1

SATELLITE COMMUNICATION – AN INTRODUCTION

Contents

1.1 INTRODUCTION

- Satellites are specifically made for telecommunication purpose. They are used for mobile applications such as communication to ships, vehicles, planes, hand-held terminals and for TV and radio broadcasting.

- They are responsible for providing these services to an assigned region (area) on the earth. The power and bandwidth of these satellites depend upon the preferred size of the footprint, complexity of the traffic control protocol schemes and the cost of ground stations.

- A satellite works most efficiently when the transmissions are focused with a desired area. When the area is focused, then the emissions don't go outside that designated area and thus minimizing the interference to the other systems. This leads more efficient spectrum usage.

- Satellite's antenna patterns play an important role and must be designed to best cover the designated geographical area (which is generally irregular in shape). Satellites should be designed by keeping in mind its usability for short and long term effects throughout its life time.

- The earth station should be in a position to control the satellite if it drifts from its orbit it is subjected to any kind of drag from the external forces.

1.2 BASICS

- Satellites orbit around the earth. Depending on the application, these orbits can be circular or elliptical. Satellites in circular orbits always keep the same distance to the earth's surface following a simple law:

  The attractive force *Fg* of the earth due to gravity equals $m \cdot g\ (R/r)^2$

  The centrifugal force *Fc* trying to pull the satellite away equals $m \cdot r \cdot \omega^2$

  The variables have the following meaning:

  m is the mass of the satellite;
  R is the radius of earth with *R* = 6,370 km;
  ri s the distance of the satellite to the centre of the earth;
  g is the acceleration of gravity with *g* = 9.81 m/s2;
  ω is the angular velocity with $\omega = 2 \cdot \pi \cdot f$, *f* is the frequency of the rotation.

To keep the satellite in a stable circular orbit, the following equation must hold:

Fg = *Fc*, i.e., both forces must be equal. Looking at this equation the first thing to notice is that the mass *m* of a satellite is irrelevant (it appears on both sides of the equation).

Solving the equation for the distance *r* of the satellite to the centre of the earth results in the following equation:

The distance $r = (g \cdot R^2/(2 \cdot \pi \cdot f)^2)1/3$

- From the above equation it can be concluded that the distance of a satellite to the earth's surface depends on its rotation frequency.

- Important parameters in satellite communication are the *inclination* and *elevation* angles. The inclination angle δ (figure 1.1) is defined between the equatorial plane and the plane described by the satellite orbit. An inclination angle of 0 degrees means that the satellite is exactly above the equator. If the satellite does not have a circular orbit, the closest point to the earth is called the perigee.

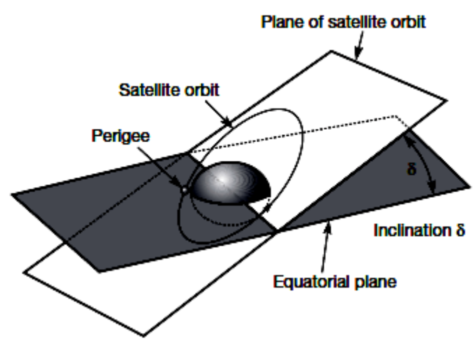

Figure 1.1: Angle of Inclination

- The elevation angle ε (figure 1.2) is defined between the centre of the satellite beam and the plane tangential to the earth's surface. A so called footprint can be defined as the area on earth where the signals of the satellite can be received.

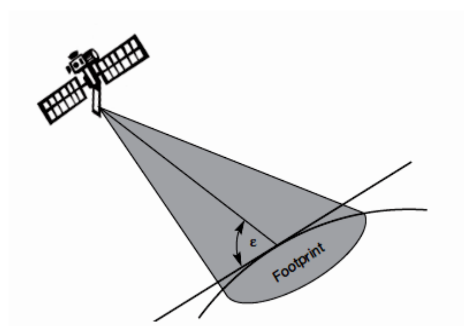

Figure 1.2: Angle of Elevation

1.3 APPLICATIONS OF SATELLITES

1.3.1) Weather Forecasting

Certain satellites are specifically designed to monitor the climatic conditions of earth. They continuously monitor the assigned areas of earth and predict the weather conditions of that region. This is done by taking images of earth from the satellite. These images are transferred using assigned radio frequency to the earth station. (Earth Station: it's a radio station located on the earth and used for relaying signals from satellites.) These satellites are exceptionally useful in predicting disasters like hurricanes, and monitor the changes in the Earth's vegetation, sea state, ocean color, and ice fields.

1.3.2) Radio and TV Broadcast

These dedicated satellites are responsible for making 100s of channels across the globe available for everyone. They are also responsible for broadcasting live matches, news, world-wide radio services. These satellites require a 30-40 cm sized dish to make these channels available globally.

1.3.3) Military Satellites

These satellites are often used for gathering intelligence, as a communications satellite used for military purposes, or as a military weapon. A satellite by itself is neither military nor civil. It is the kind of payload it carries that enables one to arrive at a decision regarding its military or civilian character.

1.3.4) Navigation Satellites

The system allows for precise localization world-wide, and with some additional techniques, the precision is in the range of some meters. Ships and aircraft rely on GPS as an addition to traditional navigation systems. Many vehicles come with installed GPS receivers. This system is also used, e.g., for fleet management of trucks or for vehicle localization in case of theft.

1.3.5) Global Telephone

One of the first applications of satellites for communication was the establishment of international telephone backbones. Instead of using cables it was sometimes faster to launch a new satellite. But, fiber optic cables are still replacing satellite communication across long distance as in fiber optic cable, light is used instead of radio frequency, hence making the communication much faster (and of course, reducing the delay caused due to the amount of distance a signal needs to travel before reaching the destination.).

Using satellites, to typically reach a distance approximately 10,000 kms away, the signal needs to travel almost 72,000 kms, that is, sending data from ground to satellite and (mostly) from satellite to another location on earth. This cause’s substantial amount of delay and this delay becomes more prominent for users during voice calls.

1.3.6) Connecting Remote Areas

Due to their geographical location many places all over the world do not have direct wired connection to the telephone network or the internet (e.g., researchers on Antarctica) or because of the current state of the infrastructure of a country. Here the satellite provides a complete coverage and (generally) there is one satellite always present across a horizon.

1.3.7) Global Mobile Communication

The basic purpose of satellites for mobile communication is to extend the area of coverage. Cellular phone systems, such as AMPS and GSM (and their successors) do not cover all parts of a country. Areas that are not covered usually have low population where it is too expensive to install a base station. With the integration of satellite communication, however, the mobile phone can switch to satellites offering world-wide connectivity to a customer. Satellites cover a certain area on the earth. This area is termed as a 'footprint' of that satellite. Within the footprint, communication with that satellite is possible for mobile users. These users communicate using a Mobile-User-Link (MUL). The base-stations communicate with satellites using a Gateway-Link (GWL). Sometimes it becomes necessary for satellite to create a communication link between users belonging to two different footprints. Here the satellites send signals to each other and this is done using Inter-Satellite-Link (ISL).

1.4 FREQUENCY ALLOCATION FOR SATELLITE

- Allocation of frequencies to satellite services s a complicated process which requires international coordination and planning. This is done as per the International Telecommunication Union (ITU). To implement this frequency planning, the world is divided into three regions:
  - Region1: Europe, Africa and Mongolia
  - Region 2: North and South America and Greenland
  - Region 3: Asia (excluding region 1 areas), Australia and south-west Pacific.
- Within these regions, he frequency bands are allocated to various satellite services. Some of them are listed below.
  - **Fixed satellite service**: Provides Links for existing Telephone Networks Used for transmitting television signals to cable companies
  - **Broadcasting satellite service**: Provides Direct Broadcast to homes. E.g. Live Cricket matches etc
  - **Mobile satellite service**s: This includes services for:
    Land Mobile
    Maritime Mobile
    Aeronautical mobile
  - **Navigational satellite services** : Include Global Positioning systems

  - **Meteorological satellite services**: They are often used to perform Search and Rescue service
- Below are the frequencies allocated to these satellites:

  Frequency Band (GHZ) Designations:
    - VHF: 01-0.3
    - UHF: 0.3-1.0
    - L-band: 1.0-2.0
    - S-band: 2.0-4.0
    - C-band: 4.0-8.0
    - X-band: 8.0-12.0
    - Ku-band: 12.0-18.0 *(Ku is Under K Band)*
    - Ka-band: 18.0-27.0 *(Ka is Above K Band)*
    - V-band: 40.0-75.0
    - W-band: 75-110
    - Mm-band: 110-300
    - **μ**m-band: 300-3000
- Based on the satellite service, following are the frequencies allocated to the satellites:

  Frequency Band (GHZ) Designations:
    - VHF: 01-0.3 ---Mobile & Navigational Satellite Services
    - L-band: 1.0-2.0 --- Mobile & Navigational Satellite Services
    - C-band: 4.0-8.0 --- Fixed Satellite Service
    - Ku-band: 12.0-18.0 --- Direct Broadcast Satellite Services

1.5 TYPES OF SATELLITES (BASED ON ORBITS)

1.5.1) Geostationary or geosynchronous earth orbit (GEO)

- GEO satellites are synchronous with respect to earth. Looking from a fixed point from Earth, these satellites appear to be stationary. These satellites are placed in the space in such a way that only three satellites are sufficient to provide connection throughout the surface of the Earth (that is; their footprint is covering almost $1/3^{rd}$ of the Earth). The orbit of these satellites is circular.

- There are three conditions which lead to geostationary satellites. Lifetime expectancy of these satellites is 15 years.
  1) The satellite should be placed 37,786 kms (approximated to 36,000 kms) above the surface of the earth.
  2) These satellites must travel in the rotational speed of earth, and in the direction of motion of earth, that is eastward.
  3) The inclination of satellite with respect to earth must be 0^0.
- Geostationary satellite in practical is termed as geosynchronous as there are multiple factors which make these satellites shift from the ideal geostationary condition.

1) Gravitational pull of sun and moon makes these satellites deviate from their orbit. Over the period of time, they go through a drag. (Earth’s gravitational force has no effect on these satellites due to their distance from the surface of the Earth.)
2) These satellites experience the centrifugal force due to the rotation of Earth, making them deviate from their orbit.
3) The non-circular shape of the earth leads to continuous adjustment of speed of satellite from the earth station.

- These satellites are used for TV and radio broadcast, weather forecast and also, these satellites are operating as backbones for the telephone networks.

- Disadvantages of GEO: Northern or southern regions of the Earth (poles) have more problems receiving these satellites due to the low elevation above a latitude of 60°, i.e., larger antennas are needed in this case. Shading of the signals is seen in cities due to high buildings and the low elevation further away from the equator limit transmission quality. The transmit power needed is relatively high which causes problems for battery powered devices. These satellites cannot be used for small mobile phones. The biggest problem for voice and also data communication is the high latency as without having any handovers, the signal has to at least travel 72,000 kms. Due to the large footprint, either frequencies cannot be reused or the GEO satellite needs special antennas focusing on a smaller footprint. Transferring a GEO into orbit is very expensive.

1.5.2) Low Earth Orbit (LEO) satellites:

- These satellites are placed 500-1500 kms above the surface of the earth. As LEOs circulate on a lower orbit, hence they exhibit a much shorter period that is 95 to 120 minutes. LEO systems try to ensure a high elevation for every spot on earth to provide a high quality communication link. Each LEO satellite will only be visible from the earth for around ten minutes.

- Using advanced compression schemes, transmission rates of about 2,400 bit/s can be enough for voice communication. LEOs even provide this bandwidth for mobile terminals with Omni-directional antennas using low transmit power in the range of 1W. The delay for packets delivered via a LEO is relatively low (approx 10 ms). The delay is comparable to long-distance wired connections (about 5–10 ms). Smaller footprints of LEOs allow for better frequency reuse, similar to the concepts used for cellular networks. LEOs can provide a much higher elevation in Polar Regions and so better global coverage.

- These satellites are mainly used in remote sensing an providing mobile communication services (due to lower latency).

- Disadvantages: The biggest problem of the LEO concept is the need for many satellites if global coverage is to be reached. Several concepts involve 50–200 or even more satellites in orbit. The short time of visibility with a high elevation requires additional mechanisms for connection handover between different satellites. The high number of satellites combined with the fast movements resulting in a high complexity of the whole satellite system. One general problem of LEOs is the short lifetime of about five to eight years due to atmospheric drag and radiation from the inner Van Allen belt1. Assuming 48 satellites and a lifetime of eight years, a new satellite would be needed every two months. The low latency via a single LEO is only half of the story. Other factors are the need for routing of data packets from satellite to if a user wants to communicate around the world. Due to the large footprint, a GEO typically does not need this type of routing, as senders and receivers are most likely in the same footprint.

1.5.3) Medium Earth Orbit (MEO) satellites:

- MEOs can be positioned somewhere between LEOs and GEOs, both in terms of their orbit and due to their advantages and disadvantages. Using orbits around 10,000 km, the system only requires a dozen satellites which is more than a GEO system, but much less than a LEO system. These satellites move more slowly relative to the earth’s rotation allowing a simpler system design (satellite periods are about six hours). Depending on the inclination, a MEO can cover larger populations, so requiring fewer handovers.

- Disadvantages: Again, due to the larger distance to the earth, delay increases to about 70–80 ms. the satellites need higher transmit power and special antennas for smaller footprints.

The above three are the major three categories of satellites, apart from these, the satellites are also classified based on the following types of orbits:

1.5.4) Sun- Synchronous Orbits satellites:

- These satellites rise and set with the sun. Their orbit is defined in such a way that they are always facing the sun and hence they never go through an eclipse.
- For these satellites, the surface illumination angle will be nearly the same every time.
  (Surface illumination angle: The illumination angle is the angle between the inward surface normal and the direction

of light. This means that the illumination angle of a certain point of the Earth's surface is zero if the Sun is precisely overhead and that it is 90 degrees at sunset and at sunrise.)

- Special cases of the sun-synchronous orbit are the noon/midnight orbit, where the local mean solar time of passage for equatorial longitudes is around noon or midnight, and the dawn/dusk orbit, where the local mean solar time of passage for equatorial longitudes is around sunrise or sunset, so that the satellite rides the terminator between day and night.

1.5.5) Hohmann Transfer Orbit:

This is an intermediate orbit having a highly elliptical shape. It is used by GEO satellites to reach their final destination orbits. This orbit is connected to the LEO orbit at the point of perigee forming a tangent and is connected to the GEO orbit at the point of apogee again forming a tangent.

1.5.6) Prograde orbit:

This orbit is with an inclination of less than 90°. Its direction is the same as the direction as the rotation of the primary (planet).

1.5.7) Retrograde orbit:

This orbit is with an inclination of more than 90°. Its direction is counter to the direction of rotation of the planet. Only few satellites are launched into retrograde orbit because the quantity of fuel required to launch them is much greater than for a prograde orbit. This is because when the rocket starts out on the ground, it already has an eastward component of velocity equal to the rotational velocity of the planet at its launch latitude.

1.5.8) Polar Orbits

This orbit passes above or nearly above both poles (north and south pole) of the planet on each of its revolutions. Therefore it has an inclination of (or very close to) 90 degrees. These orbits are highly inclined in shape.

1.6 EXAMPLES

1.6.1) INTELSAT

- International Telecommunication Satellite:
- Created in 1964
- Over 140 member countries
- More than 40 investing entities
- Early Bird satellite in 1965
- Six (6) evolutions of INTELSAT satellites between 1965-87
- Geostationary orbit
- Covers 3 regions:

- ➢ Atlantic Ocean Region (AOR),
- ➢ Indian Ocean Region (IOR), and
- ➢ Pacific Ocean Region (POR)

1.6.2) U.S DOMSATS

Domestic Satellite:

- In geostationary orbit
- Over 140 member countries
- Direct-to-home TV service
- Three (3) categories of U. S. DBS system: high power, medium, and low power.
- Measure in equivalent isotropic radiated power (EIRP).
- The upper limit of EIRP:
    - ➢ High power (60 dBW),
    - ➢ Medium (48 dBW), and
    - ➢ Low power (37 dBW).

1.6.3) Polar Orbiting Satellites

These satellites follow the Polar Orbits. An infinite number of polar orbits cover north and south polar regions.

- Weather (ultraviolet sensor also measure ozone level) satellites between 800 and 900 km
- National Oceanic and Atmospheric Administration (NOAA) operate a weather satellite system
- Satellite period is 102 minutes and earth rotated 25 degree.
- Estimate the sub-satellite point at the following times after the equator 90 degree E North-South crossing:
    - ➢ a) 10 minutes, 87.5 degree E and 36 degree S;
    - ➢ b) 102 minutes, 65 degree E and equator;
    - ➢ c) 120 minutes, 60 degree E and 72 degree S.
- The system uses both geostationary operational environment satellite (GOES) and polar operational environment satellite (POES)
    - ➢ Sun synchronous: they across the equator at the same local time each day
    - ➢ The morning orbit, at an altitude of 830 km, crosses the equator from south to north at 7:30 AM, and the afternoon orbit, at an altitude of 870 km, at 1:40 PM.
- Search and rescue (SAR) satellite: Cospas-Sarsat.

1.7 SUMMARY

This unit discusses the basics of satellite and elaborating the parameters which are needed to calculate the distance of an orbit to which a satellite is to be launched and the other factors which are necessary to define an orbit. Further this unit discusses the applications of satellites and elaborates on the global communication which has now become possible due to the presence of satellites. This unit also elaborates on the frequency bands used by each communication satellite.

Going further, this unit also elaborates on the types of orbits a satellite can follow to provide communication. The last segment of this unit discuses three examples of satellite revolving around the Earth.

1.8 EXERCISE

1) List the various applications of satellite.
2) Why is there a need for satellite communication?
3) List and discuss the various orbits defined for satellite communication.
4) Write a note on various satellite services available.
5) What are the primary factors needed for defining an orbit of a satellite?
6) Define elevation and inclination angles of a satellite orbit.

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2

ORBITS AND LUNCHING METHODS

Contents

2.1 INTRODUCTION

- The mathematical basis o satellite orbit determination has been known since the work of Newton and Kepler in the 17th Century. Since past half century some basic laws have been applied to the man made satellites commonly known artificial satellites in the Earth's orbit.

2.2 KEPLER'S LAWS

Johann Kepler developed empirically three laws of planetary motion, based on conclusions drawn from the extensive observations of Mars by Tycho Brahe (taken around the year

1600). While they were originally defined in terms of the motion of the planets about the Sun, they apply equally to the motion of natural or artificial satellites about the Earth. Kepler'sfirst law states that the satellite follows an elliptical path in its orbit around the Earth. The satellite does not necessarily have uniform velocity around its orbit. Kepler's second law states that the line joining the satellite with the centre of the Earth sweeps out equal areas in equal times. Kepler's third law states that the cube of the mean distance of the satellite from the Earth is proportional to the square of its period.

2.2.1) Kepler's First Law

- The path followed be a satellite (in our case artificial satellite) around the primary (a planet and in our case Earth) will be an ellipse.

- "The orbit of every planer is an ellipse with sun at one of the two foci. "

- An ellipse has two focal points. Let us consider F1 and F2. The centre of mass of the two body system, known as the barycentre as always cantered at one foci. Due to the great difference between the masses of the planet (Earth) and the satellite, centre of mass always coincides with the centre of Earth and hence is always at one foci.

(Note: Ellipse: A regular oval shape, traced by a point moving in a plane so that the sum of its distances from two other points (the foci) is constant.

Foci: The center of interest and in our case centre of the ellipse.)

- Parameters associated with the 1st law of Kepler:
  - ***Eccentricity (e):*** it defines how stretched out an ellipse is from a perfect circle.

  - ***Semi-Major axis (a):*** It is the longest diameter, a line that runs through the centre and both foci, its ends being at the widest points of the shapes. This line joins the points of apogee.

  - ***Semi-Minor axis (b):*** the line joining the points of perigee is called the Semi-Minor axis.

    The value of e could be determined by: $e = (\sqrt{a^2 - b^2}) / a$

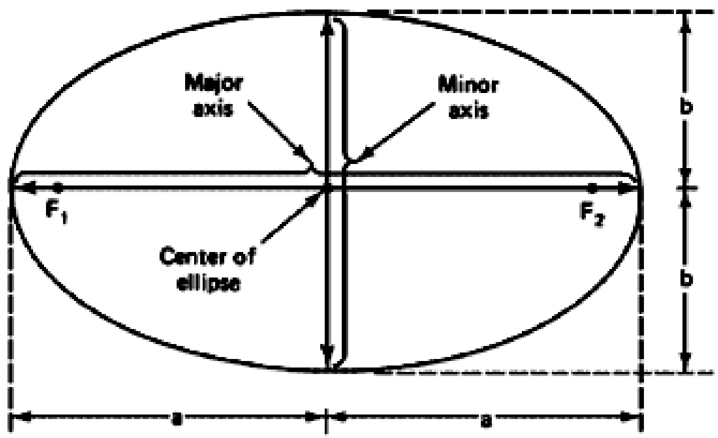

Figure 2.1: Foci F1 and F2, Semi-major axis a and semi-minor axis b of an ellipse.

<u>22.2) Kepler's Second Law</u>

- "For equal time intervals, a satellite will sweep out equal areas in its orbital plane focussed at the barycentre".

- With respect to the laws governing the planetary motion around the sun, tis law could be stated as "A line joining a planet and the sun sweeps our equal area during equal intervals of time".

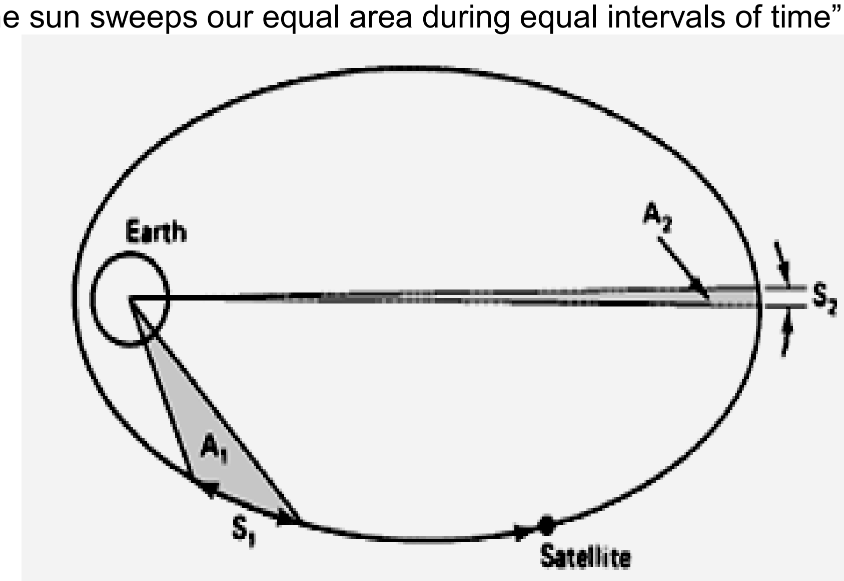

Figure 2.2: The areas A1 and A2 swept out in unit intervals of time.

- From figure 2.2 and considering the law stated above, if satellite travels distances S1 and S2 meters in 1 second, then areas A1 and A2 will be equal.

- The same area will be covered everyday regardless of where in its orbit a satellite is. As the First Keplerian law states that the satellite follows an elliptical orbit around the primary, then the satellite is at different distances from the planet at different parts of the orbit. Hence the satellite has to move faster when it is closer to the Earth so that it sweeps an equal area on the Earth.

- This could be achieved if the speed of the satellite is adjusted when it is closer to the surface of the Earth in order to make it sweep out equal areas (footprints) of the surface of the Earth.

2.2.3) Kepler's Third Law

- The square of the periodic time of orbit is proportional to the cube of the mean distance between the two bodies.

- The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit.

- This law shows the relationship between the distances of satellite from earth and their orbital period.

- Example: suppose satellite Satellite-I is four times as far from Earth as Satellite-II. Then **I** must traverse four times the distance of **II** in each orbit. Now considering the speed of **I** and **II**, suppose **I** travels at half the speed of **II**, then in order to maintain equilibrium with the reduced gravitational force (as **I** is four times away from Earth than what **II** is), then in all it will require 4 x 2 = 8 times as long for **I** to travel an orbit in agreement with the law which comes down to ($8^2 = 4^3$).

- Symbolically: $P^2 \alpha a^3$ (P^2 is directly proportional to a^3)
  Where **P** is the orbital period; **a** is the semi-major axis

  $$a^3 = \mu/n^2$$

  Where **n** is the mean motion of satellite in radians per second and **μ** is the Earth's geocentric gravitational constant.

  $$\mu = 3.986005 \times 10^{14}\ m^3/sec^2$$

Due to Earth's oblateness, a new parameter called drag is taken into account.

$$P = 2\Pi / n$$

Here, P is in seconds and n is in radians/ second

This law also confirms the fact that there is a fixed relation between period and size.

2.3 DEFINITIONS

- ***Apogee***: A point for a satellite farthest from the Earth. It is denoted as $\mathbf{h_a}$**.**
- ***Perigee*****:** A point for a satellite closest from the Earth. It is denoted as $\mathbf{h_p}$**.**
- ***Line of Apsides***: Line joining perigee and apogee through centre of the Earth. It is the major axis of the orbit. One-half of this line's length is the semi-major axis equivalents to satellite's mean distance from the Earth.
- ***Ascending Node:*** The point where the orbit crosses the equatorial plane going from north to south.
- ***Descending Node:*** The point where the orbit crosses the equatorial plane going from south to north.
- ***Inclination:*** the angle between the orbital plane and the Earth's equatorial plane. Its measured at the ascending node from the equator to the orbit, going from East to North. Also, this angle is commonly denoted as **i.**
- ***Line of Nodes:*** the line joining the ascending and descending nodes through the centre of Earth.
- ***Prograde Orbit:*** an orbit in which satellite moves in the same direction as the Earth's rotation. Its inclination is always between 0^0 to 90^0. Many satellites follow this path as Earth's velocity makes it easier to lunch these satellites.
- ***Retrograde Orbit:*** an orbit in which satellite moves in the same direction counter to the Earth's rotation.
- ***Argument of Perigee:*** An angle from the point of perigee measure in the orbital plane at the Earth's centre, in the direction of the satellite motion.
- ***Right ascension of ascending node:*** The definition of an orbit in space, the position of ascending node is specified. But as the Earth spins, the longitude of ascending node changes and cannot be used for reference. Thus for practical determination of an orbit, the longitude and time of crossing the ascending node is used. For absolute measurement, a fixed reference point in space is required. It could also be defined as "*right ascension of the ascending node; right*

ascension is the angular position measured eastward along the celestial equator from the vernal equinox vector to the hour circle of the object".

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

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

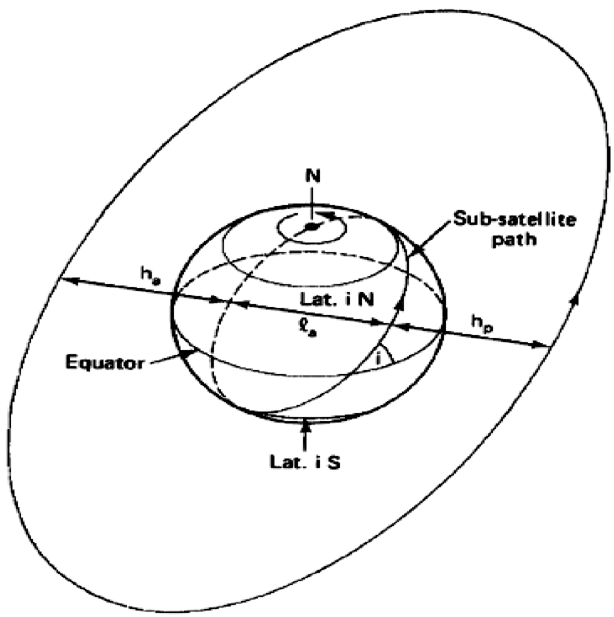

Figure 2.3: Apogee height h_a, Perigee height* h_p*,
***Inclination* i*, line of apsides* l_a**

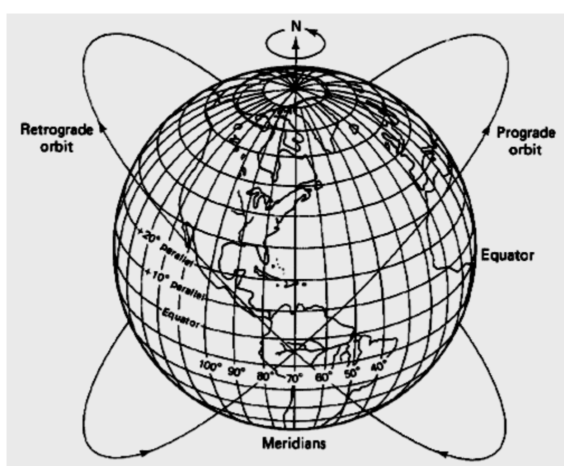

Figure 2.4: Prograde and Retrograde orbits

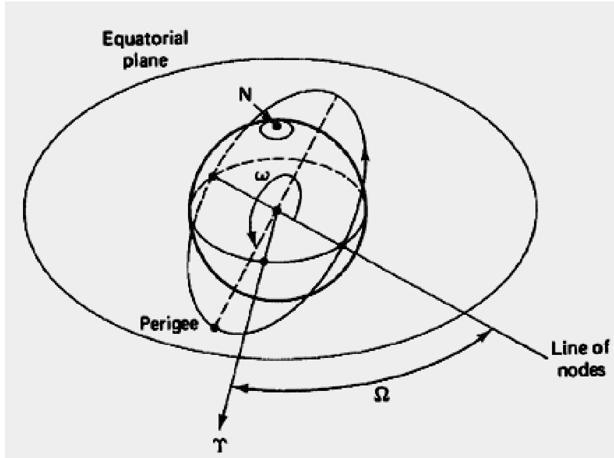

Figure 2.5: Argument of Perigee and Right ascension of ascending node

2.3.1) Orbital Elements

Following are the 6 elements of the Keplerian Element set commonly known as orbital elements.

1. Semi-Major axis (a)
2. Eccentricity (e)

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

3. Mean anomaly (M_0)
   It denotes the position of a satellite in its orbit at a given reference time.
4. Argument of Perigee
   It gives the rotation of the orbit's perigee point relative to the orbit's nodes in the earth's equatorial plane.
5. Inclination
6. Right ascension of ascending node

   They relate the orbital plane's position to the Earth.

As the equatorial bulge causes a slow variation in argument of perigee and right ascension of ascending node, and because other perturbing forces may alter the orbital elements slightly, the values are specified for the reference time or epoch.

2.4 ORBITAL PERBUTATIONS

- Theoretically, an orbit described by Kepler is ideal as Earth is considered to be a perfect sphere and the force acting around the Earth is the centrifugal force. This force is supposed to balance the gravitational pull of the earth.

- In reality, other forces also play an important role and affect the motion of the satellite. These forces are the gravitational forces of Sun and Moon along with the atmospheric drag.

- Effect of Sun and Moon is more pronounced on geostationary earth satellites where as the atmospheric drag effect is more pronounced for low earth orbit satellites.

2.4.1) Effects of non-Spherical Earth

- As the shape of Earth is not a perfect sphere, it causes some variations in the path followed by the satellites around the primary. As the Earth is bulging from the equatorial belt, and keeping in mind that an orbit is not a physical entity, and it is the forces resulting from an oblate Earth which act on the satellite produce a change in the orbital parameters.

- This causes the satellite to drift as a result of regression of the nodes and the latitude of the point of perigee (point closest to the Earth). This leads to rotation of the line of apsides. As the orbit itself is moving with respect to the Earth, the resultant changes are seen in the values of argument of perigee and right ascension of ascending node.

- Due to the non-spherical shape of Earth, one more effect called as the “Satellite Graveyard” is seen. The non-spherical shape leads to the small value of eccentricity (10^{-5}) at the equatorial plane. This causes a gravity gradient on GEO satellite and makes them drift to one of the two stable points which coincide with minor axis of the equatorial ellipse.

- Working satellites are made to drift back to their position but out-of-service satellites are eventually drifted to these points, and making that point a Satellite Graveyard.

  (Note: A graveyard orbit, also called a supersynchronous orbit, junk orbit or disposal orbit, is an orbit significantly above GEO where satellites are intentionally placed at the end of theiroperational life. It is a measure performed in order to lower the probability of collisions with operational spacecraft and of the generation of additional space debris. The points where the graveyard is made are separated by 1800 on the equator and are set approximately on 750 E longitude and 1050 W longitude.)

2.4.2) Atmospheric Drag

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

- This causes the satellite to not reach the apogee height successive revolutions. This leads to a change in value of semi-major axis and eccentricity. Satellites in service are maneuvered by the earth station back to their original orbital position.

2.5 INCLINED ORBITS

- While considering an orbit of non- geostationary orbit satellite, different parameters are referred at different reference frames. The orbital elements are calculated with respect to the plane of the orbit, which is fixed in space and the earth stations position is given by geographic coordinates that rotate with the earth.

- Other factors of consideration are azimuth and elevation angles. Thus for calculation purpose, transformations between coordinate system is required.

- The following quantities and concepts are required
    - Orbital elements
    - Various measures of time
    - Perifocal coordinate system- based on orbital plane
    - Geocentric-equatorial plane coordinate system – Earth's equatorial plane
    - Topocentric – horizon coordinate system- observer's horizon plane.

2.5.1) Calendars

- Calendars are created with respect to the position of sun. As Earth's motion around the sun is not uniform, its called "mean sun". Calendar days are "mean solar days". Tropical year has 365.2422 days. It is generally taken as 365 (commonly known as civil year).

- The extra 0.2422 is significant and for example after 100 years, there will be drift of 24 days between calendar year and tropical year. Hence the concept of Leap year came into existence.

- By the year 1582, a discrepancy was once again observed. The discrepancy existed between the civil and the tropical years. To synchronize them, days between 5th October – 14th October 1582 were abolished.

- Additional constraints were added that on years ending with two zeros to be considered as leap years. The resulting calendar is called as the Gregorian Calender; named after Pope Gregory XIII.

