satellites orbit.

* GPS are made up of 3 segment.
1. space segment :- 6 orbital planes are placed with an inclination of 55°.
2. user segment.
3. control segment.

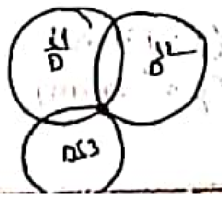
*- 1 siderial period = 2 [time of GPS to rotate].

* CS consists of 3 entities
1. Master control system.
2. Monitor station.
3. Gnd antennas.

- Rxer performs following tasks:
1. selecting one or more satellites.
2. Acquiring GPS signals.
3. Measuring & tracking.
4. Recovering navigation data.

GPS provides

- SPS → standard positioning service → C/A code → used for general purpose. → civilian purpose
- PPS → precise positioning service.
- C/A → coarse/acquisition or clear/access. ← SPS
- PPS → both P code and C/A code.
- Trilateration method → method used to locate the user on the surface of the earth.



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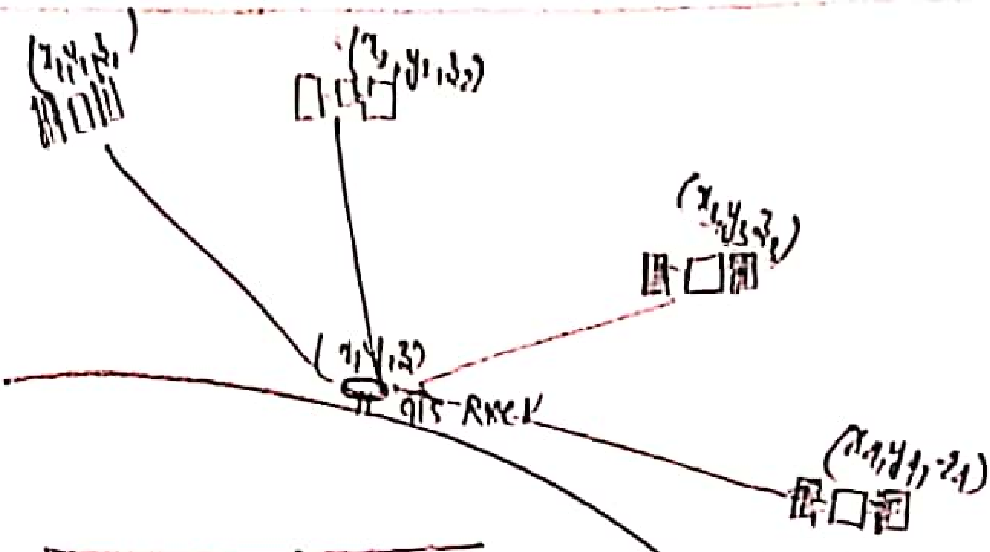


$$s_1 = \sqrt{(x_1-x)^2+(y_1-y)^2+(z_1-z)^2} + c.\Delta t$$

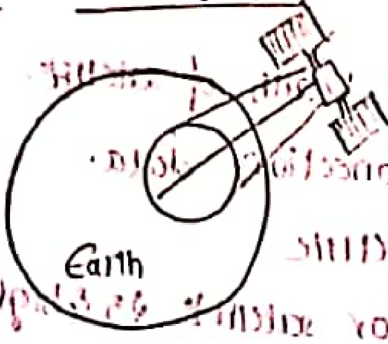
$$s_2 = \sqrt{(x_2-x)^2+(y_2-y)^2+(z_2-z)^2} + c.\Delta t$$

c = speed

$$s_3 = \sqrt{(x_3-x)^2+(y_3-y)^2+(z_3-z)^2} + c.\Delta t$$

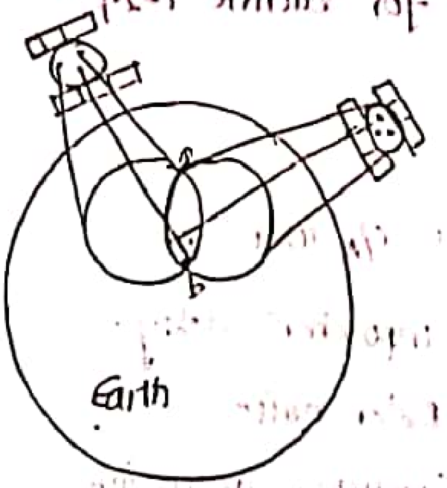
$$s_4 = \sqrt{(x_4-x)^2+(y_4-y)^2+(z_4-z)^2} + c.\Delta t$$

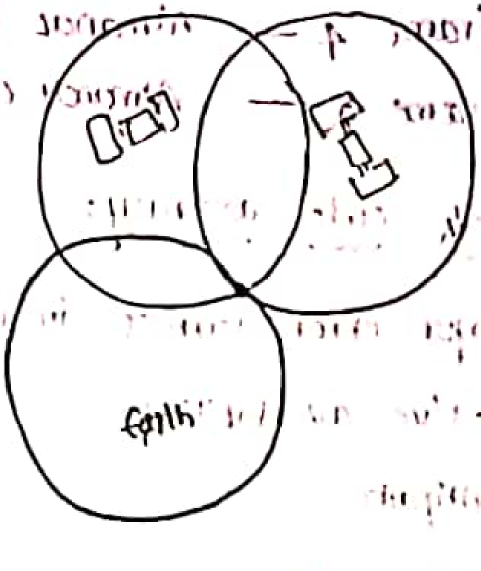
GPS Trilateration:-



eq:-

$$\boxed{\text{distance} = \text{speed} \times \text{time}}$$





Distance of GPS satellites from surface of earth is 20,200kms / 11,000 miles placed in MEO orbit.

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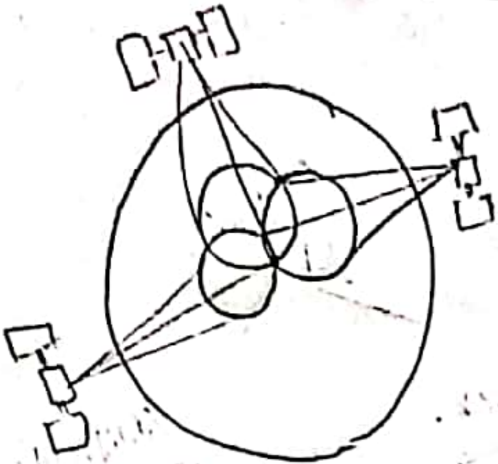

Milestones of satellite system:-

Introduction :

From invention to upto now. } 1st unit → history of satellite.

GPS navigation message:-

1500 bits → 12.5 minutes.

frame details:-

Header — Telemetry message health of satellite.
subframe 1 — satellite clock correction data.
subframe 2 & 3 — ephemeris for satellite
subframe 4 — Almanac data for satellite 25 & higher
subframe 5 — Almanac data for satellite 1-24.

GPS C/A code accuracy:-

Major error sources in a GPS C/A code are:-

a) selective availability.
b) Multipath.
C) satellite clock.
d) ephemeris error.
c) Ionospheric delay.
f) Tropospheric delay.
g) Rx'er noise.
h) Satellite geometry.

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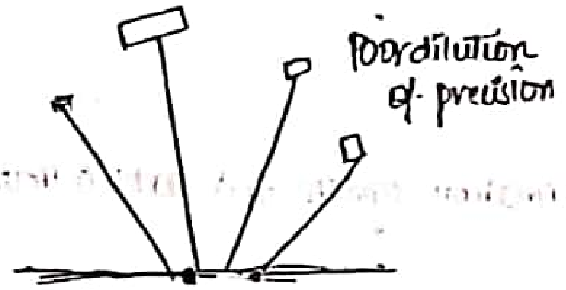
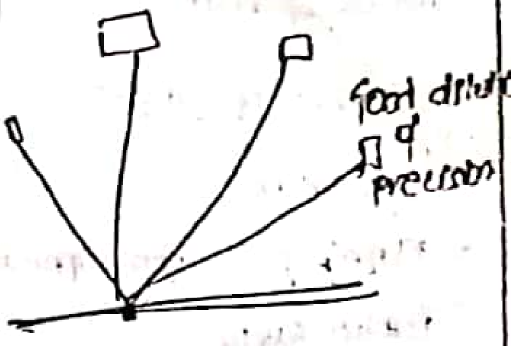
The selective availability was designed by US Department of Defense which deliberately degrades the signal, and provides less accuracy in determining the position of a user on earth. It is switched off in May 1, 2000.

Ionosphere:- X-rays & UV rays present in ionosphere.

Dilution of precision:- [Satellite Geometry]





Four dilution of precision:-

GDOP (Geometric) :- A combination of navigational position & time error.

PDOP (Positional) :- The spatial geometrical quality of the positional solution.

HDOP :- Horizontal :- Measure of the quality of the horizontal position.

VDOP :- Vertical :- Measure of the quality of the vertical position.

TDOP :- Time :- Mean error of the time estimation.

As DOP ↑, accuracy ↓

DOP —

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DOP	Rating
1	Ideal
2-3	Excellent
4-6	Good
7-8	Moderate.
9-20	Fair.
20-50	Poor

Applications of GPS:-

Industry

1) Agriculture.
2) Mapping & Geographical Information system (GIS) Data collection
3) Public safety.
4) Surveying.
5) Telecommunications.

Military

- Intelligence & Target location.
- Navigation.
- Weapon aiming & Guidance.

Transportation

- Aviation.
- Fleet tracking.
- Marine.

Science:-

- Archeology.
- Atmospheric Science.
- Environmental.
- Geology & Geophysics.
- Oceanography.
- Wildlife.

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SPADE:-

single ~~channel~~ carrier per ~~carrier~~ channel PCM multiple access demand alignment technique. It is an example of DAMA.

- With SPADE, 800 PCM encoded voice band channels separately QPSK modulate an IF carrier signal [Hence named as single channel per carrier].

→ Each 4khz voice band channel is sampled at 8khz rate and are converted into 8bit PCM code.

⇒ So 64kbps PCM code for each voiceband channel.

→ For QPSK, min req b-w = 1/2 bitrate = 32 khz.

→ Each channel is allocated 45khz with 13 khz as GB.

→ 36MHz is divided producing 2 400 channel bands (each 45khz)

→ 400 channels for Txion & 400 for Rxion.

→ Channels 1,2 & 400 are left unused. so used band channels are 397.

→ Centre of transponder band is marked by pilot frq. [f(MHz)]

→ Each RF channel capacity is 397.

→ Each RF channel has CSC
CSC code is used to establish or disconnect voice band link when 2 earth station: when demand alignment channel allocation is used.

EARTH STATION TECHNOLOGY & LOW EARTH ORBIT & GEO

Introduction :-

* The collection of equipment on the surface of the earth for communicating with the satellite is called an earth station.

* Earth stations can be used in the general case to transmit to and receive from the satellite, but in special applications only to receive or only to transmit.

* Receive-only stations are of interest for broadcast tx'ions from a satellite and transmit-only stations for the still much less developed application of data gathering.

* The below figure shows the general block diagram of an earth station capable of tx'ion, Rx'ion and a/a tracking.

Transmitter :-

There may be one or many transmit chains, dependin on the no.of seperate carrier frequencies and satellites with which the station must operate simultaneously.

Receiver :-

There may be one or many receiver/down converter chains, depending on the no.of seperate frequencies and satellites to be received and various operating consideratior

Antenna :-

usually one a/a serves for both tx'ion and Rx'ion, bu not necessarily. with in the antenna subsystem are the a/ proper, typically a reflector and feed; seperate feed syster to permit automatic tracking; and a duplex and multiplex

Unit 5

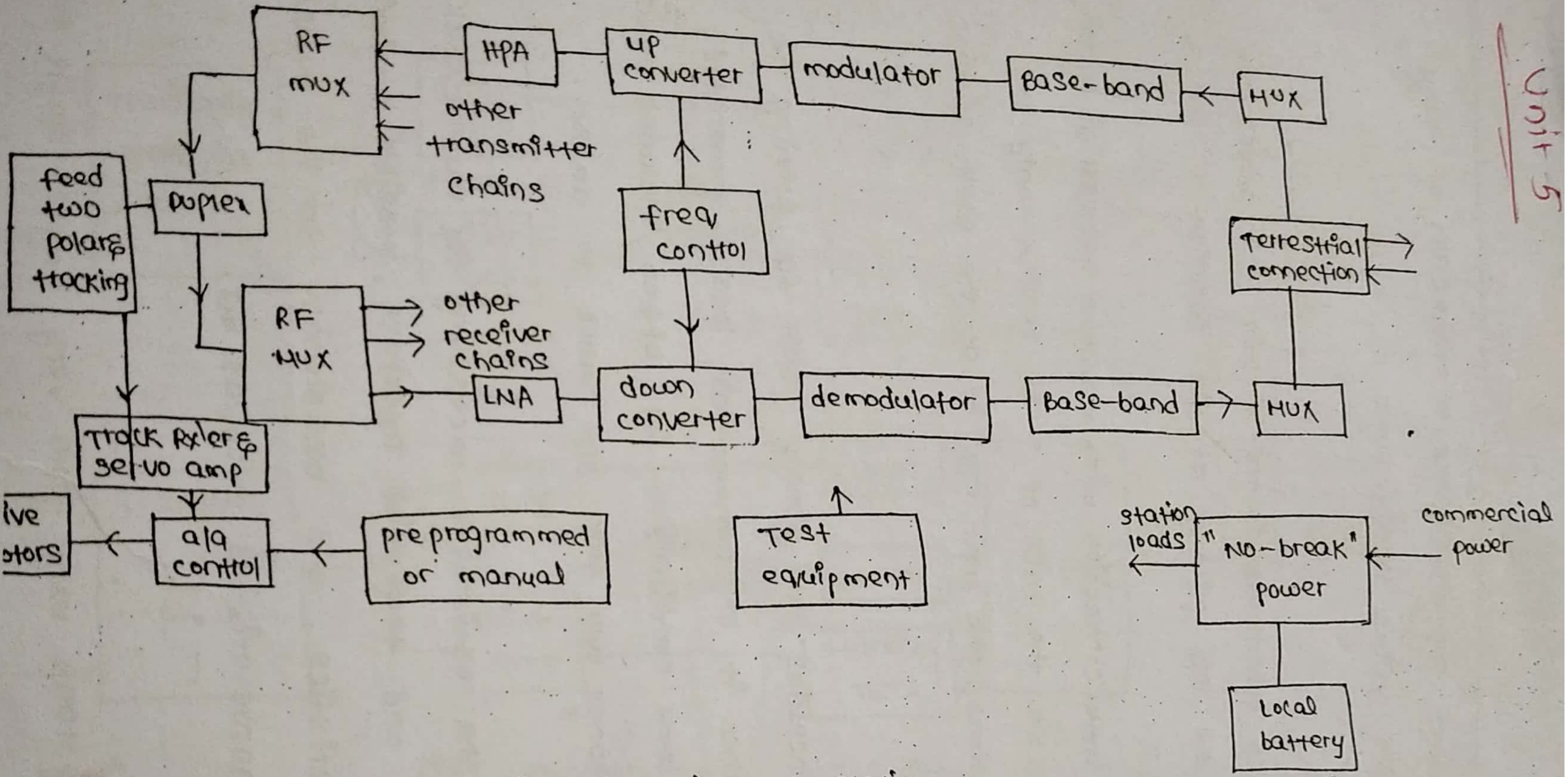

fig: General earth station

angement to permit the simultaneous connection of many
ansmit and receive chains to the same a/a.

acking system :-

This comprises whatever control circuit and drives are
essary to keep the a/a pointed at the satellite.

estrial interface :-

This is the interconnection with whatever terrestrial syster
any is involved. In the case of small receive-only (or)
nsmit-only stations, the user may be at the earth station
self.

mary power :-

This system includes the primary power for running the
th station, whether it be commercial, locally generated,
tery supplied or some combination. It often includes provis
for 'no break' change over from one source to another.

t equipment :-

This includes the equipment necessary for routine checkir
the earth station and terrestrial interface, possible monitorin
satellite characteristics, and occasionally for the measur
ent of special characteristics such as G/T.

— o —

ransmitters :-

Transmitter sub systems vary from very simple single tx'er
of just a few watts for data-gathering purposes to
multi channel tx'ers using 10-KW amplifiers.

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- * when multiple tx'er chains are required, common wide band travelling - wave tube amplifiers can be used (or) each channel can use a seperate high power amp typically a klystron
- * Two - for - one redundancy switching is shown with the TWTAS.
- * The common wide band amplifier is the more usual type, and it is suffering from the problem of intermodulation when non linear amplifiers handle more than one carrier simultaneously.

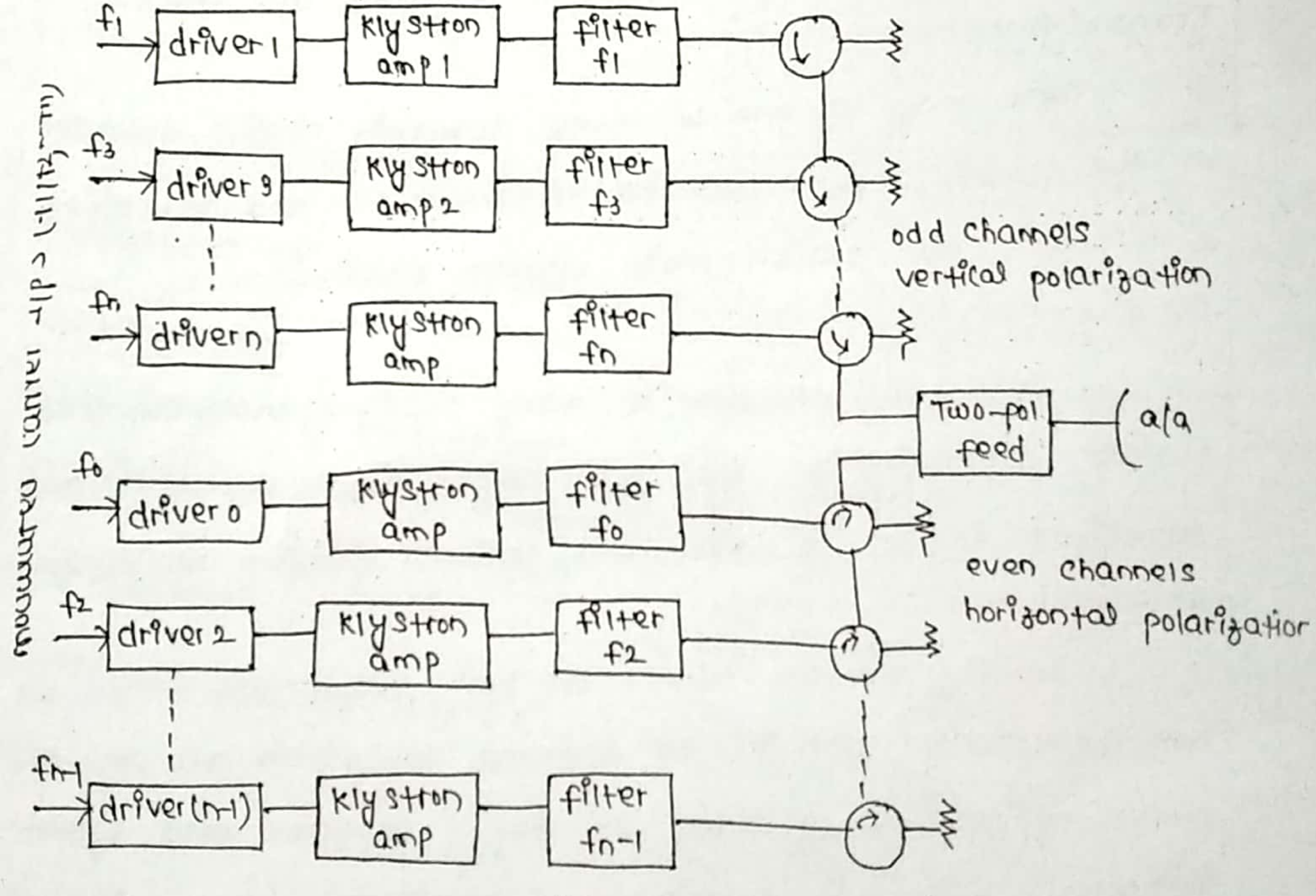

fig: multiple klystron tx'er

- * system using feedback to reduce the nonlinearity effect are coming into use and allow greater power o/p.

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performance in high power amplifiers uses predistort this method, a low level non linear amplifier of characteristics similar to the high power amp.

- * The alternative of using seperate amplifiers is less flexible in operation.
- * usually seperate amplifiers are narrowband and require retuning to change freq's.
- * A few typical high power amplifier specifications is shown below.

