BASIC CONCEPTS OF SATELLITE COMMUNICATIONS

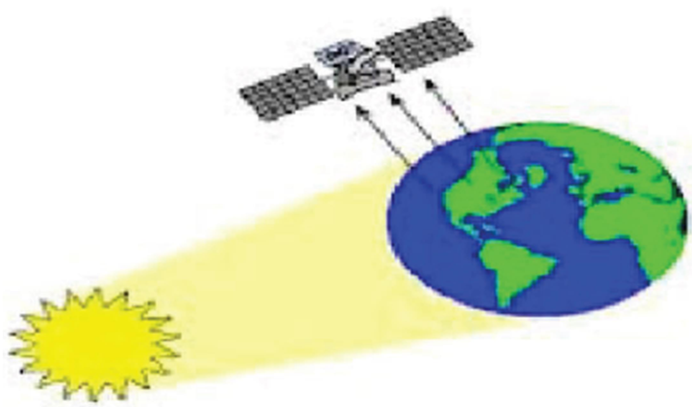
A communication satellite is an orbiting artificial earth satellite that receives a communications signal from a transmitting ground station, amplifies and possibly processes it, then transmits it back to the earth for reception by one or more receiving ground stations.

Communications information neither originates nor terminates at the satellite itself. The satellite is an active transmission relay, similar in function to relay towers used in terrestrial microwave communications.

Today's communications satellites offer extensive capabilities in applications involving data, voice, and video, with services provided to fixed, broadcast, mobile, personal communications, and private networks users.

Passive Satellites:

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

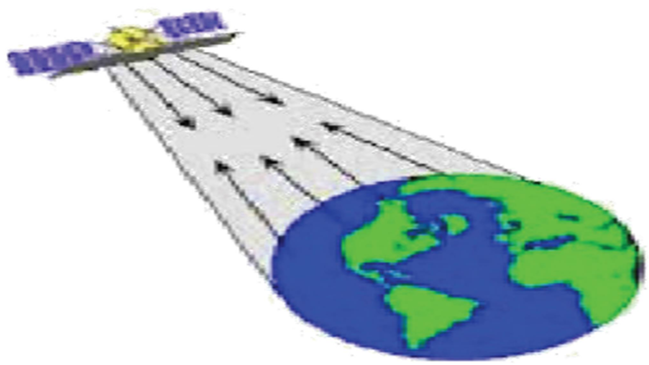


Disadvantages:

- Earth Stations required high power to transmit signals.
- Large Earth Stations with tracking facilities were expensive.
- A global system would have required a large number of passive satellites accessed randomly by different users.
- Control of satellites not possible from ground.
- The large attenuation of the signal while traveling the large distance between the transmitter and the receiver via the satellite was one of the most serious problems.

Active Satellites:

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

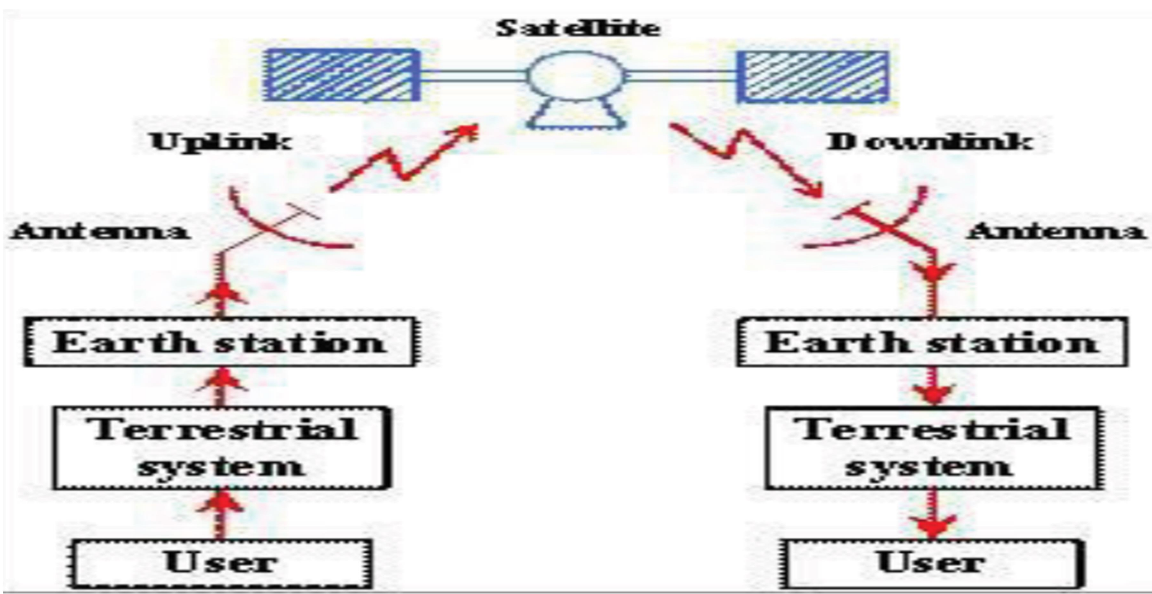


Disadvantages:

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

Two major elements of Satellite Communications Systems are:

The satellite communications portion is broken down into two areas or segments: **the space segment and the ground (or earth) segment.**



General architecture of Satellite Communication

Space Segment:

The elements of the space segment of a communications satellite system are shown in Figure. The space segment includes the satellite (or satellites) in orbit in the system, and the ground station that provides the operational control of the satellite(s) in orbit.

The ground station is variously referred to as the **Tracking, Telemetry, Command (TT&C) or the Tracking, Telemetry, Command and Monitoring (TTC&M) station**.

The TTC&M station provides essential spacecraft management and control functions to keep the satellite operating safely in orbit. The TTC&M links between the spacecraft and the ground are usually separate from the user communications links.

TTC&M links may operate in the same frequency bands or in other bands. TTC&M is most often accomplished through a separate earth terminal facility specifically designed for the complex operations required to maintain a spacecraft in orbit.

Ground segment:

The ground segment of the communications satellite system consists of the earth surface area based terminals that utilize the communications capabilities of the Space Segment. TTC&M ground stations are not included in the ground segment.

The ground segment terminals consist of three basic types:

• fixed (in-place) terminals;

• transportable terminals;

• mobile terminals.

Fixed terminals are designed to access the satellite while **fixed in-place on the ground**. They may be providing different types of services, but they are defined by the fact that they are not moving while communicating with the satellite. Examples of fixed terminals are small terminals used in private networks (VSATs), or terminals mounted on residence buildings used to receive broadcast satellite signals.

Transportable terminals are designed to be movable, but once on location remain fixed during transmissions to the satellite. Examples of the transportable terminal are satellite news gathering (SGN) trucks, which move to locations, stop in place, and then deploy an antenna to establish links to the satellite.

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

Satellite Control Centre function:

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

Advantages Of Satellite Communication

- Universal: Satellite communications are available virtually everywhere.
- Versatile: Satellites can support all of today's communications needs.
- Reliable: Satellite is a proven medium for supporting a company's communications needs.
- Seamless: Satellite's inherent strength as a broadcast medium makes it perfect.
- Fast: Since satellite networks can be set up quickly, companies can be fast-to-market with new services.
- Flexible
- Expandable
- High Quality
- Quick Provision of Services
- Mobile and Emergency Communication
- Suitable for both Digital and Analog Transmission

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

Satellite orbits in terms of the orbital height:

According to distance from earth:

- Geosynchronous Earth Orbit (GEO)
- Medium Earth Orbit (MEO)
- Low Earth Orbit (LEO)

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 1/3rd of the Earth). The orbit of these satellites is circular. Lifetime expectancy of these satellites is 15 years.

There are three conditions which lead to geostationary satellites.

1) The satellite should be placed 35,786 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.

Advantages Of GEO

- Minimal Doppler shift
- These factors make it ideal for satellite broadcast and other multipoint applications
- GEO satellites have a 24 hour view of a particular area.
- A GEO satellite's distance from earth gives it a large coverage area, almost a fourth of the earth's surface.

Disadvantages Of GEO

- 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.
- Transferring a GEO into orbit is very expensive.

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 20,000 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.

Advantages Of MEO

- A MEO satellite's longer duration of visibility and wider footprint means fewer satellites are needed in a MEO network than a LEO network.

Disadvantages Of MEO

- A MEO satellite's distance gives it a longer time delay and weaker signal than a LEO satellite, though not as bad as a GEO satellite.

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, providing mobile communication services (due to lower latency).