Example: Calculate the average length of the civil year in Gregorian calendar

Solution:
Nominal number of days in 400 years = 400 x 365
Number of leap years in 400 years = 400 / 4
This must be reduced by 3 days;
Hence, 14600 + 100 – 3 = 146097

Therefore, yearly average = 14697 / 400
= **356.2425**

2.5.2) Universal Time

Universal time coordinate (UTC) is the time used for all civic time keeping purpose. Fundamental unit of UTC is ***mean solar day***. UTC is equivalent to Greenwich mean time (GMT) and the Zullu time (Z).
1 Mean Solar Day s divided into 24 hours;
1 Hour into 60 minutes;
1 Minute into 60 seconds.
Thus there are 86,400 seconds in a day.

Example: calculate time in days, hours, minutes and seconds for epoch day 324.95616765

Solution: Mean solar day = 324^{th} + 0.95616765 mean solar day
Therefore;
24 x 0.95616765 = 22.948022
60 x 0.948022 = 56.881344
60 x 0.881344 = 52.88064

Thus; Epoch is at 22 hours 56 minutes a 52.88 seconds of the 324^{th} day of the year.

For computations, UT requires two forms:

1. Fraction of a day
2. In Degrees

2.5.3) Julian Date

- Generally time interval between two events is computed using calendar time or UT. But this notation is not suited for computations where timing of many events has to be computed.

- Thus creating a reference time in which all the events can be referred in decimal days is required. Such a time reference is provided by the Julian zero time reference, which is 12 noon (12:00 UT) on January 1, 4713 (it is a hypothetical starting point).

Example: Find the Julian Date for 13 hours UT on 18 Dec 2000

Solution:
y = 2000
mon = 12
dy = 18
hours = 13
minutes = 0
seconds = 0

d = dy + mon + hours + minutes + seconds
= 18 + 13 + 0 + 0
= 31

A = floor (y/100)
= 2000/100
= 20

B = 2 –A + floor (A/4)
= 2 – 20 + 5
= -13

C = floor (365.25 x y)
= 730500

D = floor (30.6001 x (mon + 1))
= 397.8013

JD = B + C + D + d + 1720994.5

Thus, Julian Day = 2451897.0417

Julian Time Computation

- To measure time intervals, Julian Century concept is created. A Julian century (JC) has 36525 mean solar days. The time interval is calculated with respect reference time of January 0.5, 1900 which corresponds to 2,415,020 Julian Days.

Denoting reference time as JDref, Julian century as JC and time in question as JD, then interval in JC from the reference time to the time in question is calculated as: T = (JD – JDref)/ JC

Example: Find the JD from reference time Jan 0.5 1900 to UT 13 hours of 18th December 2000

Solution:
y = 2000
mon = 12
dy = 18
hours = 13
minutes = 0
seconds = 0

d = dy + mon + hours + minutes + seconds
= 18 + 13 + 0 + 0
= 31

A = floor (y/100)
= 2000/100
= 20

B = 2 –A + floor (A/4)
= 2 – 20 + 5
= -13

C = floor (365.25 x y)
= 730500

D = floor (30.6001 x (mon + 1))
= 397.8013

JD = B + C + D + d + 1720994.5
Thus, Julian Day = 2451897.0417
JDref = 2145020
JC = 36525
Thus **T = (JD – JDref)/ JC**
= (2451897.0417 – 2415020) / 36525
T = 1.00963838 (time has no dimensions)

The Time from the referenced time to 18th Dec, 13 hours of UT is 1.00963838

<u>2.5.4) Sidereal Time</u>

The time measured with respect to stationary stars is called sidereal time. It is observed that one complete rotation of the Earth is relative to the fixed stars is not a complete rotation relative to the sun. This happens as Earth also moves in its orbit around the sun.

1 mean solar day = 1.0027379039 mean sidereal days
= 24 hours 3 minutes 56.5536 seconds sidereal time

2.6 SUMMARY

This unit discusses the basics of satellite and elaborating the parameters which are needed to calculate the distance of an orbit to which a satellite is to be launched and the other factors which are necessary to define an orbit. Further this unit discusses the applications of satellites and elaborates on the global communication which has now become possible due to the presence of satellites. This unit also elaborates on the frequency bands used by each communication satellite.

Going further, this unit also elaborates on the types of orbits a satellite can follow to provide communication. The last segment of this unit discuses three examples of satellite revolving around the Earth.

2.7 EXERCISE

1) List the various applications of satellite.
2) Why is there a need for satellite communication?
3) List and discuss the various orbits defined for satellite communication.
4) Write a note on various satellite services available.
5) What are the primary factors needed for defining an orbit of a satellite?
6) Define elevation and inclination angles of a satellite orbit.
7) Define the following:
    a) Apogee and Perigee
    b) Line of Apsides
    c) Ascending and Descending Nodes
    d) Line of Nodes
    e) Prograde and Retrograde Orbits
    f) Arguement of Perigee
    g) Right ascension of ascending node
    h) Mean and True anomaly

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3

GEOSTATIONARY ORBIT

Contents

3.1 INTRODUCTION

- A satellite that appears stationary with respect to Earth is hence named Geostationary. To appear stationary, these satellites have to fulfil three conditions:
  - It must travel eastward at the same rotational speed as the Earth.
  - The inclination of the orbit must be zero.
  - The orbit must be circular.

- If the satellite has to appear stationary, then it has to move at the same speed as the Earth (which is constant).

- Constant speed means equal areas must be swept out at equal intervals of time. This could only be attained using a circular orbit.

- Inclination must be zero as having any inclination would lead the satellite to move from north-south directions. Orbits with zero inclination lie in the Earth's equatorial plane.

- These satellites are 35,786 kms from the Earth. For the convenience of calculations, the value is rounded to 36,000.
- A worldwide network of operational geostationary meteorological satellites is used to provide visible and infrared images of Earth's surface and atmosphere. These satellite systems include:
    - the United States GOES
    - Meteosat, launched by the European Space Agency and operated by the European Weather Satellite Organization, EUMETSAT
    - the Japanese MTSAT
    - India's INSAT series

3.2 ANTENNA LOOK ANGLES

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

- For geostationary orbit, these angels values does not change as the satellites are stationary with respect to earth. Thus large earth stations are used for commercial communications, these antennas beamwidth is very narrow and the tracking mechanism is required to compensate for the movement of the satellite about the nominal geostationary position.

- For home antennas, antenna beamwidth is quite broad and hence no tracking is essential. This leads to a fixed position for these antennas.

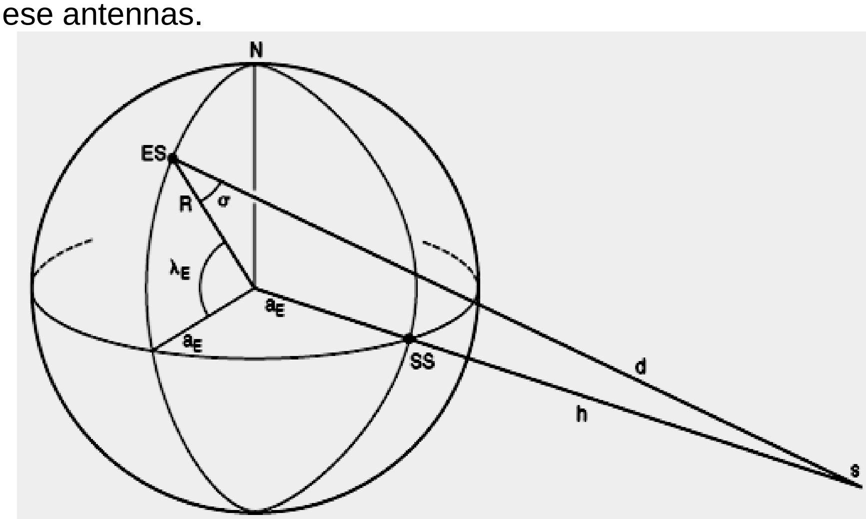

Figure 3.1: The geometry used in determining the look angles for Geostationary Satellites.

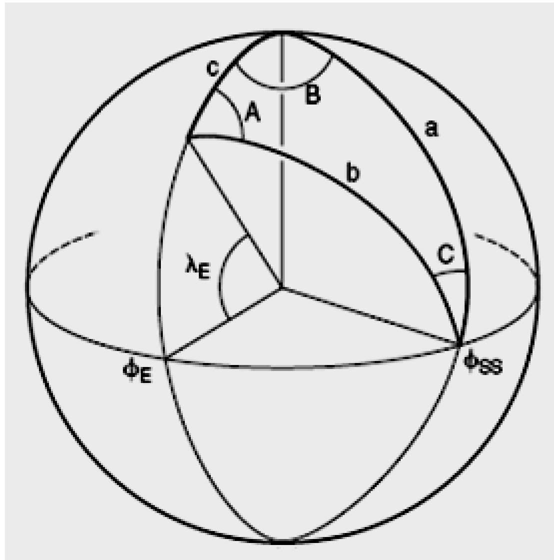

Figure 3.2: The spherical geometry related to figure 3.1

- With respect to the figure 3.1 and 3.2, the following information is needed to determine the look angles of geostationary orbit.
    1. Earth Station Latitude: λ_E
    2. Earth Station Longitude: Φ_E
    3. Sub-Satellite Point's Longitude: Φ_{SS}
    4. ES: Position of Earth Station
    5. SS: Sub-Satellite Point
    6. S: Satellite
    7. d: Range from ES to S
    8. σ: angle to be determined

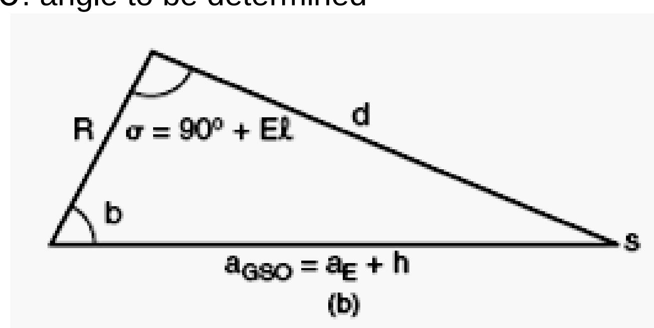

Figure 3.3: A plane triangle obtained from figure 3.1

- Considering figure 3.3, it's a spherical triangle. All sides are the arcs of a great circle. Three sides of this triangle are defined by the angles subtended by the centre of the earth.

    - Side a: angle between North Pole and radius of the sub-satellite point.

    - Side b: angle between radius of Earth and radius of the sub-satellite point.

- Side c: angle between radius of Earth and the North Pole.

a = 90^0 and such a spherical triangle is called quadrantal triangle.
c = $90^0 – \lambda$

- Angle B is the angle between the plane containing c and the plane containing a.

Thus, B = Φ_E-Φ_{SS}
Angle A is the angle between the plane containing b and the plane containing c.
Angle C is the angle between the plane containing a and the plane containing b.
Thus, a = 90^0
c = 90^0 - λ_E
B = Φ_E-Φ_{SS}
Thus, b = arcos (cos B cos λ_E)
A = arcsin (sin |B| / sin b)

Example: A geostationary satellite is located 90^0 W. Calculate the azimuth angle for an Earth station antenna located at latitude 35^0 W and longitude 100^0 W.

Solution: The given quantities are:

$\Phi_{E =}$- 100 degrees;
Φ_{SS}= - 90 degrees;
$\boldsymbol{\lambda}_{\mathbf{E}}$ = 35 degrees

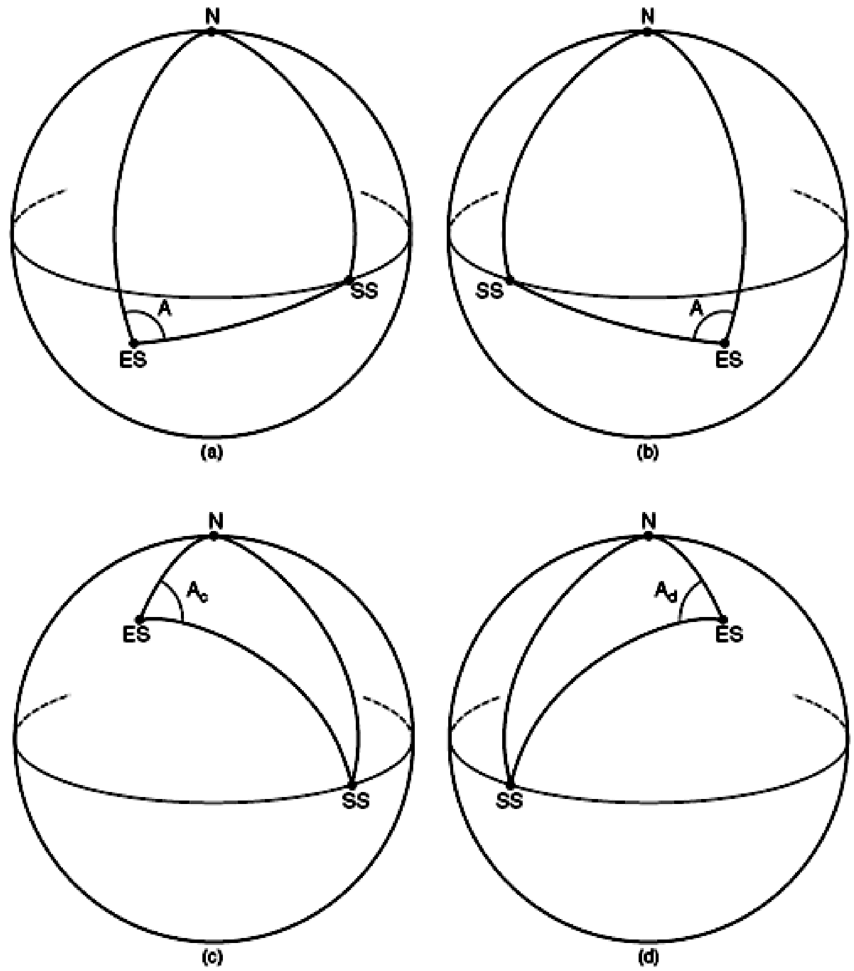

Figure 3.4: Azimuth angle related to angle A with respect to table 1.

Fig. 3.3	λ_E	B	A_z, degrees
a	<0	<0	A
b	<0	>0	$360° - A$
c	>0	<0	$180° - A$
d	>0	>0	$180° + A$

Table 1: Azimuth Angle Az from figure 3.3

$$B := \phi_E - \phi_{SS} \qquad B = -10 \cdot deg$$

$$b := acos(cos(B) \cdot cos(\lambda_E)) \qquad b = 36.2 \cdot deg$$

$$A := asin\left(\frac{sin(|B|)}{sin(b)}\right) \qquad A = 17.1 \cdot deg$$

By inspection, $\lambda_E > 0$ and B < 0. Therefore Figure 3.4 (c) applies, and;

$$A_z := 180 \cdot deg - A \qquad A_z = 162.9 \cdot deg$$

Applying the cosine rule for plane triangle to the triangle of figure 3.3 allows the range d to be found to a close approximation:

$$d = \sqrt{R^2 + a_{GSO}{}^2 - 2Ra_{GSO}\cos b}$$

Applying the sine rule for plane triangles to the triangle of figure 3.3 allows the angle of elevation to be found:

$$El = \arccos\left(\frac{a_{GSO}}{d}\sin b\right)$$

3.3 POLAR MOUNT ANTENNAS

- These antennas are pointing accurately only for one satellite. They have a single actuator which moves the antenna in a circular arc. Generally some pointing error is seen in these antennas. The dish of this antenna is mounted on an axis termed as polar axis such that the antenna bore sight is normal to this axis. As in figure 3.5.

- The angle between polar mount and the local horizontal plane is set equal to the earth station latitude λ_E, making bore sight lie parallel to the equatorial plane. Now the axis is tilted at an angle S, which is relative to the polar mount until the bore sight is pointing at a satellite position.

$$\delta = 90^0 - El_0 - \lambda_E$$

Where El_0 is the elevation required for the satellite position.

Thus $\cos El_0 = (a_{gso} / d) \sin \lambda_E$

Hence $\delta = 900 - \arccos[(a_{gso} / d) \sin \lambda_E] - \lambda_E$

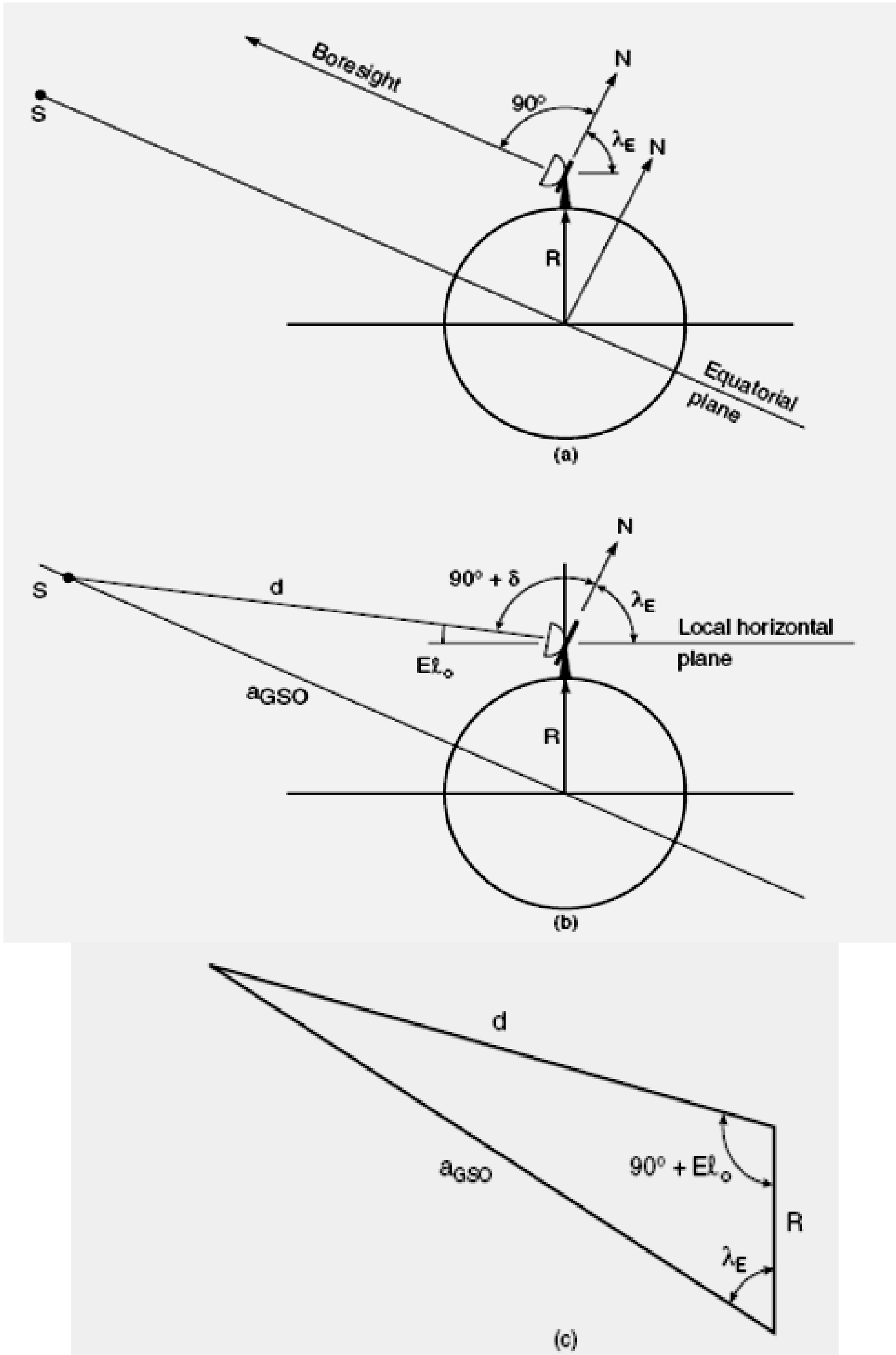

Figure 3.6 (a), (b) and (c): Polar mount Antenna

<u>Example</u>: Determine the angle of tilt required for polar mount used with an earth station at latitude 49 degrees north. Assume a spherical Earth of mean radius 6371 km, and ignore the earth station latitude.

***Solution*:**

$$\lambda_E := 49 \cdot deg \qquad a_{GSO} := 42164 \cdot km \qquad R := 6371 \cdot km$$

$$d := \sqrt{R^2 + a_{GSO}^2 - 2 \cdot R \cdot a_{GSO} \cdot \cos(\lambda_E)}$$

$$El_0 := acos\left(\frac{a_{GSO}}{d} \cdot \sin(\lambda_E)\right)$$

$$\delta := 90 \cdot deg - El_0 - \lambda_E \qquad \delta = 7 \cdot deg$$

3.4 LIMITS OF VISIBILITY

The east and west limits of geostationary are visible from any given Earth station. These limits are set by the geographic coordinates of the Earth station and antenna elevation. The lowest elevation is zero (in theory) but in practice, to avoid reception of excess noise from Earth. Some finite minimum value of elevation is issued. The earth station can see a satellite over a geostationary arc bounded by **+- (81.30)** about the earth station's longitude.

3.5 NEAR GEOSTATIONARY ORBITS

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

- Thus the earth station keeps manoeuvring the satellite to maintain its position. Within a set of nominal geostationary coordinates. Thus the exact GEO is not attainable in practice and the orbital parameters vary with time. Hence these satellites are called "Geosynchronous" satellites or "Near-Geostationary satellites".

3.6 EARTH ECLIPSE OF A SATELLITE

- It occurs when Earth's equatorial plane coincides with the plane f he Earth's orbit around the sun. Near the time of spring and autumnal equinoxes, when the sun is crossing the equator, the satellite passes into sun's shadow. This happens for some duration of time every day.

- These eclipses begin 23 days before the equinox and end 23 days after the equinox. They last for almost 10 minutes at the beginning and end of equinox and increase for a maximum period of 72 minutes at a full eclipse. The solar cells of the satellite become non-functional during the eclipse period and the satellite is made to operate with the help of power supplied from the batteries.

- A satellite will have the eclipse duration symmetric around the time t=Satellite Longitude/15 + 12 hours. A satellite at Greenwich longitude 0 will have the eclipse duration symmetric around 0/15 UTC +12hours = 00:00 UTC. The eclipse will happen at night but for satellites in the east it will happen late evening local time. For satellites in the west eclipse will happen in the early morning hour's local time. An earth caused eclipse will normally not happen during peak viewing hours if the satellite is located near the longitude of the coverage area. Modern satellites are well equipped with batteries for operation during eclipse.

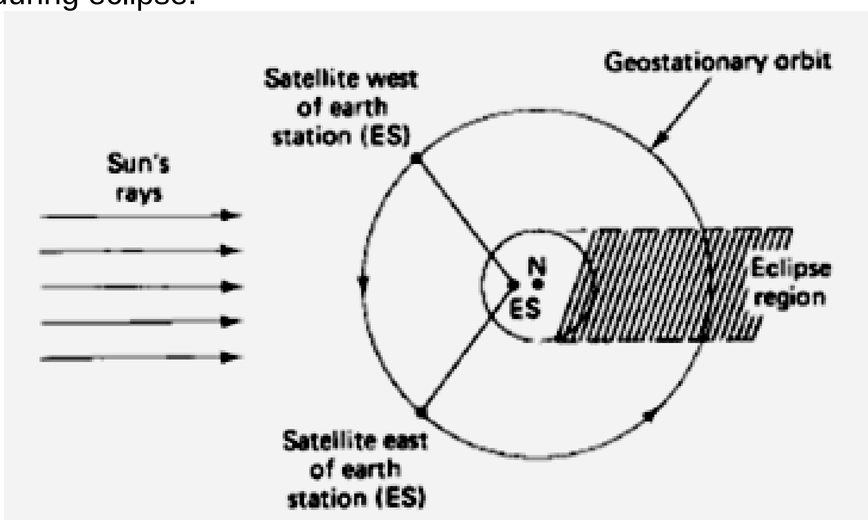

Figure 3.7: A satellite east of the earth station enters eclipse during daylight busy) hours at the earth station. A Satellite west of earth station enters eclipse during night and early morning hours (non busy time).

3.7 SUN TRANSIT OUTAGE

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

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

- The effects of a sun outage can include partial degradation, that is, an increase in the error rate, or total destruction of the signal.

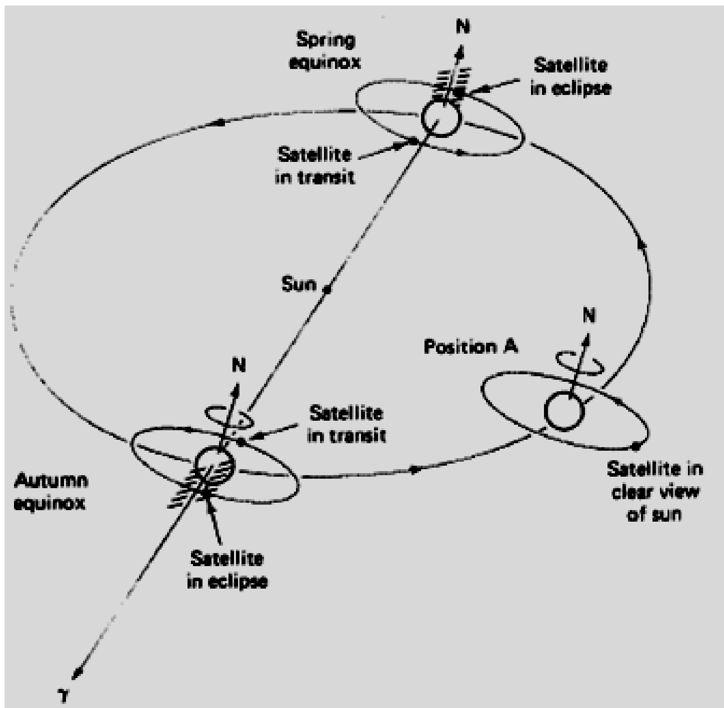

Figure 3.8: Earth Eclipse of a Satellite and Sun transit Outage

3.8 LAUNCHING ORBITS

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

- When the orbital altitude is greater than 1,200 km it becomes expensive to directly inject the satellite in its orbit. For this purpose, a satellite must be placed in to a transfer orbit between the initial lower orbit and destination orbit. The transfer orbit is commonly known as *Hohmann-Transfer Orbit.

- (*About Hohmann Transfer Orbit: This manoeuvre is named for the German civil engineer who first proposed it, Walter Hohmann, who was born in 1880. He didn't work in rocketry professionally (and wasn't associated with military rocketry), but was a key member of Germany's pioneering Society for Space Travel that included people such as Willy Ley, Hermann, and Werner von Braun. He published his concept of how to transfer between orbits in his 1925 book, The Attainability of Celestial Bodies.)

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

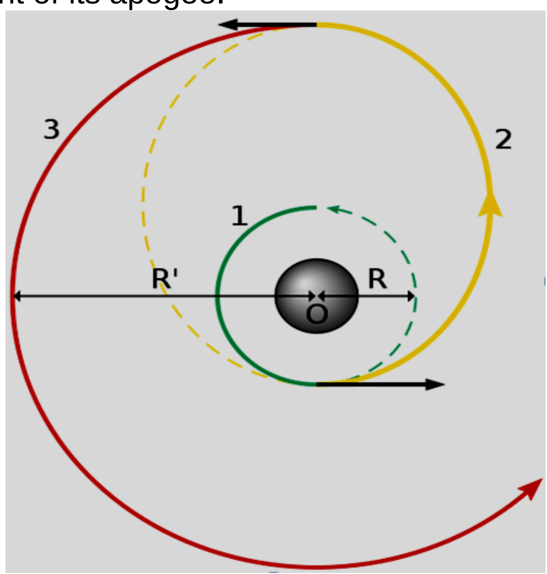

Figure 3.9: Orbit Transfer positions

- The rocket injects the satellite with the required thrust** into the transfer orbit. With the STS, the satellite carries a perigee kick motor*** which imparts the required thrust to inject the satellite in its transfer orbit. Similarly, an apogee kick motor (AKM) is used to inject the satellite in its destination orbit.

- Generally it takes 1-2 months for the satellite to become fully functional. The Earth Station performs the Telemetry Tracking and Command**** function to control the satellite transits and functionalities.

  (**Thrust: It is a reaction force described quantitatively by Newton's second and third laws. When a system expels or accelerates mass in one direction the accelerated mass will cause a force of equal magnitude but opposite direction on that system.)

(***Kick Motor refers to a rocket motor that is regularly employed on artificial satellites destined for a geostationary orbit. As the vast majority of geostationary satellite launches are carried out from spaceports at a significant distance away from Earth's equator, the carrier rocket would only be able to launch the satellite into an elliptical orbit of maximum apogee 35,784-kilometres and with a non-zero inclination approximately equal to the latitude of the launch site.)

(****TT&C: it’s a sub-system where the functions performed by the satellite control network to maintain health and status, measure specific mission parameters and processing over time a sequence of these measurement to refine parameter knowledge, and transmit mission commands to the satellite. Detailed study of TT&C in the upcoming units.)

- It is better to launch rockets closer to the equator because the Earth rotates at a greater speed here than that at either pole. This extra speed at the equator means a rocket needs less thrust (and therefore less fuel) to launch into orbit. In addition, launching at the equator provides an additional 1,036 mph (1,667 km/h) of speed once the vehicle reaches orbit. This speed bonus means the vehicle needs less fuel, and that freed space can be used to carry more pay load.

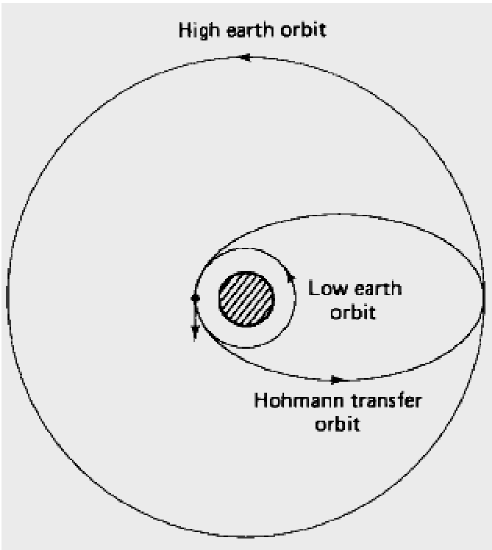

Figure 3.10: Hohmann Transfer Orbit

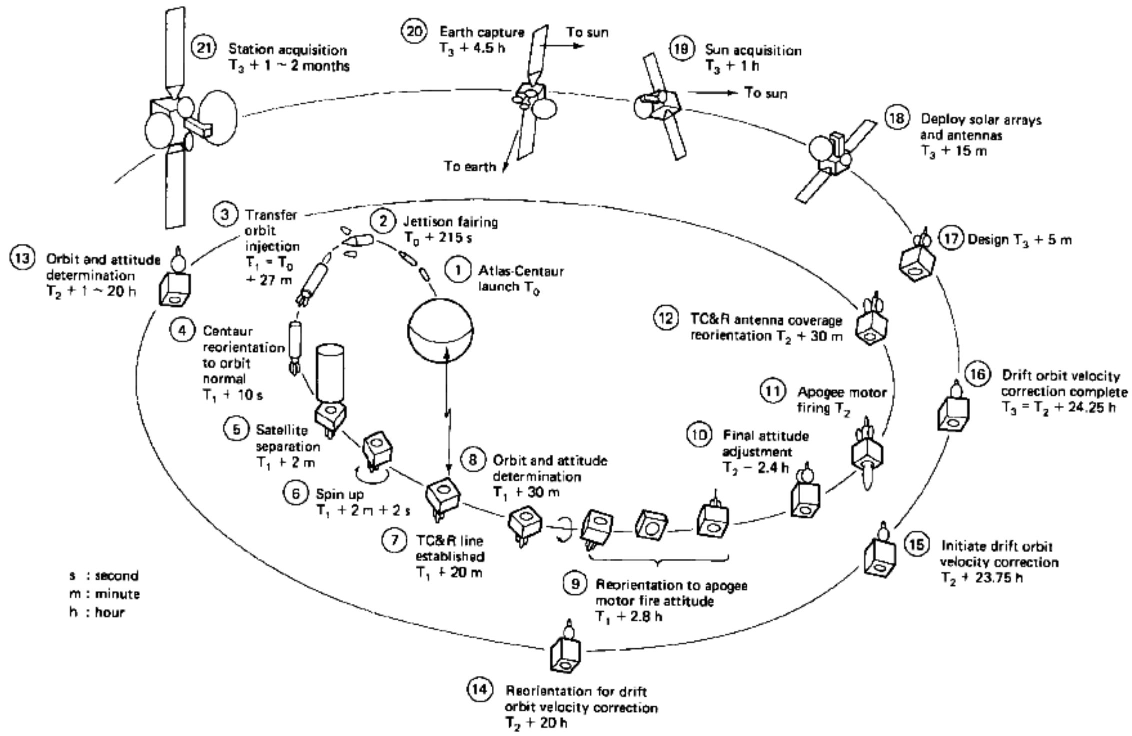

Figure 3.10: Launching stages of a GEO (example INTELSAT)

3.9 SUMMARY

- A geostationary orbit, or Geostationary Earth Orbit (GEO), is a circular orbit 35,786 km above the Earth's equator and following the direction of the Earth's rotation. An object in such an orbit has an orbital period equal to the Earth's rotational period (one sidereal day), and thus appears motionless, at a fixed position in the sky, to ground observers. Communications satellites and weather satellites are often given geostationary orbits, so that the satellite antennas that communicate with them do not have to move to track them, but can be pointed permanently at the position in the sky where they stay. A geostationary orbit is a particular type of geosynchronous orbit.

- A geostationary orbit can only be achieved at an altitude very close to 35,786 km (22,236 mi), and directly above the Equator. This equates to an orbital velocity of 3.07 km/s or a period of 1,436 minutes. This ensures that satellite is locked to the Earth's rotational period and has a stationary footprint on the ground. All geostationary satellites have to be located on this ring.

- Satellites in geostationary orbit must all occupy a single ring above the Equator. The requirement to space these satellites apart to avoid harmful radio-frequency interference during operations means that there are a limited number of orbital "slots" available, thus only a limited number of satellites can be operated in geostationary orbit. This has led to conflict between different countries wishing access to the same orbital slots (countries near the same longitude but differing latitudes) and radio frequencies.