	TWTA	TWTA	TWTA	SSPA	SSPA
freq band	c	Ku	Ka	c	Ku
power (w)	600	300	100	25	16
efficiency (%)	25	22	18	15	5
B.W (MHz)	500+	500+	2500	500	500
gain (dB)	50	70	50	50	50
Noise fig (dB)	25	28	35	6	12
Third -order intercept (dBm)	10	10	10	20	20
AH- PH	2°/dB	2°/dB	2°/dB	0.5°/dB	0.5°/dB
ean time to ail (MTTF) hrs	15-30,000	15-30,000	15-30000	150 000	150000

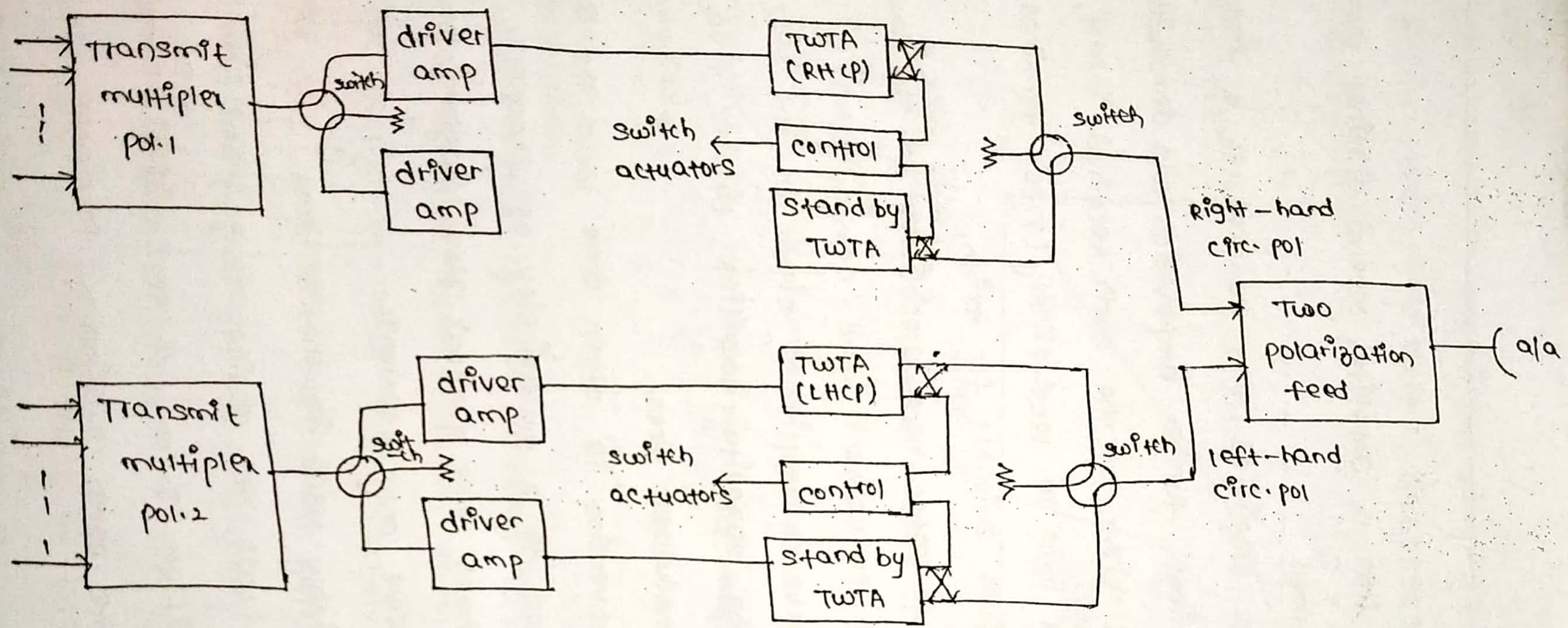

fig: common TWTA transmitted with redundancy (two polarizations)

* * *

ceivers.

To receive a signal from a satellite, several distinct operations must be performed.

The sig must first be amplified then reduced to a freq, enough for convenient further amplication and demodulatic

he sig may be used either at the earth terminal itself, ay in the case of a home TV receive-only (TVRO) terminal, converted into a form suitable for tx'ion.

In receiver chain, we refer here specifically to the low-ise amplifiers, down converters and demodulators.

own conversion can be accomplished either in one step, ping directly from the satellite downlink carrier freq, to e intermediate demodulator freq.

wo-stage down conversion is often done when the same x'ler is to be tuned to a multiplicity of channels.

The below figure shows the general block diagram for a ideo and audio receive only stations.

uch stations are widely used in the sc and such Rx'lers re used in cable heads to receive TV programs from sat.

he low-noise amplifier is one of the critical element n determining the earth station performance.

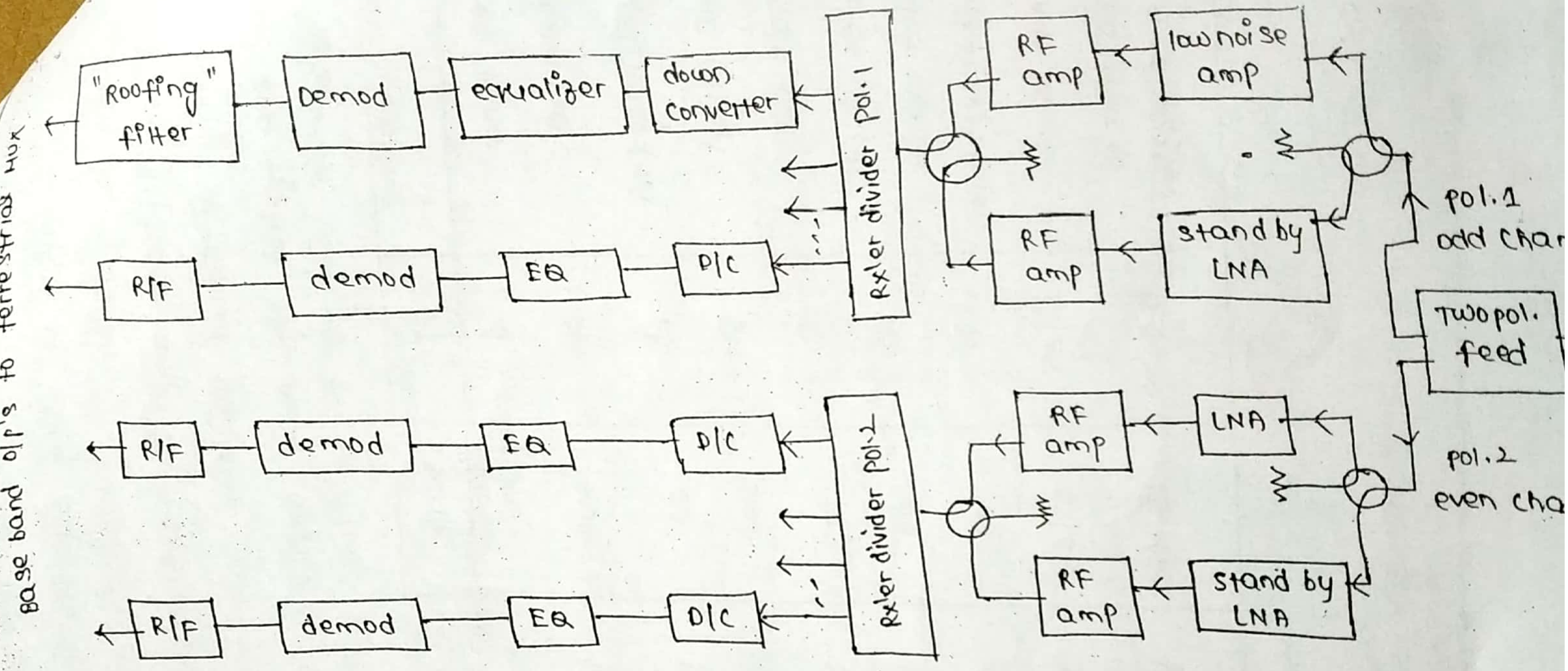

fig: Receive subsystem for multicarrier earth station

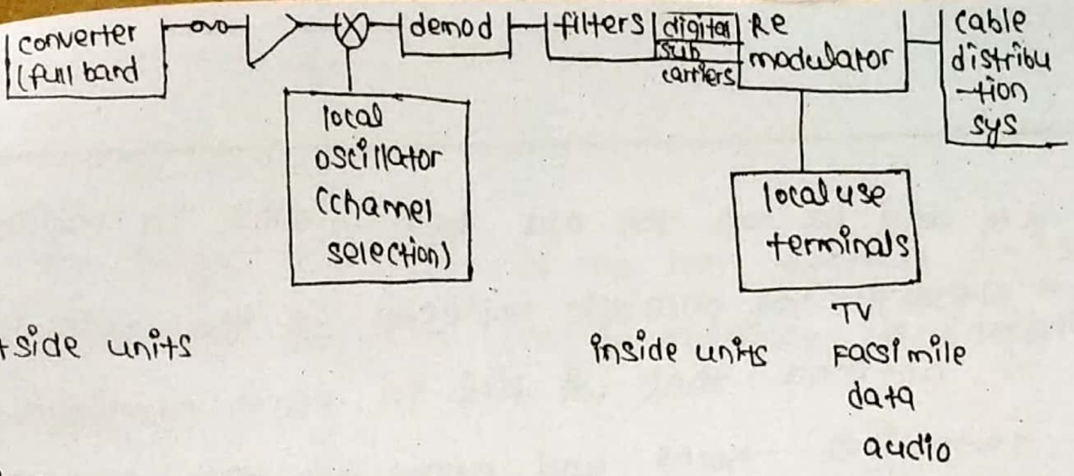

fig: General TVRO station - direct reception or cable distribution

$$T_s = T_a + (L-1)T_0 + LT_R + \frac{L(F-1)}{G_R}T_0$$

* It is not difficult to derive an expression for carrier-to-third-order modulation products. The result is

$$\left(\frac{C}{I}\right)_3 = 2(P_x - P_0)$$

here P_0 - saturated o/p power

P_x - Intercept point

	L-band	c-band	x-band	K_u-band	Ka-band
cooling	uncooled	uncooled/cooled	uncooled/Cooled	uncooled/Cooled	uncooled/cooled
recr range (GHz)	1.5-2.5	3.0-5.0	7.0-10.0	10-14	11-20
B.W (MHz)	50-100	500	500-1000	1000	1000
noise temp (K)	40-60	35-60	55-75	65-130	200-300
Gain (dB)	45-60	50-60	50-55	50-60	20-25
o/p at 1.0 dB compression (dBm)	13	13	13	13	10
Intercept dB above o/p	10-13	10-13	10-13	10	10
AM-PM (°/dB)	0.03-0.5	0.03-0.50	0.03-0.50	0.03-0.50	0.03-0.50

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the LNA.

* Most low-noise amplifiers today (1992) use gallium arseni field-effect transistors, GAASFETS or HEMTS.

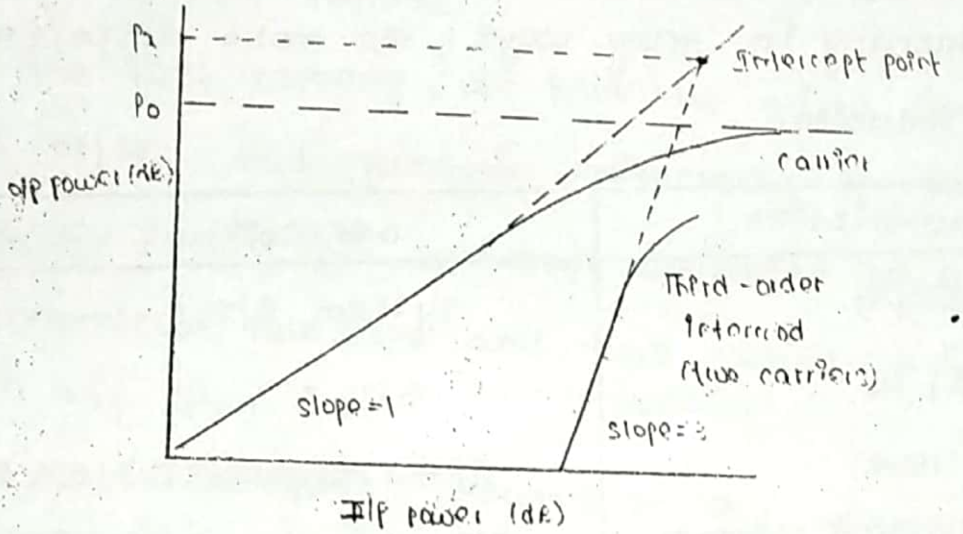

fig: Intercept point as a measure of third-order intermodulati level

* Intercept point and AM-PM conversion are two simple measures of non linearity that help in comparing diffe amplifiers.

— o —

Antennas :-

* The parabolic reflector antenna has become the symbo for a satellite communication earth terminal.

* The carrier-to-noise ratios acheivable on uplink and link, given ~~directly determined~~ fixed tx'er power an geographical coverages are directly determined by the physical size of the earth station a/a.

antennas at K band must be larger than those at band This is because of the min attenuation

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The antenna electrical performance is involved in the system planning in many ways; the most important are the following.

characteristics	affects
overall gain, G	system G/Ts
a/a temp, Ta	G/Ts
side lobe level	Interference (C/I), a/a temp
cross-polarized response	C/I and C/N for entire sys
Beam width	Geographical coverage (satellite ak tracking requirement

for system planning, a generalized antenna pattern is often useful. A good pair of equ's for such use is

on main lobe : $$\frac{G}{G_m} = \left[\frac{\sin 1.39(\theta/\theta_0)}{1.39(\theta_0/\theta_0)}\right]^2$$

far from main lobe : $$\frac{G}{G_m} = \frac{1}{1+(\theta/\theta_0)^{2.5}}$$

where θ_0 is half the half-power beam width.

Gain is defined as the ratio of radiation intensity in a given direction to that the total radiated power to be radiated isottopically.

$$G \simeq \frac{4\pi}{\theta_1\theta_2} \simeq K\frac{41253}{\theta_1^\circ\theta_2^\circ}$$

where K is a factor to allow for energy not in the main beam.

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* θ_1 and θ_2 are the a/a beamwidths in radians or degr

* Although the parabolic reflector is the most important kind of antenna that we find in earth stations and on the satellites. horns and array are also important.

* horns are widely used as primary feeds for reflectors anc occasionally as principal radiators themselves.

* Two other kinds are ocasionally seen in spacecraft. They are lenses (either the dielectric or waveguide type) and phased arrays.

* The array is controlled by varying the phase and amplitu of the individual elements.

Horn antenna :-

* Horn antennas are commonly used as primary radiators in reflector system.

* we find horn antennas on board the satellite to provide earth coverage beam.

* The angle is about 18° from geostationary orbit and simply acheived with horns.

There are two kinds of horns.

* primary horn as an extension of rectangular waveguid and conical horn as an extension of circular waveguide. The following equations are applicable for those hor that are compared to wavelength.

$$\theta_E = 51 \frac{\lambda}{B}$$

$$\theta_H = 70 \frac{\lambda}{A}$$

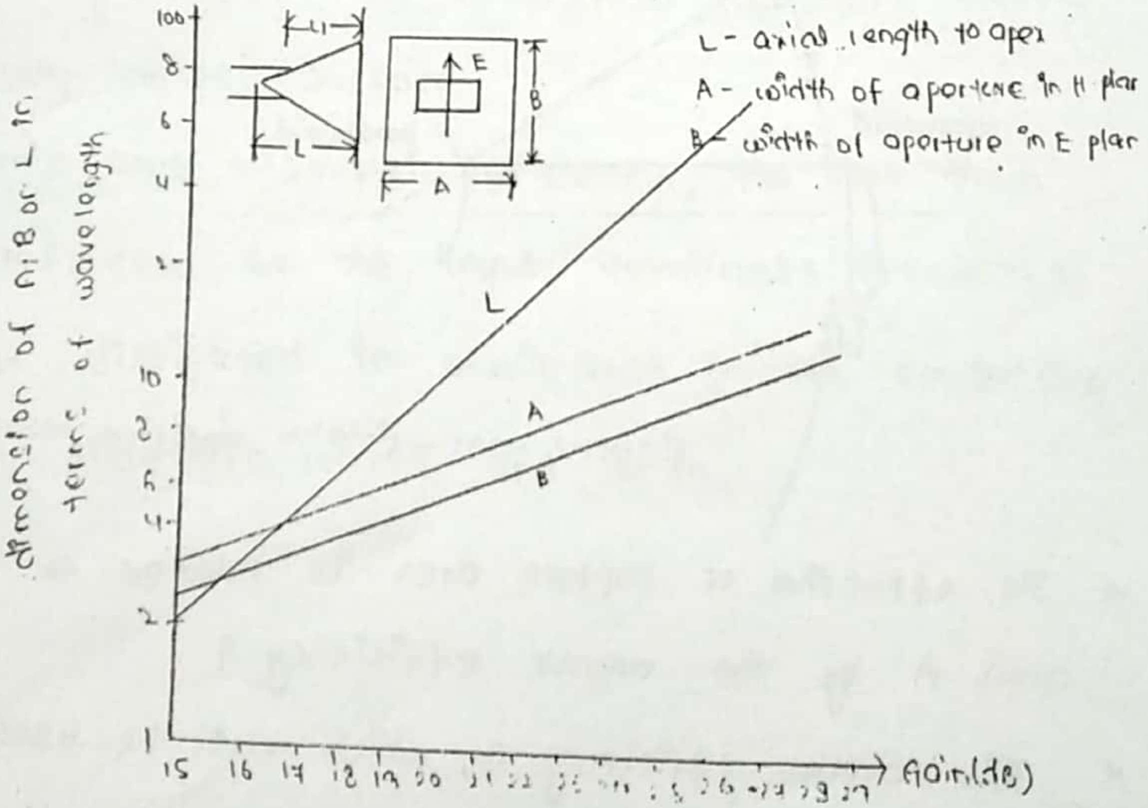
here A is the longer dimension of the horn aperture. It is desired to have the shortest length possible, that length L_1 is given by

$$L_1 = L\left(1 - \frac{a}{2A} - \frac{b}{2B}\right)$$

* conical horns, which are natural extension of circular waveguides, are used typically higher-mode propagation

* The TH_{11} and TE_{11} modes circular waveguides are superimposed on each other with suitable control of the relative amplitude and phase.

* The variation of the horn feed very much used in primary feeds for big earth station is a hybrid-mode horn.



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* we divide the reflector antennas broadly into two categ those using a single reflector and horn feed and th using multiple reflectors.

* In the first category, we have the prime focus feed the offset-fed parabolic reflectors; in the second have a family of antennas developed by analogy to astronomical telescope and thus called Newtonian, co-grain and Gregorian.

* The later categories depend on the whether the subre is plane, hyperbolic or ellipsoidal.

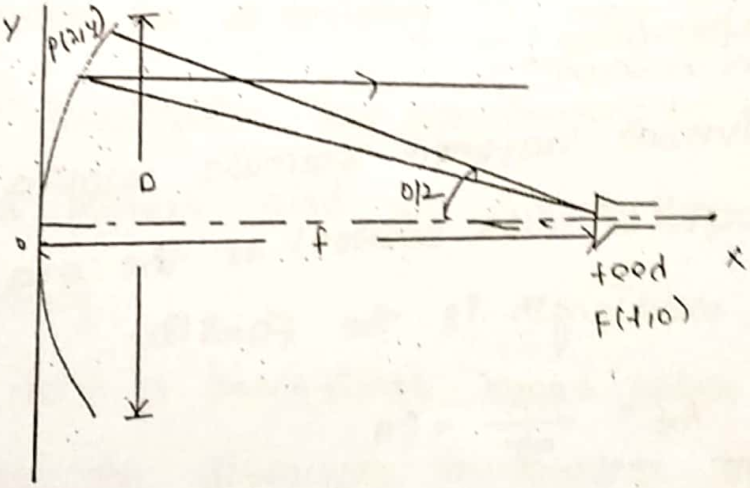


fig: Basic geometry; prime-focus-feed parabolic ref

* An important effect of the secondary reflector on a cassegrainian or Gregorian a/a is to increase the apparent focal length of the a/a. This increase called magnification.

the equivalent focal length of the cassegrainian reflector ystem is given by

$$f_e = mf = \frac{e+1}{e-1} f$$

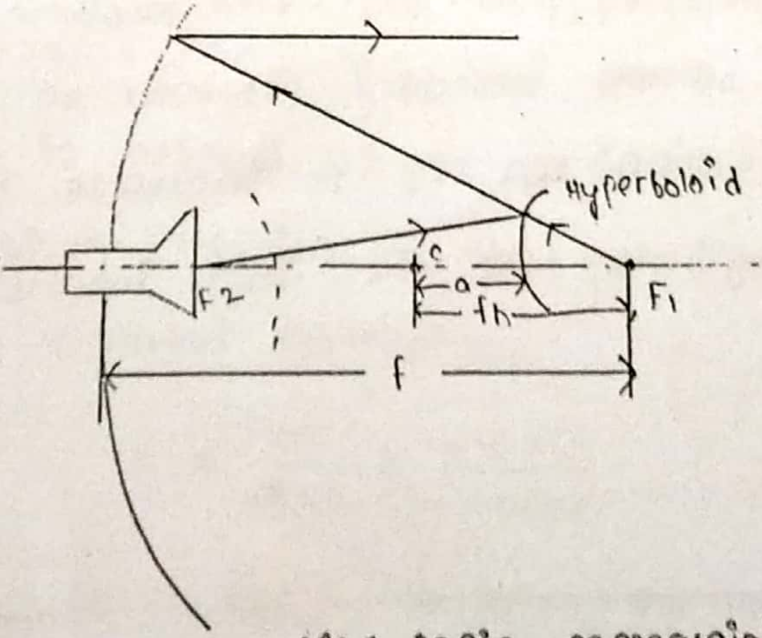
-If several horn feeds with emerging beams at diff gles are to be use a main reflector that is circular in e cross section and parabolic in the other.