Advantages Of LEO

- A LEO satellite's proximity to earth compared to a GEO satellite gives it a better signal strength and less of a time delay, which makes it better for point to point communication.
- A LEO satellite's smaller area of coverage, less waste of bandwidth.

Disadvantages Of LEO

- A network of LEO satellites is needed, which can be costly.
- LEO satellites have to compensate for Doppler shifts cause by their relative movement.
- Atmospheric drag effects to LEO satellites, causing gradual orbital deterioration.

FREQUENCY ALLOCATIONS FOR SATELLITE SERVICES

Allocation of frequencies to satellite services is 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, the frequency bands are allocated to various satellite services. Some of them are listed below.

- **Fixed satellite service:** Provides Links for existing Telephone Networks Used for transmitting television signals to cable companies.
- **Broadcasting satellite service:** Provides Direct Broadcast to homes. E.g. Live Cricket matches etc
- **Mobile satellite services:** This includes services for: Land Mobile, Maritime 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:

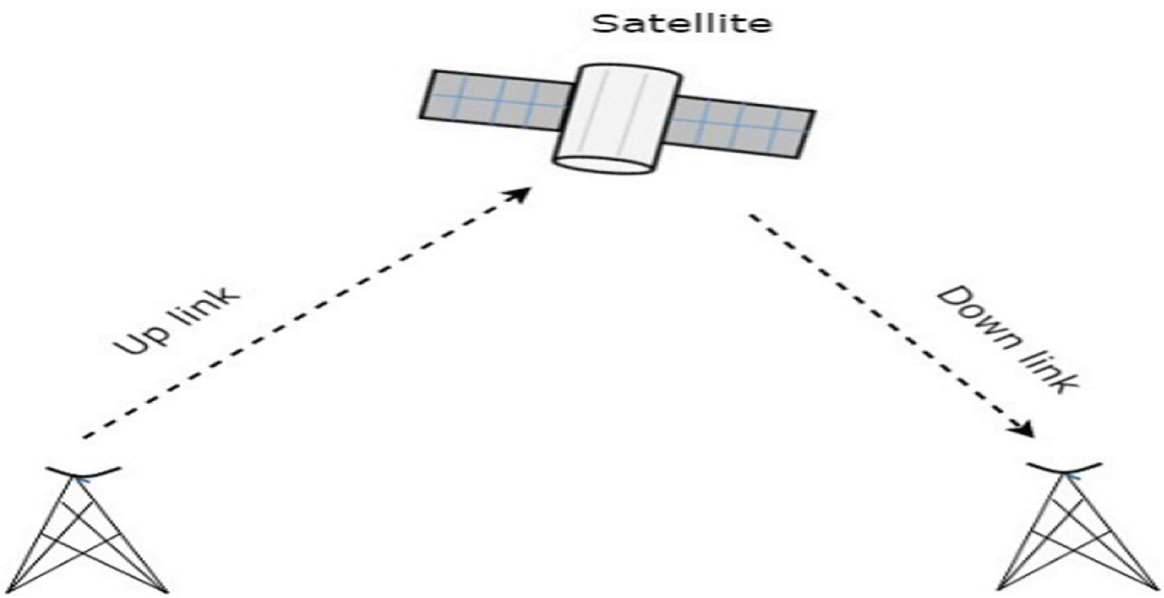
Frequency Band	**Designations (GHz)**
VHF	0.1-0.3
UHF	0.3-1.0
L-band	1.0-2.0
S-band	2.0-4.0
C-band	4.0-8.0
X-band	8.0-12.0
Ku-band	12.0-18.0 (Ku is Under K Band)
Ka-band	18.0-27.0 (Ka is Above K Band)
V-band	40.0-75.0
W-band	75-110
Mm-band	110-300
µm-band	300-3000

Uplink and Downlink frequency:

The frequency with which, the signal is sent into the space is called as Uplink frequency

Similarly, the frequency with which, the signal is sent by the transponder is called as Downlink frequency

The following figure illustrates this concept clearly.