- Further this chapter speaks about Antenna Look Angles which are the elevation and azimuth at which a particular satellite is predicted to be found at a specified time.

- And polar mount antennas which are designed to allow all visible geostationary satellites to be accessed by swinging the antenna around one axis (the main axis).

- To conclude with, how a GEO is launched using a transfer orbit is explained. Transfer orbit: Hohmann transfer orbit to bring a spacecraft from a lower circular orbit into a higher one. It is one half of an elliptic orbit that touches both the lower circular orbit that one wishes to leave and the higher circular orbit that one wishes to reach. The transfer is initiated by firing the spacecraft's engine in order to accelerate it so that it will follow the elliptical orbit; this adds energy to the spacecraft's orbit. When the spacecraft has reached its destination orbit, its orbital speed (and hence its orbital energy) must be increased again in order to change the elliptic orbit to the larger circular one.

3.10 EXERCISE

1) What is a geostationary orbit?
2) Which conditions should be fulfilled to attain a geostationary orbit?
3) Why is it more prudent to launch a satellite from a point closer to an equator?
4) Why the term ‘geosynchronous’ is used instead of ‘geostationary’?
5) How are GEO satellites made to inject to different orbits?
6) Discuss the phenomenon of Sun Transit Outage.
7) What are limits of visibility?
8) How does a satellite go through an eclipse? Explain with appropriate diagram.
9) How is a geostationary satellite launched to a GEO?
10) Does the motion of Earth beneficial for GEO satellites? Justify.
11) List the advantages and disadvantages of GEO satellites.
12) What are Look angles? Derive an equation for the same.
13) Write a note on Polar Mount Antennas.
14) It is preferable to operate with a satellite positioned at West rather than East of Earth station longitude? Justify

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4

RADIO WAVE PROPAGATION

Contents

4.1 INTRODUCTION

Radio propagation is the behavior of radio waves when they are transmitted, or propagated from one point on the Earth to another, or into various parts of the atmosphere. As a form of electromagnetic radiation, like light waves, radio waves are affected by the phenomena of reflection, refraction, diffraction, absorption, polarization and scattering.

Radio propagation is affected by the daily changes of water vapor in the troposphere and ionization in the upper atmosphere, due to the Sun. Understanding the effects of varying conditions on radio propagation has many practical applications, from choosing frequencies for international shortwave broadcasters, to designing reliable mobile telephone systems, to radio navigation, to operation of radar systems.

4.2 ATMOSPHERIC LOSSES

- Multiple losses occur due to the Earth's atmosphere. Losses maybe because of the adverse weather conditions or because of the energy absorption done by the various gases present in the atmosphere. Weather related losses are called "atmospheric attenuation". Absorption losses are called "atmospheric absorption".

- At various frequencies, different components of atmosphere cause impairments to the radio wave signals.

- Example: water vapour at 22.3 GHz and oxygen (O_2) at60 GHz.

- Considering the elevation angle of signals as 100 and absorption loss at $[AA]_{90}$ decibels. Formula for absorption loss is:

  $$[AA] = [AA]_{90} \operatorname{cosec} \theta$$

  Where θ is the elevation angle (as described in Unit III)

- A fading phenomenon, which causes the radio waves to focus and defocus because of the differences in the atmospheric refraction index is seen. This effect is called "atmospheric scintillation".

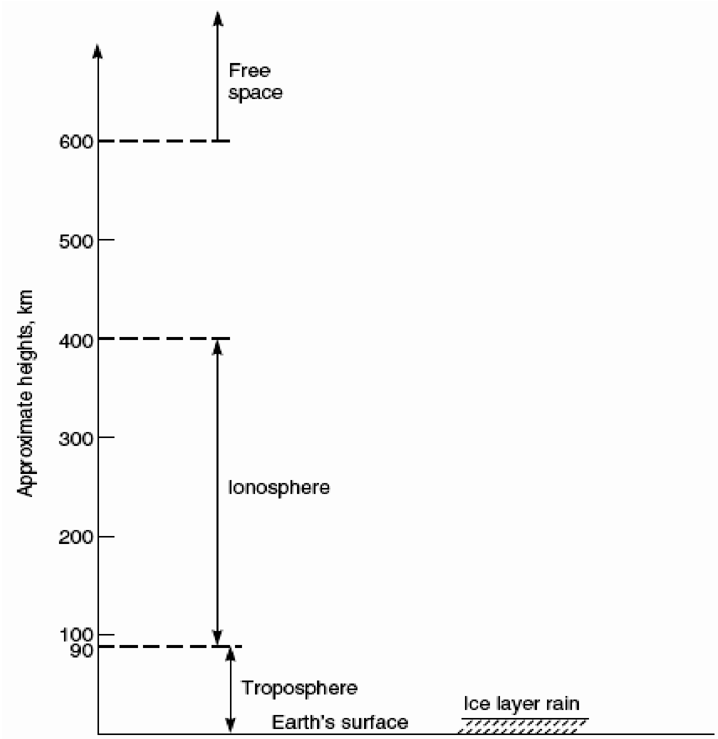

Figure 4.1: Layers of Earth's atmosphere

4.3 IONOSPHERE EFFECT

- Ionosphere is one of the layers in the Earth's atmosphere. It is situated between 90 kms to 400 kms above the surface of the Earth. All the communication signals between satellites and earth stations have to pass through this layer.

- This layer contains free electrons which are charged due to solar radiation. These ions are not uniformly distributed across the ionosphere, but move together across the ionosphere in *clusters*. Such clusters are called clouds of electrons or "travelling ionosphere disturbances". When signals pass through such electron clouds, fluctuations are caused.

- Electron clouds are created when accelerated charged particles disturb stray electrons already floating in the atmosphere, and bounce or slingshot the electrons into each other and the passing by signals. These stray electrons can be photo-electrons from synchrotron radiation or electrons from ionized gas molecules and have adverse effect on the signals passing through them especially if the density of these clouds is high.

- The other effects seen on the signal also includes scintillation, absorption, propagation delay, dispersion, and frequency change and polarization rotation. These effects decrease as the frequency increases. Out of the above effect only scintillation and polarization rotation are of major concern for satellite communication.

- ***Absorption***: Electromagnetic waves are absorbed in the atmosphere according to wavelength. Two compounds are responsible for the majority of signal absorption: oxygen (O2) and water. It is seen for frequencies at 22 GHz due to water, and at 63 GHz due to oxygen. The concrete amount of water vapour and oxygen in the atmosphere normally declines with an increase in altitude because of the decrease in pressure.

- ***Propagation Delay***: Propagation delay is the time required for a signal to travel from the sender (in our case from an earth station or a spacecraft) to the receiver. It is measured in microsecond. As distances are very much greater than those involved with terrestrial systems, propagation delay can be an issue, especially for satellites using geostationary orbits. Here the round trip from the ground to the satellite and back can be of the order of a quarter of a second.

- ***Dispersion***: Here the signals are distributed over a wide area.

- ***Polarization Rotation***: It is the phenomenon in which waves of light or other radiation are restricted in direction of vibration.

- ***Scintillation***: it is the variation in the amplitude, phase, polarization, angle of arrival of radio waves. They are caused by the irregularities in the ionosphere which change with time. Fading of signal is the major effect o ionosphere scintillation. The effect of fading can sometimes be very severe and may last upto several minutes.

Propagation impairment	Physical cause	Prime importance
Attenuation and sky noise increases	Atmospheric gases, cloud, rain	Frequencies above about 10 GHz
Signal depolarization	Rain, ice crystals	Dual-polarization systems at C and Ku bands (depends on system configuration)
Refraction, atmospheric multipath	Atmospheric gases	Communication and tracking at low elevation angles
Signal scintillations	Tropospheric and ionospheric refractivity fluctuations	Tropospheric at frequencies above 10 GHz and low elevation angles; ionospheric at frequencies below 10 GHz
Reflection multipath, blockage	Earth's surface, objects on surface	Mobile satellite services
Propagation delays, variations	Troposphere, ionosphere	Precise timing and location systems; time-division multiple access (TDMA) systems
Intersystem interference	Ducting, scatter, diffraction	Mainly C band at present; rain scatter may be significant at higher fre quencies

Table 4.1: Propagation concerns of Satellite Communication Systems

4.4 RAIN ATTENUATION

The rate at which the rain water would get accumulated in a rain gauge in the area of interest is called rain rate. Rain attenuation is a function of rain rate. It is calculated in percentage time. A percentage time is generally of a year.

Example: Rain rate of 0.001 percent means the rain rate would exceed by 0.001 percent of a year and it is be denoted as $R_{0.001}$.
Percentage time is denoted as p and rain rate as R_p.
Specific attenuation α is given by:

$$\alpha = a\, R^{b}_{p} \text{dB/km}$$

Where a and b depend upon frequency and polarization.
Total attenuation, denoted by A is given by:

$$A = \alpha\, L \quad \text{dB}$$

Where L is the effective path length of the signal through rain.

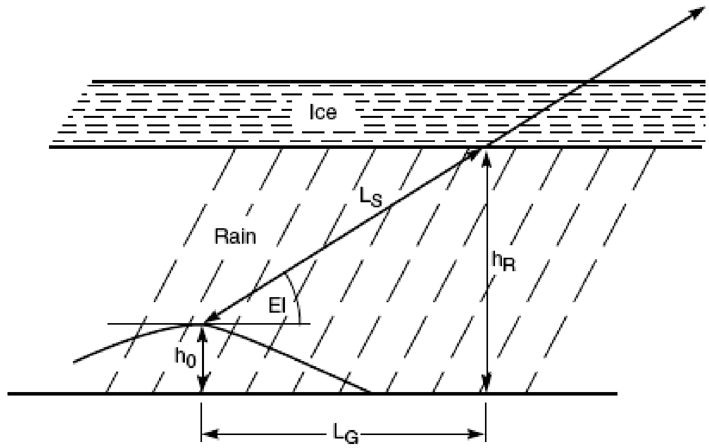

Figure 4.2: Path length through rain

Here, Ls -> Slant Height and it depends upon the antenna angle of elevation θ and rain height.
h_R -> Rain Height at which freezing occurs.
L_G -> Horizontal projection of Ls
Thus effective path length L is given by:

$$L = Ls\ r_p$$

Where r_p is the reduction factor of percentage time p and L_G

That is; $L_G = Ls \cos El$

Therefore rain attenuation is $\mathbf{A_p = a\ R^b_p\ Ls\ r_p}$ dB

4.5 OTHER IMPAIRMENTS

Due to the low water content in them, rain, ice and hail have a little effect on attenuation. Attenuation can be caused by clouds but generally its effect is comparatively low.

4.6 SUMMARY

This unit discusses how the atmosphere surrounding the earth affects the signals which pass through it. The layer of Ionosphere is majorly responsible for degrading the satellite signal. The ionosphere losses that mainly occur due to the electron clouds are pre calculated by the earth stations and accordingly the frequency of signal transmitted is adjusted. Further this Unit explains the effect of rain on a signal and calculates the rain attenuation.

4.6 EXERCISE

1. Explain the phenomenon of scintillation.
2. What are atmospheric losses?
3. Explain the effects of clouds of electrons.
4. List various propagation concerns for satellite communication systems.
5. Explain ionosphere scintillation.
6. What is meant by rain attenuation? Derive an equation for the same.
7. Explain what is meant by effective path length in connection with rain attenuation.
8. Explain what is meant by rain rate. How this is related to specific attenuation.
9. Describe the major effect that ionosphere has on satellite signals losses?

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5

POLARIZATION

Contents:

5.1 INTRODUCTION

Definitions*:*

- ✓ ***Polarization***: it is a property that describes the orientation of a signal with respect to time-varying direction and amplitude of an electromagnetic wave with respect to electric field vector.

- ✓ ***Amplitude***: it is the maximum point of a vibration or oscillation, measured from the position of equilibrium.

- ✓ ***Electromagnetic wave***: The wave of the electric field and the wave of the magnetic field are propagated perpendicularly to the direction of propagation and to each other. At extremely low frequencies, the electric field and the magnetic field are specified separately. At higher frequencies, electric and magnetic fields are not separable, and are named electromagnetic waves.

- ✓ ***Vector:***Aquantity having direction as well as magnitude, especially while determining the position of one point in space relative to another.

- ✓ ***Right-Hand Thumb Rule***: For a current-carrying wire, the rule that if the fingers of the right hand are placed around the wire so that the thumb points in the direction of current flow, the fingers will be pointing in the direction of the magnetic field produced by the wire. Also known as hand rule. For a moving wire in a magnetic field, such as the wire on the armature of a generator, if the thumb, first, and second fingers of the right hand are extended at right angles to one another, with the first finger representing the direction of magnetic lines of force and the second finger representing the direction of current flow induced by the wire's motion, the thumb will be pointing in the direction of motion of the wire.

- ✓ ***Dipole***:A pair of equal and oppositely charged or magnetized poles separated by a distance.

- ✓ ***Co-Polar Component:***
- ✓ ***Torque:***it's a tendency of force to rotate an object about its axis or fulcrum or pivot. It's the cross product between distance vector and force vector.

5.2 PLANE TRANSVERSE ELECTROMAGNETIC WAVE (TEM)

- The signal sent to a satellite is generally in the form of a Transverse Electromagnetic Wave. In TEM wave electric field vector is perpendicular to the direction of propagation. In the figure, magnetic field H and electric field E are transverse to the direction of propagation that is vector k.

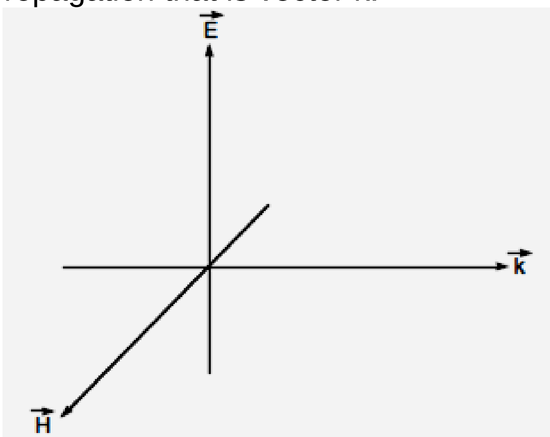


Figure 5.1: Vector diagram for TEM wave

- E, H and k are vector quantities. The path defined when rotation from E to H in the direction of rotation of right hand threaded screw, they form a right hand set. Considering TEM wave as a plane, then vectors E and H lie in the plane which is at right angles to vector k. Hence k is normal to the plane.

- The direction of the line traced out by the tip of the electric field vector determines the polarization of the wave.

- Electric and magnetic fields are varying functions of time. Magnetic field varies exactly in phase with the electric field and its amplitude is proportional to electric field's amplitude. Thus only electric field is considered.

- Tim of vector E traces out a straight line also referred as linear polarization. When E is perpendicular to the Earth's surface, it's called vertical polarization and when it's perpendicular to Earth's surface, it's called horizontal polarization.

- Let horizontal moment be x and vertical be y axes of right hand set.
  Thus vertical polarized electric field can be described as

$$Ey = \hat{a}y\ Ey \sin \omega t$$

Where: ây is unit vector in vertical direction, Ey is the peak value (magnitude) of electric field.

Similarly Horizontal polarization id

$$\mathbf{Ex = \hat{a}x\ Ex \sin \omega t}$$

- When both these fields are present together, the resultant vector is at

$$\boldsymbol{\alpha = \arctan Ey / Ex}$$

Ey and Ex are orthogonal (at right angles) but lead each other by 90^0in phase.

$$\mathbf{Ey = \hat{a}y\ E \sin \omega t}$$
$$\mathbf{Ex = \hat{a}x\ E \cos \omega t}$$

Hence, $\boldsymbol{\alpha = \omega t}$

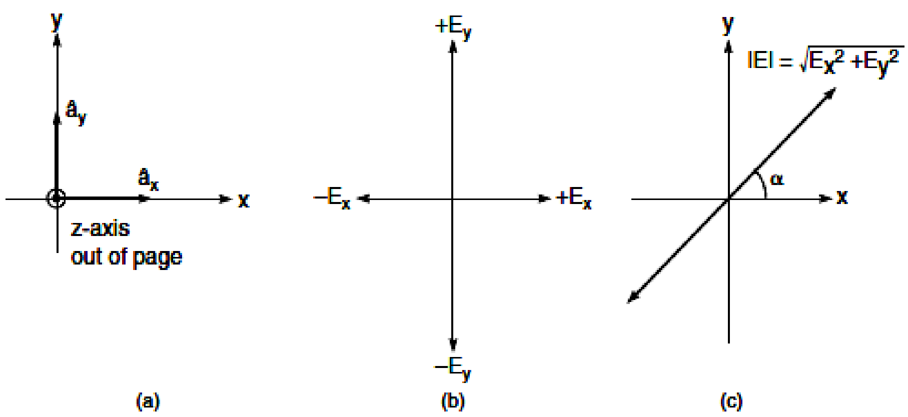


Figure 5.2: Horizontal and Vertical components of a linear polarization

- When tip of the resultant vector traces out a circle, the resultant wave is circularly polarized whose direction is defined by the rotation of the vector. It can follow right-hand circular (RHC) clock-wise direction or left-hand circular (LHC) anti-clock wise direction.

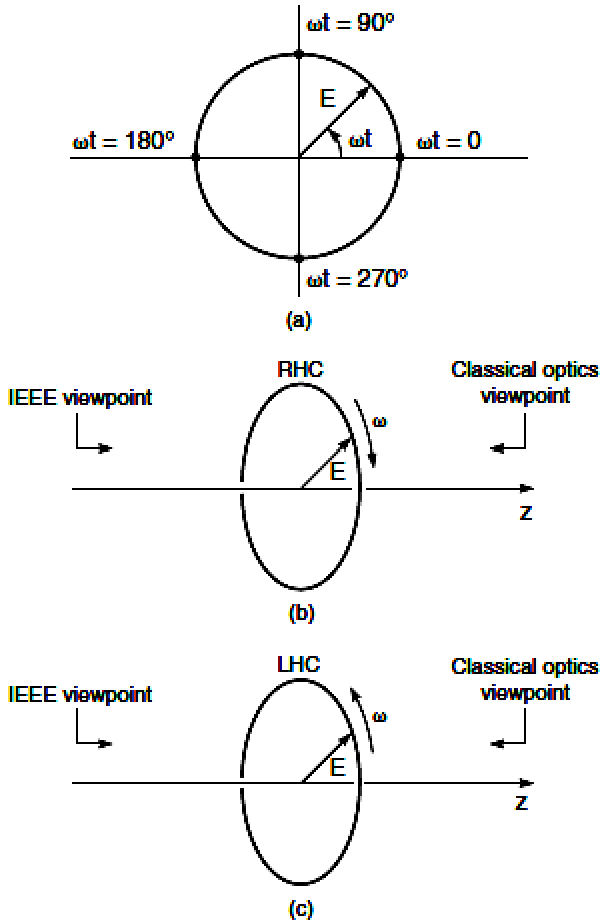


Figure 5.3: Circular Polarization

5.3 ANTENNA POLARIZATION

- It is defined by polarization (time-varying direction and amplitude) of the wave it transmits.

- The polarization of an antenna is the orientation of the electric field (E-plane) of the radio wave with respect to the Earth's surface and is determined by the physical structure of the antenna and by its orientation. It has nothing in common with antenna directionality terms: "horizontal", "vertical", and "circular". Thus, a simple straight wire antenna will have one polarization when mounted vertically, and a different polarization when mounted horizontally.

- Reflections generally influence polarization. For radio waves the most significant reflector is the ionosphere - signals which reflect from it will have their polarization changed unpredictably. For signals which are reflected by the ionosphere, polarization cannot be relied upon. For line-of-sight communications for which polarization can be relied upon, it can make a large difference in signal quality to have the transmitter and receiver using the same polarization; the difference which is commonly seen and this is more than enough to make the difference between reasonable communication and a broken link.

- Polarization is largely predictable from antenna construction but, especially in directional antennas, the polarization of side lobes can be quite different from that of the main propagation lobe. For radio antennas, polarization corresponds to the orientation of the radiating element in an antenna. A vertical Omni-directional Wi-Fi antenna will have vertical polarization (the most common type). An exception is a class of elongated waveguide antennas in which vertically placed antennas is horizontally polarized. Many commercial antennas are marked as to the polarization of their emitted signals.

- Horizontal dipole produces a horizontally polarized wave; vertical dipole produces a vertically polarized wave. When both these dipoles are mounted close to each other at right angles, they produce a circularly polarized wave.

- At the receiving end, antenna should be aligned in such a way that maximum power transfer should occur.
  - ✓ If the dipole is parallel to electric field E, induced voltage will be maximum; **V= max**
  - ✓ If dipole is perpendicular to E, then **V = 0**
  - ✓ If dipole lies in the plane of polarization and is at an angle α to E then **V = V max cos α**

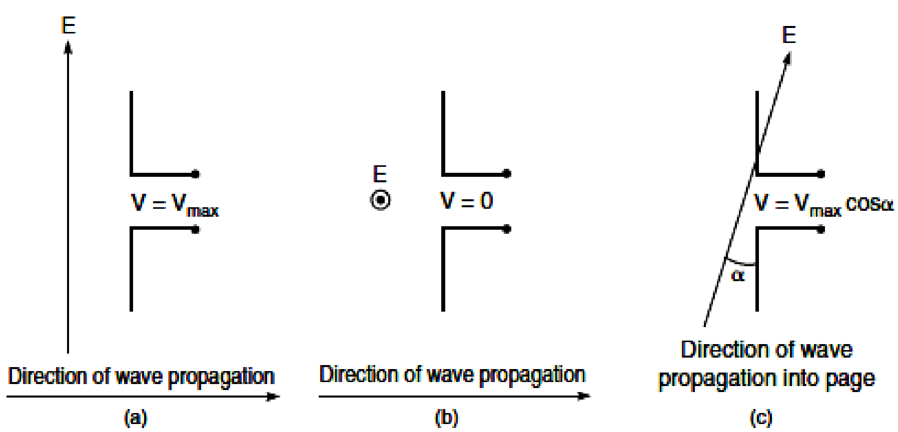


Figure 5.4: Linear polarization relative to a receiving dipole.

(If the wave is circularly polarized, maximum power is attained by the two dipoles producing it.)

- Grid of parallel wires is created to reflect a linear polarized wave when the electric field is parallel to the wires. This leads to a transmission of orthogonal wave.

- The simplest linear polarizer in concept is the wire-grid polarizer, which consists of a regular array of fine parallel metallic wires, placed in a plane perpendicular to the incident beam. Electromagnetic waves which have a component of their electric fields aligned parallel to the wires induce the movement of electrons along the length of the wires. As the electrons are free to move in this direction, the polarizer acts in a similar manner to the surface of a metal when reflecting light; and the wave is reflected backwards along the incident beam (minus a small amount of energy lost to joule heating of the wire).

- For waves with electric fields perpendicular to the wires, the electrons cannot move very far across the width of each wire; therefore, little energy is reflected, and the incident wave is able to pass through the grid. Since electric field components parallel to the wires are reflected, the transmitted wave has an electric field purely in the direction perpendicular to the wires, and is thus linearly polarized.

- For practical use, the separation distance between the wires must be less than the wavelength of the radiation, and the wire width should be a small fraction of this distance. This means that wire-grid polarizers are generally only used for microwaves and for far- and mid-infrared light. Using advanced lithographic techniques, very tight pitch metallic grids can be made which polarize visible light. Since the degree of polarization depends little on wavelength and angle of incidence, they are used for broad-band applications such as projection.

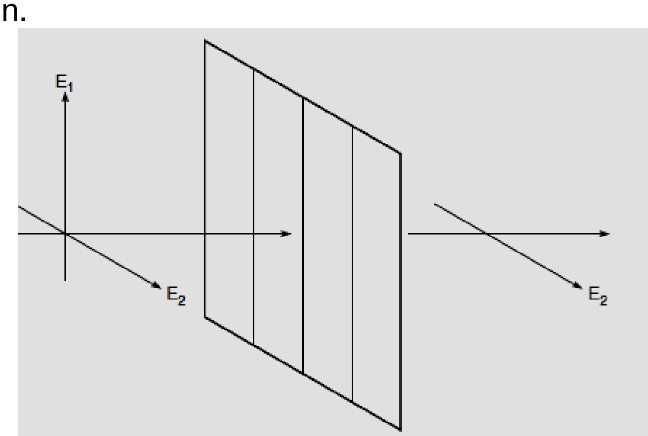


Figure 5.5: Wire Grid polarizer

5.4 POLARIZATION OF SATELLITE SIGNALS

- For a Geostationary Earth orbiting satellite transmitting a linear polarized wave, its horizontal polarization will be where the electric field is parallel to Earth's equatorial plane and its vertical polarization is where its Earth's electric field is parallel to the Earth's polar axis.

- For sub-satellite point on the equator, both the polarization vector will be at some angle relative to a reference plane. The reference plane for direction of propagation and local gravity direction is defined in the figure below.

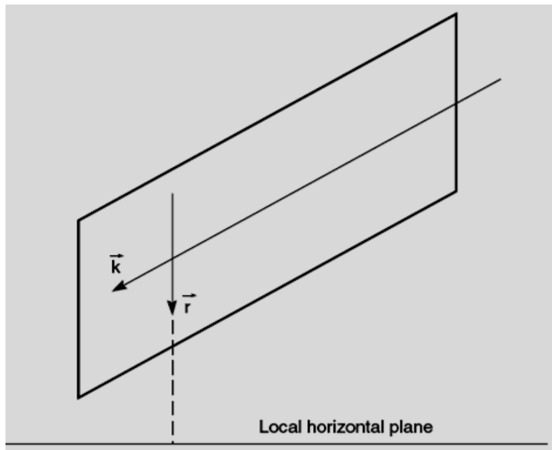
- 

Figure 5.6: Reference plane for direction of propagation and local gravity direction

<u>Derivation:</u>

I) let k → propagation direction

r→ local gravity direction

f→ direction of normal to the reference plane.

$$\mathbf{f = k \times r}$$

p→ unit polarization vector at Earth Station

n→ Angle between p and f given by vector dot product

$$\mathbf{n = \arccos (p.f / |f|)}$$

As the angle between normal and its plane is 90^0, angle between p and its reference plane is given by:

$$\boldsymbol{\xi = |90^0 - n|}$$

$$\boldsymbol{\xi = |\arcsin (p.f) / |f| \,|}$$

Note: Polarization vector is always at right angles to the direction of propagation.

II) Relation between p and e

p→ polarization vector

e→ polarization at satellite

Vp→e lies parallel to Earth's North-South axis

Hp → e lies in the equatorial plane at right angles to the geostationary radius a_{gso} to the satellite.

The cross product is: $\mathbf{g = k \times e}$

g→ normal to the plane containing e and k

Cross product of g with k is given by h

$$\mathbf{h = g \times k}$$

Unit polarization vector at Earth is:

$$\mathbf{P = h / |h|}$$

III) Taking the longitude of satellite as reference, the satellite is positioned along the positive x axis at

$$\mathbf{x_s = a_{gso}}$$

Coordinates of Earth station position vector R are:

$R_x \rightarrow R \cos \lambda \cos B$
$R_y \rightarrow R \cos \lambda \sin B$
$R_z \rightarrow R \sin \lambda$

Where $B = \Phi_E - \Phi_{SS}$ (Latitude of Earth Station and Sub-Satellite point)

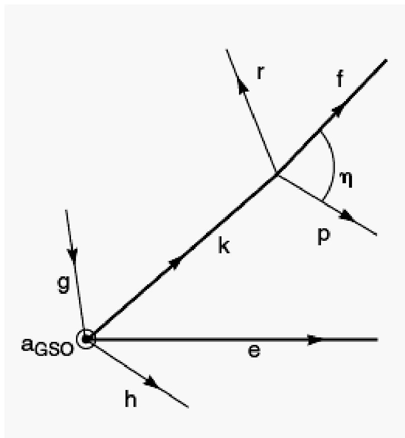


Figure 5.7: Vectors g = k x e and h = g x k

Local gravity direction is r = - R.

Thus the coordinates for direction of propagation are

$k_x = R_x - a_{gso}$
$k_y = R_y$
$k_z = R_z$

<u>Example:</u> A GEO satellite is positioned at 105^0 W and sends a vertically polarized wave. Determine its angle of polarization at an Earth station positioned 18^0 N latitude and 73^0 W longitudes.

Solution **:**

$$\lambda := 18 \cdot deg \qquad \phi_E := -73 \cdot deg \qquad \phi_{SS} := -105 \cdot deg$$

$$a_{GSO} := 42164 \cdot km \qquad R := 6371 \cdot km$$

(spherical earth of mean radius R assumed)

Calculations:

$$B := \phi_E - \phi_{SS} \qquad \text{...Eq. (3.8)}$$

Applying Eq. (5.15), the geocentric-equatorial coordinates for the earth station position vector are

$$\begin{bmatrix} R_x \\ R_y \\ R_z \end{bmatrix} := \begin{bmatrix} R \cdot \cos(\lambda) \cdot \cos(B) \\ R \cdot \cos(\lambda) \cdot \sin(B) \\ R \cdot \sin(\lambda) \end{bmatrix} \qquad \begin{bmatrix} R_x \\ R_y \\ R_z \end{bmatrix} = \begin{pmatrix} 5138.5 \\ 3210.9 \\ 1968.7 \end{pmatrix} \cdot km$$

The coordinates for the local gravity direction are

$$r := -\begin{bmatrix} R_x \\ R_y \\ R_z \end{bmatrix}$$

From Eq. (5.16), the geocentric-equatorial coordinates for the propagation direction are

$$k := \begin{bmatrix} R_x - a_{GSO} \\ R_y \\ R_z \end{bmatrix} \qquad k = \begin{bmatrix} -3.703 \cdot 10^7 \\ 3.211 \cdot 10^6 \\ 1.969 \cdot 10^6 \end{bmatrix} \cdot m$$

For vertical polarization at the satellite, the geocentric-equatorial coordinates for the polarization vector are $x = 0$, $y = 0$, and $z = 1$:

$$e := \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

$$f := k \times r \qquad f = \begin{bmatrix} 0 \\ -8.3 \cdot 10^7 \\ 1.4 \cdot 10^8 \end{bmatrix} \cdot km^2$$

$$g := k \times e \qquad g = \begin{pmatrix} 3210.9 \\ 37025.5 \\ 0 \end{pmatrix} \cdot km$$

$$h := g \times k \qquad h = \begin{bmatrix} 7.3 \cdot 10^7 \\ -6.3 \cdot 10^6 \\ 1.4 \cdot 10^9 \end{bmatrix} \cdot km^2$$

$$p := \frac{h}{|h|} \qquad p = \begin{pmatrix} 0.053 \\ -0.005 \\ 0.999 \end{pmatrix}$$

$$\xi := asin\left(\frac{p \cdot f}{|f|}\right) \qquad \xi = 58.6 \cdot deg$$

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5.5 POLARIZATION DISCRIMINATION

- The propagation path of a signal has to go through the ionosphere in order to reach the satellite from earth station and vice versa. These signal sometimes also pass through clouds, rain crystals, rain etc. all these factors alter the polarization of a signal. Sometimes an additional orthogonal signal might get generated leading to the effect of depolarization. Two measures are used to calculate the effect of depolarization.

I) Cross Polarization Discrimination (XPD)

It's the most widely used measure. The transmitted electric field has magnitude E_1 before it enters the medium (as shown in figure 5.6). On entering the medium, E_1 also gets depolarized. Thus at the receiving end antenna, electric field may have two components:

Co-polar component with magnitude $\mathbf{E_{11}}$

Cross-polar component with magnitude $\mathbf{E_{12}}$

XPD in decibels is: **XPD = 20 log E_{11} / E_{12}**

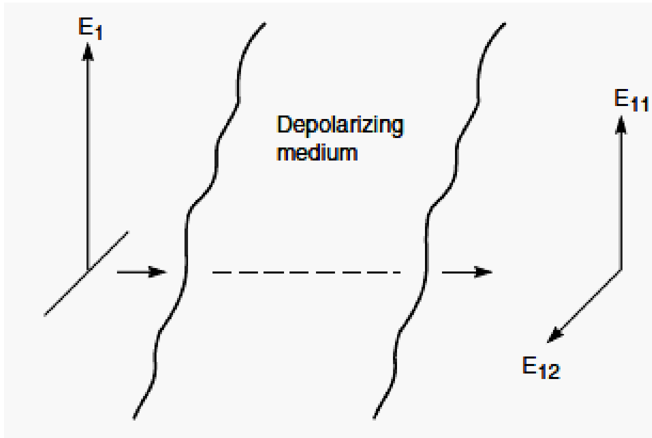

Figure 5.8: Vectors defining Cross Polarization Discrimation

II) **Polarization Isolation (I)**

Here the two orthogonally polarized signals with magnitudes E1 and E2 are transmitted. After passing through the depolarizing medium, the co-polar and cross-polar components exist for both the waves. The polarization isolation is defined by the ration of the received co-polar power to the received cross-polar power. This means it considers the additional depolarization.

$$\mathbf{I = 20 \log E_{11} / E_{12}}$$

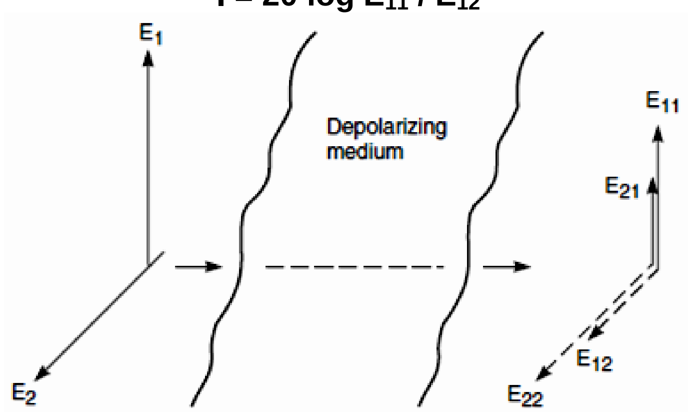

Figure 5.9: Vectors defining Polarization Isolation

- I and XPD have similar results when transmitted signals have the same magnitude ($E_1 = E_2$). The receiving system introduces negligible depolarization.