This kind of toroidal antenna was first used in large arly -warning radars to permit rapid beam scanning

tenna performance :-

The universal antenna formula relating the effective ea (or capture cross section) of the a/a Aeff and its ain and wavelength is the familiar

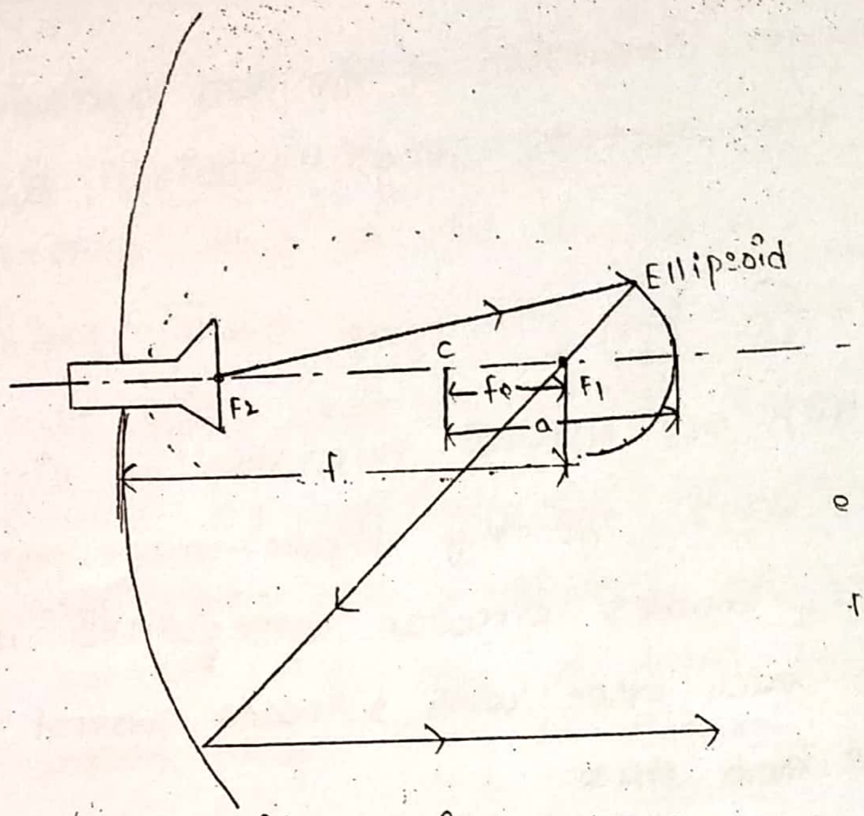
$$A_e = \frac{G\lambda^2}{4\pi} = \eta A$$



$e = \frac{f_h}{a} > 1$

$f' = \frac{e+1}{e-1} f$

fig: Basic cassegrainian antenna



$e = \frac{fo}{a} < 1$

$r' = \frac{1+e}{1-e}$

fig: Basic Gregorian antenna

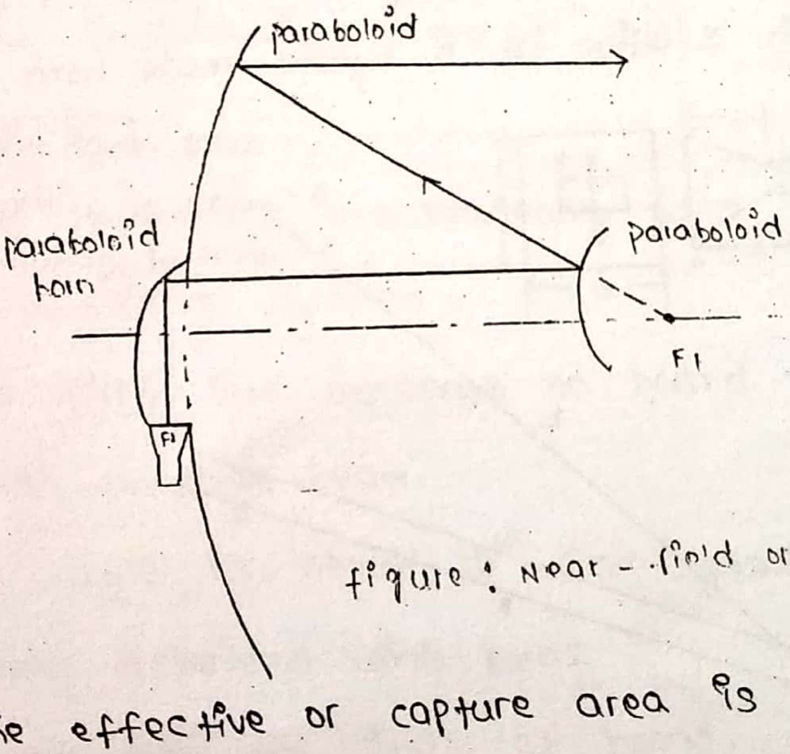


figure: Near-field or modified cassegrainian an

- * The effective or capture area is related to the physical area A by the overall efficiency η.
- * This overall efficiency η, which must be used in calculating received carrier level.

$$\eta = \eta_a \eta_b \eta_s \eta_p \eta_e \eta_L$$

, phase errors and so on; it increases as the side obe level increases.

η_b = blockage efficiency, resulting from blockage of main reflector by the subreflector or feeds

η_s = spilover efficiency, the loss of energy because the subreflectors and main reflectors do not intercept all the energy directed toward them.

η_p = cross - polarization efficiency, the loss of energy due to energy coupled into the polarization orthogonal to that desired.

η_e = surface efficiency, the loss in gain resulting from surface irregularities, the statistical departure from a theoritically correct surface

η_L = ohmic and mismatch efficiency, the loss from energy reflected at the input terminals (VSWR>1.0) and that dissipated in ohmic loss in the conducting surfaces, dielectric lenses and so on,

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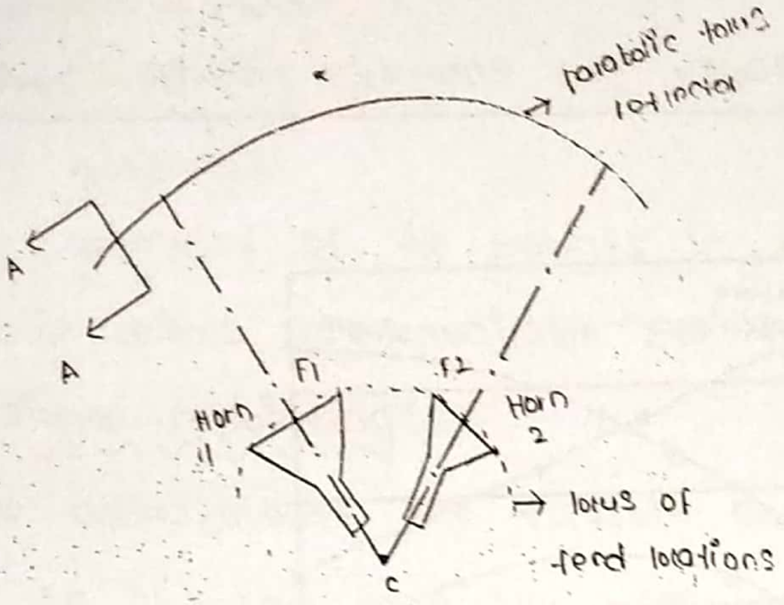

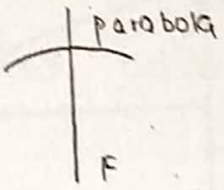

fig: multifeed toroidal antenna

* The aperture efficiency ηa is equal to unity for an aperture that is illuminated uniformly in amplitude phase, in which the directivity is max for given a

* The reflector illumination has two components : one due the horn feed pattern and one due to the inherent reflector geometry.

* The second term is sometimes called space attenua and is simply the difference in inverse square - la loss b/w the edge and centre of the aperture.

* from the geometry of the parabola, it can be show that this loss is given by

$$\text{space attenuation} = \left(\frac{R}{f}\right)^{\gamma} = \sec^{\gamma}\theta/4$$

where θ is the full angle subtended by the reflector

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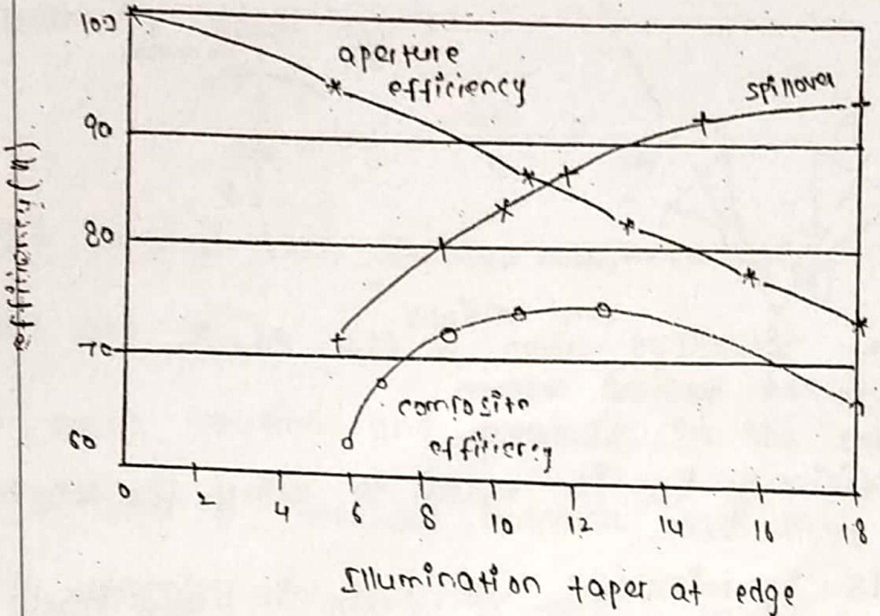

fig: Typical spillover and aperture efficiencies as a function of illumination taper

A good approximation to a cosine horn pattern is simply $(\theta / \beta_{10})^2$. where β_{10} is the horn beamwidth at the tenth power point.

The net edge taper is

$$T = 10 \log \sec^4 \frac{\theta}{4} + 10\left(\frac{\theta}{\beta_{10}}\right)^2$$

aperture blockage is a significant problem especially in cassegrainian and Gregorian antennas.

The related efficiency η_b is given by $[1 - 2a(A_B/A)^2]$, where A_B is the blocked area and A is the total aperture area.

cross - polarization efficiency η_p is another important problem in satellite antennas.

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* There is always a fundamental loss in efficiency because of random surface irregularities.

* Ruze (1952) in a classic paper developed the following equation for the effect of surface variation:

$$\eta_e = \frac{G}{G_0} = e^{-k(4\pi\delta/\lambda)^2}$$

$$K = \frac{1}{1+(D/4f)^2} \simeq 1$$

* These equations hold for gaussian distibution of phas errors due to surface imperfections.

here δ is the mass surface deviation

G_0 is the gain of a perfect surface reflector general, nongeostationary orbits require more tracking than geostationary.

* For instance, messaging systems for ground mobile service from low earth orbit often use hemispherical coverage a/a's, aeronautical and many marine terminals and require no tracking.

* on the other hand, there are successful mbl services to vehicles using ku band with the narrow beams and trackin because of vehicular motion.

* we identify a hierarchy of pointing and tracking categories as follows.

1. No tracking is necessary and only initial fixed-pointing adjustment is required.
2. Repointing of the a/a is needed to switch from one satellite to another and possibly to correct for satellite motion. This repointing can be needed rarely (or) frequently
3. Tracking is required, but it is satisfactory to drive the a/a in two axes and to preprogram this drive in accordance with the calculated satellite motion.
4. Automatic tracking is necessary but can be achieved by a simple step tracking system.
5. Fully automatic continuous tracking is necessary.

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* fixed - pointing systems are usually restricted to beam antennas.

* The geometry of the mounts is as discussed in

screw drives are available for initial adjustmer

occasional repointing: -

* The adjustments are flexible enough so that they can be changed manually with out difficulty.

* simple motor drives may be added to do it remo

preprogrammed: -

* once motor drives are available for one or two axis control, both automatic and preprogrammed can be

* If the a/a beamwidth is wide relative to the predi error, it can be preprogrammed to track open loop.

* often the principal apparent GEO satellite motion is due to imperfect inclination control.

* This motion, for small inclinations and otherwise pe orbits, is a figure eight with a period of one s real day.

* It's vertical height is twice the orbital inclinatio and it's width is only a small fraction of th value.

* If the orbit has zero inclination but has a sm

centricity e, the amplitude of the maximum longitudinx *
parture is 2e radians.

ep tracking:- *

Step tracking uses a primitive servomechanism in ich the a/a is moved a discrete amount and if e signal level increases, it is moved again in is direction.

s soon as the signal level does not increase, it turns to the previous position.

This method obviously depends on the size of the step.

lly automatic:-

fully automatic tracking can be provided using method iginally developed for the pointing of radar a/a's.

The most common is the monopulse or simultaneous lobing system, in which four beams are generated n an auxilary feed and combinations of the signals om these four beams provide left-right and up-down ror signals..

These error signals are detected, amplified and used to generate control signals for driving the a/a.

It is possible to derive the error signals either with multiple horn ~~feed~~ systems or by the use of higher

* The multiple - horn feeds use four horns grouped toge (or) sometimes four horns grouped around a single larger horn.

* where as the higher - mode error- determining signals use circular wave guide modes such as TM_{01} or TE_{01}, which have no field component on the axis.

TERRESTRIAL INTERFACE :-

* The terrestrial interface comprises a wide variety of equipment.

* At one extreme, when the terminal is a mobile or receive -only station, there may be no terrestrial interface equipment.

* The operating devices such as TV Rx'ers, telephones, data sets and so on are used at earth station.

* at other extreme, we find the interface equipment necessary in a large commercial satellite system fo fixed service.

* In such cases, hundreds of telephone channels, together with data and video are brought to the station by microwave and cable systems using eith frequency (or) time division multiplex methods.

* The signals must be changed from those formats into suitable formats for satellite tx'ion.

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frequencies,
ending on their source and put together with the corresponding outgoing circuit to make up a terristrical circuit.

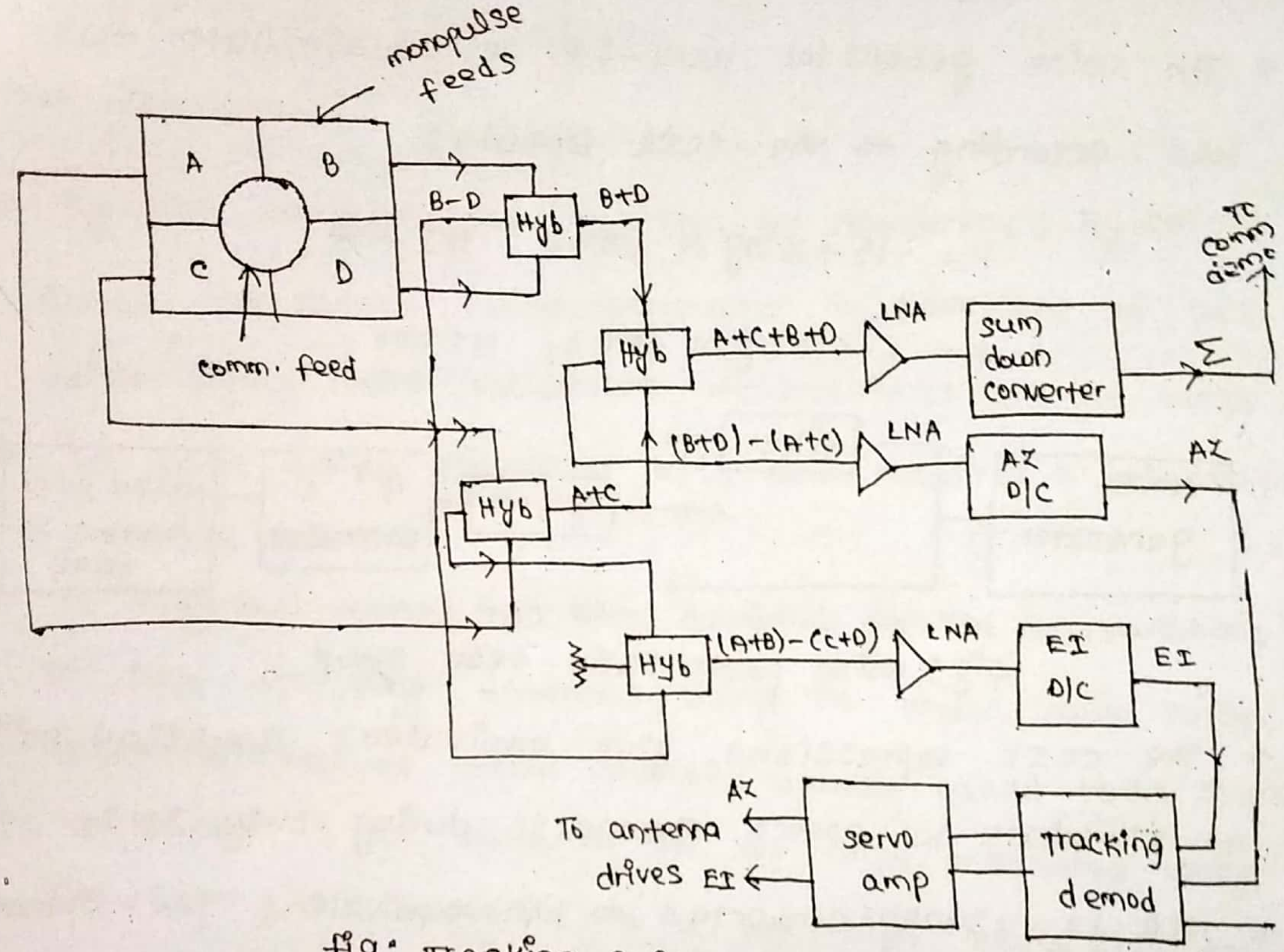

fig: Tracking system

* If the satellite tx/ion is single channel per carrier, it is necessary to bring each terrestrial carrier down to base band before remodulation.

The interfaces b/w terrestrial time division and satellite freq-division systems and vice-versa are complicated.

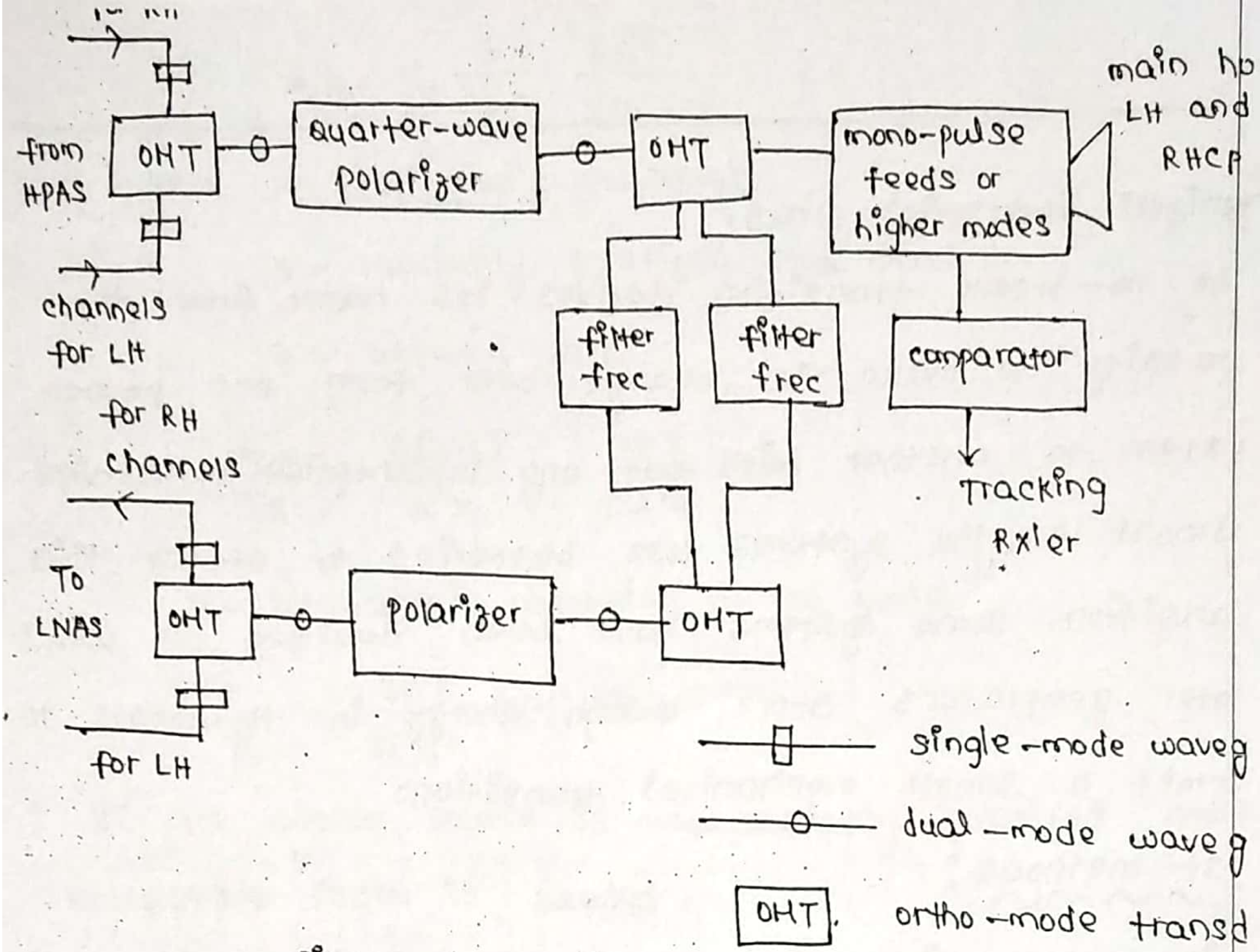

fig: Two-polarization horn-feed systems

primary power :-

* primary power systems vary from plain battery or sol - cell operated remote tx'ers for data gathering. huge, combined commercial power and diesel genera systems for large stations.

* Host transmit and Receive earth stations require s kind of "no-break" power systems, that is emerger power to continue the comm's during commercial po outages.

* such power outages are frequent, even in highly

janized industrial areas.

The no-break transition derives its name from the cessity to make the change over from one power ystem to another with out any interruption in service. lmost all the systems use batteries to effect this ransition. some systems have been devised in which otor generators store enough energy in flywheels to ermit a smooth mechanical transition.

* * *

est methods :-

oise power ratio (NPR) :-

earth stations are typically provided with complex est equipment, ranging from that necessary for outine measurements of voltage, power, temp and so on

The Noise power ratio (NPR) is the traditional meas ure of intermodulation noise for FDM systems in e comm's field.