5.6 IONOSPHERIC DEPOLARIZATION

- The layer above the Earth's surface carrying charged particles is called ionosphere (as described in Unit 4). This layer is charged because of solar radiation.

- Free electrons that are freely (non-uniformly) distributed in this layer form electron clouds. And cause travelling ionospheric disturbances. Signals passing through these clouds face fluctuations and Faraday's rotation.

- The motion of these free electrons is within the magnetic field of the Earth. But as soon as the travelling wave passes through them, their direction of motion no longer remains parallel to the electric field of the wave and these electrons react back on these waves.

- This leads to a shift in the polarization. This angular shift in polarization is also dependent on the length of the path in the ionosphere and the electron density of the region of interest. Faraday's rotation is inversely proportional to the frequency shared and is not considered as a problem for frequency above 10 GHz.

  Let linear polarization wave have electric fields E at the receiver antenna with no Faraday rotation. Thus received power is E^2
  Faraday rotation of θ_F degrees results into co-polar component of the received signal being reduced to:

  $$\mathbf{E_{co} = E \cos \theta_F}$$

  Thus the receiving power in this case is E_{co}^2
  Thus polarization loss (PL) in decibels is:

  $$\mathbf{PL = 20 \log E_{co} / E}$$

  Thus, $\mathbf{PL = 20 \log (\cos \theta_F)}$

  Similarly, cross-polar component is:

  $$\mathbf{XPD = 20 \log E_{co} / E_x}$$

  Thus, $\mathbf{XPD = 20 \log (\cos \theta_F)}$

5.7 RAIN DEPOLARIZATION

- The ideal shape of a rain drop is spherical as it minimizes the energy required to hold the raindrop together. Longer drops are oblate or elongated and they generally flatten underneath due to the gravity or air resistance.

- Linear polarized wave can have two components; they are vertical and horizontal polarized. Considering a wave with its electric vector at some angle **T** relative to the major axis of the rain drop.

- Vertical component is parallel to the minor axis of the rain drop and thus having less water content. It is vice versa for the horizontal component. Due to this, there lies a difference between the attenuation and phase shift of each electric field component.
- This is termed as differential attenuation and differentia phase shift and they result in depolarization of the signal.

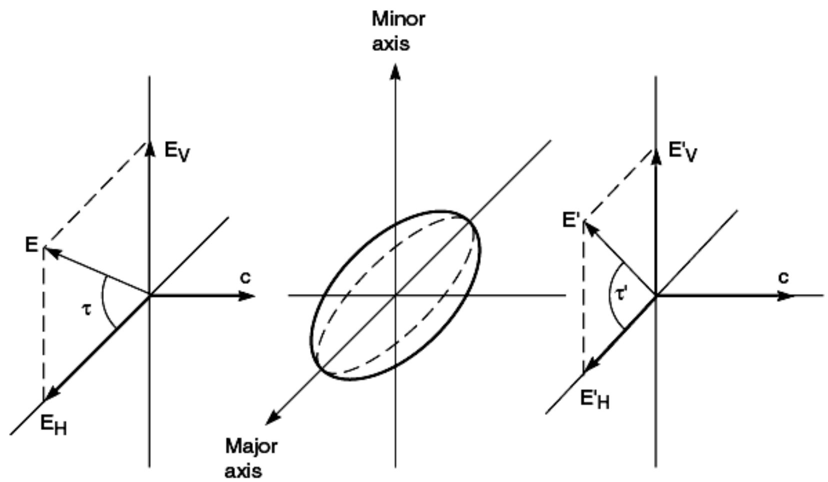

Figure 5.10: Polarization vector relative to major and minor axis of a rain drop.

- Compensation techniques for rain depolarization in satellite links are discussed from the viewpoint of system configuration, performance, and technical feasibility. The compensator using two rotatable polarizer has sufficient performance at microwave region. Two types of compensators, as combination of 90^0 and 180^0polarizer and a combination of two 90 deg polarizer, were developed and tested. Satisfactory results were obtained at 4-GHz band by using the Intelsat satellite.

- To summarize, the effect of rain depolarization has been calculated as a function of rain rate, path length, and frequency of differential phase shift and differential attenuation due to oblate raindrops. The experimental values generally agree with the theoretical predictions, but the latter tend to underestimate the effect. This underestimation is possibly due to some near-field effect plus the errors introduced by approximating the raindrops as ellipsoids, especially at high rain rates. Nevertheless, theoretical and experimental values of the level of depolarization due to rain generally differ by no more than 3dB.

5.8 ICE DEPOLARIZATION

- Ice layer that is present over the rain region causes depolarization. Ice which is comparatively a good dielectric component leads to more loss. Shape of ice crystals is like a needle or like a plate and if they are all aligned; their effect of depolarization is much more.
- Sudden increase in the XPD coinciding with lightening can cause severe damage to the signals. Generally a fixed value in decibels of XPD is calculated for account of ice depolarization.
  [***Dielectric***: it is an electric insulator that can be polarizes by an applied electric field.]

5.9 SUMMARY

Polarization is an important factor for satellite communication. Both RF antennas and electromagnetic waves are said to have a polarization. For the electromagnetic wave the polarization is effectively the plane in which the electric wave vibrates. This is important when looking at antennas because they are sensitive to polarization, and generally only receive or transmit a signal with a particular polarization.

For most antennas it is very easy to determine the polarization. It is simply in the same plane as the elements of the antenna. So a vertical antenna (i.e. one with vertical elements) will receive vertically polarized signals best and similarly a horizontal antenna will receive horizontally polarized signals.

5.10 EXERCISE

1. Discuss the plane TEM wave.
2. Write a note on Ice Depolarization.
3. Differentiate between XPD and Polarization Isolation.
4. What is Polarization Discrimination?
5. What are travelling ionospheric disturbances?
6. Write a note on Rain Depolarization.
7. Explain what is meant by orthogonal polarization and the importance of this in satellite communication.
8. Discuss Ionospheric Depolarization.

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6A

ANTENNAS

Contents:

6A.1 INTRODUCTION

- An antenna is used to radiate electromagnetic energy efficiently and in desired directions. Antennas act as matching systems between sources of electromagnetic energy and space. The goal in using antennas is to optimize this matching. Here is a list of some of the properties of antennas:
  1) Field intensity for various directions (antenna pattern).
  2) Total power radiated when the antenna is excited by a current or voltage of known intensity (or Power Flux Density)
  3) Radiation efficiency which is the ratio of power radiated to the total power (Radiation Pattern).
  4) The input impedance of the antenna for maximum power transfer (matching).
  5) The bandwidth of the antenna or range of frequencies over which the above properties are nearly constant.

- Antennas can also be classified as electrical devices which convert electric currents into radio waves and vice-versa. They are generally used with a radio transmitter and receiver. They are broadly classified in two categories:

- Transmitting antennas
- Receiving antennas

Difference is in the mode of operation, different functions etc. as the transmitting as well as the receiving antenna.

- Earth Station Antenna
- Satellite Antenna

Difference is mainly in their environmental conditions which lead to their different designs.

- Typically an antenna has an array of metallic conductors that are electrically connected. An oscillating current of electrons focused through the antenna by a transmitter creates an oscillating electric field.

- These fields are time-varying and radiate from the antenna into the space as a moving electromagnetic field wave. Certain properties of antennas such as directional characters result into reciprocity theorem.

- Different types of antennas are:
  1) ***Dipole Antennas***: The dipole is one of the most common antennas. It consists of a straight conductor excited by a voltage from a transmission line or a waveguide. Dipoles are easy to make.

  2) ***Aperture Antennas***: A horn as shown in the figure below is an example of an aperture antenna. These types of antennas are used in Satellite spacecraft more commonly.

  3) ***Reflector Antennas***: The parabolic reflector is a good example of reflectors at microwave frequencies. In the past, parabolic reflectors were used mainly in space applications but today they are very popular and are used by almost everyone who wishes to receive the large number of television channels transmitted all over the globe.

  4) ***Array Antennas:*** A grouping of similar or different antennas form an array antenna. The control of phase shift from element to element is used to scan electronically the direction of radiation.

  5) ***Loop Antennas:*** A loop of wire, with many turns, is used to radiate or receive electromagnetic energy creates a loop antenna. These antennas can be used at home to capture signals of World radios or local television channels.

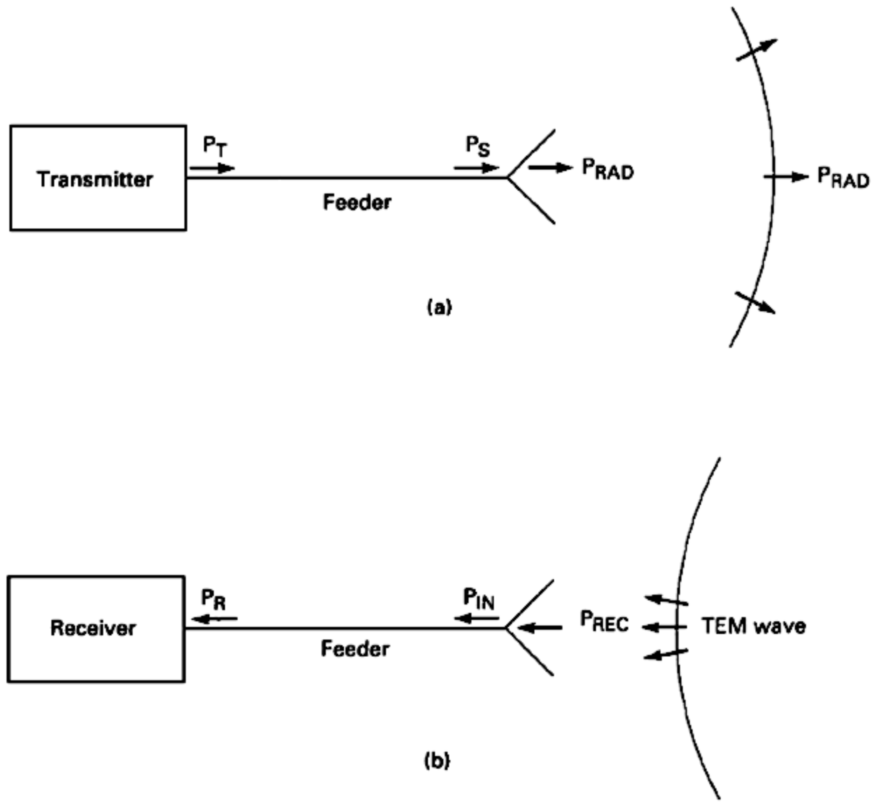


Figure 6.1: a) Transmitting Antenna; b) Receiving Antenna

a) Power amplifier is transmitter as P_T watts. Feeder connects to this antenna and the new power reaching to this antenna will be P_T – Losses at the feeder. Further loss is seen in the antenna and thus the radiated power is shown as P_{RAD}.

b) Power P_{Rec} is transferred to the antenna from a passing radio wave. Again the losses in the antenna will reduce the power at the feeder. Giving only P_{IN} to the feeder. Receiving feeder looses further reduce the power to P_R.

Definitions:

EMF (Electromagnetic Force): The electromagnetic force is a special force that affects everything in the universe because (like gravity) it has an infinite range. It has the ability to attract and repel charges. Since material in solid and liquid forms are made of charges having a unique order, they, too, may be manipulated by this force. It is also responsible for giving things strength, shape, and hardness. The electromagnetic force can be generated by three types of fields known as the electrostatic field, magneto-static field, and the electromagnetic field.

Gain: An antenna's power gain or simply gain is a key performance figure which combines the antenna's directivity and electrical efficiency. For a transmitting antenna gain is how well the antenna converts input power into radio waves headed in a specified direction. For a receiving antenna gain is how well the antenna converts radio waves arriving from a specified direction into electrical power. When no direction is specified, "gain" is understood to refer to the peak value of the gain. A plot of the gain as a function of direction is called the radiation pattern.

6A.2 RECIPROCITY THEOREM

- The Reciprocity Theorem states that if current *I* is induced in an Antenna B which is working on receiving mode, this current is applied by the EMF at the terminals of the antenna A that is working on the transmitting mode. Now if the same EMF is applied to the terminals of B, then it will induce the same current at the terminals of A.

- There are a number of consequences of this theorem:
    - In practical use, it is seen that antennas transmit more energy in some directions than others; and similarly, they also receive more energy while pointing in some directions than others.
    - Thus the directional pattern for an antenna operating in the transmit mode is the same as that when operating in the receive mode
    - Antenna’s impedance is the same or both the modes of operation.

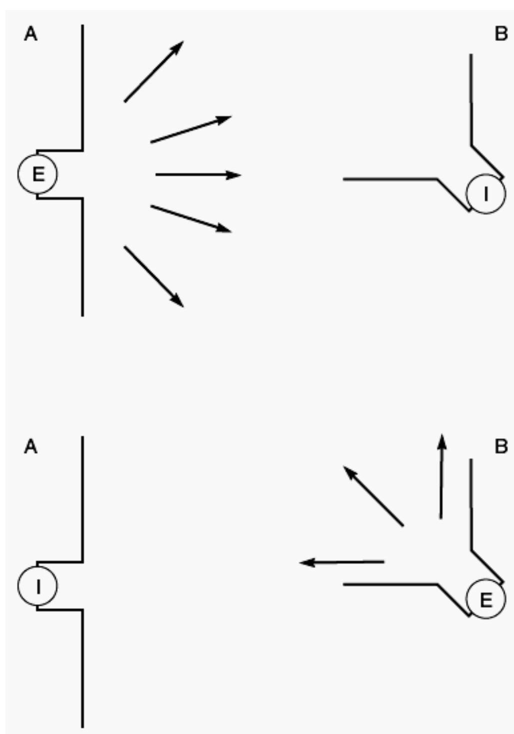


Figure 6.2: The reciprocity theorem

6A.3 POWER FLUX DENSITY

- It is the quantity used in calculating the performance of satellite communication links. The concept can be understood by:
  - Imagine the transmitting antenna is at the centre of sphere.
  - The power from the antenna radiated outward normal to the surface of the sphere; here the Power Flux Density is the power flow per unit surface area.
  - The Power Flux Density is a vector quantity given by:

$$\Psi = E^2 / Zw$$

(Here, E is the resultant magnitude of electric field in volts and Zw is in Ohms.)

6A.4 ISOTROPIC RADIATOR AND ANTENNA GAIN

- Isotropic radiator means radiating energy equally in all directions. This is a theoretical concept as no antenna (irrespective of where it is placed) can radiate signals equally in all directions.

- This concept is used for comparison purpose with the real antennas. As proved by the Reciprocity Theorem, $P_{RAD} = P_{S.}$ Let the Isotropic Radiation be at the centre of radius r, the Power Flux Density per unit area is:

$$\Psi = P_S / 4 \pi r^2$$

- As Flux Density forms a real antenna will change with direction and its maximum will occur, the gain of this antenna id the ratio of this maximum to that for the isotropic radiator at the same radius r.

$$G = \Psi_M / \Psi_i$$

- Gain is related to directivity. To improve the directivity, the difference between the power radiated by the real antenna and the power to it needs to be considered.

$$P_{RAD} = \eta_A P_S$$

- Where η_A is the antenna efficiency. The Gain by the antenna is called isotropic gain denoted by Gi. Gain varies from different types of antennas.

6A.5 COORDINATE SYSTEM

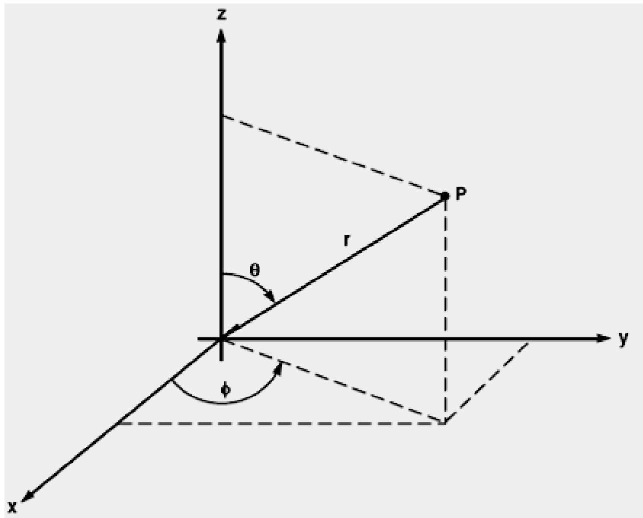


Figure 6.3: Spherical Co-ordinate system

- The antennas are located on the surface and rotate with respect to a source in the sky due the rotation of the earth. For aperture separation the antenna positions are specified in a co-ordinate system such that the separation of the antennas is the projected separation in plane normal to the phase centre. In such a co-ordinate system the separation between the antennas is as seen by the observer sitting in the source reference frame.

- An antenna coordinate system is implicit in almost every antenna measurement. Terms such as pattern, main and cross-component, beam pointing and peak gain, imply the definition of directions and/or vector field components, which require a coordinate system. Reference is often made to the cross-component of an antenna as if there is a unique definition of such a quantity when in fact the cross-component as well as the main component will depend on which coordinate system is used and how it is oriented with respect to the antenna.

- A spherical coordinate system is a coordinate system for three-dimensional space where the position of a point is specified by three numbers: the radial distance of that point from a fixed origin, its inclination angle measured from a fixed direction, and the azimuth angle of its orthogonal projection on a reference plane that passes through the origin and is orthogonal to the zenith, measured from a fixed reference direction on that plane. The inclination angle is often replaced by the elevation angle measured from the reference plane.

- In order to discuss the directional patterns of an antenna, it is necessary to set up the coordinate system to which these can be referred. With reference to figure 6.3, the antenna is imagined to be at the origin of the coordinates, and at a distant point in space is related to the origin by the coordinates r, θ and Φ. Thus r is the radius vector, the magnitude of which gives the distance between point P and the antenna; Φ is the angle measured from the x axis to the projection of r in the x plane; and θ is the angle measures from the z axis to r.

- The x, y and z axes form a right-hand set. When one looks at the positive z direction, a clock-wise rotation is required to move from positive x axis to the positive y axis. This becomes particularly significant when the polarization of the radio waves associated with antennas is described.

6A.6 RADIATION PATTERN

- Radiation pattern shows that the gain of an antenna varies with direction. At a fixed distance r, gain will vary with θ and Φ and is written as G (θ, Φ) as shown in figure 6.3. The Radiation Pattern is the gain normalized at a maximum value.

- Let the maximum gain be G. thus Radiation Pattern is denoted as g is given by:

$$g(\theta, \Phi) = G(\theta, \Phi) / G$$

- The Radiation Pattern gives directional properties of the antenna normalized to the maximum value (maximum gain). A three-dimensional representation of this shows a lobe.

- In this figure 6.4, the length of the radius line to any point on the surface of the lobe gives the value of radiation function at that point. The minimum lobe shows the beam of radiation and the beamwidth id shown as an angle by three-dimensional lines.

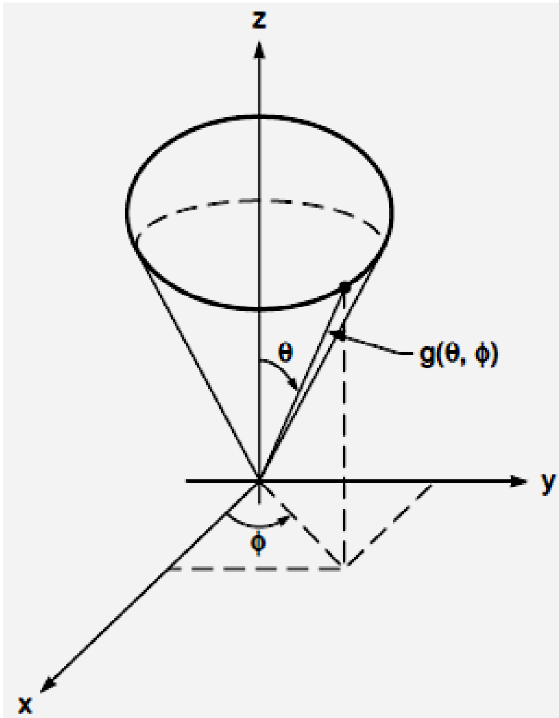
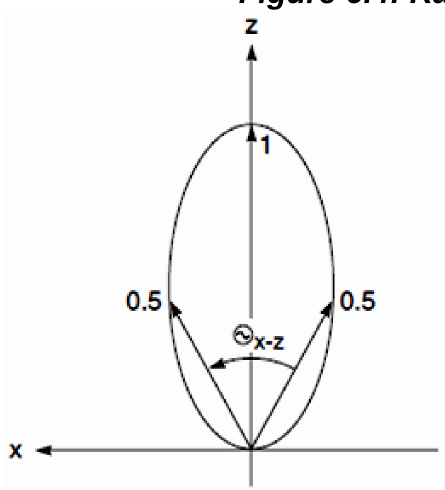


Figure 6.4: Radiation Pattern



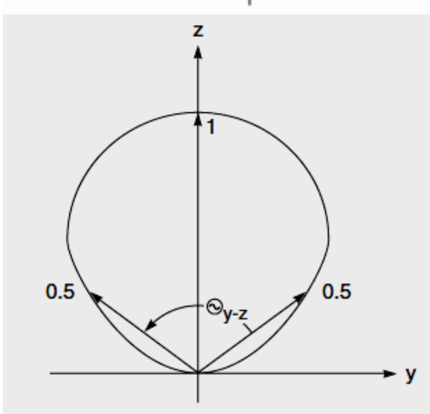


Figure 6.5: Radiation Pattern of H-Plane *Figure 6.6: Radiation Pattern of E-Plane*

- Generally, a beamwidth may be asymmetrical, then beamwidth in the H-plane is $\Phi = 0^0$ as shown in figure 6.5 and in E plane $\Phi = 90^0$ is seen in figure 6.6.

6A.6 ANTENNA APERTURE

- Antenna aperture can be visualized as the area of a circle constructed broadside to incoming radiation where the entire radiation passing within the circle is delivered by the antenna. Antenna gain can be increased by directing radiation in a single direction and thus reducing it in all the other directions.

- Hence layered antenna apertures can produce a higher gain and narrower beamwidth. The most common aperture antenna is Horn Antenna and Reflector Antenna.

- Figure 6.6 shows an idealized aperture. It consists of a rectangular aperture of sites a and b cut in an infinite ground plane. Here radiation form some parts adds constructively in some direction and destructively in others. This in result will exhibit a main lobe and a number of side lobes.

- The actual distribution of energy depends on the manner in which the aperture is energized. Distribution pattern also depends upon the physical construction of the antenna.

- As cross-polarization can occur with real antennas an unwanted signal is transmitted along with the signal send and received along with the incoming data. The unwanted signal causes interference. Hence this aspect has to be taken care of along with other practical consideration.

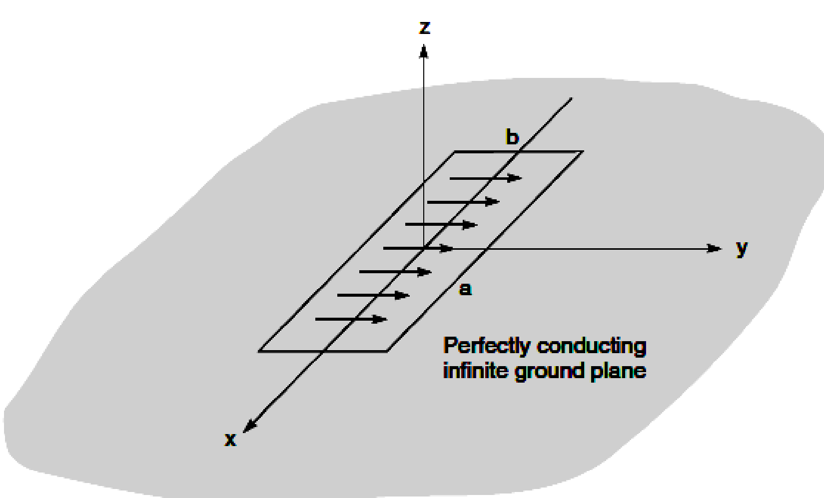


Figure 6.7: An idealized Aperture Radiator

6A.7 SUMMARY

- This unit describes the concept of antennas. An antenna is a device for converting electromagnetic radiation in space into electrical currents in conductors or vice-versa, depending on whether it is being used for receiving or for transmitting, respectively. It further gives the basic categories of antennas used in satellite communication. Further, this unit discusses the Reciprocity theorem which states that: The reciprocity theorem states that if an emf E in one branch of a reciprocal network produces a current I in another, then if the emf E is moved from the first to the second branch, it will cause the same current in the first branch.

  After defining the reciprocity theorem for antennas, this unit describes the other measures needed to calculate the functionality, position of an antenna. They are:

Power Flux Density: It calculates the performance of a communication link.

Isotropic Radiator: Defines the theoretical concept of an ideal antenna.

Antenna Gain: It calculates the efficiency of an antenna.

Coordinate System: it is a coordinate system for three-dimensional space where the position of a point is specified.

Radiation Pattern: It elaborates on the concept that the gain of an antenna varies with direction and is different than what the theoretical concept describes.

Antenna Aperture: It is an area of a circle constructed broadside to incoming radiation where the entire radiation passing within the circle is delivered by the antenna.

6A.8 EXERCISE

1. Explain the concept that 'gain of an antenna varied with direction' using radiation pattern.
2. What is an isotropic radiator?
3. Explain what is meant by reciprocity theorem as applied to antennas?
4. What is an offset feed of an antenna?
5. What are Aperture Antennas?
6. Define power flux density.
7. How are antennas classified? With an appropriate diagram, show an antenna in the transmitting and receiving modes.

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6B

ANTENNAS

Contents:

6b.1 INTRODUCTION

- In the previous unit, we have already defined an antenna and the basic parameters needed to calculate the efficiency in functionality and position of a satellite. We have defined a few antennas like Different types of antennas are: *Dipole Antennas, Aperture Antennas*, *and Reflector Antennas etc*. Now we will see antennas which are actually used by the spacecraft or the earth station for satellite communication. They include the Horn antennas, parabolic reflectors which include Gregorian and Cassegrain antennas, double reflector antennas.

Definitions:

Waveguide: A waveguide is an arrangement which guides waves, such as electromagnetic waves or sound waves. There are different types of waveguides for every type of wave. The original meaning is a hollow conductive metal pipe used to carry high frequency radio waves, mainly microwaves. Waveguides differ in their geometry which can confine energy in one dimension such as in slab waveguides or two dimensions as in fibre or channel waveguides.

Antenna Feeder: antenna feed refers to the components of an antenna which feed the radio waves to the rest of the antenna structure, or in receiving antennas collect the incoming radio waves, convert them to electric currents and transmit them to the receiver. Antennas typically consist of a feed and additional reflecting or directive structures (such as a parabolic dish or parasitic elements) whose function is to form the radio waves from the feed into a beam or other desired radiation pattern. In simple antennas the feed usually consists of the feed antenna (driven element), the part of the antenna which actually converts the radio frequency currents to radio waves or vice versa, and the feed line (transmission line), which connects the feed antenna with the receiver or transmitter.

Hyperboloid: a hyperboloid is a quadric – a type of surface in three dimensions – described by the equation a2/x2 + b2/y2 – c2/z2 = 1.

6B.2 HORN ANTENNA

[One of the first horn antennas was constructed in 1897 by Indian radio researcher Jagadish Chandra Bose in his pioneering experiments with microwaves.]

- A horn antenna is an example of aperture antenna [refer unit VI-a] which provides a smooth transition from a waveguide to a larger aperture that couples more effectively into the space. In these antennas a flaring metal waveguide is shaped like a horn to direct radio waves in a beam.

- These antennas are designed to cover large areas on Earth. They are also used as primary feeds for reflector type antennas in transmitting as well as receiving modes. Three common types of horn antennas used for satellite communication are given below.

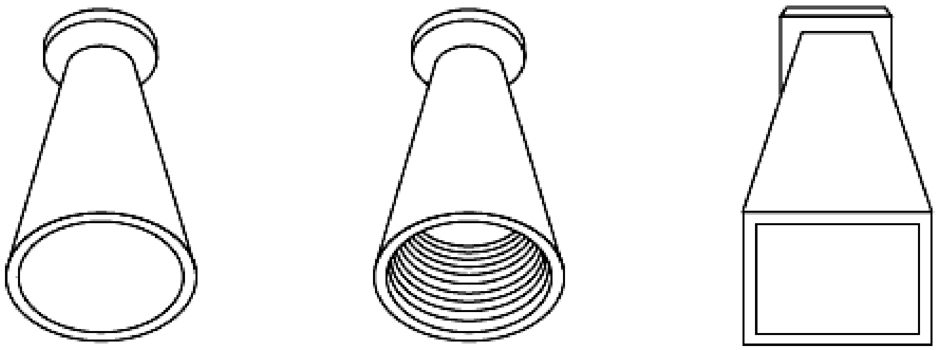

Figure 6b.1: Horn Antennas- a) Smooth-Walled Conical b) Corrugate c) Pyramidal

6b.2.1) Conical Horn Antenna

- This antenna is shown in figure 6b.1 (a). It is the simplest form of horn antenna. The inner wall of this antenna is smooth. These antennas can accept signals in rectangular form and converts them into circular wave using rectangular-to-circular transition device.

- Horn antennas may be used with circular or linear polarized wave. The smooth-walled horn antenna does not produce a symmetrical main beam even though the horn is symmetrical. This lack of symmetry is a disadvantage where global coverage is required.

  Electrical Field Distribution of Horn Antennas: The curved lines can resolve into horizontal and vertical components. Transverse electromagnetic wave is linearly polarized. Horizontal component of aperture field gives rise to the cross-polarized waves in the far-field region. As shown in figure 6b.2.

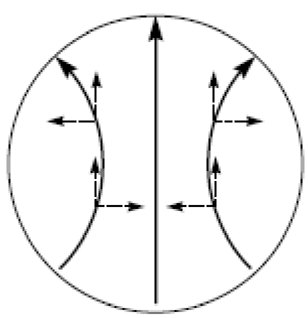

Figure 6b.2: Aperture field in smooth-walled conical horn

6b.2.2) Corrugate Horn Antenna

- By making conical horn antenna work on non-linear combination of transverse electric and transverse magnetic modes, the cross-polarization can be reduced and more efficient beam is produced.

- This can be done by making the inside wall of the horn antenna corrugate, thus making a new class of antenna called as Corrugate Horn antenna.

6b.2.3) Pyramidal Horn Antenna

- These antennas are designed for linear polarization. Its rectangular cross section a x b operates in the Transverse Electromagnetic wave mode.

- Beam width of these antennas differs in E and H planes. It can operate on the H and V polarized mode simultaneously giving rise to dual-linear polarization.

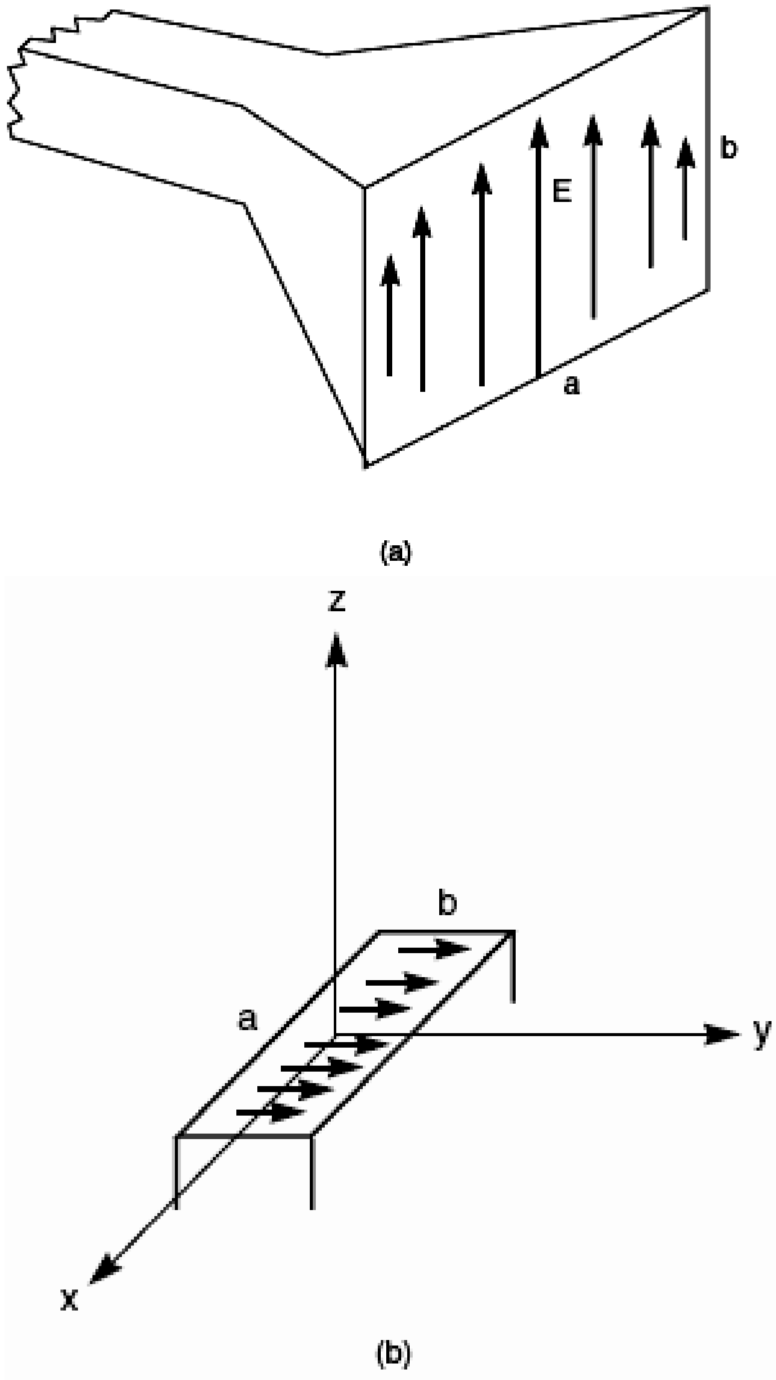

Figure 6b.3: The Pyramidal horn

6B.3 PARABOLIC REFLECTOR

- They are used to increase the gain of antennas. A parabolic reflector has a focusing device which helps to concentrate in one direction. Example: used in homes for reception of TV signals. The focusing property is associated with light.

- Parallel rays of light falling on the reflector get converged on a single point called focus. Similarly, rays originating from the focus are reflected as a parallel beam of light. This property of light is applicable to electromagnetic waves.

- The parabolic reflector, which takes the shape of a parabola, traces out a curve with the reflector on any plane normal to the aperture plane containing the focus. Radiations from these antennas appear to originate as a plane wave from a plane normal to the axis and containing a directrix (directrix is a fixed line used in describing a curve or surface).
    - The radio link behaves like a far-field component.
    - Reflected wave is a plane wave.
    - Waves falling on the reflector, originating from an isotropic source have a spherical wavefront.
    - The power flux density is a plane wave and is independent of the distance.
    - Power flux density in a plane wave decreases in a far-field component and is inverse to the distance squared.

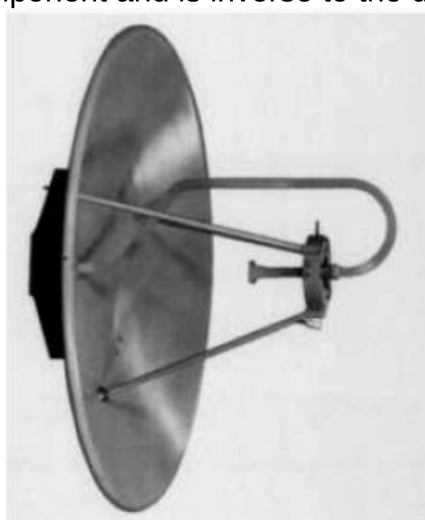

Figure 6b.4: a Parabolic Reflector

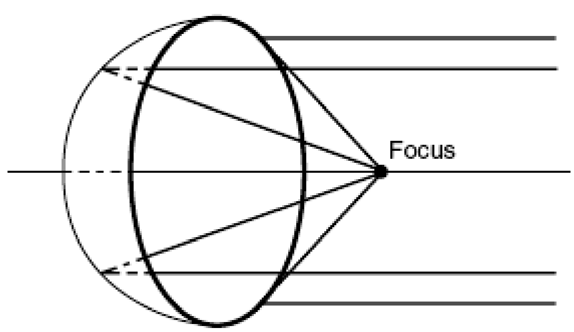

Figure 6b.5: Parabolic Reflector's focusing property

6B.4 OFFSET FEED

- Figure 6b.6 shows a paraboloidal reflector with horn feed at the focus. In this instance, the radiation pattern of the horn is offset so that it illuminates only the upper portion of the reflector. He feed horn and the support can be placed well clear of the main beam so that no blockage occurs. Blockage results in 10 percent of the efficiency.

- The main disadvantage of offset feed are that a stronger mechanical support is required to maintain the reflector shape and because of the symmetry, the cross-polarization with a linear polarized feed is worst compared with the centre-fed antenna. Because of the limited transmitter power provided by their solar cells, satellite antennas must function as efficiently as possible.

- Polarization compensation can be introduced into the primary feed to correct for the cross-polarization or a polarization-purification grid can be incorporated into the antenna structure. Offset feed is also used with double-reflector earth station antennas and id being used increasingly with small receive-only earth station antennas. The offset design is also widely used in radar antennas. These must collect as much signal as possible in order to detect faint return signals from faraway targets.

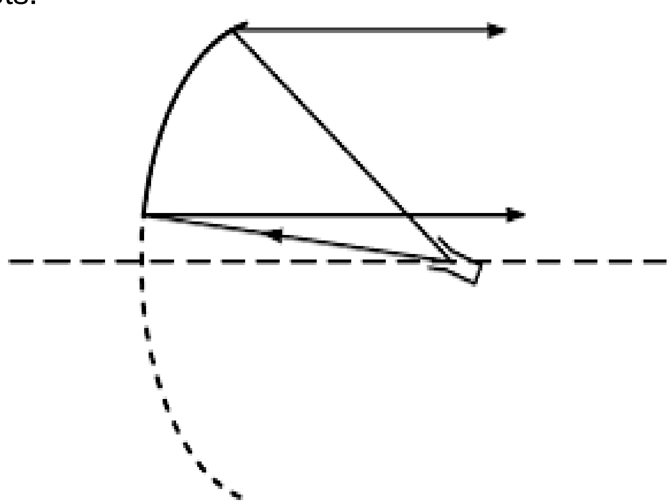

Figure 6b.6: Ray paths of a offset reflector

6B.5 DOUBLE-REFLECTOR ANTENNAS

- In these antennas, a short feeder is used to minimize losses. It is used by large earth stations where transmit power is sufficiently high and thus low receiver noise is required. From figure 6b.7; the rear mount makes a compact feed, which is an advantage where steerable antennas must be used and access for servicing becomes easier. The sub-reflector, which is mounted at the front of the main reflector, is generally smaller than he feed horn and causes less blockage.

- The two main types of double-reflector antennas used in satellite communication are:
  a) Cassegrain Antenna
  b) Gregorian Antenna

Figure 6b.7: Double Reflector Cassegrain Antenna.

6b.5.1) Cassegrain Antennas

- A Cassegrain antenna is a parabolic antenna in which the feed radiator is mounted at or behind the surface of the concave main parabolic reflector dish and is aimed at a smaller convex secondary reflector suspended in front of the primary reflector. The beam of radio waves from the feed illuminates the secondary reflector, which reflects it back to the main reflector dish, which reflects it forward again to form the desired beam.

- This antenna has a main parabolic and sub-reflector which is hyperboloid. The sub-reflector has two focal points; one focal point is made to coincide with that of the main reflector and the other with the phase centre of the feed horn.

- Uniform illumination is achieved in Cassegrain and these antennas are used by large earth stations.

- If the curvature of the centre section of this antenna is altered and is made greater than that the hyperboloid allows it to reflect more energy towards the edge of the main reflector, making the amplitude distribution more uniform.

- The curvature of the centre section is made smaller to compensate on the reduced path length so that the constant phase condition across the aperture is maintained. The edge of the sub-reflector is designed to reduce the “spill over”.

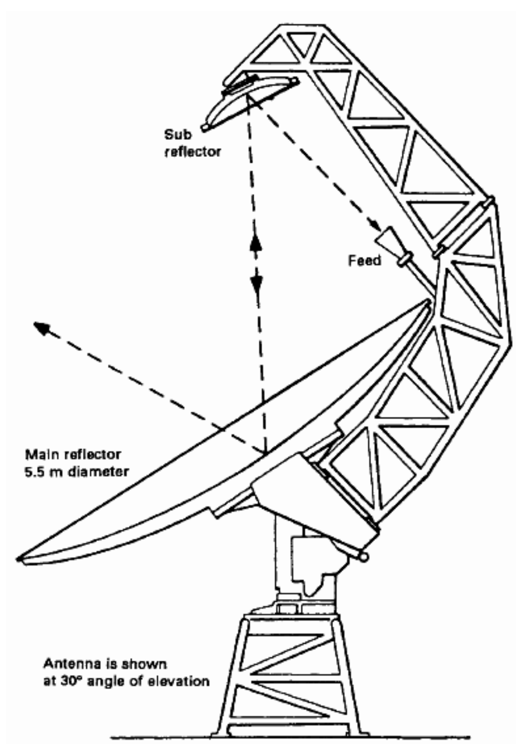

Figure 6b.7: Double Reflector Gregorian Antenna.

6b.5.1) Gregorian Antennas

- Gregorian antenna, like Cassegrain antenna is a parabolic reflector. It consists of a main paraboloid sub-reflector which is an ellipsoid with the hyperboloid. Sub-reflector has two focal points, one which is made to coincide with that of the main reflector and other with phase centre of the feed horn.

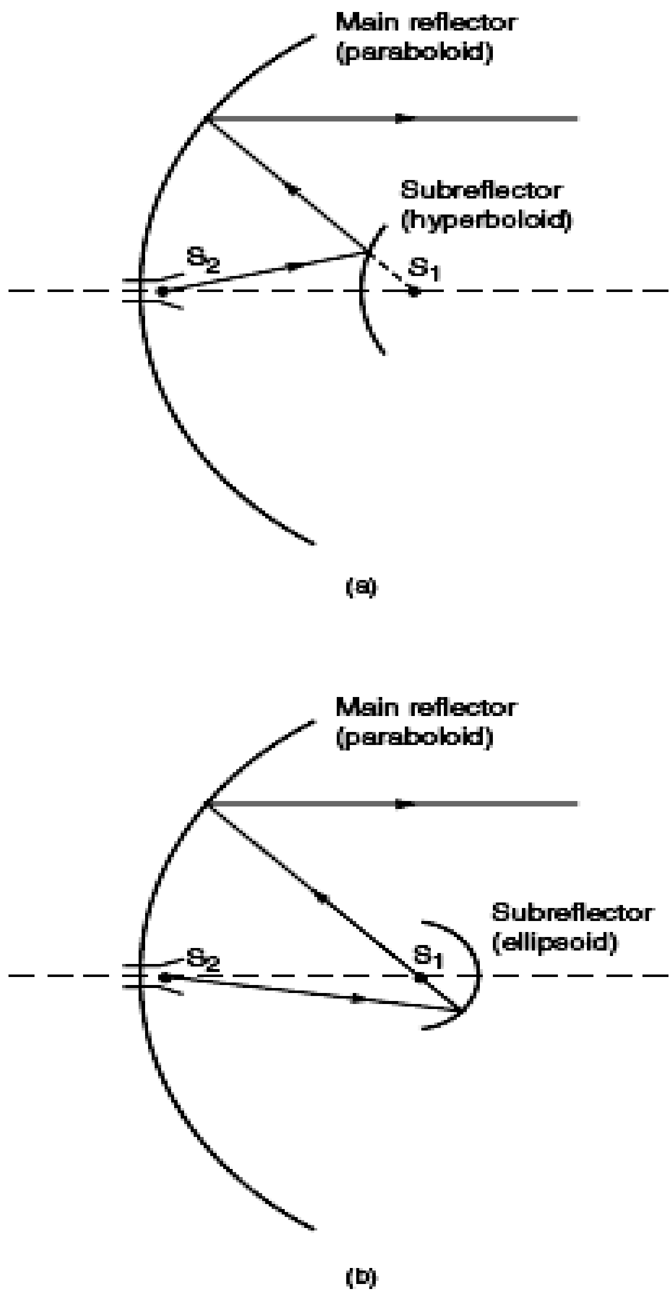

Figure 6b.8: Ray Paths for a) Cassegrain b) Gregorian Antennas.

6B.6 SHAPED REFLECTOR SYSTEM

- Ripples/ Dimples are created on the surface of the antenna. Their depth is approximately equal to the wavelength of the signal. Due to these ripples, reflection of the wave takes place. These reflections reinforce more radiation in some direction and less in others.

- This Shaped Reflector is also called Hughes Shaped Reflector. (Hughes Aircraft Company was a major American aerospace and defence contractor founded in 1932 by Howard Hughes in Culver City, California as a division of Hughes Tool Company. The company was known for producing, among other products, the Hughes H-4 Hercules "Spruce Goose" aircraft, the atmospheric entry probe carried by the Galileo spacecraft, and the AIM-4 Falcon guided missile.)
- ***Design of Shaped Reflector System:***
  - Design of these reflectors is based on the ground area of interest (where the antenna is to be places). A grid is lain on the map (again, the area of interest) and at each grid intersection a weighing factor is assigned which corresponds to antenna gain desired in that direction. Intersection points coincide with the Azimuth angle and Elevation angles (Refer Unit 1-2 for definition) of earth station.
  - The beam shaping stage starts by selecting a smooth parabolic reflector that forms an elliptical beam encompassing the coverage area.
  - The reflector surface is computer modeled as a series of mathematical functions which change until model produces a desired coverage.
- ***Performance Check of Shaped Reflector System:***
  - On the first pass, the computer analyses the function change and translates it into surface ripple.
  - The bam foot print computed for the ripple surface is compared with the coverage area.
  - The function change analysis is refined and the passes are repeated until a good match is obtained.
- ***Uses of Shaped Reflector System***
  - Shaped reflector systems are used to compensate for rainfall attenuation and are mostly used by direct broadcast satellites.

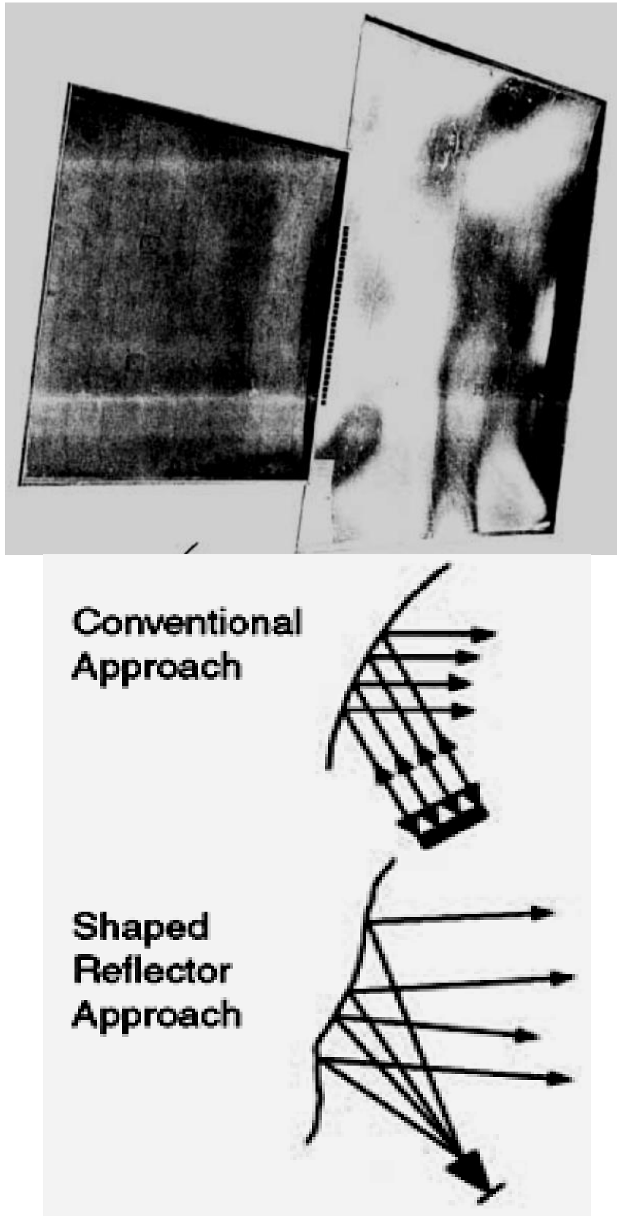

Figure 6b.9: Shaped- Reflector showing ray path.

6B.7 SUMMARY

In continuation with Unit Via, this unit discusses various antennas and their structures which are used by different types of satellites revolving around the earth for various purposes. This unit begins with the Horn Antennas, they are of three types: Conical, Corrugated and Pyramidal.

Further this unit discusses the Parabolic reflectors reflector which has a focusing device which helps to concentrate in one direction. Going further, the next topic discussed is the double-shaped reflector antennas. These antennas are generally located at the earth station and their structure resembles a parabola. These antennas are of two types depending on their shape; Cassegrain and Gregorian.

To conclude with, this unit discusses a discovery by Sir Hughes which is called as Shaped-Reflector system which is designed to trap the signal coming to the antenna with a special modification in antenna's shape and creating ripples on its surface for making the surface appropriate for reflection in certain angles only.

6B.8 EXERCISE

8. What is the need of creating ripples on the surface of Hughes shaped reflector antennas?
9. Write a note on describing the shaped reflector system.
10. What are double reflector antennas? Elaborate on its two types.
11. Write a note on Cassegrain Antenna.
12. Write a note on Gregorian Antenna.
13. What is an offset feed of an antenna?
14. How can parabolic reflectors used in satellite communication to enhance the gain of antennas?
15. Write a note on Horn antennas.

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COMMUNICATION SATELLITES PART I

Contents:

7.1 INTRODUCTION

- Communication satellites are specifically made for telecommunication purpose. They are used for mobile applications such as communication to ships, vehicles, planes, hand-held terminals and for TV and radio broadcasting.

- They are responsible for providing these services to an assigned region (area) on the earth. The power and bandwidth of these satellites depend upon the preferred size of the footprint, complexity of the traffic control protocol schemes and the cost of ground stations.

- A satellite works most efficiently when the transmissions are focused with a desired area. When the area is focused, then the emissions don't go outside that designated area and thus minimizing the interference to the other systems. This leads more efficient spectrum usage.

- Satellite's antenna patterns play an important role and must be designed to best cover the designated geographical area (which is generally irregular in shape).

- Satellites should be designed by keeping in mind its usability for short and long term effects throughout its life time.

- The earth station should be in a position to control the satellite if it drifts from its orbit ir is subjected to any kind of drag from the external forces.

- The designing of a satellite begins with a base line space craft design, meeting all the technical requirements such as EIRP and coverage. The synthesis process provides useful parameters such as size and weight of the spacecraft.

- Let us consider some major design considerations of a communication satellite.

7.2 DESIGN CONSIDERATIONS

7.2.1) Communication Considerations

- For telecommunication satellite, the main design considerations are:
  - i) Type of service to be provided
  - ii) Communication capacity
  - iii) Coverage area
  - iv) Technological limitations

- Depending upon the type of service to be provided be the satellite, basic specifications are laid down.
- For domestic fixed satellite services, the main parameters are EIRP per carrier, number of carriers and the assigned coverage area.
- For direct broadcast satellites, the number of television channels and coverage area is specified.
- Based on these parameters, satellites are designed to fulfill the areas needs and at the same time it should be made in the specified cost fulfilling all the technical constraints.
- While developing a satellite, the earth station's previous experience and in-house capabilities are also taken into account.
- Often, for same set of requirements, different types of configurations are often proposed.

7.2.2) Environmental Conditions

Different environmental conditions are encountered by a satellite during its mission. Some of them are mentioned below.

7.2.2.1) Zero Gravity:

- In geostationary earth orbit, effect of earth's gravity is negligible thus making the "zero gravity" effect.

- Disadvantage: This causes a problem for liquids to flow. The major issue of fuel is encountered. Thus an external provision has to be made to force the liquids to flow.
- Advantage: Absence of gravity leads to operation of deployment mechanism used for stowing antennas and solar panels during the launch.

7.2.2.2) Atmospheric pressure and temperature:

- At geostationary earth orbit, atmospheric pressure is very low, thus making the thermal conditions negligible which further leads to the increase in friction between surfaces.

- Thus additional lubricants are required to keep the satellite parts in motion.

- Due to the presence of electronic components inside the satellite, pressure us the satellite is higher making the functioning of the inner components of the satellite more manageable.

- Sun's heat also affects the external components of the satellite.

7.2.2.3) Space Particles:

- Besides planets, natural and artificial satellites, many other particles like cosmic rays, protons, electrons, meteoroids and manmade space debris exists in space.

- These particles collide with the satellites causing permanent damage to it and sometimes degrading the solar cells.

- Space debris, also known as orbital debris, space junk and space waste, is the collection of objects in orbit around Earth that were created by humans but no longer serve any useful purpose. These objects consist of everything from spent rocket stages and defunct satellites to explosion and collision fragments.

- The debris can include slag and dust from solid rocket motors, surface degradation products such as paint flakes, clusters of small needles, and objects released due to the impact of micrometeoroids or fairly small debris onto spacecraft. As the orbits of these objects often overlap the trajectories of spacecraft, debris is a potential collision risk.

- The vast majority of the estimated tens of millions of pieces of space debris are small particles, like paint flakes and solid rocket fuel slag. Impacts of these particles cause erosive damage, similar to sandblasting. The majority of this damage can be mitigated through the use of a technique originally developed to protect spacecraft from micrometeorites, by adding a thin layer of metal foil outside of the main spacecraft body.

- Impacts take place at such high velocities that the debris is vaporized when it collides with the foil, and the resulting plasma spreads out quickly enough that it does not cause serious damage to the inner wall. However, not all parts of a spacecraft may be protected in this manner, i.e. solar panels and optical devices (such as telescopes, or star trackers), and these components are subject to constant wear by debris and micrometeorites.

- The present means for spacecraft shielding, such as those used for the manned modules of the International Space Station, are only capable of protecting against debris with diameters below about 1 centimeter. The only remaining means of protection would be to maneuver the spacecraft in order to avoid a collision. This, however, requires that the orbit of the respective object be precisely known.

- If a collision with larger debris does occur, many of the resulting fragments from the damaged spacecraft will also be in the 1 kilogram mass range, and these objects become an additional collision risk.

- As the chance of collision is a function of the number of objects in space, there is a critical density where the creation of new debris occurs faster than the various natural forces that remove these objects from orbit. Beyond this point a runaway chain reaction can occur that quickly reduces all objects in orbit to debris in a period of years or months.

7.2.2.4) Magnetic Fields:

- Due to the magnetic field of earth, charged particles which are trapped in the surrounding region of the earth get deflected.

- This effect is more seen in the layers around the equator where the magnetic power of the earth is of maximum effect. This region is called the Van Allen’s Belt.

- Even though satellites in geostationary earth orbit are not really affected by the earth’s magnetic field, they have to pass through the Van Allen’s belt during orbit raising (launching).

- The electric charges present in this belt affect the electronic components against radiation.

- To overcome this effect, large coils are used by satellites.

7.2.2.5) Other Considerations:

- During eclipses, satellite’s solar cells face a loss of power and over the period of years, they degrade.

- Satellites in geostationary earth orbit are also affected by a number of external forces (like gravitational pull from sun and moon) which eventually makes them deviate gradually from their orbit.

- Moreover the solar radiation falling on the surface of the satellite generates pressure which gradually leads to a change in the eccentricity of the orbit.

- As satellite rotates full 360^0along its North – South axis over a sidereal day, the net effect of these forces on the satellite is to cause a gradual drift from its nominal position together with a short – term variations in pointing towards the earth. These perbutations are controlled by an on-board orbit control system.

7.3 LIFETIME AND RELIABILITY

7.3.1) Lifetime:

- The useful lifetime of a geostationary satellite is determined by the highest tolerable deviation in inclination and orbit location together with reliability of satellite’s critical sub-system.

- A lifetime could be improved by increasing the fuel capacity and by saving fuel by accepting orbital deviation to the maximum extent that is possible. Saving fuel couldn’t be implemented to a great level. So for this purpose propulsion is used.

- Propulsion: It is a method used to accelerate spacecraft and artificial satellites.

7.3.2) Reliability

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

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

- The main attraction of these devices is their very high gain (30-60 dB), linear characteristics and 1-2 octave bandwidth. They are quite widely used professionally, but are still rather scarce in amateur circles. This article describes a little of the theory of twts, and explains how to use them, in the hope that more amateurs may be able to acquire and use these fascinating components.

- When used as receiver RF amplifiers they are characterized by high gain, low noise figure and wide bandwidth, and are known as low noise amplifiers (LNAS). These usually come with tube, mount and power supply in one integral unit, with no external adjustments to make-just input socket, output socket and mains supply connections. A typical LNA has an octave bandwidth (eg 2-4 GHz), 30 dB gain, 8 dB noise figure, and a saturated power output of 10 mW, within a volume of 2 in by 2 in by 10 in.

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

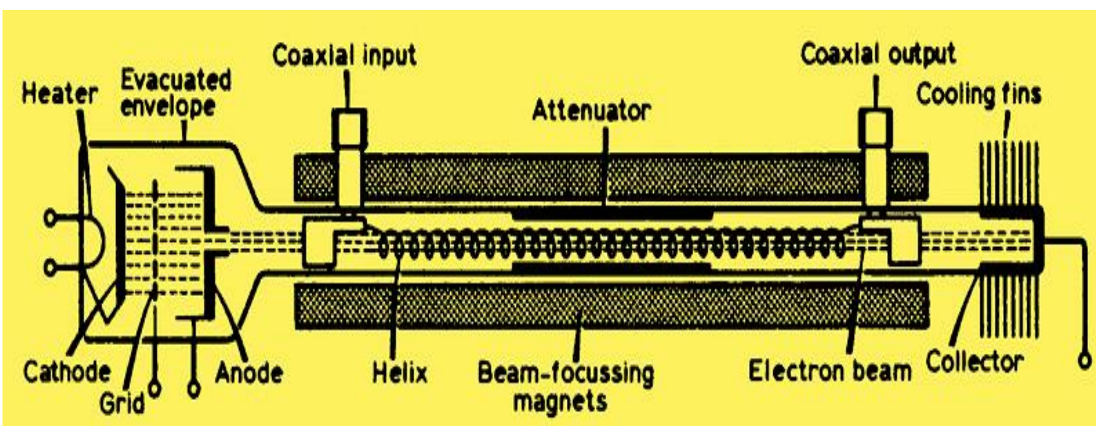

Figure 7.1: TWTA

- Other critical components are antenna reflectors, beaming assemblers etc.

- A reliability model is used to calculate the satellite's reliability. It is defined as "the probability that a given component or system performs its functions as desired within a specific time t.

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

  - Early high failure rate region: used for manufacturing faults, defects in material etc.
  - Low failure: used for random component failure.
  - High failure rate: used for components weave-out.

- Certainly early failures criteria is eliminated as most of the components are tested before used in the satellite.

- Random failures are more seen. They could be reduced by using reliable engineering techniques.

- The life-spam of component could be increased by improving manufacturing techniques and the type of material used to reduce the number of worn out parts and hence reducing the high failure rate criteria.

- It is sent that the failure rate is constant over time and is looking at this reliability can be determined.

- The system is made of several components, connected in a series, then the overall reliability is determined.

- By duplicating the less reliable and critical components, the overall reliability of the system could be improved. If any failure occurs in operational unit, then the standby unit takes over to develop a system with redundant components, its redundant elements are considered in parallel.

- Parallel redundancy is useful when the reliability of an individual sub-system is high.

- Example: consider a system having *i* parallel components in which reliability of each element is independent of others.

- If Qi is the unreliability of the $\mathbf{i^{th}}$ parallel element, then the probability that all units will fail is the product of the individual un-reliabilities:

$$Qs = Q1\ Q2\ Q3\ \ldots\ Qi$$

- When the un-reliability of all elements is equal, then Qs = Qi where Q is the un-reliability of each element.

- By doing a complete failure analysis, one could find out which failure occurs more than the rest and such analysis help in finding out the manufacturing defects in the product of a given batch of components or probably a design defect.

- This analysis is done to reduce the overall reliability to a value less than that predicted by the above analysis.

- Co-related failures could also be reduced by using units from different manufacturers. The design defects are generic to all satellite produced in a series. Generally these defects are detected and corrected to minimize their impact. This is done when a complete design change cannot be implemented.

- Even through the reliability can be improved by adding redundant devices and components, the weight of the satellite increases which again becomes a problem. Redundant component also increase the cost of the satellite.

- The two major cost components are:
    - Cost of equipment together with the switching and failure sensing mechanism used.
    - The associated increase in weight of the satellite resulting in an increased launch cost.

- Optimization techniques are performed for cost minimization purpose.

7.4 EXERCISE

1. Discuss the design considerations of a communication satellite.
2. What issues are faced by communication satellites wrt lifetime and reliability?
3. What are space particles? What is their impact on the satellites?
4. Explain the design and functionality of a travelling wave tube amplifier.

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8

COMMUNICATION SATELLITES – PART II

Contents:

8.1 SPACE CRAFT SUB-SYSTEMS

A communication satellite consists of two main functions, they are payload and bus. Payload is required for communication whereas bus is required for mechanical and electrical support. Bus supports altitude and orbit controls, propulsion, TT&C and electrical power where as payload supports the band used for communication, the space links and the devices to remove interferences.

8.2 PAYLOAD

The payload comprises of a Repeater and Antenna sub-system and performs the primary function of communication.

8.2.1) REPEATER

- It is a device that receives a signal and retransmits it to a higher level and/or higher power onto the other side of the obstruction so that the signal can cover longer distance.
- A repeater in the satellite receives the uplink RF signal and converts it to an appropriate downlink frequency.
- It does the work of processing the received signal. Two types of repeater architectures are used. They are given below.

8.2.1.1) Transparent Repeater

- It only translates the uplink frequency to an appropriate downlink frequency. It does so without processing the baseband signal. The main element of a typical transparent repeater is a single beam satellite. Signals from antenna and the feed system are fed into the low-noise amplifier through a bandpass filter.
- The bandpass filter attenuates all out-of band signals such as transmission from the ground stations of adjacent satellite systems. The low-noise amplifier provides amplification to the weak received signals.

- The spacecraft antenna is pointed towards a relatively warm earth having noise temperature about 300K. thus there is not much point in reducing the noise temperature below a certain point.

8.2.1.2) Regenerative Repeater

- A repeater, designed for digital transmission, in which digital signals are amplified, reshaped, retimed, and retransmitted. Regenerative Repeater can also be called as a device which regenerates incoming digital signals and then retransmits these signals on an outgoing circuit.

- It not only translates and amplifies the signal, but is also does the task of demodulation, baseband processing and demodulation. This architecture of repeater is the best suited for digital systems and it offers several advantages over transparent repeaters.

- When any digital signal is transmitted over a pair of wires, it degrades in amplitude. Regenerative repeaters receives the incoming signal, extracts the clock, then regenerates the original signal as a clean digital square wave as if it was the original signal transmitted from the source.

8.2.2) Antennas

- The function of an antenna of a space craft is to receive signals and transmit signals to the ground stations located within the coverage area of the satellite. The choice of the antenna system is therefore governed by the size and shape of the coverage area. Consequently, there is also a limit to the minimum size of the antenna footprint.

- An antenna (or aerial) is a transducer that transmits or receives electromagnetic waves. In other words, antennas convert electromagnetic radiation into electrical current, or vice versa. Antennas generally deal in the transmission and reception of radio waves, and are a necessary part of all radio equipment.

- Antennas are used in systems such as radio and television broadcasting, point-to-point radio communication, wireless LAN, cell phones, radar, andspacecraft communication. Antennas are most commonly employed in air or outer space, but can also be operated under water or even through soil and rock at certain frequencies for short distances.

- Physically, an antenna is an arrangement of one or more conductors, usually called *elements* in this context. In transmission, an alternating current is created in the elements by applying a voltage at the antenna terminals, causing the elements to radiate an electromagnetic field.

- In reception, the inverse occurs: an electromagnetic field from another source induces an alternating current in the elements and a corresponding voltage at the antenna's terminals. Some receiving antennas incorporate shaped reflective surfaces to collect the radio waves striking them and direct or focus them onto the actual conductive elements.

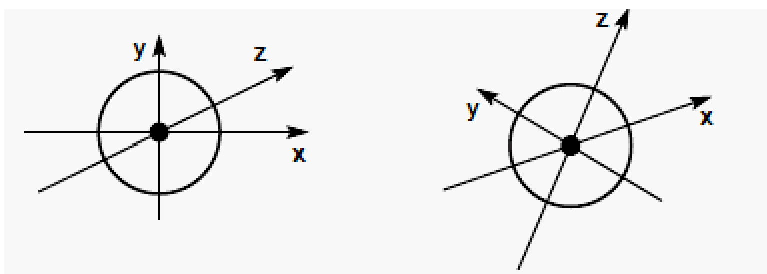
- 

Figure: 8.1: Radiation pattern of an isotropic radiator

- A theoretical reference antenna is the *isotropic radiator*, a point in space radiating equal power in all directions, i.e., all points with equal power are located on a sphere with the antenna as its center. The *radiation pattern*is symmetric in all directions (see figure 8.1).

  (Radiation Pattern: The radiation pattern of an antenna is the geometric pattern of the relative field strengths of the field emitted by the antenna. For the ideal isotropic antenna, this would be a sphere. For a typical dipole, this would be a toroid. The radiation pattern of an antenna is typically represented by a three dimensional graph, or polar plots of the horizontal and vertical cross sections.)

- This is a theoretical definition of an antenna, in real, the intensity radiation is not equal in all directions, and this is called *directive effects.* The simplest antenna is a *dipole antenna*, which can be made by a simple wire with a center-fed driven element. The current amplitude on such an antenna decreases uniformly from maximum at the center to zero at the ends.It's also called *Hertzian dipole* as this antenna was created by Heinrich Rudolph Hertz around1886.

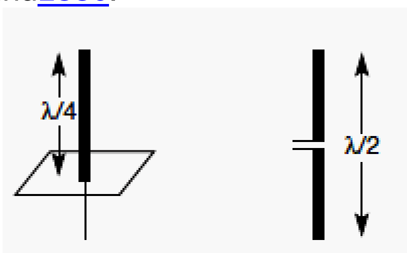


Figure 8.2: Simple Antenna

- The length of the dipole is not arbitrary, but, for example, half the wavelength *λ* of the signal to transmit results in a very efficient radiation of the energy. If mounted on the roof of a car, the length of *λ*/4 is efficient. This is also known as Marconi antenna. A *λ*/2 dipole has a uniform or *omni-directional*radiation pattern in one plane and a figure eight pattern in the other two planes as shown in Figure 8.3. This type of antenna can only overcome environmental challenges by boosting the power level of the signal.