The principle of NPR measurement involves loading e entire base band spectrum, save for the noise ne voice-freq channel slot, with noise.

NPR is measured by a set up as shown in below fig.

The noise generator band is limited by filters to the base band.

* The noise generator band is limited by

* The noise generator level is set to simulate full load according to the CCIR formulas.

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

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

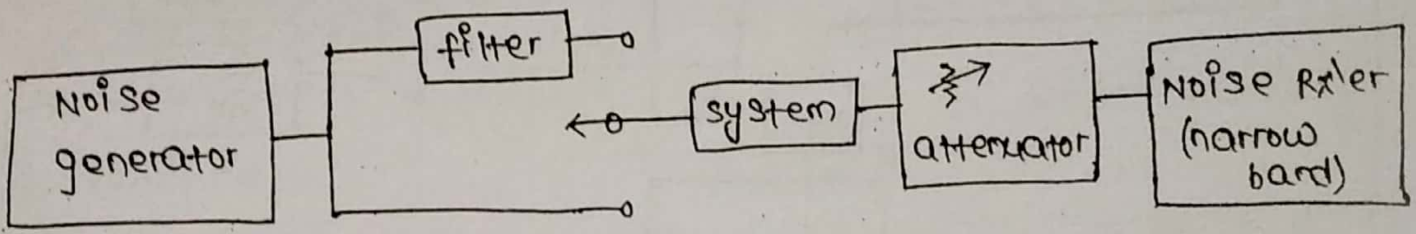

fig: Noise power ratio test setup

* The CCIR expressions give equivalent Gaussian nois to simulate N speech channels during busy hors.

* NPR is usually converted to an equivalent per-channe signal-to-noise-ratio.

$$BWR = 10\log \frac{\text{base band total B.W}}{\text{signal channel B.W}}$$

$$NLR = 10\log \frac{\text{base band noise test power}}{\text{test-one power per channel}}$$

$$= \text{dBm0 of loading calculation}$$

* The equivalent base band signal-to-noise ratio du to intermodulation is then

$$S/N = NPR + BWR - NLR$$

$$B = 4028 - 60$$

then $$BWR = \frac{4028 - 60}{3} = 31.2\,dB$$

$$NLR = 10\log 960 - 15 - 14.8\ dBm0$$

$$(S/N)_{equiv} = 71.4\ dB$$

The measurement of G/T:-

- * system temperature T_s can be determined by conventional laboratory noise generator measurement of Rx'er noise figure and radiometric measurements of a/a temp.
- * The basic system parameter G/T_s also requires a knowledge of antenna gain.
- * An ingenious method has been developed for the measurement of G/T_s for large antennas using the known radio noise characteristics of stellar sources usually called radio stars.
- * Y factor is the ratio of the o/p noise measured when the Rx'er is connected to a hot noise source (T_h), to the o/p noise measured when connected to a cold source(T
- * excess noise T_c is related to the Y factor by

$$T_\omega = \frac{T_h - Y T_c}{Y - 1}$$

- * If the cold source is the normal sky and the hot Sourc the radio star, the operating system temperature T_s is

$$T_s = \frac{T_h - T_c}{Y - 1} = \frac{\Delta T_a}{Y - 1}$$

$$\Delta T_a = \frac{S}{2aK} \frac{G\lambda^2}{4\pi}$$

Here K - Boltzman's constant

S - randomly polarized flux density

G - antenna gain

$$\frac{G}{T_s} = \frac{G(Y-1)}{\Delta T_a} = \frac{8\pi K}{S\lambda^2 a}(Y-1)$$

a - atmospheric absorption at the zenith

$$\frac{G}{T_s} = \frac{8\pi K}{S\lambda^2 a A}(Y-1) \sin\theta$$

* If the stellar source is not randomly polarized, anoth correction factor is needed.

* Cassiopeia A is the most commonly used source.

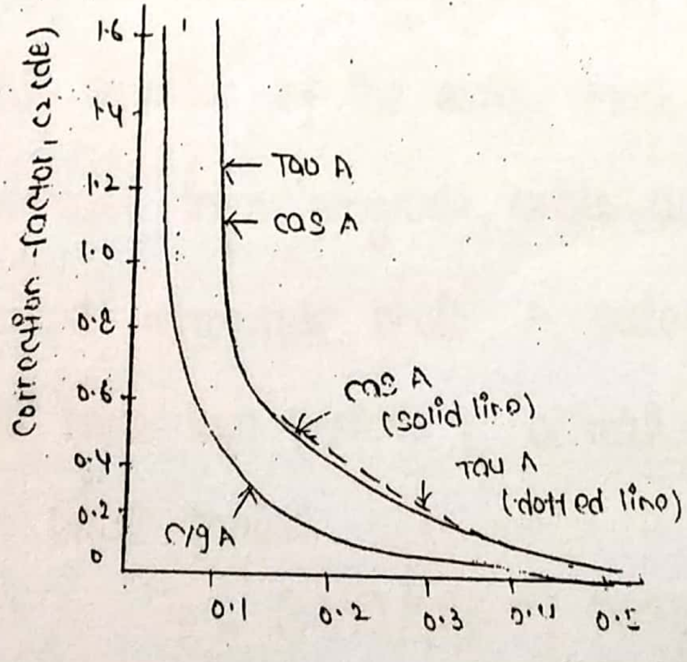

fig: correction factor for G/T measurement using extended sources ome further correction may be necessary if the beamwidth : the a/a under test is narrow compared to the stellar radi source.

) extended source of varying brightness can be considered

3 equivalent to a Rayleigh - Jeans black - body radiator.

The primary reason for the use of LEO was the generally small "throwmass" of the launchers.

→ Throw mass includes both payload and spacecraft bus syst also includes additional rocket motors and fuel.

→ LEO range is 500 km to 1500 km.

→ LEO and MEO are generally refered as Non-geo-stationary ort -s mostly used for internet

→ NGSO satellites brought us the first communication satellite (SCORE), the first pictures of our cloud cover of weather forecasting (TIROS), the first Navigation aids in space (TRANSIT, the first live television pictures across oceans (TELSTAR) etc.

GEO stationary:

→ The reason for using GEO is "more bits can be sent per dollor of capital investment".

→ There are some specialized applications:

* Surveillance of earth's surface for military and gathering the earth resources.

* Providing global navigation such as GPS.

GPS uses 24 satellites in orbits with an altitude of 20,000 km and an inclination of 55°.

* For cellular telephone system.

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satellite television broadcasting.

→ The major drawback of LEO satellite system is "buildi launching and maintaining of communication satellites i expensive.

Orbit considerations:

The satellite motion is determined by orbital mechanics with balanced centripetal and centrifugal for The motion of the satellite in orbit depends on the spe design goals, sun light, gravitational pull of sun and m and also the thermal radiation levels in space.

Equatorial orbits:

Equatorial orbits lie exactly in the plane of the geographical equator of the earth. Most satellites are laun toward the east into prograde orbit and westerly directe orbit is called retrograde orbit. A satellite in eastwardly directed will have two periods : a real orbital period and apparent or bital period.

$$P = (24T)/(24-T) \text{ hours}$$

where T = real orbital period

P = apparent orbital period.

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Table for orbital periods and observing time:

orbital height (km)	orbital period		observing time (hours)
	True (hours)	Apparent (h)	
500	1.408	1.496	0.183
1000	1.577	1.638	0.283
5000	1.752	1.890	0.587
10,000	5.794	7.645	2.894
35,786	23.934	∞	∞

Inclined orbits:

→ The greater the inclination of the orbit is, larger the surface area of earth that the satellite will pass over.

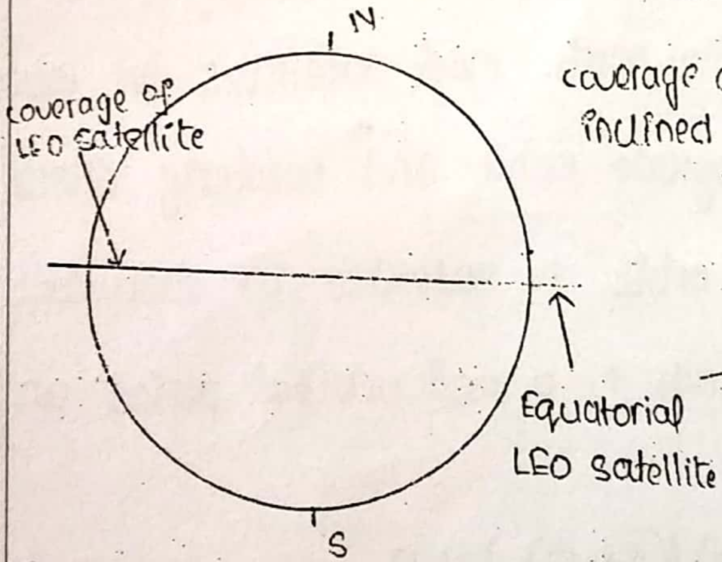

fig (a): coverage of an equatorial orbit LEO satellite

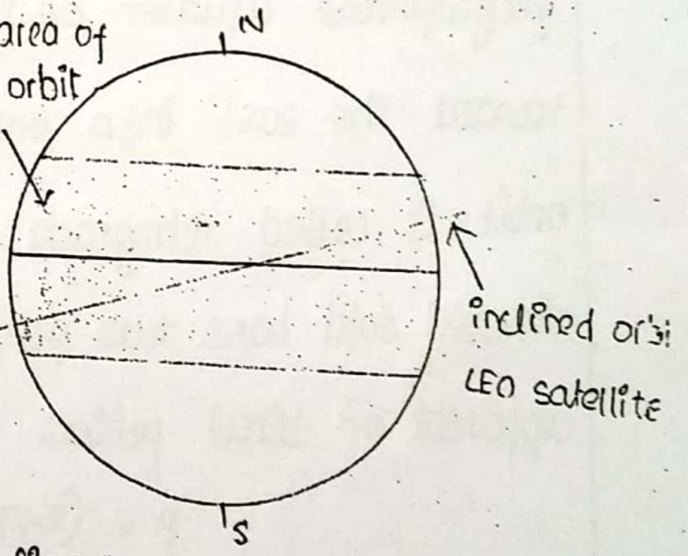

fig (b): coverage of an inclined orbit LEO satellite.

Disadvantage: MCS (master control station) when covering large geographical area

→ Multiple satellites stations are required to avoid the errors when

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→ It uses the store-and-forward mechanism.

→ It requires continuous real time connection b/w LEO Satelli and MCS as

- To locate control stations around the world so that LEO satellite is never out of sight and establishing terristrial or geo satellite connections b/w many control stations and MC
- Establishing inter satellite links (ISL's) to relay the LE data traffic back to the MCS.

Elliptical orbits:

Elliptical orbit will have a non zero eccentricity. The orbit eccentricity 'e' is determined by the lengths of semi major axis 'a' and the semi minor axis 'b'

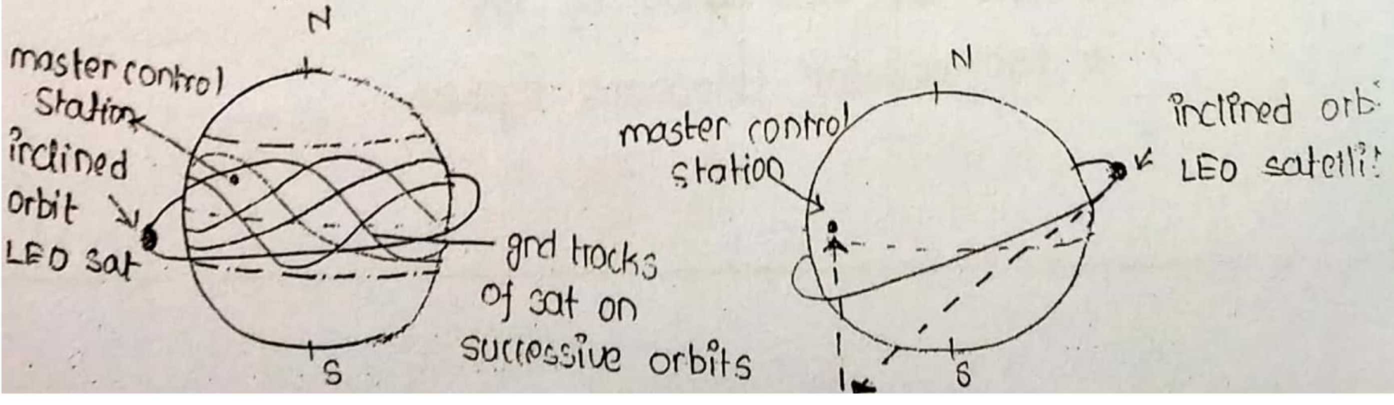
$$e^2 = 1-(b^2/a^2)$$

$$e = (Ra-Rp)/(Ra+Rp)$$

where Ra = distance b/w earth center and apogee poi of orbit.

Rp = distance b/w earth center and perigee po

if a=b & Ra=Rp ⇒ $\boxed{e=0}$ ⇒ circle.



ΔR = variation in the radius of the orbit.

- if $e = 10^{-4}$ => $\Delta R = \pm 4.2$ km, 800 km above the earth ($R_{av} = 42,164.17$ km) for GEO

if $e = 10^{-4}$ => $\Delta R = \pm 0.7178$ km for LEO.

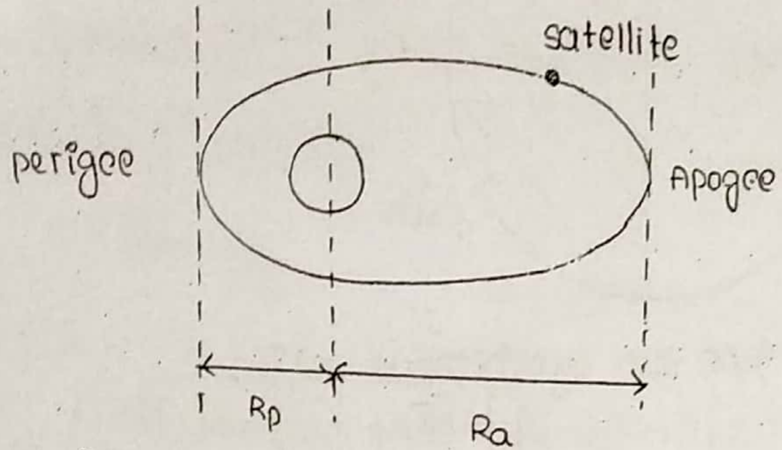


fig: schematic of an elliptical orbit.

→ if eccentricity ≈ 0.74 is a special case of highly elliptical orbit (HEO) known as Molniya orbit.

Molniya orbit:

The eccentricity is equal to 0.74, it is molniya orbit. The first Molniya satellite was launched in April 1965. The word Molniya means "flash of lightning" in Russian. The apogee is at 39,152 km and perigee is at 500km for Molniya

→ The orbital period is 12 hours 38 minutes

→ orbital inclination is 62.9°

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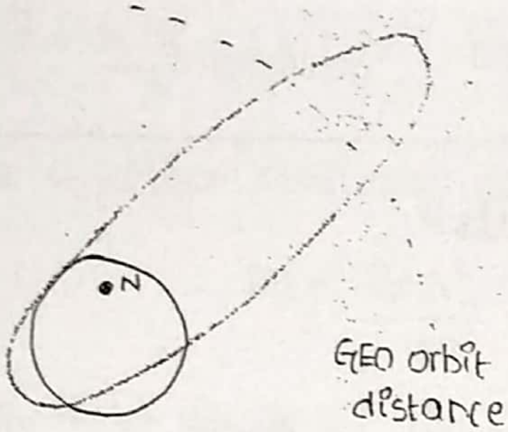
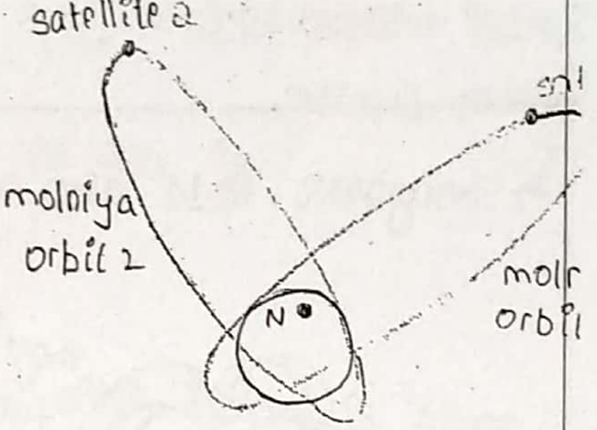


fig (a) : schematic of a molniya orbit.



fig(b) : schematic of a
operational molniya sy

→ used for specific services

→ long delay occurs

→ The first requirement to track the spacecraft

<u>Radiation effects</u>:

The effect of radiation on electronics in space is gene seperated out into 2 aspects

i. <u>total dose</u> : the culmulative effect of the radiation over the lifetime of electronics and it will mainly due to trapped electrons and protons in the van allen belts.

ii. <u>single event upsets</u> : These are more critical if the bit flip is permanent i.e latch up occurs.

→ The geomagnetic latitude ϕ can be computed as

$$\phi = \arcsin\left[\sin\alpha \sin 78.5^\circ + \cos\alpha \cos 78.5^\circ \cos(69^\circ + \beta)\right]$$

where α = geographic latitude

β = geographic longitude.

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→ Magnetic field also 'effects.

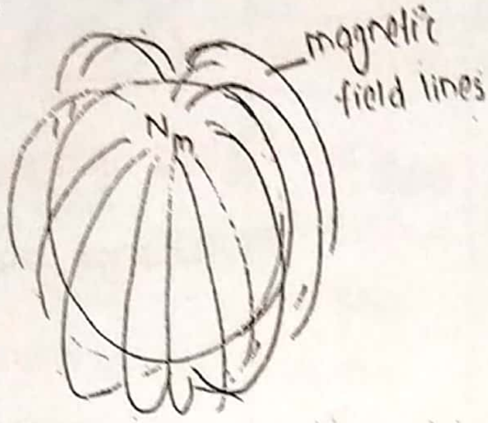

fig (a): Representation of magnetic field lines.

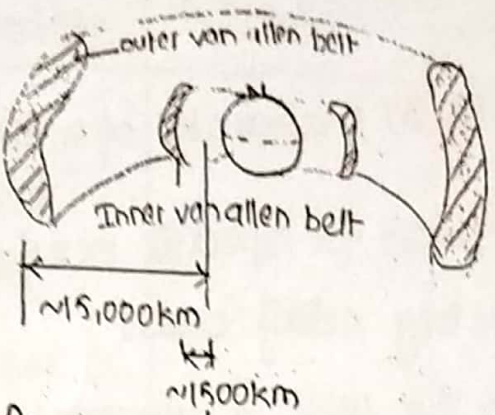

fig (b): pictorial representation of two van allen radiation bel'

→ table for typical total Doses for various orbits

orbital type (degrees)	orbital height (km)		
	800	1100	8000
polar orbit (90°)	30krad(si)	100krad(si)	>500krad(si)
Equatorial orbit (0°)			>2000krad(si)

→ choosing an orbit that has reduced level of radiation can reduce ~~redu~~ the potential for radiation damage

→ Radiation hardend devices must be used

→ developing electronic devices withstand total radiation doeses of 1Mrad (si) is possible with rad-hard technologies.

These are the methods to overcome radiation effects.

Sun synchronous orbit:

It is a special form of low earth orbit where the plan

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to the sun.

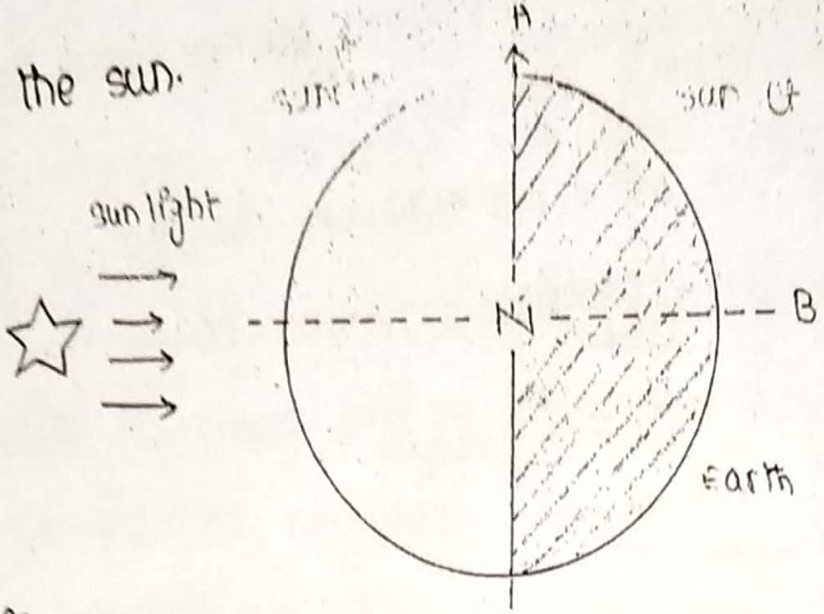

fig: Examples of two sun synchronous orbits.