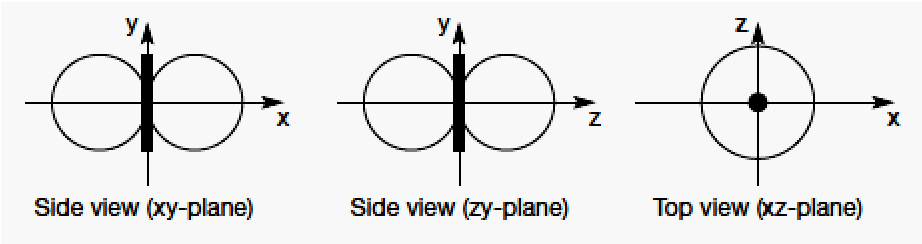


Figure 8.3: Radiation pattern of simple dipole

- Obstructions for these antennas could be mountains, valleys, buildings etc. as if they are placed between mountains or buildings, the omni-direction pattern doesn't work well. Thus, in these places, a *directional antenna* proves to be more effective. A *directional antenna* radiates greater power in one or more directions allowing for increased performance on transmit and receive and reduced interference from unwanted sources. Directional antennas provide increased performance over dipole antennas when a greater concentration of radiation in a certain direction is desired.
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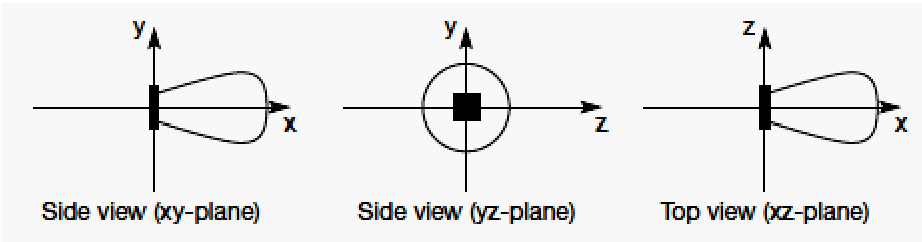

Figure 8.4: Radiation pattern of a directional antenna

- Many directional antennas can be combined together to form a *sectorized antenna*.

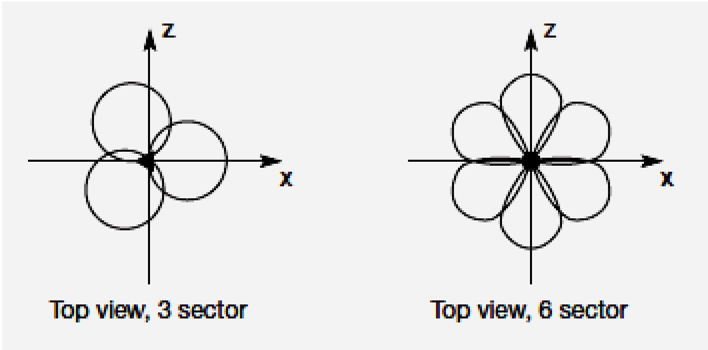

Figure 8.5: Radiation pattern of sectorized antenna

- Two or more antennas can also be combined to improve reception by counteracting the negative effects of multi-path propagation. These antennas, also called *multi-element antenna arrays*, allow different diversity schemes. One such scheme is *switched diversity*or *selection diversity*, where the receiver always uses the antenna element with the largest output.

- *Diversity combining*constitutes a combination of the power of all signals to produce gain. The phase is first corrected to avoid cancellation. As shown in Figure 8.6, different schemes are possible. On the left, two $\lambda/4$ antennas are combined with a distance of $\lambda/2$ between them on top of a ground plane. On the right, three standard $\lambda/2$ dipoles are combined with a distance of $\lambda/2$ between them. Spacing could also be in multiples of $\lambda/2$.

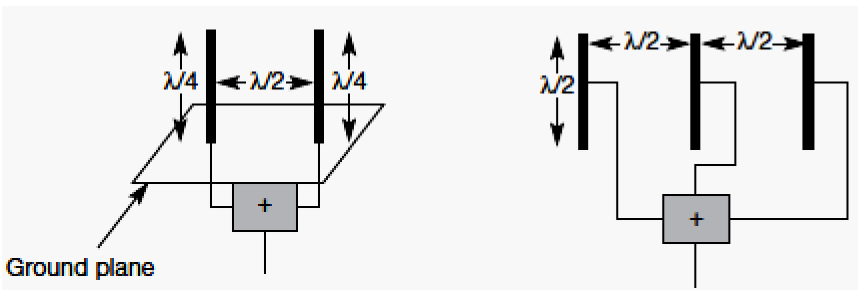

Figure 8.6: Diversity antenna systems

- Another type of antennas is *smart antennas*, which combine multiple antenna elements with signal processing to optimize the radiation/reception pattern in response to the signal environment. These antennas can adapt to changes in reception power, transmission conditions and many signal propagation effects. They are also known as also known as adaptive array antennas. They use smart signal processing algorithms used to identify spatial signal signatureto track and locate the antenna beam on the mobile/target.

- It would not just be base stations that could follow users with an individual beam. Wireless devices, too, could direct their electromagnetic radiation, e.g., away from the human body towards a base station. This would help in reducing the absorbed radiation.

(Antenna gain relates the intensity of an antenna in a given direction to the intensity that would be produced by a hypothetical ideal antenna that radiates equally in all directions and has no losses. Since the radiation intensity from a lossless isotropic antenna equals the power into the antenna divided by a solid angle of 4π, we can write the following equation:

$$Gain = 4\pi\left(\frac{\text{Radiation Intensity}}{\text{Antenna Input Power}}\right)$$

Although the gain of an antenna is directly related to its directivity, the antenna gain is a measure that takes into account the efficiency of the antenna as well as its directional capabilities. In contrast, directivity is defined as a measure that takes into account only the directional properties of the antenna and therefore it is only influenced by the antenna pattern. However, if we assumed an ideal antenna without losses then Antenna Gain will equal directivity as the antenna efficiency factor equals 1 i.e. 100% efficiency. In practice, the gain of an antenna is always less than its directivity.**)**

8.3 BUS

The bus or payload platform consists of the subsystems that support the payload. These subsystems typically include:

- ***Structures subsystem*****:** the physical structure of the spacecraft, to which all electronics boxes, thrusters, sensors, propellant tanks, and other components are mounted;

- ***Electric power/distribution subsystem (EPS or EPDS):*** the hard- and software used to generate and distribute electrical power to the spacecraft, including solar arrays, batteries, solar-array controllers, power converters, electrical harnesses, battery-charge-control electronics, and other components;

- ***Telemetry, tracking, and command subsystem (TT&C):*** The electronics used to track, monitor, and communicate with the spacecraft from the ground. TT&C equipment generally includes receivers, transmitters, antennas, tape recorders, and state-of-health sensors for parameters such as temperature, electrical current, voltage, propellant tank pressure, enable/disable status for various components, etc.;

- ***Propulsion subsystem:*** Liquid and solid rockets or compressed-gas jets and associated hardware used for changing satellite attitude, velocity, or spin rate. Solid rockets are usually used for placing a satellite in its final orbit after separation from the launch vehicle. The liquid engines (along with associated plumbing lines, valves, and tanks) may be used for attitude control and orbit adjustments as well as final orbit insertion after launch;

- ***Power supply:*** The primary electrical power for operating electronic equipment is obtained from solar cells. Individual cells can generate small amounts of power, and therefore array of cells in series-parallel connection are required. Cylindrical solar arrays are used with spinning satellites, thus the array are only partially in sunshine at any given time. Another type of solar panel is the rectangular array or solar sail. solar sail must be folded during the launch phase and extended when in geo-stationary orbit. Since the full component of solar cells are exposed to sun light ,and since the Sail rotate to track, the sun , they capable of greater power output than cylindrical arrays having a comparable number of cells.To maintain service during an eclipse, storage batteries must be provided.

- ***Attitude control:*** The attitude of a satellite refers to its Orientation in space. Much of equipment carried abroad a satellite is there for the purpose of controlling its attitude. Attitude control is necessary, for example, to ensure that directional antennas point in the proper directions. In the case of earth environmental satellites the earth-sensing instrument must cover the required regions of the earth, which also requires attitude control. A number of forces, referred to as disturbance forces can alter attitude, some examples being the gravitational forces of earth and moon, solar radiation, and meteorite impacts.

- ***Station keeping:*** A satellite that is normally in geo-stationary will also drift in latitude, the main perturbing forces being the gravitational pull of the sun and the moon. The force causes the inclination to change at the rate of about 0.85 deg/year. If left uncorrected, the drift would result in a cycle change in the inclination going 0 to 14.67deg in 26.6 years and back to zero, when the cycle is repeated. To prevent the shift in inclination from exceeding specified limits, jets may be pulled at the appropriate time to return the inclination to zero. Counteracting jets must be pulsed when the inclination is at zero to halt that change in inclination.

- ***<u>Thermal control:</u>*** Satellites are subject to large thermal gradients, receiving the sun radiation on one side while the other side faces into space. In addition, thermal radiation from the earth, and the earth's abedo, which is the fraction on the radiation falling on the earth which is reflected can be sight for low altitude, earth-orbiting satellites, although it is negligible for geo-stationary satellites. Equipment in the satellite also generates heat which has to be removed. The most important consideration is that the satellite's equipment should operate as near as possible in a stable temperature environment. Various steps are taken to achieve this. Thermal blankets and shields may be used to provide insulation. Radiation mirrors are often used to remove heat from communication payload. These mirrored drums surrounded the communication equipment shelves in each case and provide good radiation paths for the generated heat to escape in to surround space.To maintain constant-temperature conditions, heaters may be switched on to make up for the hearts may be switched on to make reduction that occurs when transponders are switched off.

8.4 TELEMETRIC TRACKING AND COMMAND SUBSYSTEM

The main functions of TT&C are:

1) Monitor the performance of all the satellite sub-systems and transmit the monitored data to the satellite control center.
2) Support the determination of orbital parameters.
3) Provide a source earth station for tracking.
4) Receive commands from the control center for performing various functions of the satellite.

<u>Telemetry system</u>

- The telemetry, tracking, and command (TT&C) subsystem performs several routine functions abroad a spacecraft. The telemetry or "telemetering" function could be interpreted as "measurement at a distance". Specifically, it refers to the overall operation of generating an electrical signal proportional to the quantity being measured, and encoding and transmitting this to a distant station, which for satellite is one of the earth stations, which for the satellite is one of the earth stations.

- Data that are transmitted as telemetry signals include attribute information such as obtained from sun earth sensors; environmental information such as magnetic field intensity and direction; the frequency of meteorite impact and so on ;and spacecraft information such as temperatures and power supply voltages, and stored fuel pressure.

- Summary of the parameters monitored by the Telemetry system are:
  1) Voltage, current and temperature of all major sub-systems.
  2) Switch status of communication transponders.
  3) Pressure of the propulsion tanks
  4) Outputs from altitude sensors.
  5) Reaction wheel speed

Command systems

- Command system receives instructions from ground system of satellite and decodes the instruction and sends commends to other systems as per the instruction.

- Example of commands are:
  1) Transponder switching
  2) Switch matrix configuration
  3) Antenna pointing control
  4) Controlling direction and speed of solar array drive
  5) Battery reconditioning
  6) Beacon switching
  7) Thruster firing
  8) Switching heaters of the various sub-systems

Tracking

- Tracking of the satellite is accomplished by having the satellite is accomplished by having the satellite transmit beacon signals which are received at the TT&C earth stations. Tracking is obviously important during the transmitter and drift orbital phases of the satellite launch.

- When on-station, a geo-stationary satellite will tend to shifted as a result of the various distributing forces, as described previously. Therefore it is necessary to be able to track the satellites movements and send correction signals as required. Satellite range is also required for time to time. This can be determined by measurement of propagation delay of signals specially transmitted for ranging purposes.

8.5 EXERCISE

1. Discuss the TT&C system of a communication satellite.
2. Elaborate on the bus system of the communication satellites.
3. Write a note on antennas used for communication satellites.

4. What is a Regenerative Repeater? How is it different from Transparent Repeater?

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9

MULTIPLE ACCESS TECHNIQUES

Contents:

9.1 INTRODUCTION

- Multiple accesses is defined as the technique where in more than one pair of earth stations can simultaneously use a satellite transponder.It is a technique used to explore the satellite’s geometric advantages and is at the core of satellite networking.

- In a wireless communication system, radio resources must be provided in each cell to assure the interchange of data between the mobile terminal and the base station. Uplink is from the mobile users to the base station and downlink is from the base station to the mobile users. Each transmitting terminal employs different resources of the cell. A multiple access scheme is a method used to distinguish among different simultaneous transmissions in a cell. A radio resource can be a different time interval, a frequency interval or a code with a suitable power level.

- All these characteristics (i.e., time, frequency, code and power) univocally contribute to identify a radio resource. If the different transmissions are differentiated only for the frequency band, we have the Frequency Division Multiple Access (FDMA). Whereas, if transmissions are distinguished on the basis of time, then they are consider the Time Division Multiple Access (TDMA). Finally, if a different code is adopted to separate simultaneous transmissions, we have the Code Division Multiple Access (CDMA).

- However, resources can be also differentiated by more than one of the above aspects. Hence, hybrid multiple access schemes are possible (e.g., FDMA/TDMA). In a satellite communication, radio resources can be re-used between sufficiently far stations, provided that the mutual interference level is at an acceptable level.

- This technique is adopted by FDMA and TDMA air interface, where the reuse is basically of carriers. In the CDMA case, the number of available codes is so high that the code reuse among cells (if adopted) does not increase the interference. In uplink, a suitable Medium Access Control (MAC) protocol is used to regulate the access of different terminals to the resources of a cell that are provided by a multiple access scheme.

In this unit, we concentrate on all the three schemes of multiple access.

9.2 FREQUENCY DIVISION MULTIPLE ACCESS (FDMA)

- FDMA is a channel access method used in multiple-access protocols as a channelization protocol. FDMA gives users an individual allocation of one or several frequency bands, or channels. Multiple Access systems coordinate access between multiple users.

Key features of FDMA are:

- FDMA requires high-performing filters in the radio hardware, in contrast to TDMA and CDMA.
- FDMA is not vulnerable to the timing problems that TDMA has. Since a predetermined frequency band is available for the entire period of communication, stream data (a continuous flow of data that may not be packetized) can easily be used with FDMA.
- Due to the frequency filtering, FDMA is not sensitive to near-far problem which is pronounced for CDMA.
- Each user transmits and receives at different frequencies as each user gets a unique frequency slot

- It is important to distinguish between FDMA and frequency-division duplexing (FDD). While FDMA allows multiple users simultaneous access to a certain system, FDD refers to how the radio channel is shared between the uplink and downlink (for instance, the traffic going back and forth between a mobile-phone and a base-station).

- Furthermore, frequency-division multiplexing (FDM) should not be confused with FDMA. The former is a physical layer technique that combines and transmits low-bandwidth channels through a high-bandwidth channel. FDMA, on the other hand, is an access method in the data link layer.

- FDMA also supports demand assignment in addition to fixed assignment. Demand assignment allows all users apparently continuous access of the radio spectrum by assigning carrier frequencies on a temporary basis using a statistical assignment process. The first FDMA demand-assignment system for satellite was developed by COMSAT for use on the Intelsat series IVA and V satellites.

- In this scheme, a bandwidth is assigned to an earth station and is divided into n segments to manage the network traffic.

  FDMS is divided into two categories:
  - Multiple Channel Per Carrier
  - Single Channel Per Carrier

A) Multiple Channel Per Carrier (MCPC)

- Each base band filter is an earth station receiver, which correspondent to a specific transmitting station.
- Changes in the traffic are not favorable.

- MCPC is referred as Frequency Division Multiplexing / Frequency Modulation/ Frequency Division Multiple Access scheme.

B) Single Channel Per Carrier

- Certain applications have a low requirement. At such times, the earth station's load is comparatively less. Here, instead of assigning multiple channel carriers to each station demand assign or pre-assigned schemes are preferred and used.

- In demand-assign, pool of frequencies is shared by each earth station which they use as and when required by requesting a channel from the pool manager.

- In pre-assigned method, channels are permanently assigned to an earth station for its use.

- Demand-assign is more preferred over pre-assigned method, as a reduction in cost is possible through sharing of equipments.

- The frequency pool is managed in two ways: Distributed and Centralized.

- *Distributed:* Each earth station can obtain a channel from the pool on its own i.e. without taking the permission from the pool manager. This scheme is more reliable as failure of one earth station will not affect the entire network. Nevertheless, this scheme is less cost efficient due to increase complexity in earth station's working in the network.

- *Centralized:* this scheme is simple to control and it provides a higher usage of channels because of the availability of all information at a single point. This scheme also offers a lower time connection time. Nevertheless, this network is less reliable, as it is prone to a single point failure. If the pool manager crashes, the entire system fails.

- It is also possible to have a hybrid frequency management schemes in which the network provides acombination of Distributed and Centralized frequency management functions to get the advantage of both the systems.

9.2.1) Design Considerations of FDMA system

Design considerations of FDMA system are as follows:

A) Impairments caused by Satellite's High Power Amplifiers:

- High power amplifiers in satellites face the problem of non-linearity when the output level approaches saturation. This leads to inter modulation noise.

  (Inter modulation noise: It is the unwanted amplitude modulation of signal containing two or more different frequencies).

- To minimize the effect of inter modulation noise, the derive level of the output stage of satellite transmitter is made to *back off* (i.e. its power is reduced). Thus the full power capacity of the amplifier is not utilized causing reduction in the capacity.

B) Other Impairments:

- To increase the frequency utilization, carriers are brought as close to each other as possible. This causes the spectrum to overlap, leading to *adjacent channel interference.*
  (Spectrum: It is an ordered array of the components of an emission / wave)

- Convolution noise can occur when adjacent carrier has smaller amplitude than the desired carrier. Impulse noise can occur when adjacent carrier has greater amplitude than the desired carrier.

- The above interferences can be minimized by filtering the out of the band inter modulations in each transponders.

  (Transponder: It is an electrical device designed to receive a specific signal and it automatically transmits a specific reply.)

- Delay occurs in filters in transmission path leading to another source of distortion. This again increases the noise.

9.2.2) Transponder Utilization

- Two factors limit the number of FDMA accesses through a transponder.
  - i) Inter modulation noise
  - ii) Spectrum utilization efficiency

9.2.3) Summary of salient features of FDMA

A) Advantages of FDMA:

- Uses existing hardware and hence this technology is cost efficient
- Network timing is not required, hence making the system less complex.
- No restrictions regarding the type of baseband type of modulation is there.

B) Disadvantage of FDMA

- Inter modulation noise in the transponder leads to interference with other links sharing new spectrum and thus reduces the capacity of satellite.
- Flexibility in channel allocation is less (as seen in MCPC, but not in SCPC).
- Uplink power control is required to maintain the link quality.
- As strong and weak carriers, both are used, weak carriers are often suppressed.

9.3 TIME DIVISION MULTIPLE ACCESS (TDMA)

- Time division multiple access (TDMA) is a channel access method for shared medium networks. It allows several users to share the same frequency channel by dividing the signal into different time slots. The users transmit in rapid succession, one after the other, each using his own time slot. This allows multiple stations to share the same transmission medium (e.g. radio frequency channel) while using only a part of its channel capacity.

- TDMA is a type of Time-division multiplexing, with the special point that instead of having one transmitter connected to one receiver, there are multiple transmitters. In the case of the uplink from a mobile phone to a base station this becomes particularly difficult because the mobile phone can move around and vary the timing advance required to make its transmission match the gap in transmission from its peers.

Features of TDMA

- Shares single carrier frequency with multiple users
- Non-continuous transmission makes handoff simpler
- Slots can be assigned on demand in dynamic TDMA
- Less stringent power control than CDMA due to reduced intra cell interference
- Higher synchronization overhead than CDMA
- Advanced equalization may be necessary for high data rates if the channel is "frequency selective" and creates inter-symbol interference
- Cell breathing (borrowing resources from adjacent cells) is more complicated than in CDMA
- Frequency/slot allocation complexity
- Pulsating power envelop: Interference with other devices

For satellite communication TDMA works in the following manner.

- TDMA systems are used in commercial satellite applications. The first system type is the classic TDMA implementation employing a single modulated carrier occupying the full transponder's bandwidth.

- This system is most common for TDMA networks and is also most efficient from a capacity standard's point.
- Each user is allocated a specific time slot for transmission due to which overlapping is avoided.
- System capacity is increased as only a single carrier is present at any given time.
- Disadvantage is that the messages need to be stored, compressed and transmitted during one or more specific time slots. At network level, all transmissions must be synchronized to avoid collision between the bursts.

(Burst: It is a term used in a number of information technology contexts to mean a specific amount of data sent or received in one intermittent time.)

- An earth station has a full access to a transponder during its allocated time slot.
- Transmissions are in frame format.
- On receiving al the bursts, earth station removes the data addresses from it.
- Guard time is used to separate time-slots. The time-slot size depends on the traffic requirements.
- TDMA also works on demand- assign method.
- Reference burst has three parts

Carrier and Bit Recovery	**Unique Word**	**Control Bits**
Used by the receivers for recovering the carrier and bit time which is essential for coherent demodulation	It is used for burst synchronization. This is done by co-relating a stored replica of the unique word with the received bits.	Control bits contain information such as station ID and engineering service messages for network management.

- Carrier and bit recovery, unique word and control bits together are called the *preamble*.
- CDMA uses two methods for synchronization:

9.3.1) Design Considerations

Design considerations of TDMA system are as follows:

I) Closed Loop:

- Whatever adjustments are made to the burst's position is based on the real-time measurements.

Transmission begins at *i*
Assigned time slot is acquired.
Estimated position of the initial burst is *Tm*
Transmission is done at lower power.

Received burst comparison with the desired position is done- *Ta*
Time-slot correction *(Ta – Tm)* is done.

- A carried modulated with a pseudo random signal is transmitted. Such a signal has a noise like property and when transmitted at low power does not affect the other bursts.

- Receiver has a co-relation receiver where a correction is equal to the difference between the received and desired burst position is used. This method is applied to the original burst position to obtain the current burst position.

II) ***Frame Efficiency:***It is defined as the ratio of time devoted for useful transmission to the total frame length in a TDMA system.

III) Transponder Utilization:

- Transponder utilization depends upon the EIRP (Equivalent isotropically radiated power) or the bandwidth.

- Maximum permissible bit rate is governed by the available transponder bandwidth possible when EIRP is sufficient.

9.3.2) Summary of salient features of TDMA

I) Advantages:

- Here, satellite power utilizations can be maximized as inter modulation noise is minimum.
- Uplink power control is not required.
- Transmission plans and capacity management is done by the satellite are very flexible.
- The digital format of TDMA allows utilization of all advantages of digital techniques.

II) Disadvantages

- It requires a network wide time synchronization which makes the entire system very complex.
- Analog of digital conversions are required.
- Interface with analog terrestrial plan is expected.

9.4 FDMA & TDMA

- In situations where connectivity is required between multiple spot beams, then routing of signal to an appropriate beam is done by having frequency-to-beam correspondence.

- Sub-bands are made and each of them provides a unique route between two spot beams.

- Here transponders can be accessed in FDMA or TDMA mode. As each earth station have to hop between transponders to route the traffic to the desired spot beam this technique is called transponder hopping.
- For *n* spot beams, n^2transponders are required.
- To make this work, flexibility in altering the frequency bands is required. This is done by using switchable routing method.
- In switchable routing method, channels are switched as desired in order to change the available bandwidth of each beam.
- A programmable switch located on the satellite router bursts to spot beams according to a set plan.
- The earth station can direct its transmission to any spot by transmitting in the appropriate time slot.
- Beams are arranged in non-overlapping time-slots.

9.5 CODE DIVISION MULTIPLE ACCESS (CDMA)

- CDMA uses a modulation technique called spread spectrum.Here all the users transmit signals simultaneously on the multiple access schemes.(Spread Spectrum: It refers to a modulation technique that converts the baseband signal to a modulated signal with a spectrum bandwidth that covers or is spread over the band orders of magnitude larger than that normally necessary to transmit the baseband signal itself.)
- It could be used as a multiple access system by giving each user a unique pseudo random code rather than a unique carrier frequency or time slot.
- All the users contribute to the noise background.
- To detect the desired signal in the presence of all the interferences, the composite signal is cross-correlated with the known pseudo random number spreading sequence.
- The net performance is improved essentially by the ration of the un-spread signal bandwidth.

9.5.1) Features of CDMA are:

- Highly resistant to interferences and thus satellite spacing could be reduced considerably without causing unacceptable degradation in the received signal quality.

- Spread spectrum sequences are resistant to multiple noises present in the mobile terminals.

- Small antennas can be used without any interference issues from the neighboring satellites.

- CDMA is a very secure form of communication.

9.5.2) Implementing CDMA

- CDMA technique could be implemented in two forms: Direct sequence spread spectrum and Frequency hopping spread spectrum.

- The property of pseudo random sequences is used by CDMA.

I) Pseudo-Random Sequences

- They are a set of signals which appear ti be a set of random sequences. They are repeated over a time interval, say of Tr.

- In order to use such pseudo (false) random sequences signals in digital form, shift registers are required.These shift registers could be used for maximum length of code of the value $p=(2^{m-1})$,where m-bit register is used.

- This is also called maximum length linear shift register sequence.

- These sequences have 2^{m-1} *ones* and 2^{m-1}*-1zeros* that are places randomly, thus making the entire sequence look random.

II) Direct Sequence Spread Spectrum (DSSS)

- Definition: Direct sequence spread spectrum is a modulation technique where the transmitted signal takes up more bandwidth then the information signal that is being modulated.

- Direct sequence spread spectrum transmissions multiply the data being transmitted by a ‘noise’ signal.

- The noise signal is the pseudo random sequence and has a frequency much higher than that of the original signal. It thus spreads the energy of the original signal into a much wider band

- The resultant signal appears like noise which could be reconstructed to the original signal at the receiving end by multiplying it by the same pseudo random sequence.This process is known as de-spreading. For de-spreading to work correctly, the transmitter and receiver must be synchronized.

- Sometimes while sending the signal from the transmitter's end, other noises like inter modulation noise and thermal noise are transmitted to the receiver. This is also called as narrow-band interference.

- The receiving signal is given as:

  $R_x (t) = C_1 (t) + C_2 (t) + \ldots + C_n (t)$

  Where: C_n (t) is the received signal from the n^{th} transmitter n (t) is the system noise

III) Frequency Hopping Spread Spectrum (FHSS)

- It is a method of transmitting radio signals by rapidly switching a carrier among many frequency channels, using the pseudo random sequences (which are known to both transmitter and receiver).

- Frequency hopping spread spectrum offers three main advantages over fixed frequency transmission techniques:
  i) Spread spectrum signals are highly resistant to narrow band interferences. The process of re-collecting a spread signal spreads out the interfering signal, causing t to recede into the background.

  ii) Spread spectrum signals are difficult to intercept. Frequency hopping spread spectrum signals simply appears as an increase in the background noise to a narrow band receiver.

  iii) Spread spectrum transmission can share a frequency band with many types of conventional transmissions with minimal interference.

- Interference in frequency hopping spread spectrum is caused at instants when an unwanted signal appears within the pass band of the desired signal. It can occur under following conditions:

  i) Transmission of other users of multiple-access channel falls within the range of receiver's pass band.

  ii) Inter modulation noise can be generated due to non-linearities of receiver's channels.

- Interference is noise like when hopping rate is much higher than the information rate. Interference is coherent when hopping rate is smaller than the information rate.

9.6 ACCESS PROTOCOLS FOR DATA TRAFFIC

- All the previous schemes were dealing only with continuous streams of data. The other forms of transfers include the transfer of large amounts of data, channel allocation in demand-assign systems etc.

- Such transfers are categorized as “burst of high activity”. Here the system should be prepared for larger data traffic and delays in message deliveries. Hence, to overcome this problem, allocation of capacity of *pre message* or *packet basis* should be used.

- Accessing schemes for data traffic are categorized as following:
    - Channel reservation scheme
    - Contention protocols

- Packet reservation protocols

9.6.1) Channel Reservation Scheme

- Here the channels are reserved according to the duration of each message transmission. Channels can be pre-assigned or demand-assigned for a particular transaction.

- TDMA and FDMA schemes use this kind of technique.

- When the traffic load is high on the network, then the channel connection time becomes comparable to message transfer time, otherwise its negligible.

- The upper and the lower bound the channel throughput is calculated and it is observed for fixed assigned schemes, where the throughput reaches the maximum value, then the traffic becomes less busty and vice versa. (Throughput is the average rate of successful message delivery over a common channel).

- Generally the inter-arrival message delay does not effects the throughput of the demand-assigned scheme but it is affected by the delay factors on the message.

9.6.2) Contention Protocol

- Here, each use accesses multiple access channels without co-coordinating with any other user that is using the network. Due to this, collisions occur, leading to the loss of packets (data).

- Thus, a re-transmission of lost packets is done and again the network channel is utilized.

- To reduce the probability of collision, various schemes are applied. Such schemes which are suitable for large population of busty users with very short messages are discussed below.

9.6.3) ALOHA Scheme

- This scheme is also known as random access protocol as no coordination is required between the users. Terminals can transmit their data regardless of the activity of other terminals. If the message is successful, then the base station sends an acknowledgement (over the feedback channel).

- If the terminal does not receive an acknowledgement, it retransmits the message after waiting for a random amount of time.

- Here the delay is mainly determined by the probability that a packet is not received (which is because of the interference from other transmissions leading to collision) and the average value of random waiting time before transmission is considered.

9.6.4) Reservation ALOHA

- The main difference between slotted ALOHA and reservation ALOHA is that, any slot is available for utilization without regard to its prior usage in the slotted ALOHA scheme.

- In Reservation ALOHA contention based reservation scheme.A slot is temporarily considered to be 'owned' by a station that successfully used it. Once the station has completed its transmission, it simply stops sending the data. Here the idle slots are considered to be available to all the stations which may then implicitly reserve the slot on contention basis.

- This scheme has shorter delays and it efficiently supports higher level of utilization.

9.6.5) Slot Reservation ALOHA

- This extension of the slotted-ALOHA scheme allows time-slots to be reserved for transmission by an Earth station. This can be achieved implicitly, by which the transmitting station initially contends for an available slot with other transmitting terminals.

- Available slot locations are made known to all transmitting stations within the network by the network control station using a broadcast channel. Once a transmitting station successfully gains access to a particular slot by contention, the network controller informs all other transmitting stations that the slot is no longer available, and the successful transmitting station retains the slot until transmission is complete.

- The network controller then informs all stations on the network that the slot is available for contention once more. The other means of slot reservation is achieved explicitly, whereby a transmitting station requests the network to reserve a particular slot prior to transmission. In general terms, this mode of operation is termed a packet reserved multiple access scheme (PRMA).

9.7 EXERCISE

1. Discuss channel reservation scheme for Satellite communication.
2. Explain the principle used in spectrum spreading and dispreading. How is this used to minimize interference in a CDMA system?
3. Explain the technique of TDMA. How TDMA network is advantageous over FDMA network?
4. Discuss the features of CDMA.
5. Differentiate DSSS with FHSS.

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10

EARTH STATIONS – PART I

Contents:

10.1 INTRODUCTION

- Earth Stations are a vital element in any satellite communication network. The function of an earth station from and transmit information to the satellite network in the most cost efficient and reliable manner while retaining the desired signal quality.

- Depending on the earth application, an earth station may have both transmit and receive capabilities or may only have both transmit and receive capabilities or may only be capable of either transmission or reception.

- Further categorization can be based on the kind of service provided. The fundamental parameter is describing an earth station in the carrier to noise ratio.

10.2 DESIGN CONSIDERATIONS

The design considerations depend on a number of factors, some of them are:

1) Type of service: fixed satellite service, mobile satellite service or broadcast satellite service.

2) Type of communication requirements: telephony, data, television etc.

3) Required baseband signal quality at the destination.
4) Traffic requirements: number of channels, type of traffic-continuous or bursty
5) Cost
6) Reliability

10.2.1) International Regulations

- Most of the fixed satellite service frequency bands are shared with the terrestrial systems. For them to coexist, the International Telecommunication Union (ITU) has specified certain constraints in the transmitted effective radiated power (EIRP) of satellites.

- By limiting the EIRP of satellite for applications like direct broadcast and mobile communication, a smaller diameter antenna could be used. This leads to exclusive allocation of frequency bands. The limitations seen in these applications are mainly because of the technological constraints of the space and ground segments.

10.2.2) Technical Constraints

- The transmitter power of a satellite is limited by the maximum DC power which a satellite can generate and the upper limit of the reliable power amplifiers. The maximal spacecraft antenna gain is limited by the practical constraints imposed on the satellite antenna diameter, if the gain falls for a given antenna size with the decrease in the frequency and therefore the EIRP limitation is more acute at lower frequencies.

- Technical constraints apply to the earth stations hardware and software. Factors which need to be included are the cost for *antennas at earth station, QoS to be maintained, cost of other equipments, floor area, environmental factors, interference considerations and recurring costs.*

10.3) INTRODUCTION TO GENERAL CONFIGURATIONS

Any earth station consists of four major subsystems: Transmitter, Receiver, Antenna, Tracking equipment

Two other important subsystems are

1) Terrestrial interface equipment
2) Power supply.

The earth station depends on the following parameters

i) Transmitter power
ii) Choice of frequency
iii) Gain of antenna
iv) Antenna efficiency
v) Antenna pointing accuracy

vi) Noise temperature
vii) Local conditions such as wind, weather etc,
viii) Polarization
ix) Propagation losses

The functional elements of a basic digital earth station are shown in the below figure 10.1

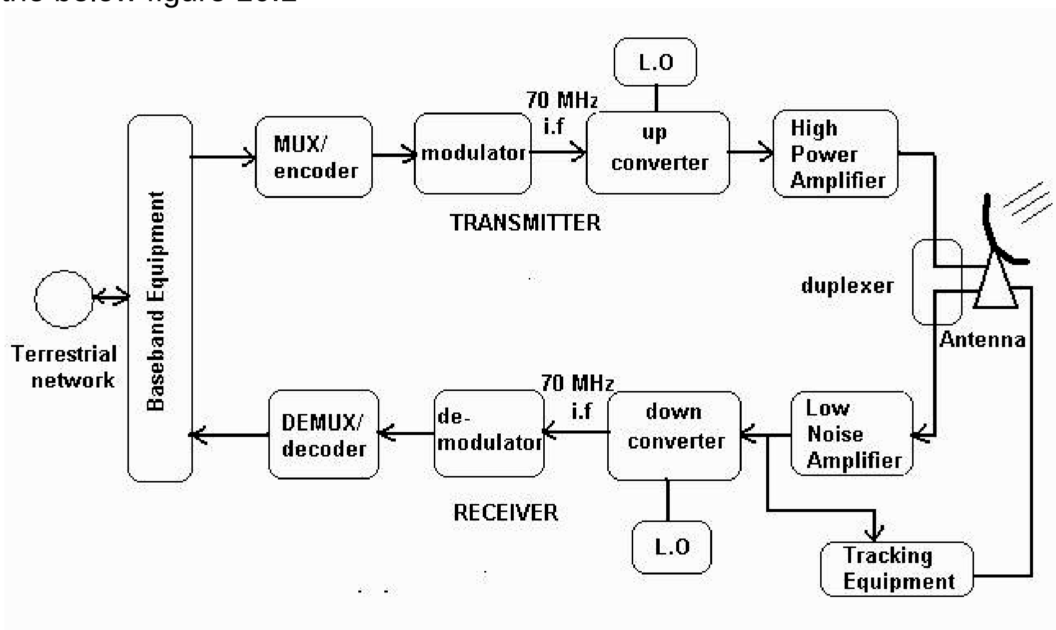

Figure 10.1 A general configuration of an earth station

- Digital information in the form of binary digits from terrestrial networks enters earth station and is then processed (filtered, multiplexed, formatted etc.) by the base band equipment.

- The encoder performs error correction coding to reduce the error rate, by introducing extra digits into digital stream generated by the base band equipment. The extra digits carry information. The presence of noise and non-ideal nature of any communication channel produces error rate is established above which the received information is not stable.

- The function of the modulator is to accept the symbol stream from the encoder and use it to modulate an intermediate frequency (I.F) carrier. In satellite communication, I.F carrier frequency is chosen at 70 MHz for communication using a 36 MHz transponder bandwidth and at 140 MHz for a transponder bandwidth of 54 or 72 MHz. The I.F is needed because it is difficult to design a modulator that works at the uplink frequency of 6 GHz (or 14GHz) directly.

- The modulated I.F carrier is fed to the up-converter and frequency-translated to the uplink r-f frequency.

- This modulated R.F carrier is then amplified by the high power amplifier (HPA) to a suitable level for transmission and radiation by the antenna to the satellite.

- On the receive side, the earth station antenna receives the low-level modulated R.F carrier in the downlink frequency spectrum.

- The low noise amplifier (LNA) is used to amplify the weak received signals and improve the signal to Noise ratio (SNR). The error rate requirements can be met more easily.

- R.F is to be reconverted to I.F at 70 or 140 MHz because it is easier design a demodulation to work at these frequencies than 4 or 12 GHz. The demodulator estimate which of the possible symbols was transmitted based on observation of the received if carrier.

- The decoder performs a function opposite that of the encoder. Because the sequence of symbols recovered by the demodulator may contain errors, the decoder must use the uniqueness of the redundant digits introduced by the encoder to correct the errors and recover information-bearing digits.

- The information stream is fed to the base-band equipment for processing for delivery to the terrestrial network.The tracking equipments track the satellite and align the beam towards it to facilitate communication.

10.3.1)Antenna Systems

Most of the earth stations use reflector antennas as these antennas provide high gain and desirable side lobe characteristics. The antenna system options are

1. Large antenna: say, for INTELSAT earth station typical diameter: 30M(Cassegrain geometry used)

2. Small antenna: say, for option o0f direct broad television (DBS – TV). For deep space communication, the diameter of antenna may be very large, say over 35m.

The efficient utilization of two natural resources- the radio spectrum and the geostationary orbit- are affected by the side lobe characteristic.

10.3.2) Asymmetric Configurations

In an axi-symmetric configuration the antenna axes are symmetric with respect to the reflector, which results in a relatively simple mechanism structure and antenna mount. The axi-symmetric antenna configuration has been used very widely until recently. Depending on the feed arrangement, several types of configurations are possible. Two most commonly used arrangements are:

i. Prime Focus Feed:

- It consists of a parabolic reflector antenna which is fed from a primary feed source located at the focus of the parabolic reflector. Owing to the geometry of the arrangement, the signal reflected from the parabolic reflector posses a planner wave front in the aperture plane, essential in producing the desired radiation pattern.

- Such a feed arrangement leads to a larger antenna noise temperature because the feed horn is pointed towards a relatively hot earth and therefore picks up a significant amount of noise. Additional between the feed and the low-noise amplifier (LNA); unless the LNA is mounted close to the waveguide used to connect the HPA (high power amplifier) to the antenna.

ii. Cassegrain and Gregorain systems

- The operating principle of a parabolic antenna is that a point source of radio waves at the focal point in front of a parabolic reflector will be reflected into a collimated plane wave beam along the axis of the reflector. Conversely, an incoming plane wave parallel to the axis will be focused to a point at the focal point.

- A typical parabolic antenna consists of a parabolic reflector with a small feed antenna at its focus, pointed back toward the reflector. The reflector is a metallic surface formed into a paraboloid of revolution and usually truncated in a circular rim that forms the diameter of the antenna.

- The reflector dish can be of sheet metal, metal screen, or wire grill construction, and it can be either circular or various other shapes to create different beam shapes. A mesh screen reflects radio waves as well as a solid metal surface as long as the holes are smaller than 1/10 of a wavelength, so screen reflectors are often used to reduce weight and wind loads on the dish.

- To achieve the maximum gain, it is necessary that the shape of the dish be accurate within a small fraction of a wavelength, to ensure the waves from different parts of the antenna arrive in phase. Large dishes often require a truss structure behind them to provide the required stiffness.

- The feed antenna at the reflector's focus is typically a low-gain type such as a half-wave dipole or more often a small horn antenna called a feed horn. In more complex designs, such as the Cassegrain and Gregorian, a secondary reflector is used to direct the energy into the parabolic reflector from a feed antenna located away from the primary focal point. The feed antenna is connected to the associated RF transmitting or receiving equipment by means of a coaxial cable transmission line or waveguide.

- *Feed pattern:* The radiation pattern of the feed antenna has a strong influence on the aperture efficiency, which determines the antenna gain (see next section). Radiation from the feed that falls outside the edge of the dish is called "spillover" and is wasted, reducing the gain and increasing the back lobes, possibly causing interference or (in receiving antennas) increasing susceptibility to ground noise. However, maximum gain is only achieved when the dish is uniformly illuminated with constant field strength to its edges. So the ideal radiation pattern of a feed antenna would be constant field strength throughout the solid angle of the dish, dropping abruptly to zero at the edges. However, practical feed antennas have radiation patterns that drop off gradually at the edges, so the feed antenna is a compromise between acceptably low spillover and adequate illumination.

iii. <u>Asymmetric Configuration:</u>

- The performance of an axi-symmetric configuration is affected by the blockage of the aperture by the feed and the sub-reflector assembly. The result is a reduction in the antenna efficiency and an increase in the side lobe levels. The asymmetric configuration can remove this limitation.

- This is achieved by offsetting the mounting arrangement of the feed so that it does not obstruct the main beam. As a result, the efficiency of the side lobe level performance is improved. The latter improvement is desirable because of the more stringent performance requirements. Hence the trend is to use this configuration where possible- especially for lower antenna sizes.

10.3.3) Antenna Mounts

- Description Today's requirements for secure, interoperable communications systems, as well as rapidly deployable networks for emergency response, are driving the need for inexpensive, simple, satellite earth station antennas, ranging in size from sub-meter to 5 meters in diameter. When selecting and siting antennas, systems engineers rarely consider the earth station antenna's vulnerability to damage or destruction by the forces of nature or man.

- Content when selecting the location for an earth station antenna of any size, the primary consideration is to ensure a clear view of the orbital arc, which allows the antenna to "see" the maximum number of satellites. Placing an antenna on a rooftop is often the optimal solution. However, extremely high winds can damage or destroy a parabolic dish antenna.

- Most properly installed earth station antennas are designed to survive winds of at least 60 or 70 miles per hour. When located in areas prone to hurricanes, tornadoes, or seasonal periods of high winds that can exceed these speeds, special considerations should be made in selecting the location of the antenna.

- Properly siting the antenna can increase the chances of surviving high wind conditions. Locating an antenna on the leeward side of buildings or hillsides, or using large roof structures, such as air conditioning units as windbreaks, while maintaining a clear view of the orbital arc, can make the difference between an antenna's survival or destruction in a storm. As every rooftop antenna installation is unique, it is important to work with the building owner or landlord in order to determine the optimum location.

- Many manufacturers make antennas and antenna mounts capable of surviving higher wind conditions, than standard units. High wind antennas are more robust, and reinforced mounts should be considered in areas having an elevated risk of wind damage to outdoor structures.

- In the case of non-penetrating roof mounted antennas being installed in high wind areas, the maximum amount of ballast recommended by the manufacturer must be installed, or even exceeded, in order to ensure that the antenna does not move from its moorings during high wind conditions. The ability of the roof to bear this additional load must be considered to avoid damaging the building upon which the antenna is mounted. In general, hard mounting an antenna to a building is preferred over the use of a non-penetrating roof mount.

- Having a replacement antenna available in the event of an emergency is a costly, yet highly effective means of mitigating the risk of prolonged outages in crucial networks. Installing a second, fully equipped and operational antenna on a nearby building provides full redundancy, and "pace diversity" for the system. While costly, this risk mitigating option may be appropriate in high priority, high value communications networks.

- **The most common antenna mounts used are:**
  - ***Azimuth elevation mount:*** An azimuth mount is a simple two-axis mount for supporting and rotating an instrument about two mutually perpendicular axes; one vertical and the other horizontal. Rotation about the vertical axis varies the azimuth (compass bearing) of the pointing direction of the instrument. Rotation about the horizontal axis varies the altitude (angle of elevation) of the pointing direction. These mounts are used, for example, with telescopes, cameras, radio antennas, heliostat mirrors, solar panels, and guns and similar weapons. Several names are given to this kind of mount, including altitude-azimuth, azimuth-elevation and various abbreviations thereof. A gun turret is essentially an alt-azimuth mount for a gun, with some armour to protect the weapon and its operators.

  - ***The X-Y Mount:*** This uses two orthogonal horizontal axes, one above the other, to permit dish rotation to any point by a combined rotation around each axis. Both designs suffer from the 'keyhole' problem. In the azimuth mount, the problem occurs at the zenith, that is, vertically above the azimuth axis. A satellite whose path passes close to the zenith will cause the antenna to slew rapidly as it tries to follow the spacecraft through a rapidly changing range of azimuth angles. Theoretically, the required slew rate approaches infinity as the satellite path approaches the zenith. With the advent of higher frequency operation, the antenna beam width is becoming narrower, and this leads to higher slew rate requirements if the signal is not to be lost near the zenith. For operation at 8 Ghz, the beam width is about 0.5 degrees. The solution has been to use large drive motors and bearings, with a consequent increase in the overall size and mass of the system, and a large intermittent load on the power supply.

    The X-Y mount has two 'keyholes' at opposite ends of a horizontal line through the pedestal, extended to the horizon. These horizon keyholes require a rapid exchange of angular position between the two axes, before the antenna can continue sweeping around or close to the horizon. Apart from the bearings and drives these mounts suffer the disadvantage of requiring large and costly pedestals. Along with heavy bearings and drives these are required to resist the substantial wind-age forces experienced on an inevitably exposed site. Again these forces are applied entirely through each bearing axis, which must be designed accordingly. Another problem with mounts of this type is that maintenance, for instance of a bearing, will often require the dish to be removed, which is an expensive undertaking.

10.4 EXERCISE

1. Explain the Azimuth Mount.
2. Discuss some general configurations of an Earth Station.
3. Write a note on Cassegrain and Gregorain systems.
4. Elaborate on X-Y mount antennas. How they are different from Azimuth mount antennas?
5. List and discuss the factors on which the general configurations of an earth station depend upon.

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11

EARTH STATIONS – PART II

Contents:

- Satellite television receivers

11.3 Exercise

11.1 GENERAL CONFIGURATION

11.1.1) Feed System

- The primary feed system used in existing earth stations performs a number of functions. Depending on the type of earth station, these functions may be:
  - To illuminate the main reflector.
  - To separate the transmit and receive bands to separate and combine polarizations in a dual polarized system.
  - To provide error signals for some types of satellite tracking system.

- A horn antenna is commonly used as the primary feed at microwave frequencies.A horn antenna consists of an open waveguide which is flared at the transmitting end so that the impedance of the free space matches the impedance of the waveguide.This ensures an efficient transfer of power.

- The figure below shows the block diagram of an orthogonal polarization feed assembly.A higher mode coupler (mode extractor) provides the error signal to the mono-pulse tracking system, if such a method is used.The orthogonal mode junction (OMJ) assembly is used to separate the dually polarized transmit and receive signal.
- The orthogonal mode transducer (OMT) separates the two linear orthogonally polarized signals into a composite linear orthogonally polarized signal on the transmit side.Because OMT operates on linearly polarized signals, polarizer's are used to convert a circular polarization to a linear.

- Polarizer's are therefore not required for linearly polarized system.Some earth stations have the capability to compensate polarization variations introduced by atmospheric effects by means of a feedback control system.The polarization properties of an antenna are mainly affected by the characteristics of the primary radiator and the polarizer.

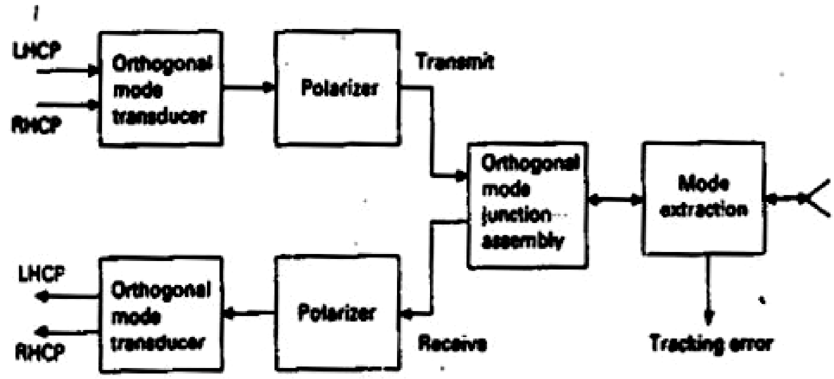

Figure 11.1: Feed System

11.1.2) Tracking System

- Tracking is essential when the satellite drift, as seen by an earth station antenna is a significant fraction of an earth station’s antenna beam width.An earth station’s tracking system is required to perform some of the functions such as
  - i) Satellite acquisition
  - ii) Automatic tracking
  - iii) Manual tracking
  - iv) Program tracking.

- The operation of the tracking system is explained by using its block diagram which show below.Communication satellites transmit a beacon which is used by earth stations for tracking.

- The received beacon signal is fed into the auto-track receiver where tracking corrections or, in some auto-track systems estimated positions of the satellite, are derived. In other auto-tack techniques the feed system provides the required components of error signal.
- The output of the auto-track receivers are processed and used to drive each axis of the antenna to the estimated satellite position.In manual mode, an operator sets the desired angles for each axis on a control console.

- This position is compared with the actual antenna position, obtained through shaft encoders, and the difference signal is used to drive the antenna.In the program track mode the desired antenna position is obtained form a computer.The difference in the actual and the desired antenna positions constitutes the error and is used to drive the antenna.

11.1.3) Recent Tracking Techniques

- There have been some interesting recent developments in auto-track techniques which can potentially provide high accuracies at a low cost. In one proposed technique the sequential lobing technique has been I implemented by using rapid electronic switching of a s single beam which effectively approximates simultaneous lobing.

- The high rate of switching is achieved by the use of an electronically controlled feed.This technique, sometimes referred to as electronic beam squinting, requires a simple single channel receiver and has been reported to achieve a tracking accuracy approaching that of the auto-track technique.

- Another approach, sometimes called as intelligent tracking, the satellite position is computed by optimal control techniques. The relatively complex computations are readily performed in an inexpensive microcomputer. The satellite position is obtained by optimally combining the antenna position estimate obtained from an accurate gradient tracking algorithm with predictions obtained from a simple, self learning satellite position model.

- There have also been some interest in employing phase array technique for satellite tracking specially in applications where the important design criteria are agility, low-profile and aesthetic. Here the antenna beam can be steered by exciting elements of an array antenna electronically. If a phase shift is introduced between successive elements of an array, the beam formed by the array is tilted in a direction determined by the sign of the phase-shift and the amount of tilt by its magnitude.

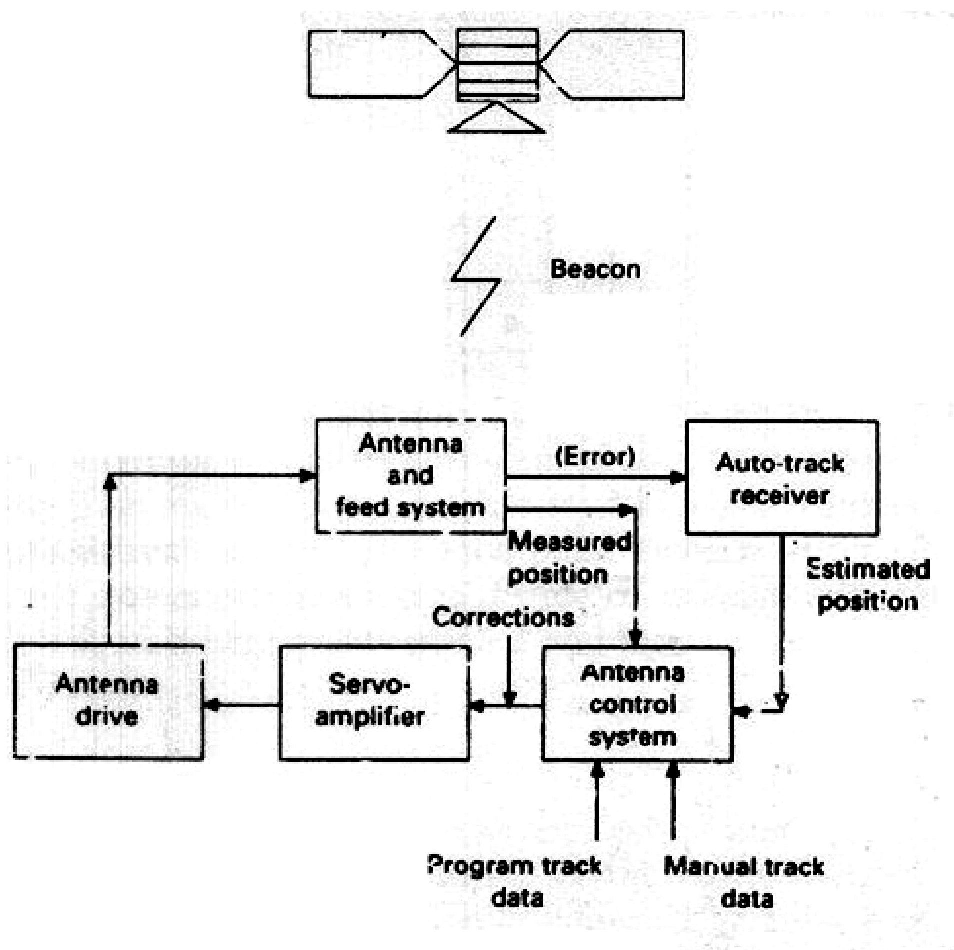

Figure 11.2: Tracking Device

11.1.4) Low noise amplifier

- In the earliest earth stations, MASERs were used as the front-end amplifier.These devices are relatively narrow band, require liquid helium temperatures and henceare expensive with difficult maintenance requirements.Thus, these were replaced by parametric amplifiers which could provide wide bandwidths, with the required low-noise temperatures at lower cost and complexity.

- Several improvements have been made to parametric amplifiers over the years.These have been made possible by the availability of improved devicesand the use of thermoelectric cooling. In recent years the advent of gallium arsenide field-effect transistors has greatly simplified the front-end amplifier design of earth stations.

- These devices provide similar orders of noise temperature and bandwidths as those of parametric amplifiers but at a lower cost.

11.1.5) High-power amplifier

- The high power amplifier (HPA) in an earth station provides the radio frequency (RF) carrier power to the input terminals of the antenna that, when it is combined with the antenna gain, it yields the equivalent isotropic radiated power (EIRP) required for the uplink to the satellite. The waveguide loss between the HPAis responsible for the calculation of the EIRP.

- The output power typically may be a few watts for a single data channel, around a hundred watts or less for a low capacity system or several kilowatts for high capacity traffic. The choice of amplifier is highly dependent on its application, the cost of installation and long term operation, and many other factors.

Types of amplifiers

- Generally, the earth station terminals use high power amplifiers designed primarily for operation in the Fixed Satellite Service (FSS) at C-band (6 GHz), military and scientific communications at X-band (8 GHz), fixed and mobile services at Ku-band (14 GHz), the Direct Broadcast Service (DBS) in the DBS portion of Ku-band (18 GHz), and military applications in the EHF/Q-band (45 GHz).

- Supplementary frequency bands include the ones allocated for the emerging broadband satellite services in Ka-band (30 GHz) and V-band (50 GHz). Mostly, the frequency used for the earth-to-space uplink is higher than the frequency for the space-to-earth downlink within a given band.

- An earth station HPA can be one of three types: a klystron power amplifier (KPA), a traveling wave tube amplifier (TWTA), or a solid state power amplifier (SSPA). The KPA and TWTA achieve amplification by modulating the flow of electrons through a vacuum tube.

- Solid state power amplifiers use gallium arsenide (GaAs) field effect transistors (FETs) that are configured using power combining techniques. The klystron is a narrowband, high power device, while TWTAs and SSPAs have wide bandwidths and operate over a range of low, medium, and high powers.

- The principal technical parameters characterizing an amplifier are its frequency, bandwidth, output power, gain, linearity, efficiency, and reliability. Size, weight, cabinet design, ease of maintenance, and safety are additional considerations. Cost factors include the cost of installation and the long term cost of ownership. KPAs are normally used for high power narrowband transmission to specific satellite transponders, typically for television program transmission and distribution.

- TWTAs and SSPAs are used for wideband applications or where frequency agility is required. Originally, TWTAs provided high power but with poor efficiency and reliability. Compared to a KPA, these disadvantages were regarded as necessary penalties for wide bandwidth. SSPAs first became available about 20 years ago. They were restricted to low power systems requiring only a few watts, such as small earth stations transmitting a few telephone channels.

11.2 CHARACTERISTICS

11.2.1) Fixed satellite service earth stations

- FSS earth stations use the C band, and the lower portions of the K_u bands. They are normally used for broadcast feeds to and from television networks and local affiliate stations as well as being used for distance learning by schools and universities, business television (BTV), Videoconferencing, and general commercial telecommunications. FSS satellites are also used to distribute national cable channels to cable television headends.Free-to-air satellite TV channels are also usually distributed on FSS satellites in the K_u band.

- In connection with the terrestrial networks, the traffic originating from these networks have to be reformatted according to the satellite network. This function is performed by an interface at the earth station, the configuration of which depends upon the type of traffic. Traffic signals may be available as frequency division multiplexed (FDM) analog telephony channels or time division multiplexed (TDM) streams with data or digitized telephony channels. Then traffic signals are demultiplexed at the earth station and rearranged on the basis of destination. A similar procedure is performed at the receiver’s end.

- Fixed Satellite Service Earth Station uses ***VSAT*** is an abbreviation for a Very Small Aperture Terminal. It is basically a two-way satellite ground station with a less than 3 meters tall (most of them are about 0.75 m to 1.2 m tall) dish antenna stationed. The transmission rates of VSATs are usually from very low and up to 4 Mbit/s. These VSATs’ primary job is accessing the satellites in the geosynchronous orbit and relaying data from terminals in earth to other terminals and hubs.

- They will often transmit narrowband data, such as the transactions of credit cards, polling, RFID (radio frequency identification) data, and SCADA (Supervisory Control and Data Acquisition), or broadband data, such as satellite Internet, VoIP, and videos. However, the VSAT technology is also used for various types of communications.

- Equatorial Communications first used the spread spectrum technology to commercialize the VSATs, which were at the time C band (6 GHz) receive only systems. This commercialization led to over 30,000 sales of the 60 cm antenna systems in the early 1980s. Equatorial Communications sold about 10,000 more units from 1984 to 1985 by developing a C band (4 and 6 GHz) two way system with 1 m x 0.5 m dimensions.

Implementations of VSAT

- Currently, the largest VSAT network consists of over 12,000 sites and is administered by Spacenet and MCI for the US Postal Service. Many huge car corporations such as Ford and General Motors also utilizes the VSAT technology, such as transmitting and receiving sales figures and orders, along with announcing international communications, service bulletins, and for distance learning courses.

- Two way satellite Internet providers also use the VSAT technology. Many broadband services around the world in rural areas where high speed Internet connections cannot be provided use VSAT.

VSAT Configurations

Most of the current VSAT networks use a topology:

- Star topology: This topology uses a central uplink site which transports the data to and from each of the VSAT terminals using satellites

- Mesh topology: In this configuration, each VSAT terminal will relay data over to another terminal through the satellite, acting as a hub, which also minimizes the need for an uplink site

- Star & Mesh topology: This combination can be achieved by having multiple centralized uplink sites connected together in a multi-star topology which is in a bigger mesh topology. This topology does not cost so much in maintaining the network while also lessening the amount of data that needs to be relayed through one or more central uplink sites in the network.

VSAT's Strengths

- VSAT technology has many advantages, which is the reason why it is used so widely today. One is availability. The service can basically be deployed anywhere around the world. Also, the VSAT is diverse in that it offers a completely independent wireless link from the local infrastructure, which is a good backup for potential disasters. Its deployability is also quite amazing as the VSAT services can be setup in a matter of minutes.

- The strength and the speed of the VSAT connection being homogenous anywhere within the boundaries is also a big plus. Not to forget, the connection is quite secure as they ar private layer-2 networks over the air. The pricing is also affordable, as the networks they do not have to pay a lot, as the broadcast download scheme allows them to serve the same content to thousands of locations at once without any additional costs. Last but not least, most of the VSAT systems today use onboard acceleration of protocols (eg. TCP, HTTP), which allows them to delivery high quality connections regardless of the latency.

VSAT's Drawbacks

- As the VSAT technology utilizes the satellites in geosynchronous orbit, it takes a minimum latency of about 500 milliseconds every trip around. Therefore, it is not the ideal technology to use with protocols that require a constant back and forth transmission, such as online games.

- Although VSAT is not as bad as one way TV systems like DirecTV and DISH Network, the VSAT still can have a dim signal, as it still relies on the antenna size, the transmitter's power, and the frequency band. Last but not least, although not that big of a concern, installation can be a problem as VSAT services require an outdoor antenna that has a clear view of the sky. An awkward roof, such as with skyscraper designs, can become problematic.

11.2.2) Mobile satellite service earth stations

- Satellites are well suited for a large area mobile communication. However the practical constraints imposed on the design of mobile earth stations meant that the constraints are imposed on the design of mobile earth stations means that the introduction of this service had to wait until the technology matured to a stage where these constraints could overcome in a cost efficient manner.

- The main features in design optimization of an SS earth station are:
  1) Limited mounting space implies that the antenna size on mobile is severely restricted.
  2) Minimization of the earth station cost is important for service uptake specially for personal communications.
  3) Traffic flow through the earth station is low.
  4) For personal communication the size, cost and power consumption approaches those of the cellular telephone, with a capability to operate with the part new terrestrial mobile system, with a capability to operate with a partner terrestrial mobile system. Transmitted power should conform to radiation safety standards.

11.2.3) Satellite Television Receivers

- It is atelevision delivered by the means of communications satellite and received by an outdoor antenna, usually a parabolic mirror generally referred to as a satellite dish, and as far as household usage is concerned, a satellite receiver either in the form of an external set-top box or a satellite tuner module built into a TV set.

- Satellite TV tuners are also available as a card or a USB stick to be attached to a personal computer. In many areas of the world satellite television provides a wide range of channels and services, often to areas that are not serviced by terrestrial or cable providers.

- Direct broadcast satellite television comes to the general public in two distinct flavors - analog and digital. This necessitates either having an analog satellite receiver or a digital satellite receiver.

- Analog satellite television is being replaced by digital satellite television and the latter is becoming available in a better quality known as high-definition television.

11.3 EXERCISE

1. Discuss the functions and features of VSAT.
2. Briefly discuss the general configurations of Earth Stations.
3. What are high power amplifiers?
4. Write a note on Tracking System. List its characteristics.
5. What are low noise amplifiers?
6. Discuss Fixed Satellite Service earth station.

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12

NON-GEOSTATIONARY ORBIT SATELLITE SYSTEMS

Contents:

12.1 INTRODUCTION

Non-geostationary satellites are mostly used for communication applications as the distance between them and earth is comparatively less and hence the delay seen is less. These satellites are also known as Low Earth Orbiting satellites (LEO) and Medium Earth Orbiting satellites (MEO).

12.2 REASONS

Although all types of orbits were considered for satellite communication during the initial years of satellite communication, geostationary orbits became very popular as they had several advantages, especially those pertaining to the antennas used for communicating with them.

The advantages and disadvantages of Non-geostationary satellites are given below:

12.2.1) Advantages

- LEO and MEO systems can provide true global coverage.
- Lower path loss makes it possible to use hand-held terminals.
- These satellites undergo low propagation delay.

12.2.2) Disadvantages

- A large number of satellites are required to cover the radius of the earth.
- The satellite visibility is 10-180 minutes which necessitates satellite-satellite handover leading to more complex network architecture.
- Doppler Effect is high.
- Signal strength at the receiver varies due to the continuous varying range and elevation angle.
- Maintenance of the network and the orbit in the longer term are challenging.
- These satellites also undergo a good number of eclipses; thus their batteries are expected to take charge of the satellite's functionality, hence their lifelong is also expected to be higher.
- Interferences of the satellite cannot be predicted as the distance is very high and the atmospheric effects are constantly changing.

12.3 DESIGN CONSDERATIONS

12.3.1) Traffic distribution and coverage

- Anorbit design is governed by the service area and geographical distribution of traffic within the area. In developing the coverage, distinction must be made between geometric visibility and RF visibility.

- A good RF visibility ensures that adequate signal strength is received before a connection is established. Further to increase the spectrum reuse, the coverage area is divided into smaller sets which are each covered by a spot beam.

- One of the unique traffic features of low earth orbit (LEO) satellite networks is time-variant and non-uniform load distribution. This feature results in a locally biased congestion problem for the LEO satellite systems. To solve the congestion problem, LEOs use of near-neighbor residual bandwidth information to allocate excess bandwidth from congested satellites to their under loaded neighbors in the network. Each traffic load balancing process is performed on the domain basis.

12.3.2) Satellite capacity

- LEO systems are designed to have more than one satellite in view from any spot on Earth at any given time, thus minimizing the possibility that the network will loose out on the transmission. LEO systems have to incorporate complicated tracking equipments to maintain consistent service coverage. The need for complex tracking schemes is minimized, but not obviated, in LEO systems designed to handle only short-burst transmissions.

- In addition, because the signals to and from the satellites need to travel a relatively short distance, LEOs can function with much smaller user equipment can systems using a higher orbit. In addition, a system of LEO satellites is designed to maximize the ability of ground equipment to "see" a satellite at any time, which can overcome the difficulties caused by obstructions such as trees and buildings.
  There are two types of LEO systems, Big LEOs and Little LEOs,

- **Little LEO** satellites are very small, often weighing no more than a human being, and use very little bandwidth for communications. Their size and bandwidth usage limits the amount of traffic the system can carry at any given time. However, such systems often employ mechanisms to maximize capacity, such as frequency reuse schemes and load delay tactics. Little LEO systems support services that require short messaging and occasional low-bandwidth data transport, such as paging, fleet tracking and remote monitoring of stationary monitors for everything from tracking geoplatonic movements to checking on vending machine status. The low bandwidth usage may allow a LEO system to provide more cost effective service for occasional-use applications than systems that maximize their value based on bulk usage.

- **Big LEO** systems are designed to carry voice traffic as well as data. They are the technology behind "satellite phones" or "global mobile personal communications system".Most Big LEO systems offer mobile data services and some system operators intend to offer semi-fixed voice and data services to areas that have little or no terrestrial telephony infrastructure. Smaller Big

LEO orbits also are planned to serve limited regions of the globe. MEO systems' larger capacity relative to LEOs may enable them to be more flexible in meeting shifting market demand for either voice or data services. MEO systems, as well as some Big LEOs, targeted at the voice communications market may have a disadvantage when compared with cellular and other terrestrial wireless networks. A satellite signal is inherently weaker and is more subject to interference than those of terrestrial systems, thus requiring a larger antenna than a traditional mobile phone. By contrast, the trend in the mobile phone market is toward smaller and smaller phones.

12.3.3) State of spacecraft technology

Orbit design is influenced by the chosen spacecraft technology. The following parameters are of significance.

- Antenna size and complexity: increasing the altitude trends to reduce the number of satellites in a orbit, but it also required the use of larger antennas to meet the link quality objectives and maintain the same frequency reusability.

- Spacecraft DC power: the DC power of a satellite determines the capacity of a satellite.

- Inter-satellite link: satellites with inter-satellite links influence the network routing scheme.

12.3.4) Terminal characteristics and communication requirement

- The size of the terminal and their communications capabilities influence a satellite's power and its sensitivity requirements. RF power of a handset is limited b safety considerations, battery size/capacity and the target terminal cost. If satellites are brought closer to a handset, power requirements reduce but the number of satellite in the orbit increases. Similarly, satellites require lower transmit power if the orbital altitude decreases.

12.3.5) Quality of service

- Quality of service (QoS) depends upon the reliability of RF link, propagation delays and signal quality measure as bit rate errors.

- For a given satellite EIRP; higher link reliability requires operation at higher elevation angle and path diversity ie more than one satellite must be visible from a terminal at a given time. Propagation conditions improve as the elevation angle increases because the number of obstructions reduces as the elevation angle is made to improve.

- Owing to the movement of satellite, propagation conditions fr LEOs and MEOs orbits are quite severe. The user could receive a high signal from a specific direction but not from others.
- Selection of the best orbit could be done from propagation and availability aspect can be done on the basis of the average, maximum and minimum elevation angles over the area of interest or using other criteria such as probability of a successful completion of voice calls.

12.3.6) Spectrum availability

- Each operation has access to a limited amount of RF spectrum and therefore whishes to maximize the use of this resource. Frequency reusability can be incremented by spatial and polarized diversity.

- Spatial reuse is achieved by spot and shaped beams. Within a specified area; and for a given spot beam size, a lower-altitude constellation tends to increase frequency reusability. Additional considerations in maximizing the radio recourse are modulation, coding and multiple access schemes.