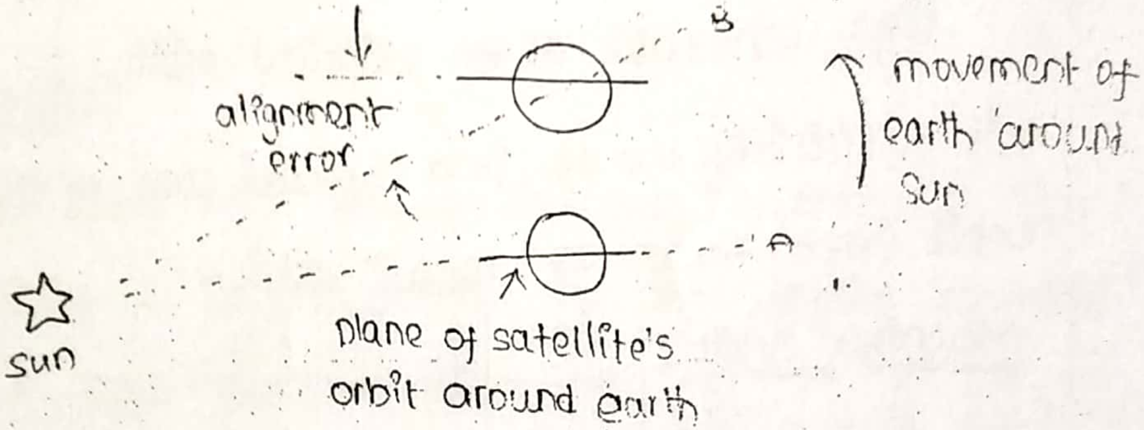

fig: Illustration of alignment changes of the orbital plane due to the movement of earth around the sun.

→ Elliptical orbits with different retrograde inclinations will al yield sun synchronous orbits.

→ The change in the orbital plane is called precession

→ The adv of sun synchronous orbit is it will repeat track every half day.

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In some cases the designer of a satellite system has few degrees of freedom in designing a payload to provide optimum coverage This leads to selection of orbi payload technologies etc. A GEO orbit can be selected or a constellation NGSO satellites can be designed to provide necessary coverage

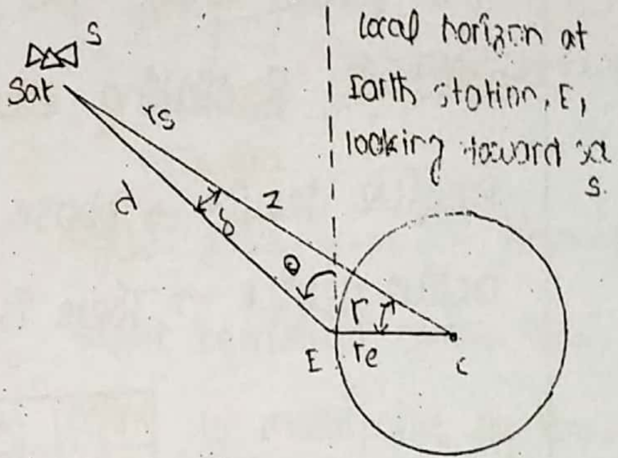

fig: geometry for calcul-ating coverage are

from fig

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

$$\cos\theta = \frac{r_s \sin\phi}{d}$$

where θ is the elevation angle

r_s is the distance from earth center to spacecraft.

⇒ coverage & frequency considerations

Frequency band:

Low earth orbit satellite systems providing data & voice service to mobile users tend to use the lowest availab RF frequency.

→ EIRP = (RF freq downlink)^2

→ Power that must be tx'd by mbl tx'r also proportional to the RF frequency, L band is used for mbl satellite service

→ consider a sat LEO sat with 'A m^2' earth coverage

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$F = \frac{P_t G_t}{A}$ watts/m² here $P_t G_t$ = EIRP (effective isotropi radiated power)

→ The effective receiving area of a/a is.

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

→ The Rx'd power at the mbl earth station is given

$$P_r = F \times A$$

$$\boxed{P_r = \frac{P_t G_t G_r \lambda^2}{4\pi A} \text{ watts}}$$ (for omnidirectional

→ Relay LEO sat system uses VHF and UHF frequencies.

→ L band uses for mobile satellite services, VHF also achieve the same applications.

→ High noise power due to environment is the disadva of VHF & UHF frequency bands.

→ ka band is worst choice due to it's down link opera at 20 GHz requires 22.5 dB more tx'd EIRP, a/a cost also expensive for ka band.

Elevation angle considerations:

Most commercial satellite systems require ea stations operate above certain minimum elevation angle. Most sat systems now, whether for the mbl sat service

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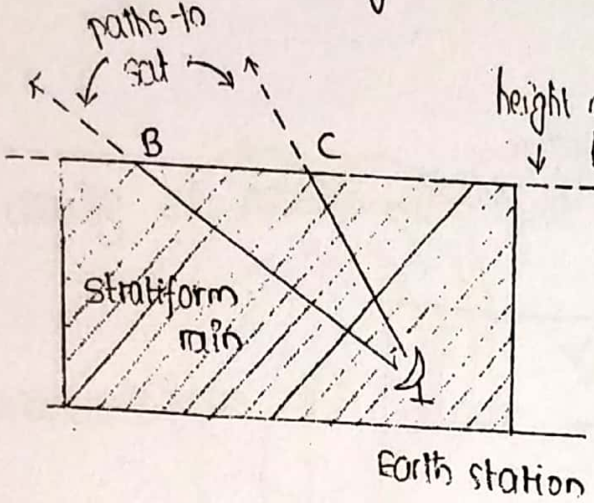
the elevation angle of the user to no less than 10dB.



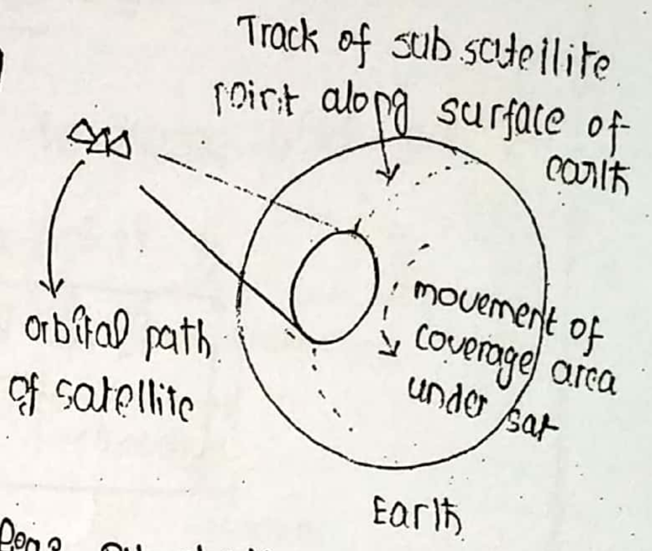


fig: Illustration in the decrease in the path through rain as the elevation angle to sat increases.

fig: Illustration of coverage arc under a satellite.

→ Three cell reuse pattern is developed to analyze the coverg area of satellite on the surface of the earth.

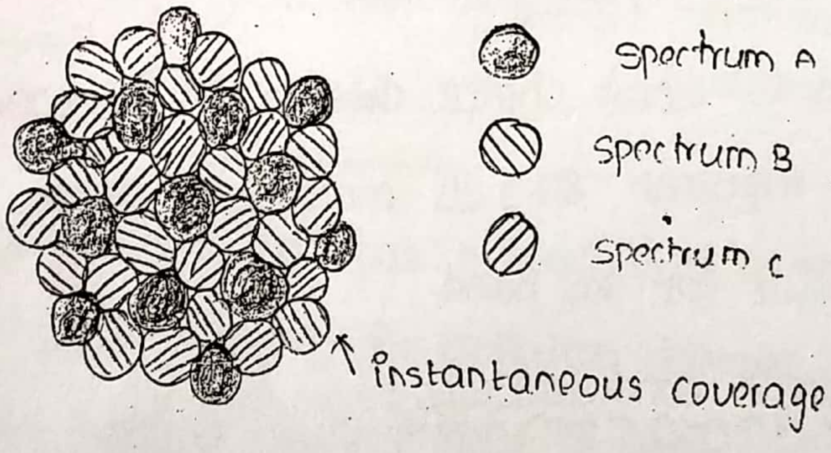


fig: Illustration of a three cell reuse pattern.

→ Each cell have a sp seperate beam from the satellite a/a, a portion of spectrum allocated to it.

Number of beams per coverage:

→ MSS (mbl sat service) have very small spectrum allocation

→ Traditional satellite a/a's have evolved from simple, fr fed reflector a/a with one feed horn, to offset-fed designs with more than a hundred feeds.

→ A phased array a/a has non mechanically steered array o radiators. Radiating element can be active or passive device

Passive device → phase control is achieved in the feed matri

active device → There is a phase shifter per element per beam.

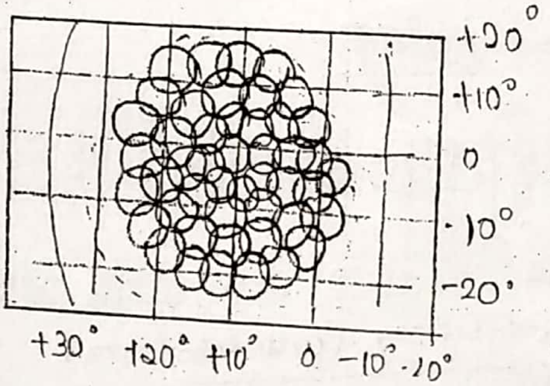
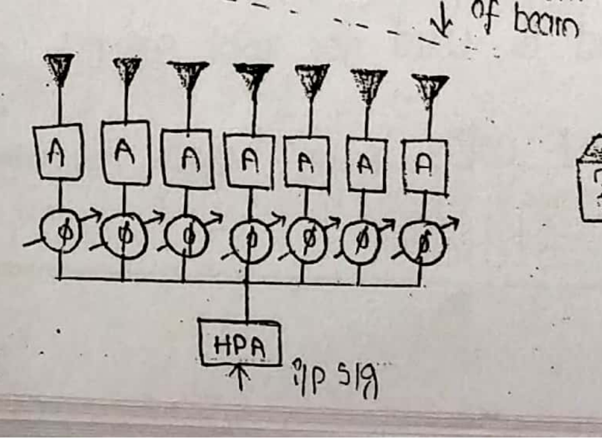
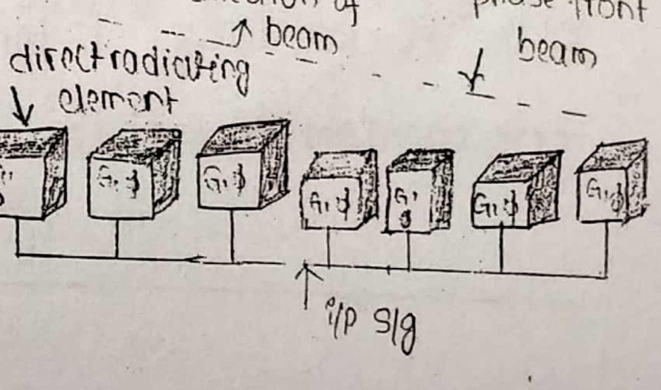


fig : User spot beams developed by an Iridium satellite.

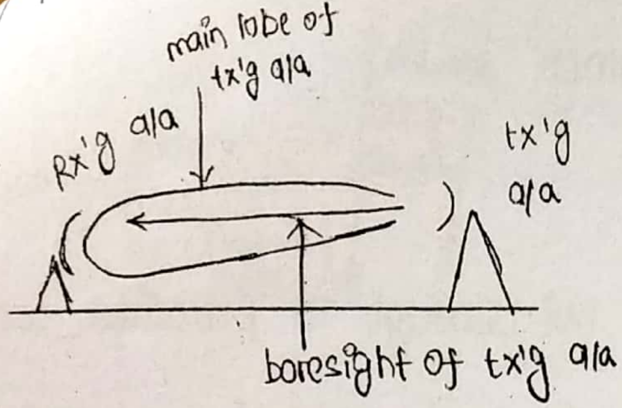
Off - Axis scanning :

The design of a point to point wireless communication system requires a/a's at either end or be directed toward each other for maximum gain advantage.

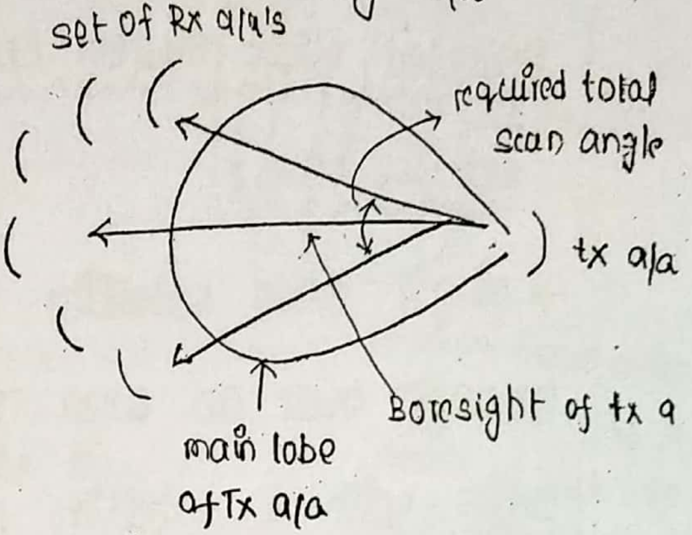




a/a's are located at different positions, it leads to the Rx a/a's will not be on the bore sight of the tx'g a/a



fig(a): point-to-point line-of-sight terristrial links



fig(b): point-to-point line-of sight terristrial comm. lins.

* satellite is a prime example of point to multipoint system. There are 2 basic parameters that are used in initial design

i. Orbital height : LEO, MEO, GEO

ii. Instantaneous coverage requirements for single satellite.

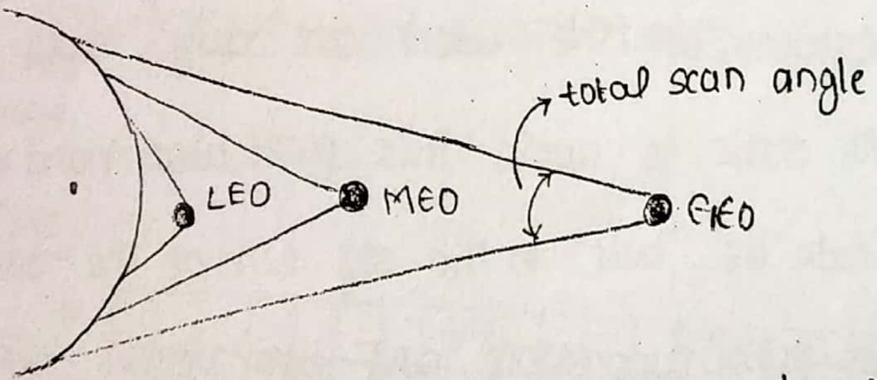


fig: schematic of the total scan angles for LEO, MEO and GEO

* A fixed a/a with parabolic reflector is able to scan its main beam away from electrical boresight axis

* When the plane wave is distorted from the focused parabolic

orbit & orbital height	LEO		MEO		GEO
	750km	1800km	10,000km	14,000km	35,786k
scan angle	±57.2°	±47.1°	±21.5°	±17.1°	±8
latitude / longitude range	±12.8°	±22.9°	±48.5°	±52.9°	±6

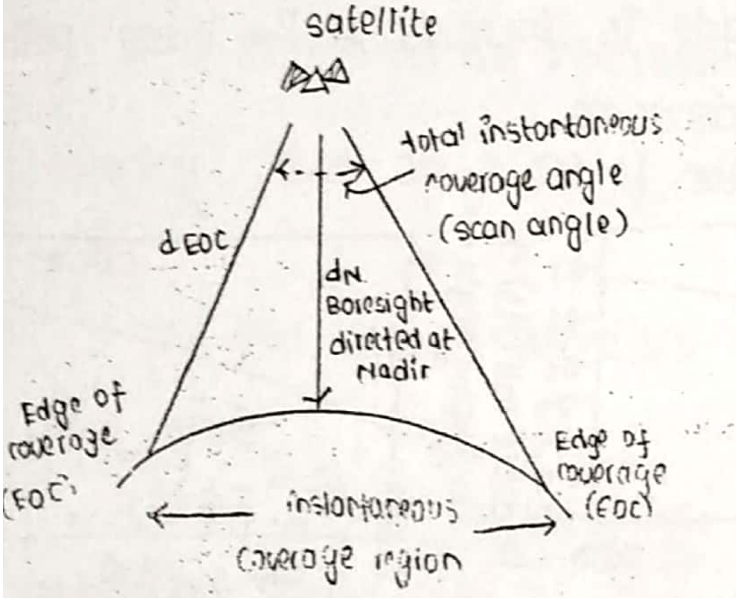


fig: Illustration of path loss & scan angle loss for phased array

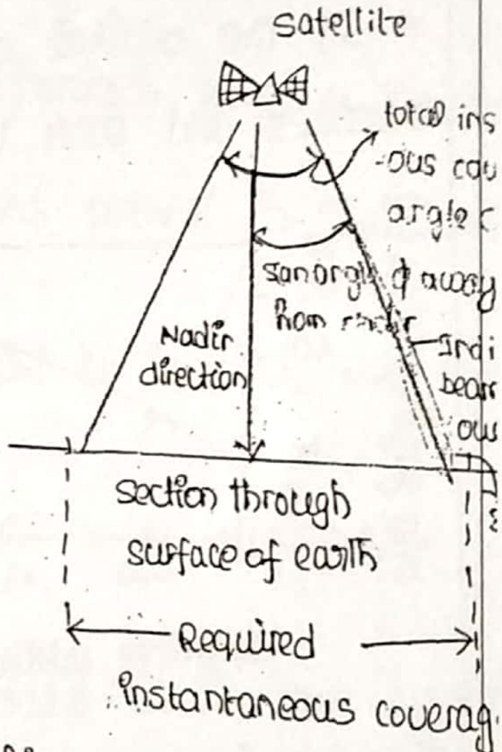


fig: Illustration of scan of individual beam.

* scan loss for a phased array follows the relationship

$$-\text{Scan loss} = (\text{cosine}\,\phi)^k$$

where φ, K are emphirical values of 57.2 & 1.3

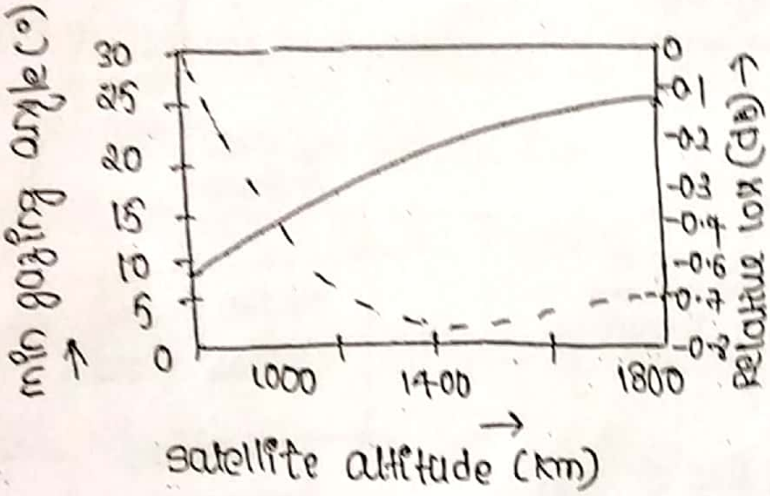
$$-\text{Scan loss} = (\text{cosine } 57.2)^{1.3}$$

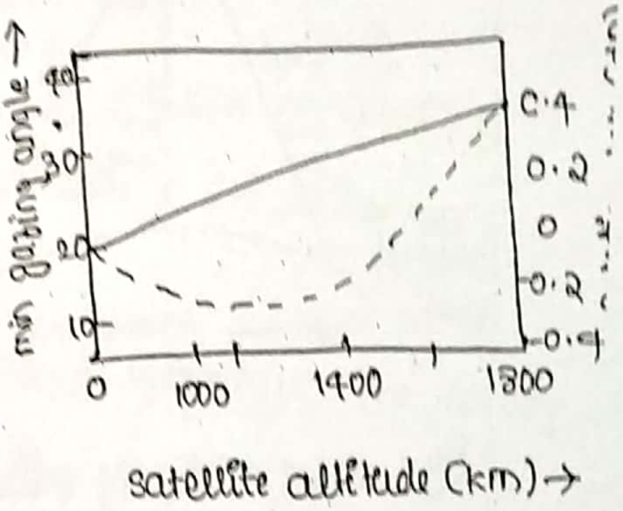
$$= 0.4507 \Rightarrow -3.5\,\text{dB}$$

Determination of optimum orbital altitude:

* Minimizing the total additional loss in the tx'n path to edge of coverage is a design goal.

* If the orbital altitude is increased - free space path loss increases and scan loss decreases.





* The locations at the edge of coverage within the instantanea coverage region presents the problems in design

Radiation safety and satellite telephones:

In united states the federal communication commission (FCC) mandates strict limits on radiated power levels throughout the spectrum. FCC provides many guidelines on the specific absorption rate (SAR) for wireless phones & devices through IEEE committees. Less handset powers causes ionization damage to tissue.

Projected NGSO system customer

service base:

→ single NGSO satellite is not enough to provide con 24-h coverage over an area. This leads to adopting two molniy orbits with 2 satellites provide continuous 24-h service.

→ Most of NGSO systems are aimed at mobile users, the problem for mbl users is at to generate sufficient tr't power in a handheld terminal.

Delay and throughput considerations:

Delay in communications link is not normally a prob unless the interaction b/w the users are very rapid. call interruption will occur to avoid this particular hand off is needed with code as "over" to the sig end of the users i/p. development of echo suppressors and even better, echo canceller solved the problem. customer acceptance on a service has bee found to be driven by three factors : i. access ability , ii. availability iii. performance

Delay occured when the sig is mismatched, if th mismatch is large then strong echo sig will return.

The vocoders sample the incoming analog sig

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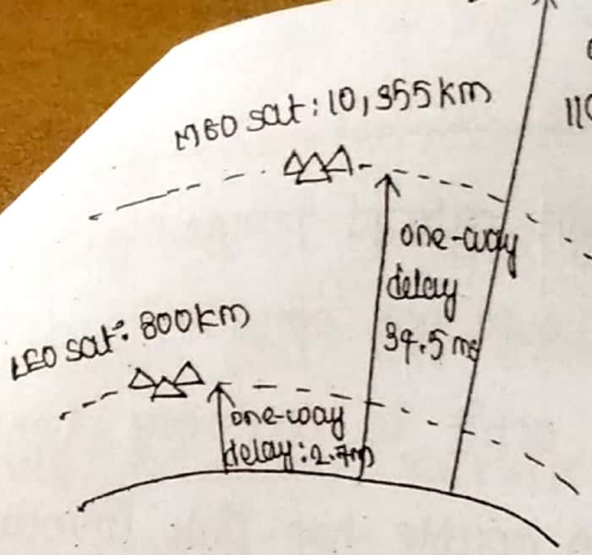
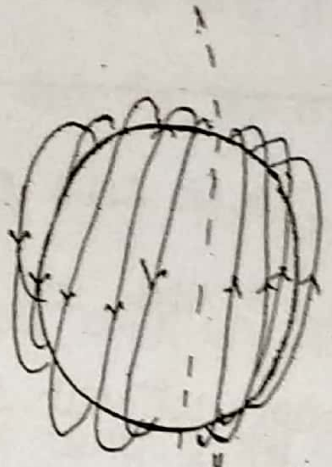




"seam" across which microwave ISLs a unable to track LEO sat in adjacent plane

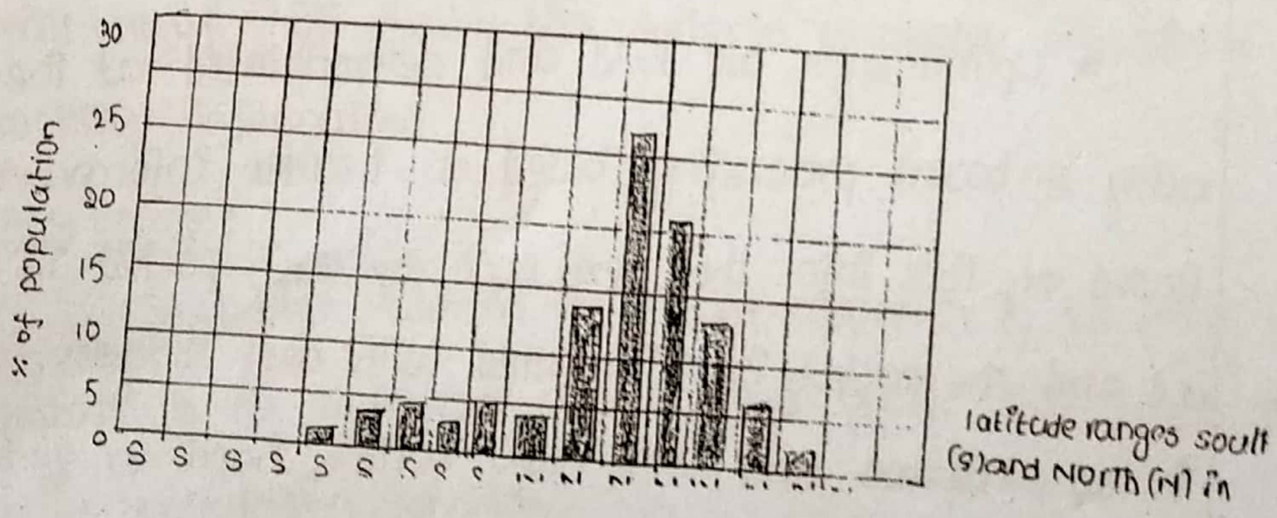
fig: One-way propogation delay for the three orbits: LEO, GEO, MEO

fig: Schematic of ISL seam in the Iridium constellation.

⇒ Operational NGSO constellation Designs:

Seven satellite constellation designs are reviewed briefly in following. Four MSS offering with multiple beams, one with single beam coverage providing both two-way and one-way store-and-forward services and two internet-multimedia satellite systems.

Ellipso:



..... studies of wo

population distribution and the potential market for MSS

from the above graph more than 85% of the wo population lives North of the equator and equatorial constellation of MEO sat could serve the bulk of the wo population.

"Ellipso is an intermental approach ~~th~~ to their s offering." There are 3 set of satellites present in their re orbits.

i. The first set of satellites would be in a circular equ -rial orbit.

ii. The 2nd set of satellites would be in elliptical equatorial orbit

iii. The 3rd set of satellites would be in sun sync -us 3-hour orbit inclined at 116.6°.

→ The equatorial orbit groups of the Ellipso system are ca "concordia" and the sun synchronous group is called "Borealis"

→ No ISL (inter satellite link) are used.

__Global star:__

Global star elected to develop a constellation that a aimed at the populous regions of the earth.

The globalstar orbitals are inclined at 52° to the

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equator

To minimize the power requirements of the user handset the constellation altitude is lowered to below the first van allen radiation belt. This results 48 satellites needed. No ISL's are used

The s/g is transponded down and the gateway earth stations process the s/g.

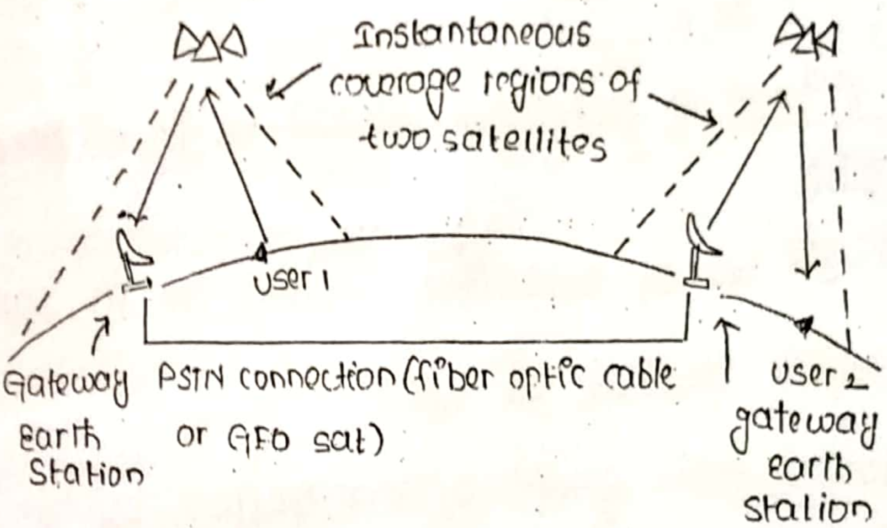

fig: schematic of end-to-end connection for satellites that have no onboard processing or ISL's.

<u>New ICO</u>:

* ICO global is the company that was spun off from the International maritime satellite organization (Inmarsat)

* New ICO is the company that emerged from bankruptcy protection in 2000.

* New ICO is primarily aimed at the LMS (land mbl

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* No ISL's or any significant onboard processing is nee

* Here LEO constellation would not provide maritime coverage without ISL's, a higher orbit is necessary hence th use of double-hop link used. A double hop link involves two uplinks and two downlinks.

* New ICO threfore adopted a MEO constellation

Iridium:

The genesis of Iridium was formed around the need to communicate from anywhere to any where on The surface of the earth even there is no telecommunication infrastructure existed.

* The system must stand alone. The satellites in th constellation act as switching nodes.

* Uplink sig's are Rx'd and demodulated at the satelli using onboard processing based on header information. Based on this info. the next node for each packet is determ-ed and the packet is reformatted with next address. The sig is up converted and it is tx'd with L band to gnd at 20 The gateway earth station Rx've the sig, here onboard processing is needed for msg routing and formatting

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Tracking of high value cargo on trucks and measuring water characteristics in revers and sea are the major applications. A GPS receiver on the cargo determines it's location and this information is sent with an ID. numbe via orbcomm satellite. If the truck carrying the cargo is hijacked it's route can be followed and the truck intercepted.

Orbcomm developed their system around this requirement and have orbited with both two-way data communicatio and store-and-forward capabilities.

These satellites are simple and lightweight (40kg) simple in design and execution. Single beam is used for coverag

A terminal with in the coverage area send short msg to gate way station in real time. The msg length is limited to a few hundred bytes. Orbcomm satellites carry short msgs. the system is therefore most attractive to users who want to sen small no. of high value bits, helps in emergency situations or tracking information.

Sky Bridge:

Sky bridge evolved a similar approach to coverage as Globalstar by selecting an inclined orbit that covers the major population densities do not have inter satellite links (ISLs), so all traffic is transponded down to the gateway earth stations for proc and onward routing.

Skybridge satellites are intended to carry wide traffic and uses the freq's above 10GHz. It uses Ku ba frequencies for GEO : 12.75 - 14.5 GHz for uplink and 10.7-1 for downlink.

Large no.of satellites (80 vs 40) are required. No are used. Skybridge uses the concept of fixed cell.

Table for system parameters of two NGSO constellations ai at internet multimedia communications.

system parameter	skybridge	Teledesic.
No.of planes	20	12
satellite per plane	4	24
Total complement	80	288
orbital inclination	53°	~90°
orbit type	circular	circular
orbital height (km)	1469	~1400
spot beams per sat	18	-
satellite life time.	~7 years	~7 years

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Tele desic :

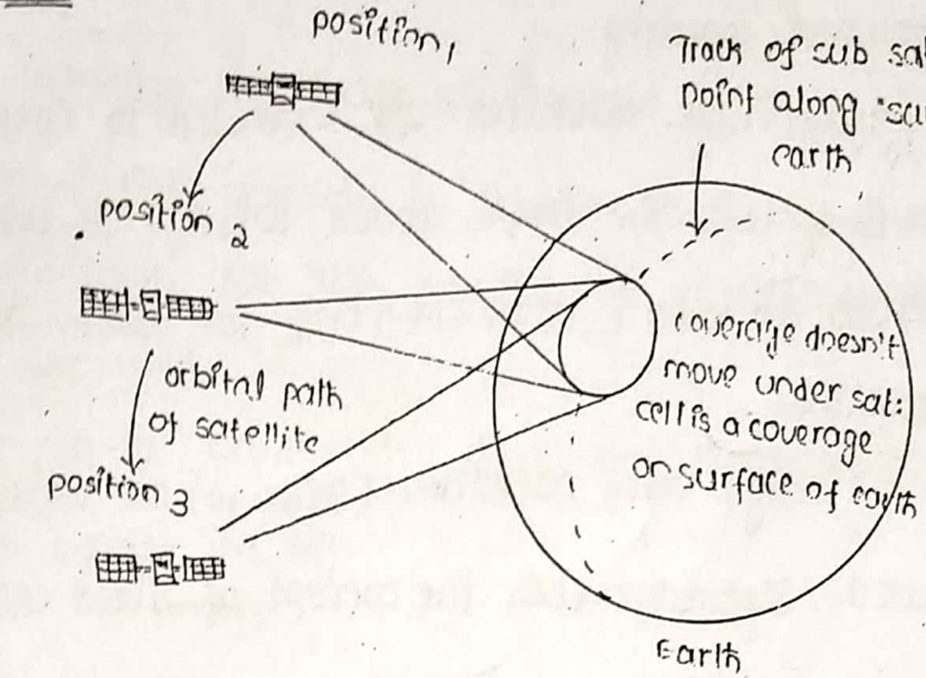

fig: concept of stationary cell.

Teledesic started from the same precept as Iridium but is designed for Internet like data traffic rather than voice communication. Any user can access any other user or ISP (internet service provider).

The concept of Teledesic is to provide a complete worldwide data communications system above the surface of the earth using satellites instead of earth surface fiber optic cables on earth.

Teledesic also limited the elevation to angle to 40° and it choose the Ka band for tx'n.

The initial Teledesic constellation had a compleme

The orbital altitude later moved up from 700km to about 1400 km which reduced the planes to 12.

Reduction of no. of satellites to 288 lowered the cost significantly and further the satellites are decreased in numb

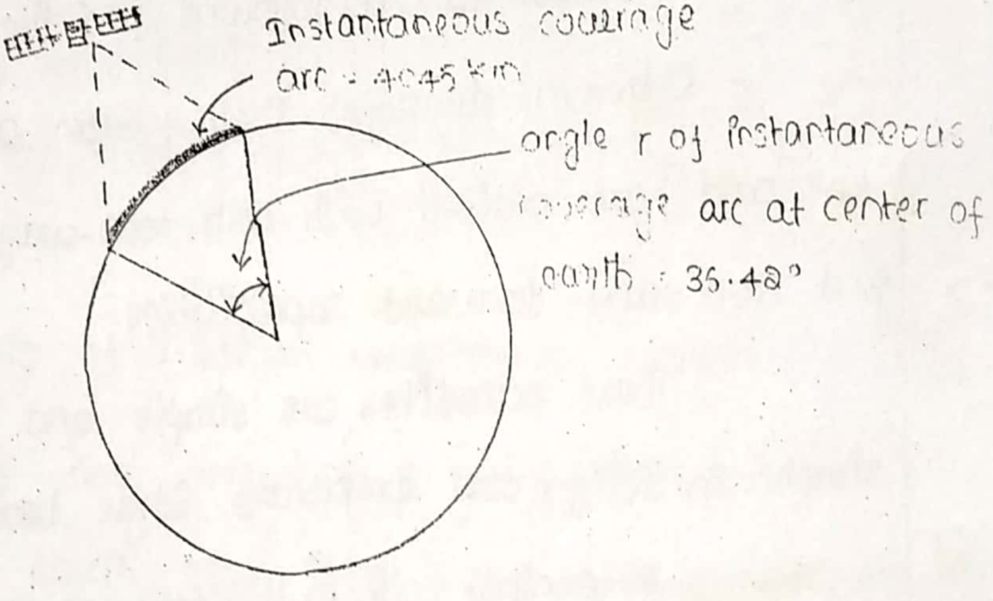

fig: coverage of one satellite orbiting at 750km altitu

comparision of NGSO system constallation parameters.

system parameter	Ellipso	Globalstar	New Ico	Iridium	orbcomm
No.of planes	1→3→5	8	2	6	4→5
satellites per plane	1x7 then 1x7 and 2x3 then 1x7, 2x3, 2x5	8	5	11	4x8 then 4x8 and 1x4
Total complement	23	48	10	66	36
orbital inclination	3 at 0°, 2 at 116.6°	52°	45°	86.5°	4 at 45°, 1 at 72°
orbital type	1 circular (0°) 2 elliptical (0°) 2 sun synchronous	circular	circular	circular	circular (45° and
orbital height (km)	1 circular → 8050 2 elliptical → 649-8050 2 sun syn → 633-7605	1414	10,285	780	775
spot beams per sat	161	16	163	48	1

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UNIT-VI

Satellite Navigation & THE Global positioning System

Syllabus :- Radio and satellite Navigation, Gps position location principles, Gps Receivers and Codes, Satellite Signal acquisition, Gps Navigation Message, Gps signal levels, Gps receiver operation, GPS C/A Code accuracy, Differential Gps

⇒ Radio and Satellite Navigation :-

* Prior to development of radio, navigation was by Compass and landmarks on the land and by the Sun and stars at Sea. Neither techniques provides high accuracy and ship wrecks Caused by inaccurate navigation and foggy weather were common occurence.

* Gps Can provide a Single navigation System with better accuracy and reliability than all earlier radia navigation aids. It Can provide navigation of aircraft directly between airports, instead of indirectly via airways, while providing absolute position readout of latitude and longitude

* Differential Gps Can be used instead ILS (Instrument landing System) to provide required Straight line in the sky for an instrument approach to a runway, and can be linked to an autopilot to provide automatic landing of aircraft in zero visibility Conditions.

* Gps Was preceded by an earlier Satellite navigation system called Transit, built for the U.S. Navy for ship navigation, which achieved much lower accuracy and became obsolete when Gps was introduced.

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- * Transit system observe Doppler shift for position location. Observation of the Doppler shift with time, which may need to be as long as 10 min, and a knowledge of the satellite orbit, allows calculation of receiver's position.

- * There was never a sufficient number of transit satellites to provide continuous position data and the long time required to obtain an accurate position fix was disadvantage

- * A similar system called SARSAT, for search and rescue sat is used to find emergency locator transmitters (ELTs) on aircraft that have crashed.

- * Most general aviation aircraft carry an ELT, which turns on frequency at of 121.5MHz when subjected to high g forces, as might be experienced if the aircraft crashes.

- * Almost 97% of ELT locations turn out to be false alarms the ELT was dropped (or) accidentally turned on. It seems probable that GPS and cellular phones (or) satellite phones will eventually replace the SARSAT system.

⇒ GPS Position Location Principles :-

The basic requirement of a satellite navigation system like GPS is that there must be four satellites transmitting suitable coded signals from known positions. Three satellites are required to provide the three distance measurements and the fourth to remove receiver clock error

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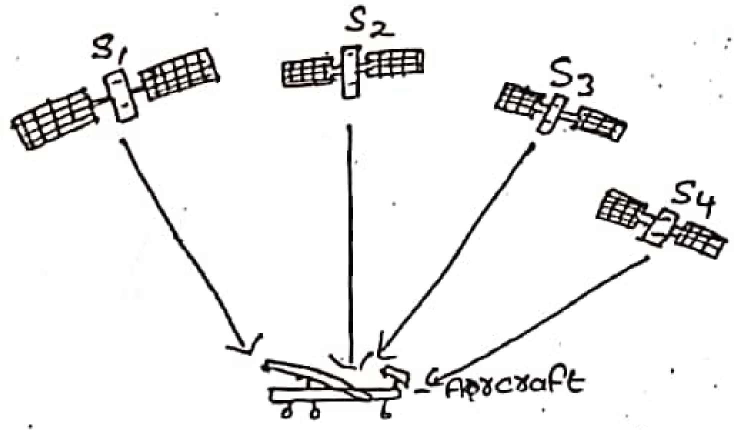

figure : General arrangment of position locations with Gps.

* The aircraft must receive signals from four Gps Satellites to be
able to determine its positions. The three Satellites provide
distance information when the Gps receiver makes three measure-
known points.
ments of range, Ri from the receiver to the three

* Each distance Ri can be thought of as the radius of a sphere
with a Gps satellite at its Center. The receiver lies at the
intersection of three Such Spheres, with a satellite at its center.

* Gps Satellites each carry four atomic clocks which are Calibrated
against time standards in the Gps Control stations around the
world.

* The result is Gps time, a time standard that is available in
every Gps satellite. The accuracy of an atomic Clock is
typically 1 part in 10^{11}. However, it too expensive to include
an atomic clock in most Gps receivers, so standard Crystal
oscillator with accuracy of 1 in 10^5 or 1 in 10^6 is used instead

* ~~However, it is too expensive to include an atomic clock in most Gps receivers, so a standard Crystal oscillator with an accur-acy~~

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* The receiver clock is allowed to have an offset relativ the GPS satellite clocks & when a time delay measurem is made, the measurement will an error caused by cloc offset.

Position location in GPS :-

* GPS receivers use the WGS-84 parameters to calculate the orbits of GPS satellites with accuracy required for precise measurement of the range of the satellites. The Z-axis of the coordinate system is directed through the earth's North pole and x-and y-axes are in the equatorial plane

* The x-axis passes through the Greenwich-meridian - the line of zero longitude on earth's surface and the y-axis passes through the 90° east meridian.

* The ECEF coordinate system rotates with the earth. The rece coordinates are (U_x, U_y, U_z) and four satellites have coordinates (X_i, Y_i, Z_i) where $i = 1,2,3,4$.

* There may be more than four satellites signals available but we use only four signals in a position calculation. The measured distance to satellite i is called a Psuedorange, PR_i, because it uses the internal clock of the receiver to make a timing measurement that includes errors caused by receiver clock offset

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seudorange, denoted as PR_i, is measured from the propagation time delay T_i between the satellite (number i) and Gps receiver, assuming the Em 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 by

$$R^2 = (x_A - x_B)^2 + (Y_A - Y_B)^2 + (z_A - z_B)^2$$

The equation which relate pseudo range to time delay are called range equations.

$$(X_1 - U_x)^2 + (Y_1 - U_y)^2 + (Z_1 - U_z)^2 = (PR_1 - Tc)^2$$
$$(X_2 - U_x)^2 + (Y_2 - U_y)^2 + (Z_2 - U_z)^2 = (PR_2 - TC)^2$$
$$(X_3 - U_x)^2 + (Y_3 - U_y)^2 + (Z_3 - U_z)^2 = (PR_3 - TC)^2$$
$$(X_4 - U_x)^2 + (Y_4 - U_y)^2 + (Z_4 - U_z)^2 = (PR_4 - TC)^2$$

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* The four unknowns are the location of the GPS receiver (U_x, U_y, U_z) relative to the Center of the earth and clock offset T- Called clock bias in GPS terminology.

* The receiver position is then referenced to the Surface of the earth, and can be displayed in latitude, longitude and elevation.

* Typical accuracy for low cost GPS receiver using the GPS C/A Code is 30m defined as a 2DRMS error. The term DRMS means the distance root mean square error of the measured position relative to the true position of the receiver.

* Selective availability and atmospheric propagation effects all Cause errors in the timing measurement made by GPS receiver, leading to the position location errors.

* The atmospheric and ionospheric introduce timing errors becau the propagation velocity of GPS signals deviates from the assumed free space value.

* The stations observe the GPS Signals and Compute the corr error in position as calculated from GPS data. This informa Can then be broadcast to all GPS users as a set of correction to be applied to GPS measurements. The system is Called Wide area augmentation system (WAAS).

* For example an airport Can determine the local meas error in GPS and broadCast this information to GPS user. So that greater accuracy Can be obtained with C/A Code re

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* This is one form of differential GPS (DGPS). More complex forms of differential GPS use a reference station which transmits the signals received from GPS satellite so that phase comparisions can be made by the receiver.