12.3.7) Launch Considerations

- Important practical consideration relates to the launch cost, as well as the feasibility of launching the satellites in the constellation within an acceptable time frame. A number of launchers may be used to expedite launches as well as to spread the risk. The probability of launch failure and in-orbit satellite failure is likely to increase as the number of satellites in a constellation increases.

12.3.8) Orbital Debris

(As discussed in Unit 7)

- Besides planets, natural and artificial satellites, many other particles like cosmic rays, protons, electrons, meteoroids and manmade space debris exists in space.These particles collide with the satellites causing permanent damage to it and sometimes degrading the solar cells.

- Space debris, also known as orbital debris, space junk and space waste, is the collection of objects in orbit around Earth that were created by humans but no longer serve any useful purpose. These objects consist of everything from spent rocket stages and defunct satellites to explosion and collision fragments. The debris can include slag and dust from solid rocket motors, surface degradation products such as paint flakes, clusters of small needles, and objects released due to the impact of micrometeoroids or fairly small debris onto spacecraft. As the orbits of these objects often overlap the trajectories of spacecraft, debris is a potential collision risk.

- The vast majority of the estimated tens of millions of pieces of space debris are small particles, like paint flakes and solid rocket fuel slag. Impacts of these particles cause erosive damage, similar to sandblasting. The majority of this damage can be mitigated through the use of a technique originally developed to protect spacecraft from micrometeorites, by adding a thin layer of metal foil outside of the main spacecraft body.

- Impacts take place at such high velocities that the debris is vaporized when it collides with the foil, and the resulting plasma spreads out quickly enough that it does not cause serious damage to the inner wall. However, not all parts of a spacecraft may be protected in this manner, i.e. solar panels and optical devices (such as telescopes, or star trackers), and these components are subject to constant wear by debris and micrometeorites.

- The present means for spacecraft shielding, such as those used for the manned modules of the International Space Station are only capable of protecting against debris with diameters below about 1 centimeter. The only remaining means of protection would be to maneuver the spacecraft in order to avoid a collision. This, however, requires that the orbit of the respective object be precisely known.

- If a collision with larger debris does occur, many of the resulting fragments from the damaged spacecraft will also be in the 1 kilogram mass range, and these objects become an additional collision risk.

- As the chance of collision is a function of the number of objects in space, there is a critical density where the creation of new debris occurs faster than the various natural forces that remove these objects from orbit. Beyond this point a runaway chain reaction can occur that quickly reduces all objects in orbit to debris in a period of years or months.

12.3.9) Operational Considerations

- The monitoring and maintaining of a large orbit is a complex and expensive task. Monitoring has to be done in order to ensure that satellite transmissions meet the required specification in terms of frequency and power, traffic flow is normal, all satellites and links are operating satisfactorily, all the gateways are functioning correctly, reception is interference free and the user is satisfied with the signal quality.

- Maintenance of an orbit includes maintaining correct altitude and phase o satellites, which would typically require station-keeping every few weeks, replaced of failed spacecraft and so on. Again, the complexity tends to increase as the size of the orbit increases.

12.3.10) Network Issues

- Network issues comprise of network architecture including call connection strategy, intra and inter system routing considerations, mobility management and space segment resource management.

12.3.11) Network Architecture

- This depends up to the nature of services offered by the satellite, which is categorized as follows:
    - Non real time services such as messaging
    - Real time services such as voice or video conferencing
    - Combination of real time and non real time services.

- Non real time services include satellite based store and forward services; earth station based store and forward.

- Real time services include connectivity via inter-satellite links, distributed routing schemes, centralized routing schemes, flooding schemes, connection via ground relays, and connectivity via geostationary satellites.

12.3.12) Mobility Management

- In network, where user terminals are not fixed to a location, it becomes necessary to manage mobility of terminals so that the calls are successfully established. To minimize call set up time and network signaling requirements during the setup, and to improve the call set up success rate, it is necessary for the switching center t have knowledge of the location of each mobile in the network. The process of the terminal registering its location is called as location registration. The terminal or the network must have a provision for estimating the user's position.

- Handover increases the complexity of the network as the need for real-time signaling between various network entities. In general the number of handovers reduces with the increase in the orbital altitude because of a corresponding increase in the orbital period.

12.4 EXERCISE

1. Discuss the design considerations of Non-Geostationary orbit satellites.
2. Write a note on mobility management of Non-Geostationary orbit satellites.
3. How Non-Geostationary Orbit Satellites are different from Geostationary Orbit Satellites? Discuss their advantages and disadvantages.
4. Write a short note on Orbital Debris? How do they harm the Satellites?
5. Discuss the Satellite Capacity of Non-Geostationary orbit satellites.

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13

THE SPACE LINK – PART I

Contents:

13.1 INTRODUCTION

This unit describes how link-power budget calculations are done. These calculations generally relate two quantities, the transmission power and the receiver power. This unit also discusses how the difference between these two powers is accounted for.

Link-power budget calculations also need the additional losses and noise factor which is incorporated with the transmitted and the received signals. Losses can be of various types, the major ones considered for satellite communication are discussed here.

Along with losses, this unit also discusses the system noise parameters. Various components of the system add to the noise in the signal that has to be transmitted. Most of the calculations discussed in this unit are in decibel quantities.

13.2 EQUIVALENT ISOTROPIC RADIATED POWER

- The key parameter in link-power budget calculations is the equivalent isotropic radiated power factor, commonly denoted as EIRP. Is the amount of power that a theoretical isotropic antenna (which evenly distributes power in all directions) would emit to produce the peak power density observed in the direction of maximum antenna gain. EIRP can take into account the losses intransmission line and connectors and includes the gain of the antenna.

- The EIRP is often calculated in terms of decibels over a reference power emitted by an isotropic radiator with equivalent signal strength. The EIRP allows comparisons between different antennas in satellite communication regardless of type, size or form.EIRP can be defined as the power input to one end of the transmission link and the problem to find the power received at the other end.

$$EIRP = G\ Ps$$

Where,

G → Gain of the Transmitting antenna and G is in decibels.

Ps→ Power of the sender (transmitter) and is calculated in watts.

$$\mathbf{[EIRP] = [G] + [Ps]\ dBW}$$

Exercise: A satellite downlink is at 12 GHz operate with a transmit power of 6 W and an antenna gain if 48.2 dB. Calculate the EIRP in dBW.

Solution:

$$[EIRP] = 10 \log 6 + 48.2$$
$$= \mathbf{56\ dBW}$$

13.3 TRANSMISSION LOSSES

- As EIRP is thought of as power input of one end to the power received at the other, the problem here is to find the power which is received at the other end. Some losses that occur in the transmitting – receiving process are constant and their values can be pre – determined.

- Other losses can be estimated from statistical data and a few of them are dependent on the climatic conditions including rain and snow fall. To begin theses computations, generally the constant losses are determined considering a clear sky condition. Below listed are the losses which are generally taken as a constant value.

13.3.1) Free-Space Transmission Losses (FSL)

- This loss is due to the spreading of the signal in space. Going back to the power flux density equation (discussed in unit VI a):

$$\mathbf{\Psi_m = P_S / 4\pi r^2}$$

- The power that is delivered to a matched receiver is the power flux density. It is multiplied by the effective aperture of the receiving antenna. Hence, the received power is:

$$P_R = \Psi_M A_{\text{eff}}$$
$$= \frac{\text{EIRP}}{4\pi r^2} \frac{\lambda^2 G_R}{}$$
$$= (\text{EIRP})\,(G_R)\left(\frac{\lambda}{4\pi r}\right)^2$$

Where

r→ distance between transmitter and receiver

G_R→ power gain at the receiver

In decibels, the above equation becomes:

$$[P_R] = [\text{EIRP}] + [G_R] - 10\log\left(\frac{4\pi r}{\lambda}\right)^2$$

$$[\text{FSL}] = 10\log\left(\frac{4\pi r}{\lambda}\right)^2$$

$$[P_R] = [\text{EIRP}] + [G_R] - [\text{FSL}]$$

13.3.2) Feeder Losses (RFL)

- This loss is due to the connection between the satellite receiver device and the receiver antenna is improper. Losses here occur is connecting wave guides, filers and couplers. The receiver feeder loss values are added to free space loss. Similar losses will occur in filters, couplers and waveguides that connect the transmission antenna to a high-power amplifier output.

13.3.3) Antenna Misalignment Losses (AML)

- To attain a good communication link, the earth station's antenna and the communicating satellite's antenna must face each other in such a way that the maximum gain is attained.

- Sometimes, misalignment (also called as off-axis loss) can occur in two ways:
  - The off-axis loss at satellite is taken into account by designing the link for operation on the actual satellite contour.
  - The off-axis loss at the earth station is referred to as antenna pointing loss. These losses are usually only a few tenths of a decibel.

- In addition to pointing losses, losses can occur due to the misalignment of the polarization direction. These losses are generally small and it will be assumed that the antenna misalignment loss includes pointing as well as polarization losses value.

- The value of this loss can be estimated using statistical data which are based on errors that are actually observed or a large number of earth stations.

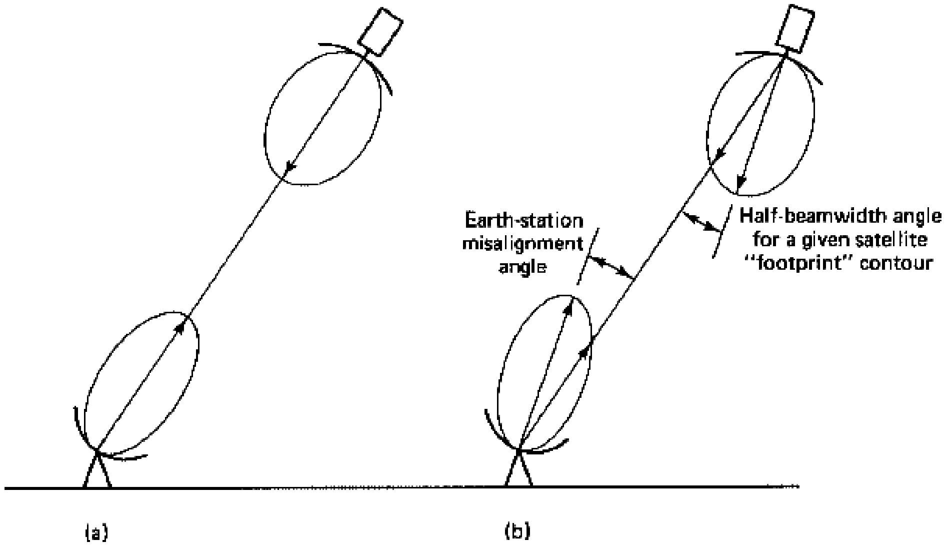

Figure 13.1: a) Satellite and Earth station's antennas aligned for maximum gain; b) Earth station is situated at the given satellite's footprint it's antenna is misaligned.

13.3.4) Fixed Atmospheric (AA) and Ionospheric losses (PL)

The gases present in the atmosphere absorb the signals. This kind of loss is usually of a fraction of decibel in quantity. Along with the absorption losses, the ionosphere introduces a good amount of depolarization of signal which results in loss of signal.

13.4) Link - Power Budget Equation

The EIRP can be considered as the input power to a transmission link. Due to the above discussed losses, the power at the receiver that is the output can be considered as a simple calculation of EIRP – losses.

Losses = [FSL] + [RFL] + [AML] + [AA] + [PL]

The received power that is P_R:P_R = [EIRP] + [G_R] – [Losses]

Where;

[P_R]→ received power in dB.

[EIRP] → equivalent isotropic radiated power in dBW.

[G_R]→ isotropic power gain at the receiver and its value is in dB.

[FSL]→free-space transmission loss in dB.

[RFL] → receiver feeder loss in dB.

[AA] →Atmospheric absorption loss in dB.

[AML] →Antenna misalignment loss in dB.

[PL] → depolarization loss in dB.

Example: a satellite link operating at 14 GHz has receiver feeder losses of 1.5 dB and a free-space loss of 207 dB. The atmosphericabsorption loss is 0.5 dB and the antenna pointing loss is 0.5 dB. Depolarization losses may be neglected. Calculate the total link loss for a clear – sky condition.

Solution: the total loss is the sum of all losses:

Losses = [FSL] + [RFL] + [AML] + [AA] + [PL]
= 207 + 1.5 + 0.5 + 0.5 + 0
= 209.5 dB

Where;
[FSL] → free-space transmission loss in dB.
[RFL] → receiver feeder loss in dB.
[AML] →Antenna misalignment loss in dB.
[AA] →Atmospheric absorption loss in dB.
[PL] → depolarization loss in dB.

13.5 SYSTEM NOISE

- Electrical noise is always present at the input and unless the signal is significantly larger than the noise, amplification will be of least help as it will amplify the signal as well as the noise to the same extent. There is a possibility, that after the amplification, the situation can get worst by the noise that will be added by the amplifier.

- The main source of noise in the satellite equipments is the noise arising from the random thermal motion of electrons in the various devices in the receiver. Thermal noise is also generated in the lossy components of the antenna and a thermal – like noise is picked – up by the antenna as radiation.
  Power from a thermal noise source is given by:
  $$P_N = k\, T_N\, B_N$$
  Where:
  T_N→ noise temperature
  B_N→ Noise Bandwidth
  k→Boltzman Constant having the value 1.38 x 10^{-23} J/k
  - The main characteristic of thermal noise is that it has a *flat frequency spectrum*; that is, noise power per unit bandwidth is a constant. The noise power per unit bandwidth is termed as *noise power spectral density*.
    Denoting this by NO
    $$N_O = P_N / B_N$$
    Thus, $\mathbf{N_O = k\, T_N}$Joules
  - Noise temperature is <u>directly proportional</u> to the physical temperature but not always equal.
  - Noise power per unit bandwidth is <u>always constant</u>.

Example: An antenna has noise temperature of 35 K and is matched into a receiver which has a noise temperature of 100 K calculate: a) noise power density and b) the noise power for a bandwidth of 36 MHz.
Solution:
a) $N_O = k\, T_N$
   $= 11.38 \times 10^{-23} \times (35 + 100)$
   $\mathbf{= 1.86 \times 10^{-21}}$ **J**

b) $PN = N_O B_N$
$= 1.86 \times 10^{-21} \times 36 \times 10^{6}$
= 0.067 pW

13.5.1) Antenna Noise

- The received signal power is pointless unless compared with the power received from unwanted sources over the same bandwidth. Such noise sources consist of thermal radiation from the earth and sky, cosmic background radiation and random thermal processes in the receiving system. An additional noise due to non - stationary radio frequency interference from pagers, cellular phones, etc., often needs to be considered, but in this analysis we will concentrate on two classifications of the antennas noise: a) Sky noise, and, b) Noise originating from the antenna losses.

a) ***Sky Noise***: it is a term used to describe microwave radiation which is present throughout the universe and which appears to originate from matter in any form at finite temperature. Such radiation covers wider spectrum. Any absorptive loss mechanism generates thermal m\noise, there being direct connection between loss and the effective noise temperature. Rainfall introduces attenuation and thus it further degrades transmission in two ways:
1) It attenuates the signal; 2) it introduces noise.
The detrimental effects of rain are much worse at Ku-Band frequencies than at C-band (refer Unit I for Ku and C Band features and bandwidth), and the downlink rain fade margin also must allow the increased noise which is generated.

b) ***Antenna Losses:*** Satellite antennas are generally pointed towards the earth and therefore they receive the full thermal radiation from it. In this case the equivalent noise temperature of the antenna, excluding the antennas losses is approximately 290 K. Antenna losses add to the noise received as radiation and the total antenna noise temperature is the sum of equivalent noise temperatures of all these sources.

13.5.2) Antenna Noise Temperature

- Antenna noise temperature is the temperature of a theoretical resistor at the input of an ideal noise-free receiver that would generate the same output noise power per unit bandwidth as that at the antenna output at a specified frequency.Antenna noise temperature has contributions from several sources:
  - Vast radiation
  - Earth heating

- The sun
- Electrical devices
- The antenna itself

- The available power gain of the amplifier is denoted as G, and the noise power output as P_{no}. Considering noise power per unit bandwidth which is noise energy in joules is given by:

$$N_{o,ant} = k\,T_{ant}$$

- The output noise energy in $N_{o,out}$ will be $GN_{o,out}$ plus the contribution made by the amplifier. The summation of all the amplifier noise is referred to the input in terms of an equivalent input noise temperature for the amplifier Te. Thus output could be written as:

$$N_{o,out} = Gk\,(T_{ant} + T_e)$$

The total noise referred to the input is

$$N_{o,out}/\,G$$

OR

$$\mathbf{N_{o,in} = k\,(T_{ant} + T_e)}$$

13.5.3) Amplifier in Cascade

- A cascade amplifier is any amplifier constructed from a series of amplifiers, where each amplifier sends its output to the input of the next amplifier in a daisy chain.

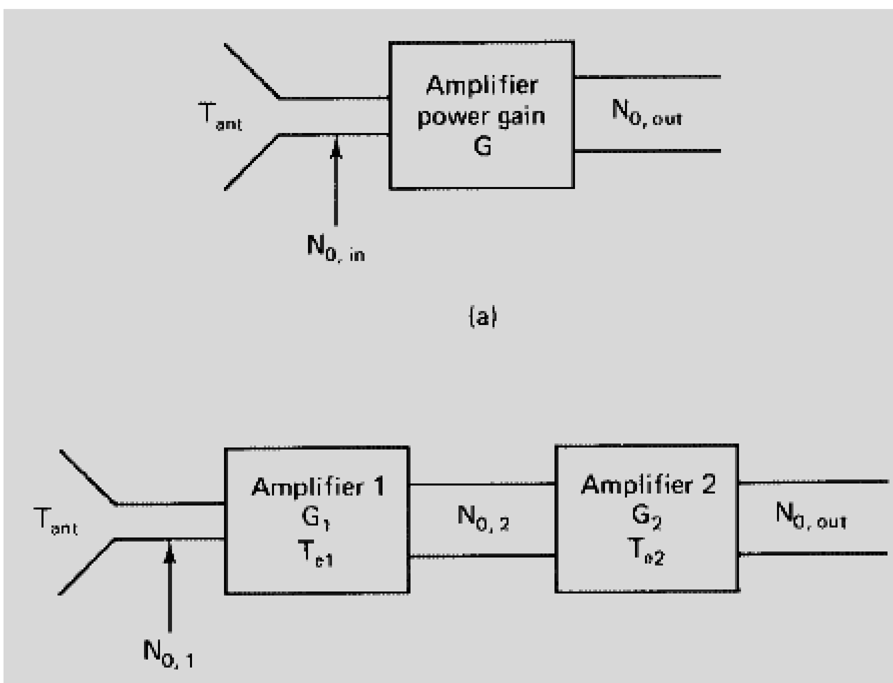

Figure 13.2: a) An amplifier; b) An amplifier in Cascade

For the arrangement of amplifiers shown in fig. 13.2 b; the overall gain can be considered as:

$$G = G_1\,G_2$$

- The noise energy of amplifier 2 referred to its own inputs is imply kT_{e2}. The noise input to amplifier 2 from the preceding stages is G_1 k (T_{ant} + T_{e1}), and thus the total noise energy referred to amplifier 2 input is:

$$N_{o,2}= G_1k\ (T_{ant} + T_{e1}) + kT_{e2}$$

- This noise energy may be referred to amplifier 1 input by dividing by the available over gain of amplifier 1:

$$N_{o,2}= N_{o,2} / G_1$$
$$= k\ (T_{ant} + T_{e1} + T_{e2} / G_1$$

A system noise temperature may now be defined as T_S by

$$N_{o,1}= k\ T_S$$

And hence it will be seen that $T_S$is given by

$$\mathbf{T_S = T_{ant} + T_{e1}+ T_{e2} / G_1}$$

13.5.4) Noise Factor

- Definition: An alternative way of representing amplifier noise is by the means of its noise factor F. for defining it, the source is taken at room temperature, denoted by T_0. The input noise from such a source is kT_0 and the output noise from the amplifier is:

$$N_{o,out}= FGkT_0$$

Where:

G is the available power gain of the amplifier

F is its noise factor

13.5.5) Noise Temperature of Absorptive Networks

- An absorptive network is one which contains resistive elements. These introduce losses by absorbing energy from the signal and converting it into heat. Resistive attenuators, transmission lines and wave guides are all examples of absorptive networks. Even natural phenomenon like rainfall, which absorbs energy from radio signals passing through it can be considered as a form of absorptive network. As these absorptive networks contain resistance, they generate thermal noise.

13.5.5) Overall System Noise Temperature

It's a summation of all the above discussed noise parameters. It is denoted as T_S. This parameter of system noise is considered for satellite communication computations.

13.6 SUMMARY

This unit discusses the equivalent isotropic radiated power factor which can be defined as the power input to one end of the transmission link and the problem to find the power received at the other end.

Further, this unit discusses various transmission losses face by a signal travelling between earth station and satellite. They include atmospheric losses, depolarization losses, misalignment of antenna loss, feeder loss and free space loss. Combining these losses, one can calculate the link-power budget value and estimate the loss of a particular signal by studying the statistics of a communication link.

Further, this unit discusses the system noise faced in a satellite. This includes atmospheric loss which is calculated with the antenna loss, sky noise, noise temperature of an antenna and an amplifier cascade. Along with these noise parameters, noise factor are also calculated which helps in calculating the overall system noise of a spacecraft.

13.7 EXERCISE

1. Write a note on Equivalent Isotropic Radiated Power (EIRP).
2. Discusses the transmission losses seen between a space craft and earth station.
3. What is antenna misalignment loss? Propose a solution to overcome these losses.
4. Derive the Link-Power Budget equation.
5. Write a note on system noise.

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14

THE SPACE LINK – PART II

Contents:

14.1 INTRODUCTION

This unit discusses the Noise factor faced by the signal while transmission. Considering the difficulties achieving a terrestrial link, it might be surprising that satellitelinks, covering much greater distance are possible at all. One of the most important factorsto explain this is the noise involved.When signals originate at the satellite; they are virtuallyfree of noise. The origin of noise and the meaning of the noise pressure and temperature inrelation to receivers will be explained. The effect of the Earth atmosphere on signal-to-noiseratio (SNR) will be illustrated with a real-life example.This noise is considered separately for uplink and downlink. Based on the transmission / receiving frequency band, a carrier to noise ratio for every travelling signal is calculated to determine the loss in each signal. Once the noise value is estimated, measures to overcome this are calculated.

14.2 NOISE

- Many types of noise are transmission related. Sometimes it's nothing more than a normal noise that sounds louder because of bad bases or because part of the transmission is touching the frame or underbody of the car. Then there are actual components like pumps, planets, final drives etc. that can cause good amount of disturbance in any travelling wave. The idea is to find a way to make the noise change, or stop, and then examine what this change did to affect the noise.

- There are several rules that will help isolate the component that is causing the problem. First of all, a component cannot generate a noise if it is not moving.Isolating moving components and calculating statistically the amount of noise they produce can help us estimate the signal loss.

- Next, if the noise is pressure related, it will change when the pressure changes.So again, estimation helps in determining the loss that can occur in a particular signal. There is variation in n noise in a particular link while the signal is moving upward and while is it moving downward. Presence and absence of atmospheric pressure, gravity and amount/ impact of sun's radiation also add to the noise factor of a signal.

14.3 CARRIER – TO – NOISE RATIO

A measure of a performance of a satellite link is considered as a ratio of carrier power to noise power at the receiver input along with the link budget calculations which are considered to estimate this ratio. This ratio is denotes as C/N and is calculated in decibels.

$$C/N = [P_R] – [P_N]$$

where:
C/N → carrier to noise ratio
P_R→ Receiver Power
P_N→Noise Power

Thus, the resultant C/N can be calculated with the following parameters (for parameters refer unit 13):

$$[C/N] = [EIRP] – [G_R] – [LOSSES] – [k] – [T_S] – [B_N]$$

To complete the calculations, we need to consider the gain is to temperature ratio as well. It is commonly denoted ad G/T. it is denoted as:

$$[G/T] = [G_R] – [T_S]$$

Thus, the C/N equation could be written as:

$$\mathbf{[C/N] = [EIRP] + [G/T] - [LOSSES] – [k] – [B_N]}$$

The ratio of carrier to noise power density P_R / $P_N$can be the quantity that is actually required. Since $P_N = k\ T_N B_N$ (proved in Unit 13), then:

$$[C/N] = [C / N_O\ B_N]$$
$$= [C / N_O] – [B_N]$$

And therefore,

$$[C/No] = [C / N_O] +[B_N]$$

[C/N] is true power ration in units of decibels, and [B_N] is in decibels relative to one hertz or dBHz. Thus the units for [C/No] are dBHz. Applying this value to the above equation, we get:

$$[C/N_0] = [EIRP] + [G/T] - [LOSSES] - [k]$$

14.4 THE UPLINK

The uplink of a satellite circuit is where the earth station is transmitting the data to the space craft and the space craft is receiving it. The above discusses carrier – to – noise ratio equation can be determined for an uplink with an annotation of U. it is given by:

$$[C/N_0]_U = [EIRP]_U + [G/T]_U - [LOSSES]_U - [k]$$

14.5 THE DOWNLINK

The downlink of a satellite circuit is where the space craft is transmitting the data to the earth station and the earth station is receiving it. The above discusses carrier – to – noise ratio equation can be determined for andownlink with an annotation of D. it is given by:

$$[C/N_0]_D = [EIRP]_D + [G/T]_D - [LOSSES]_D - [k]$$

14.6 COMBINED UPLINK AND DOWNLINK C/N RATIO

- The complete satellite circuit consists of an uplink and a downlink. Noise will be introduced on the uplink at the satellite receiver input. Denoting the noise power per unit bandwidth by P_{NU} and the average carrier at the same point by P_{RU}, the carrier – to – noise ratio on the uplink is:

$$(C/N_0) / U = (P_{RU} / P_{NU})$$

- It is important to note that power levels, and not decibels, are being used here. The carrier power at the end of the space link is shown as P_R, which of course is also the received carrier power for the downlink. This is equal to γ times the carrier power input to earth station input, as given in the below figure.

- It includes the satellite transponder and transmits antenna gains, the downlink losses, and the earth station receives antenna gain and feeder losses. The noise at the satellite input also appears at the earth station input multiplied by γ and in addition, the earth station introduces its own noise which is denoted as P_{ND}. Thus the end – of – link noise is γ P_{NU} + P_{ND}.

- The C/N_0ratio for the downlink alone, not counting the γ P_{NU}contribution, is P_R / $P_{ND}$and the combined C/N_0ratio at the ground receiver is $P_R(\gamma P_{NU} + P_{ND})$. The power flow diagram is shown figure 14.1 b). The combined carrier – to – noise ratio can be determined in terms of the individual link values. To show this, it is more convenient to work with the noise – to – carrier ratios rather than the carrier – to – noise ratio, and again, these must be expressed as power ratios, not decibels. Denoting the combined carrier – to – noise values by N_0 / C, the uplink value by $(N_0 / C)_U$ and the downlink value by $(N_0 / C)_D$ then,

$$N_0 / C = P_N / P_R$$
$$= (\gamma P_{NU} + P_{ND}) / P_R$$
$$= (\gamma P_{NU} / P_R) + (P_{ND} / P_R)$$
$$= (\gamma P_{NU} / \gamma P_R) + (P_{ND} / P_R)$$
$$\mathbf{N_0 / C = (N_0 / C)_U + (N_0 / C)_D}$$

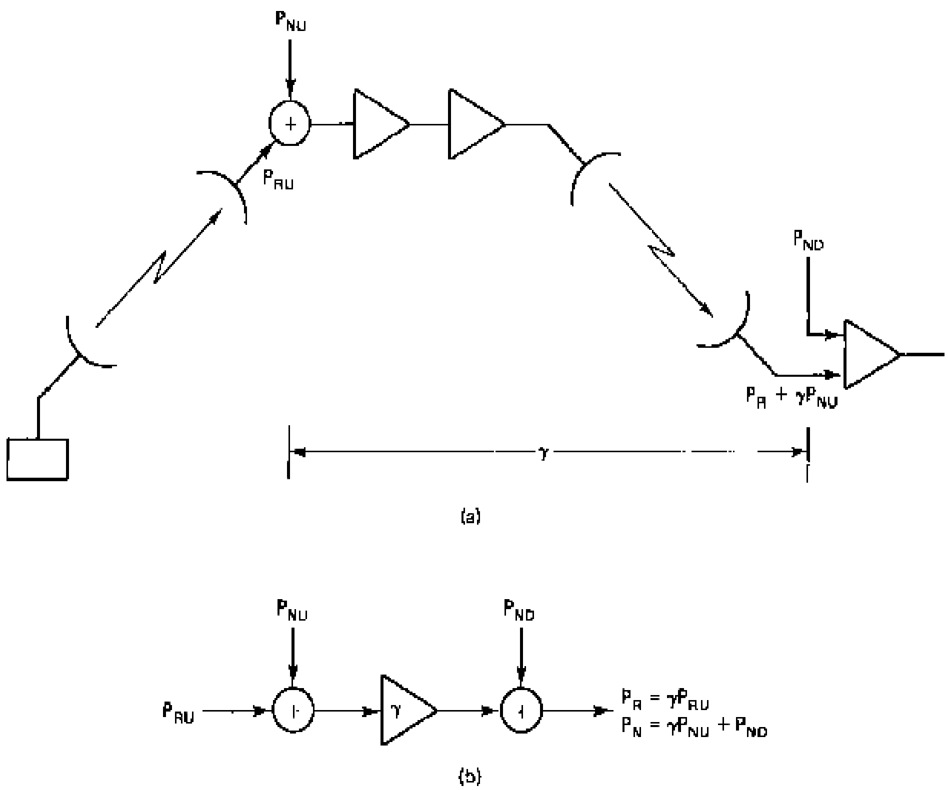

Figure 14.1: a) Combined uplink and downlink; b) power flow diagram for (a)

The above derived equation is the combine value of C/N_0 , the reciprocals of individual values must be added to obtain the N_0 / C ratio and then reciprocal of this taken to get C/N_0.

14.7) INTERMODULATION NOISE

- Intermodulation noise is the amplitude modulation of signals containing two or more different frequencies in a system with nonlinearities. The intermodulation between each frequency component will form additional signals at frequencies that are not just atharmonic frequencies (integer multiples) of either, but also at the sum and difference frequencies of the original frequencies and at multiples of those sum and difference frequencies.

- Intermodulation is caused by non-linear behavior of the signal processing being used. The theoretical outcome of these non-linearities can becalculated by generating a series of the characteristic, while the usual approximation of those non-linearities is obtained by generating aTaylor series.

- Intermodulation is rarely desirable in radio or audio processing, as it creates unwanted spurious emissions, often in the form of sidebands. For radio transmissions this increases the occupied bandwidth, leading to adjacent channel interference, which can reduce audio clarity or increase spectrum usage.

- In satellite communication systems, this most commonly occurs in the travelling – wave tube high – power amplifier abroad the satellite. Both amplitude and phase non – linearities give rise to this intermodulation noise.

- The carrier – to – intermodulation - noise ratio is usually found experimentally or in some cases it may be determined by computer methods. Ratio can be combined with the carrier –to – thermal noise ratio by the addition of the reciprocals. Denoting intermodulation noise term by $(C/N)_{IM}$ and bearing in mind that the reciprocals of C/N power ratios must be added. The ratio can be re-written as:

$$\mathbf{(N_0/C) = (N_0/C)_U + (N_0/C)_D + (N_0/C)_{IM}}$$

14.8 SUMMARY

This unit discusses the Noise in satellite commination link. This noise is calculated using two forms: Uplink and Downlink. The uplink of a satellite circuit is where the earth station is transmitting the data to the space craft and the space craft is receiving it. The downlink of a satellite circuit is where the space craft is transmitting the data to the earth station and the earth station is receiving it.

Further it derives an equation for combined uplink and downlink which is:
$N_0 / C = (N_0 / C)_U + (N_0 / C)_D$.

The last segment of the unit discusses Intermodulation noise. Intermodulation noise is the amplitude modulation of signals containing two or more different frequencies in a system with nonlinearities. This noise is commonly seen in satellite communication link. To conclude the unit, the total noise is computed combining the uplink, downlink and the intermodulation noise and is given by the equation: $(N_0/C) = (N_0/C)_U + (N_0/C)_D + (N_0/C)_{IM}$

14.9 EXERCISE

6. Write a note on system noise.
7. Diagrammatically explain the combined Uplink and Downlink carrier to noise ratio.
8. What is understood by intermodulation noise?
9. Derive the Equation for Combined Uplink and Downlink.
10. What is Uplink?
11. What is Downlink?

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121. http://www.britannica.com/EBchecked/topic/524891/satellite-communication

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CLASS: M. Sc (Computer Science)
Sub: Satellite Communications

Introduction:

General background, frequency allocations for satellite services, basic satellite system, system design considerations, applications.

2. Satellite Orbits:

Introduction, laws governing satellite motion, orbital parameters, orbital perturbations, Doppler effects, geostationary orbit, antenna look angles, antenna mount, limits of visibility, Earth eclipse of satellite, sun transit outage, inclined orbits, sun-synchronous orbit, launching of geostationary satellites.

3. Wave Propagation and Polarization:

Introduction, atmospheric losses, ionospheric effects, rain attenuation, other impairments, antenna polarization, polarization of satellite signals, cross polarization discrimination, ionospheric depolarization, rain depolarization, ice depolarization.

4. Satellite Antenna:

Antenna basics, aperture antennas, parabolic reflectors, offset feed, double reflector antennas, shaped reflector systems.

5. Link Design:

Introduction, transmission losses, link power budget equation, system noise, carrier to noise ratio for uplink and downlink, combined uplink and downlink carrier to noise ratio, inter modulation noise

6. Communication Satellites:

Introduction, design considerations, lifetime and reliability, spacecraft sub systems, spacecraft mass and power estimations, space segment cost estimates.

7. Earth Stations:

Introduction, design considerations, general configuration and characteristics.

8. Multiple Access Techniques:

Introduction, FDMA, TDMA, FDMA/TDMA, operation in a multiple beam environment, CDMA, multiple access examples

9. Non Geostationary Orbit Satellite Systems:

Introduction, reasons, design considerations, case study, example of systems.

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