* With lengthy integration times and a sophisticated phase comparision receiver, differential GPS accuracies of 1cm can be obtained.

GPS Time :-

* The clock bias value 'T' which is found as part of the position location calculation process can be added to the GPS receiver clock time to yield a time measurement that is synchronized to the GPS time standard.

* The crystal oscillator is the stable one but it also have temperature variations constraints which effects the frequency generated by the crystal oscillator. This is enough to produce errors.

* Every GPS receiver is automatically synchronized to every other GPS receiver any where in the world through GPS time. This makes every GPS receiver a super clock, which knows time more accurately than any other time standard

* The time standard on board each GPS satellite consists of two cesium clocks plus two rubidium clocks. An atomic clock uses the fundamental resonance of the cesium (or) rubidium reference to lock a crystal oscillator

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* In the Gps Satellites, the master oscillator is 10.23MHz; all code rates, the L1 and L2 RF frequencies are multiples and submultiples of 10.23MHz. ~~all code rates, the L1 and the L2 RF~~

* The atomic clocks are updated by the controlling ground stations to keep them with in 1μs of universal time Coordinated (UTC) and the navigation message broadcast by each Satellite Contains information about its current clock errors relative to Gps time. (UTC is a world wide time standard. Green which mean time is equal to UTC).

⇒ Gps Receivers and Codes :-

* Gps Satellites transmit using pseudorandom Sequence (PN) Codes. All satellites transmit a C/A code at the same carrier frequency, 1575.42MHz called L1, using Bpsk modulation.

* The C/A Code has a clock rate of 1.023 MHz and C/A code Sequence has 1023 bits, So the PN Sequence lasts exactly 1.0ms.

* The exact values of frequencies are known about 0.005 Hz lower than stated here to allow for relative effects caused by high velocity of the satellites in their orbits (3.865 km/s)

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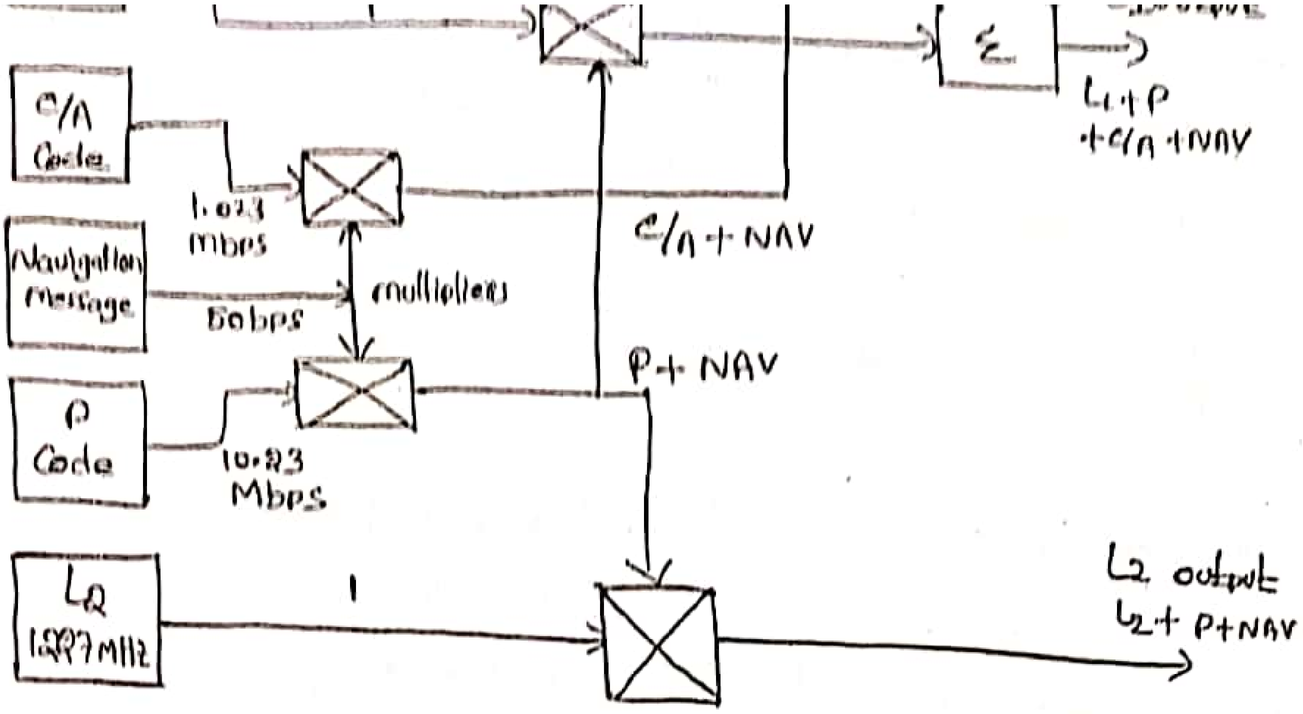

Figure :- Signal generation in a Gps Satellite.

- The P code is transmitted using Bpsk Modulation at the L2 carrier frequency of 1227.6 MHz (120 × 10.23 MHz) and also transmitted with Bpsk modulation on the L1 carrier frequency in phase quadrature with the C/A code Bpsk modulation

- The C/A and P code transmissions from all Gps Satellites are overlaid in the L1 and L2 frequency bands making Gps a direct sequence spectrum (DS-SS) system.

- At most, 12 Gps Satellites can be seen by the receiver at any one time, So the coding gain in Spread Spectrum must be sufficient to over come the interference created by 11 wanted signals while recovering the twelth wanted signals.

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The C/A Code :-

- The C/A Codes transmitted by GPS Satellites are all 1023 b Gold Codes. GPS C/A Gold codes are formed from two 102 bit m-Sequences, Called G1 and G2, by multiplying together the G1 and G2 sequences with different time offsets

- An m-Sequence is a maximum length pseudo-random (PN) Sequence, which is easy to generate with a shift register and feedback taps.

- A shift register with n stages can generate a pn Sequen $2^n - 1$ bits in length. The bit pattern is set by the feed bac taps and combining logic of the shift register.

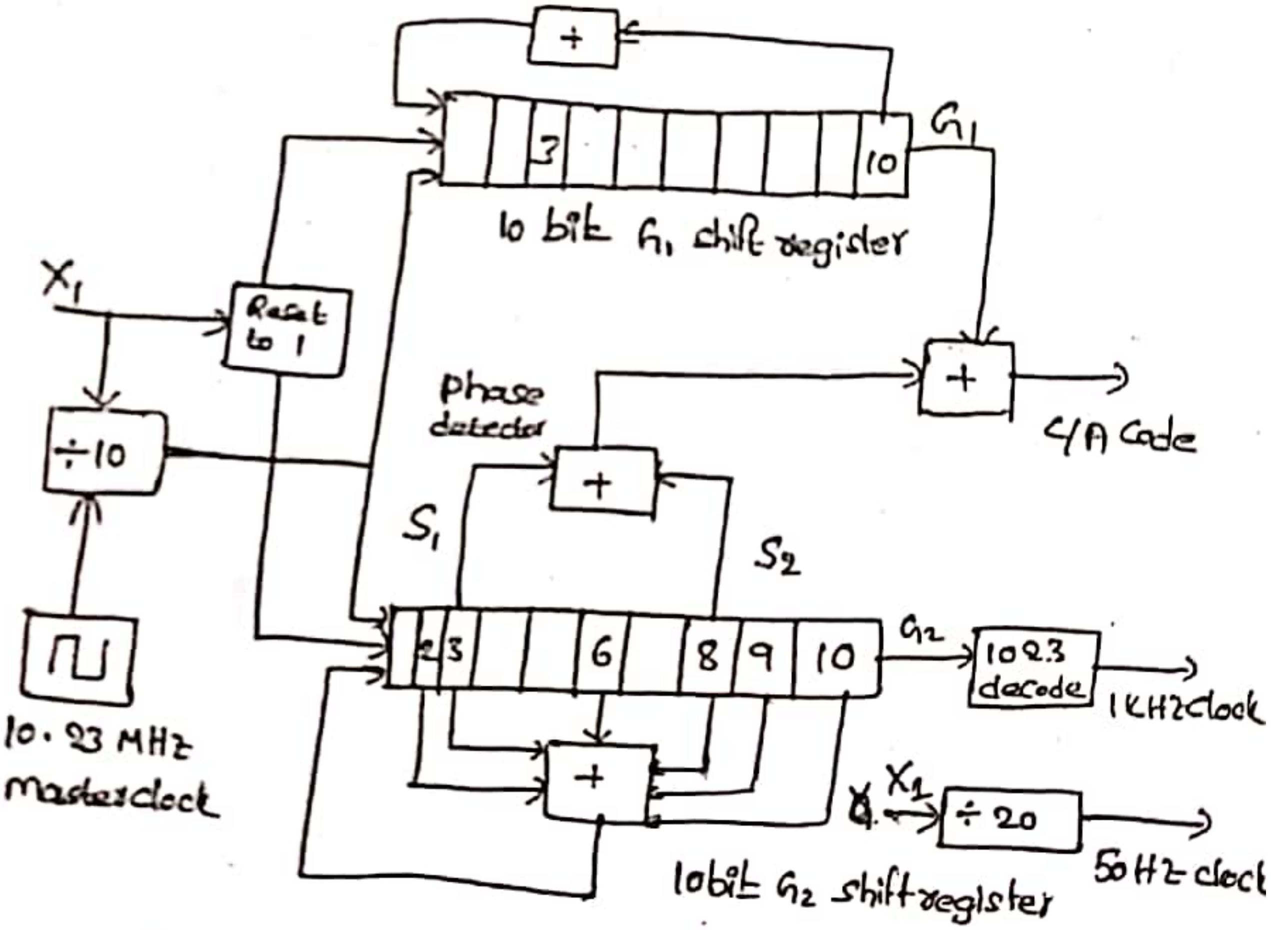

Fig : C/A Code generator

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* The C/A Code for a particular Satellite is created with an algorithm that includes the identification number of the GPS Satellite, thus creating a unique Code for each Satellite. The Satellite with ID number i has a C/A Code Sequence $C_i(t)$

$$C_i(t) = G1(t) \times G2(t + 10iT_c)$$

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

* There are 64 Gold Sequences available for satellites numbered 1 through 64. A total of 100 Gold Sequences can be correlated using the algorithm in above equation but not all the sequences have sufficiently low cross correlation Properties, and reference 4 states that only 37 are actually used in GPS System.

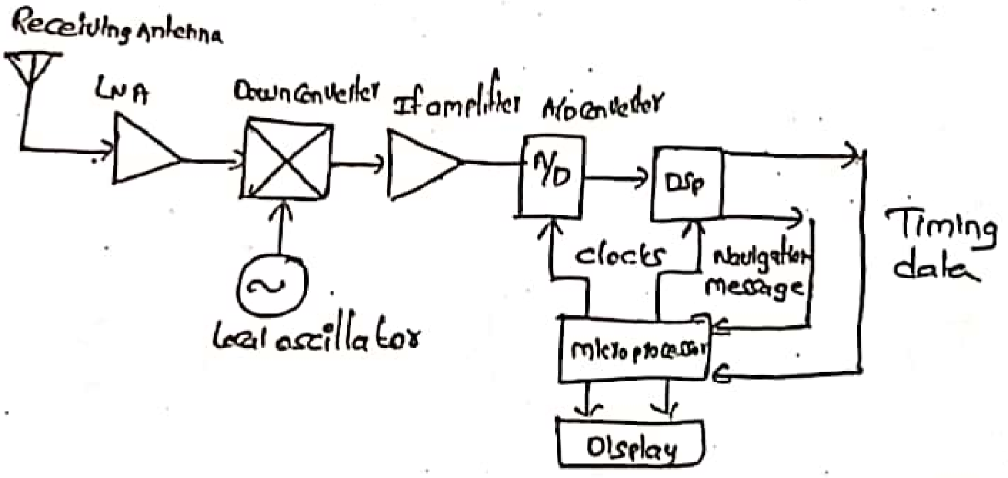

Fig:-: Simplified GPS Receiver

* Above figure shows a simplified block diagram of a C/A code GPS receiver. The antenna is typically a circulary polarized Patch antenna with an LNA mounted on printed circuit board

* A Conventional Superhet receiver is used to generate IF signal in a bandwidth of about 2 MHz, which is sampled using I and and processed digitally.

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Starting
* If the
no

* The digital portion of the receiver includes a C/A generator, a correlator and a microprocessor that mak the timing measurements and calculate the receivers an

⇒ Satellite Signal ACQUISITION :-

* The GPS receiver must find the starting time of unique C/A Code for each of four Satellites. This is done by Correlating the received Signal with the store C/A codes, as in any direct Sequence spread spectrum system.

* Usually the receiver will automatically select the four strongest and correlate them if the selected signal have close pseudo~~random~~ ranges, then the receiver have to correlate 37 possible C/A Code until it can correlate with one.

* Once Correlation is obtained, the data Stream (Called navigation message) from that Satellite can read by the receiver. The data Stream Contains the information about the adjacent Satellite. So, once one Signal is correlated, the receiver no longer nee to search all other 36 possible Codes to find next Satellit

* If the starting time for the locally generated Code was not selected correctly, Correlation will not be obtained immediat. The ~~process~~ locally generated Code is then moved forward one bit in time, and correlation is attempted again.

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- * The process is continued 1023 times until all possible starting times for locally generated code have been tried

- * If the satellite with particular C/A code is not visible, no correlation will occur and lock will not be achieved. It takes a minimum 1s to search all 1023 bit positions of 1023 bit C/A code.

- * So in a typical case, it will take atleast 15s to acquire the first satellite. Many receivers search for given C/A code several times before moving to the next code, so several minutes may elapse before correct C/A code is found given no other information.

- * Once one C/A code is found, the remaining satellites can then be acquired in a few seconds because their IDs are known from the data transmitted in the navigation message of each satellite.

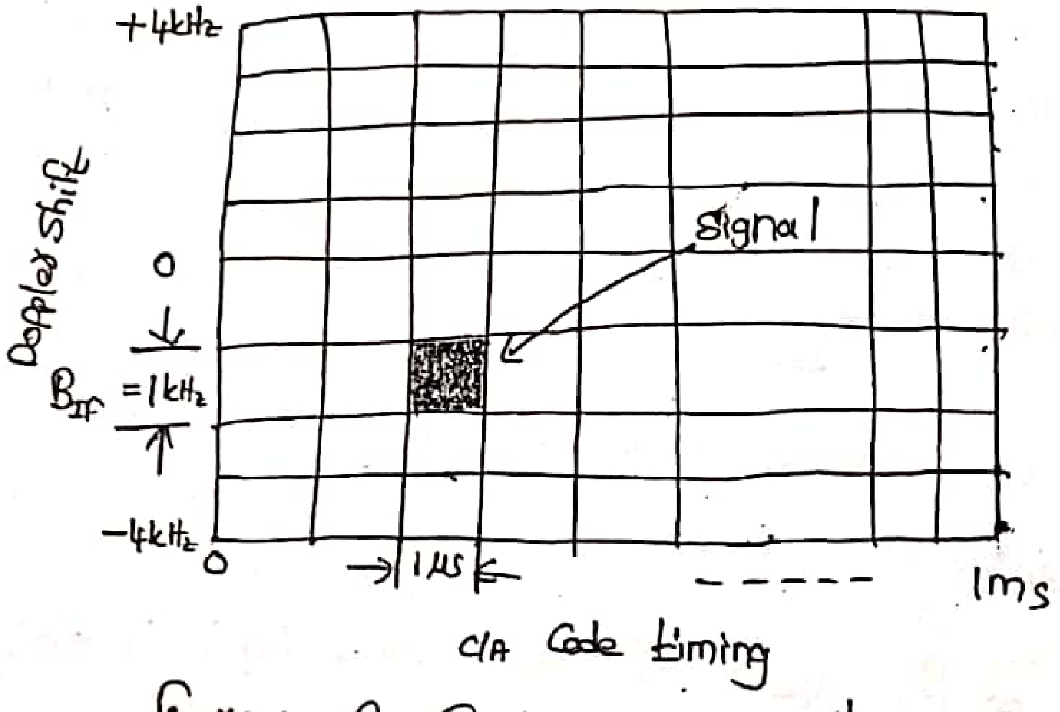

figure : Code Synchronization and Doppler tracking Matrix

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* Although it takes only 20s on average to lock to the C/ Code of one Satellite, the receiver must find the Doppler frec offset for at least one Satellete before correlation can occu

* The receiver band width is matched to the bandwidth of C/A Code. The theoritical noise bandwidth of the C/A Code receive is 1.023 MHz and the Velocity of the Satellites is 3.865 km/s.

* The angle between the Spacecraft Velocity Vector and a receiver on Earth is 76.1° when GPS Satellite is at the horizon, So the maximum Doppler shift in the L1 Signal $V_r/\lambda = 4.872$ kHz ignoring the effect of earth rotation.

* Allowing the Satellite to reach an elevation angle of 5° before it is used for position measurement limits the Doppler shift must ~~by~~ eight Doppler frequency ~~shifts~~ ~~upto~~ Doppler shift must accomidate by the receiver to ~~upto~~ Doppler shift must accomidate

±4kHz.

* Above figure illustrates the Search process. There are eight possible Doppler shifts for each Signal, and illustrat the search process.

There are eight possible Doppler shifts for each Sig and 1023 possible Code positions, giving 8184 possible Signal States that much searched.

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* The P code for the ith satellite is generated in a similar way to the c/A code. The algorithm is

$$P_i(t) = X1(t) + X2(t + iT_c)$$

Where T_c is the period of X1 sequence, which contains 15,345,000 bits and repeats every 1.5s. The X2 sequence is 37 bits longer. The Pcode repeats after 266.4 days, but is changed every 7 days for security reasons.

GPS Navigation Message:-

* ~~A~~ The Navigation message contains a large amount of information that is used by GPS receivers to optimize the acquisition of Satellite signals and Calculate position.

* The navigation message is sent at 50 bps by BPSK modulation of c/A and Pcodes.

* The ~~extracted~~ navigation signal is extracted by a 50-bps BPSK demodulator that follows the c/A (or) P code correlator.

* The Complete navigation message is 1500 bits sent as 30-s frame with 5-subframes. However, some information is contained in a sequence of frames, and complete data set requires 12.5 min ~~fro~~ for transmission.

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Header	Telemetry Message : health of satellite, handover Word
Subframe 1	Satellite clock Correction data. Age of transmitted data.
Subframe 2 and 3	Ephemeriks for Satellite.
Subframe 4	Almanac data for satellites 25 and higher. Ionospheric model
Subframe 5	Almanac data for satellites 1-24. Health data for satellite 1-2

* Subframes 1, 2, and 3 repeat all data every 30 s. Subframes 4 and 5 repeat every 30s, but transmission of the full data set requires 25 subframes over a period of 12.5 min.

* The calculation of position in a GPS receiver requires very accurate knowledge of the location of satellite at time that measurement of pseudo range is measured to an accuracy of 2.4m, we must know the satellite position to a even greater and that require very accurate calculation of GPS satellite orbits.

* The GPS System uses modified WGS-84 data to define the earth's radius, kepler constant, and the earth's rotational rate.

* Data on the Speed of EM waves is taken from the International Astronomical union.

* The WGS-84 data Set also includes a very detailed description of the eaths gravitation field which is essential for precise location of the satellites in their orbits.

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⇒ GPS signal levels :-

- * GPS satellites have an array of helical antennas that provide gain toward the earth, and low transmitters, leading to EIRP values in the range 19 to 27 dBW.

* The C/A code transmitted by the satellite is a direct sequence spread spectrum signal, so the C/N ratio in the C/A code's RF bandwidth will be less than 0dB.

* The low C/N ratio of the spread spectrum signal is converted to usable S/N by correlation of the code sequences, which adds a despreading gain to the C/N ratio.

* The theoretical processing gain of a direct sequence spread spectrum signal is equal to the ratio of chip rate to the bit rate in the spreading sequence, but losses in the correlation process always make practical gains a little lower.

* For the C/A code transmitted at 1.023 Mbps and a 1-ms correlation time, the theoritical processing gain is 1023, or 30.1 dB. The corresponding process gain for the P code is 40.1 dB.

* The GPS receiver can pick up signals from upto 10 satellites at the same time. The RF energy from the satellite spread spectrum transmissions adds to noise in the reciever as an interference term I.

* The interference from the nine C/A code spread spectrum signals of equal power is given by the sum of received power from each sattelites

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$I = 9 \times 10^{-16} W \Rightarrow -150.5 dBW$

* The thermal noise power, N, in a noise bandwidth of 2,
for a noise temperature of 273 K is kTB_n watts, where

$$N = -141.2 dBW \Rightarrow 7.59 \times 10^{-15} W$$

The noise and interference powers must be added in wa
not in decibels:

$$N + I = 8.49 \times 10^{-15} W \Rightarrow -140.7 dBW$$

Hence the worst case C/N for one C/A code signal in this scenario is

$$C/(N+I) = -160.0 - (-140.7) = -19.3 dB$$

* The navigation message has a 50-bps bit rate, and each b rate, and each bit extends over 20 C/A code correlation periods.
* The C/A code correlator output is passed through a 50 Hz bandwidth filter which integrates the 20 pulses from th correlator to give a single message bit, in the form of a 50 bps BPSK signal.

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Timing Accuracy :-

* The position location process requires an accurate measurement of the time arrival of the code sequence at the receiver.

* The output of C/A code correlator is a 1μs wide pulse that repeats every millisecond. The accuracy with which a timing measurement can be made on single pulse is given by approximat relationship

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

Where δt is the rms timing error.

B_n is noise bandwidth of RF channel

S/N ratio is the signal to noise power ratio for pulse in noise bandwidth B_n

The S/N ratio after correlator is

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

Where G_p is the correlator processing gain. for C/A code

$$G_p = 1023 = 30.1\,dB$$

&

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

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

If we assume the specification value for S/N of 11.7dB and loss of 1.7dB, [illegible] S/N = 10dB, a power ratio of 10.

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*

The theoritical noise bandwidth of the Correlator is

$B_n = 1 MHz$.

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

* A typical Gps receiver will update the display no mo than twice a second, So the pulses from the Correlator Can be averaged over a period of half a Second, which will decrease the rms error by $\sqrt{500} = 22.4$ to an rms Value of 14ns, assuming randomly distributed errors.

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GPS Receiver Operation :-

* A C/A Code GPS receiver must be able to correlate signals from at least four satellites calculate time delays, read the navigation message, calculate the orbits of the GPS satellites and calculate position from pseudoranges.

* Most C/A Code GPS receivers use an IC chip set contains 12 parallel correlators. This allows the receivers to proces signals from upto 12 satellites at the same time which helps keep all signals synchronized.

* Some simpler receivers use a single correlator and process four satellite signals sequentially, with consequent lower accuracy.

* The received GPS signals are converted to a suitable IF frequency in the front end of the receiver, and then processed to recover the C/A codes.

* The IF signal in the GPS receiver will consists of the sum of a number (up to 12) of signals from visible GPS satellites. The IF carrier signal has several BPSK modulation applied to it by the satellites, and when received or earth has been doppler shifted by satellite and earth motion.

* The IF signal from N GPS satellites in view is

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$$S(t) = \sum_{i=1}^{N} \left\{ A_i C_i(t) D_i(t) \sin\left[(w_I + w_d)t - \phi_i(d_i) + \phi_i \right.\right. \quad — ①$$

Where A_i is the amplitude of received Signal

$C_i(t)$ is the Gold Code modulation

$D_i(t)$ is the navigation message modulation

w_i is the IF frequency of the received Carrier

$\phi_i(d_i)$ is the phase shift along the path

ϕ_i is the phase angle of transmitted Signal.

w_d is the Doppler shift of the received singal

* The receiver must measure $\phi_i(d_i)$ in Eq ① as a time c in order to obtain the pseudorange for each of the N satellites View, and it must recover the $C_i(t)$ modulation by Correlation.

* The $D_i(t)$ modulation Contains the navigation massage as a 50 modulation of $C_i(t)$ Signal. Both the $C(t)$ and $D(t)$ Signa are modulated onto the Carrier of the satellite Signal b binary Shift keying and therefore have Values ±1.

* Demodulation of BPSK Signals requires a locally generated Carr which is locked to the phase of the received Carrier, and fo recovery of the data signal requires a bit clock the quency is locked to the bit rate of received signal.

* The delay lock loop shown in figure takes advanta of Coherent nature of GPS/CA Signals So that the Vco be both a time reference for C/A Code Signals and also the Chip clock

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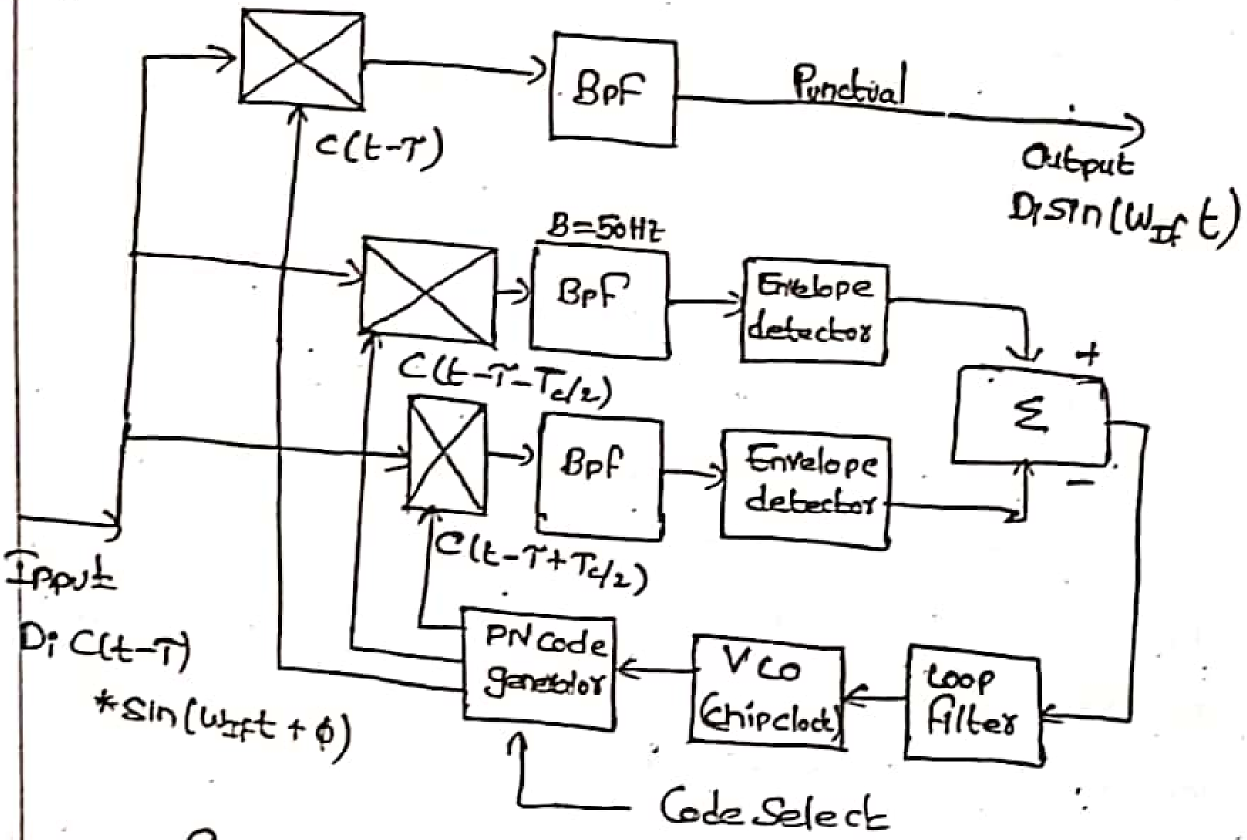

Figure: Non Coherent Code lock loop & navigation message recovery.

* The delay lock loop has three paths: punctual, early (half chip ahead) late (half chip behind). The delay lock loop steers the chip clock so that the punctual output can be used to drive the C/A code generator.

* The early/late channels in the delay lock loop generate output signals which steer the phase of the VCO so that navigation message acquired correctly.

* The output of the C/A code correlator with Doppler corrected IF frequency for the satellite signal with code number M is

$$x(t) = A_m R(T_m - T)\, D_m(t) \sin[\omega_m(t) - \phi_m(t_m) + \phi_m] + n(t)$$

Where $R(T_m - T)$ is the auto correlation function of the wanted code number M, — ②

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$n(t)$ is the output from Cross correlation with all other codes.

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

$$y(t) = A_m R(T_m - T) D_m(t) \sin\left[(\omega_m(t) - \phi_m(t_m) + \phi_m\right] + n(t) \quad —③$$

The IF Carrier signal is limited to remove any amplitude variations, which sets $A_m = 1$, then

$$y'(t) = R(T_m - T) D_m(t) \sin(\omega_m(t) - \phi'_m] + n(t) \quad —④$$

The demodulated message signal is

$$z(t) = R(T_m - T) D_m(t) + n'(t) \quad —⑤$$

* Provided that the Correlation peak of $z(t)$ Crosses the threshold and $n'(t)$ doesn't we can recover the data message $D_m(t)$ Correctly.

* If everything works Correctly in the receiver, the S/N of the Signal $y'(t)$ is at least 17 dB, So there will be no bit errors.

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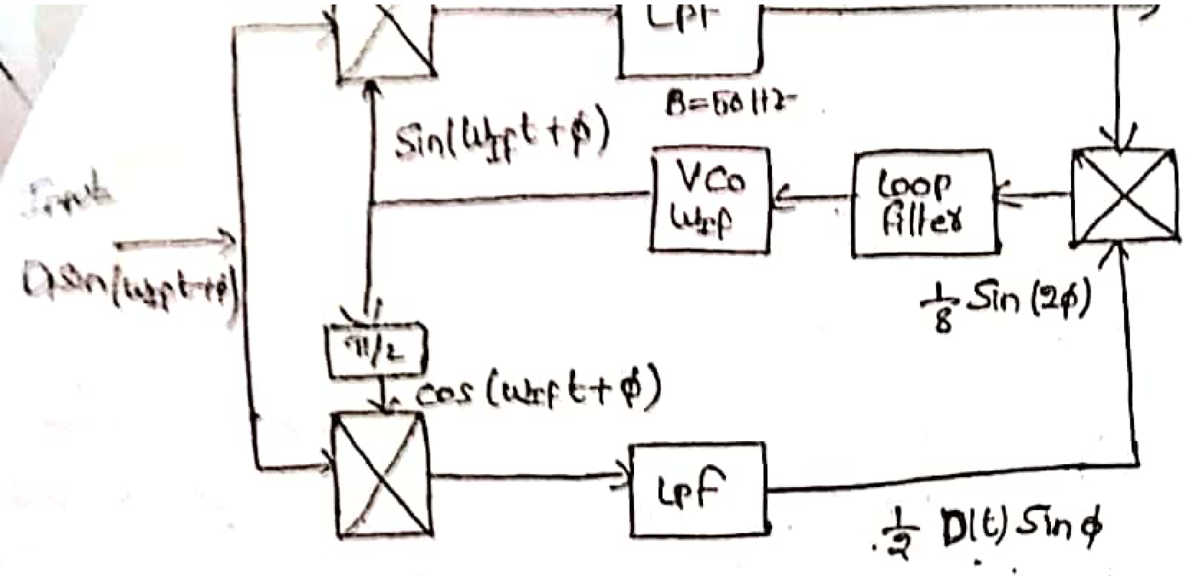

figure: Castas loop. LPF, Low pass filter

- * Above figure shows a Costas loop which is often used as the demodulator for low speed BPSK signals such as the 50bps GPS navigation message.
- * The loop has an I channel and a Q channel driven by a VCO. The VCO frequency is set by the sum of the outputs from the I and Q channel detectors, which steers the VCO phase such that the I channel is in phase with the signal.
- * The I channel output is then (ideally) a zero ISI waveform which can be integrated and sampled to recover the navigation message bits.

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⇒ GPS' C/A Code ACCURACY :-

The Major Sources...of error in a GPS receiver that Calculates of position are:

Satellite clock and ephemeris error.
Selective availability (when switched on)
Ionospheric delay (advance)
Receiver noise
Multipath.

* The range error introduced by the ionosphere and the troposphere can be partially removed by receiving identical signals at two difference carriers frequencies.

* This technique is used by high precision P code receiver: The pcode Signal is transmitted on the L1 Carrier at 1575.42MHz, in phase quadrature with the C/A code sign

* The P-code is also transmitted on L_2 Carrier at 1227.6 Algorithms are used in the pcode receiver to calculate the net delay of the signal caused by the ionosphere then to remove the errors from Calculated ranges

* Receiver Position is Calculated in (x, y, z) Coordinates, and errors in x, y, and z depend on elevation angle of Satel the Satellite geometry, and other parameters in the error f

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* ~~To account for these, will have different level errors in x, y, and~~

* To account for these differences several dilution of precision factors (DOP) are defined. A DOP factor multiples the basic position measurement error to give a large error caused by the particular DOP effect.

Dilution of precision : HDOP, VDOP, and GDOP

HDOP :- Horizontal dilution of precision is one of the most important DOP factors for most GPS users. It provides an error metric for x and y directions, in the horizontal plane. A typical HDOP value is 1.5, and it is often the smallest of DOP.

There are may DOP factors in GPS. The more important ones are HDOP, VDOP, Geometric (DOP) othe DOP's include position (PDOP), & Time DOP.

In general, VDOP and GDOP are most likely to degrade in the accuracy of GPS position measurements.

VDOP is is most important in aircraft position measurements whose height shows the where heights above the ground is a critical factor especially when landing.

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⇒ Differential Gps :-

- * The Most accurate forms of differential Gps use the relative phase of the many signals in the Gps transmissions to increase the accuracy of timing measurements.
- * Suppose that you Could Count the number of cycles of the 1575MHz L1 carrier wave between a satellite and a Gps receiver, and that Gps satellites are stationary for the length of time it takes to make the Count at two separate locations.
- * In principle, measurements which Compare the phase angle of the received L1 carriers from Several Gps Satellites Could therefore be used to detect receiver movements at the Centimeter level. This is called differential phase (or) kinematic DGps
- * DGps Can make phase measurements and time of arrival Comparisions for Various Gps Signals at two different locations and resolve motion between the two locations.

If one of the receivers is a fixed reference Station, it is then possible to locate the Second Gps receiver Very accurate with respect to that fixed location

The Satellites are moving and measurements over a Considerable time are required to resolve ambiguity to the centimeter level.

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* The P-code Can be used for real time differential measurement without knowledge of pcode itself, becuase only a comparision of the time of arrival of code bits is required.

* In Wide Area Augmentation System (WAAS) developed by FAA for aircraft flying in north America, 24 WAAS receive Station Continously monitor their position as calculated from C/A Codes of all visible Satellites in the GPS System.

* The Stations also use the pcode transmission to make accurate differential measurements of the pseudo range to each visible Satellites.

* The 24 WAAS Stations Sed their data to a Central Station with an uplink to a GEO Satellite. The Central Station validates the data, Combines all the information, and Sends a Sequense of pseudorange Correction data all GPS users via Satellite.

* The Central Station also determines whether any of the data is in error, and Sends a warning signal called an integrity message to instruct aircraft not to use the GPS System (or) particular satellite, becuase the data are not reliable.

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[illegible] a signal transmitted
a Gps Satellite.

* A Conventional Gps receiver with Suitable Software extract the pseudorange error values from the WAA Satellite transmission and obtain markedly improved Accura in its position determination

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Code No: **R1642043** **R16** **Set No. 1**

IV B.Tech II Semester Regular Examinations, September - 2020

SATELLITE COMMUNICATIONS

(Electronics and Communication Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B
Answer ALL sub questions from Part-A
Answer any FOUR questions from Part-B

*****

PART–A*(14 Marks)*

1\. a) What is sub satellite point of a satellite system? [2]
b) List out the various orbital elements. [2]
c) Why uplink and down link frequencies are different for a satellite system? [3]
d) Write the differences between multiplexing and multiple access. [2]
e) What are the earth station design considerations? [3]
f) What are the functions of GPS monitoring stations? [2]

PART–B*(4x14 = 56 Marks)*

2\. a) What are the various orbital effects in satellite communication system performance? Explain. [7]
b) A satellite is in an elliptical orbit with a perigee of 1000 km and an apogee of 4000 km. using a mean earth radius of 6378.14 km, find the period of the orbit. [7]

3\. a) What are the various satellite subsystems? Explain TTC & M subsystem with a neat block diagram. [7]
b) Explain the 14/11 GHz transponder with a neat block diagram. [7]

4\. a) Derive the expression for C/N ratio of a satellite link. [7]
b) Suppose, we have a 4-GHz satellite receiver with the following gains and noise temperatures: T_{in} = 25 K, T_{RF} = 50 K, T_{IF} = 1000 K, T_m = 500 K, G_{RF} = 23 dB and G_{IF} = 30 dB. Calculate the system noise temperature, if the mixer has a
i) gain of 0 dB and
ii) 10 dB loss. [7]

5\. a) What is intermodulation in FDMA? Explain in detail with relevant expressions. [7]
b) Explain the principle and advantages of CDMA technique. [7]

6\. a) What are the different types of antenna mounts used at satellite earth station? Explain. [7]
b) Compare the low earth orbit and geostationary satellite systems with respect to orbit, coverage and operating frequency. [7]

7\. a) Explain the basic GPS receiver with the help of a block diagram. [7]
b) Explain the principle and advantages of Differential GPS. [7]

Code No: **R1642043** **R16** **Set No. 2**

IV B.Tech II Semester Regular Examinations, September - 2020

SATELLITE COMMUNICATIONS

(Electronics and Communication Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B
Answer ALL sub questions from Part-A
Answer any FOUR questions from Part-B

*****

PART–A*(14 Marks)*

1. a) What are the differences between the geosynchronous and geostationary orbits? [2]
   b) What is a transponder? Write the various types of transponders used with a satellite. [3]
   c) Define the G/T ratio of a satellite link. [2]
   d) Write the advantages of CDMA technique. [2]
   e) List out the different types of antennas used at satellite earth station. [2]
   f) Write the different sources of GPS errors. [3]

PART–B*(4x14 = 56 Marks)*

2. a) What is elevation angle with respect to a satellite? Derive the expression for it. [8]
   b) The coordinates of the INSAT GEO satellite are 83^0E and 0^0N. The earth station is located at Hyderabad 78^0E and 17^0N. Find the earth station elevation angle to INSAT. [6]

3. a) What are the various satellite subsystems? Explain attitude and orbit control system in detail. [7]
   b) Explain the 6/4 GHz single conversion transponder with a neat block diagram. [7]

4. a) Derive the expression for system noise temperature in a satellite system. [7]
   b) A satellite in GEO orbit is at a distance of 39000 km from an earth station. The required flux density at the satellite to saturate one transponder at a frequency of 14.3 GHz is -90 dBW/m^2. The earth station has a transmitting antenna with a gain of 52 dB. Find the output power of the earth station transmitter. [7]

5. a) Explain the TDMA frame structure with the help of a neat diagram. [7]
   b) Compare FDMA and TDMA. [7]

6. a) Explain the operation of earth station receiver with the help of a neat block diagram. [7]
   b) What are various NGSO constellation designs? Explain in detail. [7]

7. a) Explain the generation of GPS L1 and L2 signals. [7]
   b) Explain the principle of Differential GPS. [7]

Code No: **R1642043** **R16** **Set No. 3**

IV B.Tech II Semester Regular Examinations, September - 2020

SATELLITE COMMUNICATIONS

(Electronics and Communication Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B
Answer ALL sub questions from Part-A
Answer any FOUR questions from Part-B

*****

PART–A*(14 Marks)*

1. a) Write the applications of satellite communications. [2]
   b) What are the causes for attitude and orbital changes for a satellite system? [3]
   c) Write the expression for overall C/N ratio of a satellite system. [2]
   d) Define the efficiency of TDMA and write the expression for it. [3]
   e) List out the disadvantages of LEO satellites. [2]
   f) What are the functions of GPS master control station? [2]

PART–B*(4x14 = 56 Marks)*

2. a) Explain the brief history of satellite communication systems. [7]
   b) What are the look angles with respect to a satellite? Explain with relevant diagrams. [7]

3. a) What are the various satellite subsystems? Explain communication subsystem with a neat block diagram. [8]
   b) Explain the various types of antennas used for satellite communication. [6]

4. a) Derive the expression for satellite link equation. [7]
   b) A satellite at a distance of 40000 km from a point on the earth's surface radiates a power of 10 W from an antenna with a gain of 17 dB in the direction of the observer. Find the power received by an antenna with an effective area of 10 m^2. [7]

5. a) Explain the principle, advantages and disadvantages of FDMA with necessary diagrams. [9]
   b) Find the number of channels for a satellite system with FDMA that has a bandwidth of 12.5 MHz with a channel bandwidth of 30 KHz and guard band of 10 KHz. [5]

6. a) Explain the operation of earth station tracking subsystem with the help of a neat diagram. [7]
   b) What are the different satellite constellation designs? Explain any one. [7]

7. a) Draw the basic architecture of GPS and explain in detail. [7]
   b) Compare the performance of GPS and Differential GPS. [7]

Code No: **R1642043** **R16** **Set No.4**

IV B.Tech II Semester Regular Examinations, September - 2020

SATELLITE COMMUNICATIONS

(Electronics and Communication Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B
Answer ALL sub questions from Part-A
Answer any FOUR questions from Part-B
*****

PART–A*(14 Marks)*

1. a) What is apogee and perigee of a satellite system? [3]
   b) Define telemetry and tracking. [2]
   c) Write the various losses to be considered for a satellite link. [3]
   d) Write the disadvantages of FDMA. [2]
   e) What are the various types of power amplifiers used at satellite earth station? [2]
   f) What are the limitations of GPS? [2]

PART–B*(4x14 = 56 Marks)*

2. a) Explain the Keppler's laws of planetary motion. [7]
   b) What is azimuth angle with respect to a satellite? Derive the expression for it. [7]

3. a) What are the various satellite subsystems? Explain the power system. [7]
   b) Explain the redundancy type of approach used for improving equipment reliability in satellite. [7]

4. a) Derive the expression for G/T ratio of a satellite link. [7]
   b) The thermal noise in an earth station receiver results in a $(C/N)_{dn}$ ratio of 20 dB. A signal is received from a transponder with a carrier to noise ratio $(C/N)_{up}$ of 20 dB.
      i) What is the value of overall (C/N) ratio at the earth station?
      ii) If the transponder introduces intermodulation products with (C/I) ratio of 24 dB, what is the overall (C/N) ratio? [7]

5. a) Explain the principle, advantages and disadvantages of TDMA with necessary diagrams. [7]
   b) Find the frame efficiency of a satellite system with TDMA that has a time slot consists of 6 trailing bits, 8.25 guard bits, 26 training bits, and 2 traffic bursts of 58 bits of data. [7]

6. a) Draw the general configuration of an earth station and explain each block. [7]
   b) Explain the delay considerations of LEO, MEO and GEO satellites. [7]

7. a) Explain the various functions of Ground segment of GPS architecture. [7]
   b) Describe the format of GPS navigation message. [7]