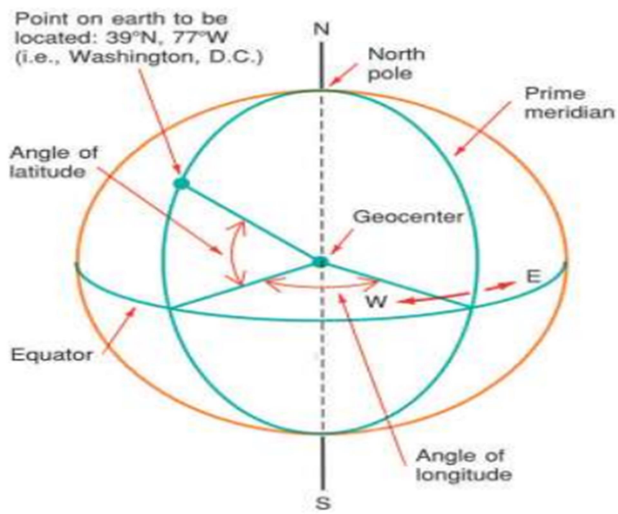
The transmission of signal from first earth station to satellite through a channel is called as Uplink. Similarly, the transmission of signal from satellite to second earth station through a channel is called as Downlink.

Uplink frequency is the frequency at which, the first earth station is communicating with satellite. The satellite transponder converts this signal into another frequency and sends it down to the second earth station. This frequency is called as Downlink frequency. In similar way, second earth station can communicate with the first one.

Latitude and Longitude:-

Latitude of a given point is defined as the angle between (the line drawn from the point on the surface of the earth to the geocenter) and (the line between the geocenter and the equator)

The 0° latitude is at the equator, and 90° latitude is at either the north or south pole (90N, 90S).



The Longitude (or Meridian) of a given point is the angle between (the line connecting the geocenter of the earth to the point where the prime meridian and equator intersect) and the meridian containing the given point of interest intersect.

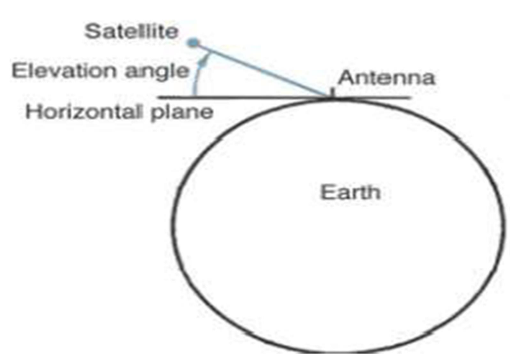
- The 0 longitude is called the prime meridian (passing by Greenwich, England).
- The designation east or west is usually added to the longitude angle (10W, 20E)

Look Angles (Elevation and Azimuth Angle)

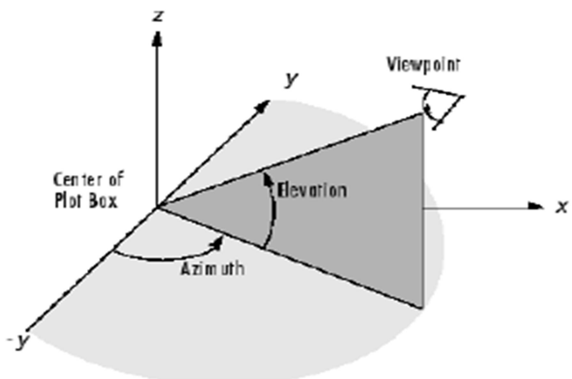
Knowing the location of the satellite is insufficient information for most earth stations that must communicate with the satellite. The earth station need to know the azimuth and elevation settings of its antenna to intercept the satellite.

Elevation angle is the vertical angle formed between the direction of travel of an electromagnetic wave radiated from an earth station antenna pointing directly toward a satellite and the horizontal plane.

- The smaller the angle of elevation, the greater the distance a propagated wave must pass through Earth's atmosphere.
- As distance increases, the signal quality deteriorates.
- Generally, 5° is considered as the minimum acceptable angle of elevation.



Azimuth angle is defined as the horizontal pointing angle of an earth station antenna. Azimuth angle is generally referenced north (0°) or to south (180°) in clockwise.



For geostationary orbit, the look angles values does not change as the satellites are stationary with respect to earth.

Angle of elevation and azimuth angle both depend on the latitude of the earth station and the longitude of both the earth station and the orbiting satellite.

The procedure for determining angle of elevation and azimuth for geostationary satellites is as follows:

1. From a good map, determine the longitude and latitude of the earth station.

2. From Table 1, determine the longitude of the satellite of interest.

3. Calculate the difference, in degrees (ΔL), between the longitude of the satellite and the longitude of the earth station.

4. Then from Figure 12 determine the azimuth angle, and from Figure 13 determine the elevation angle.

Table 1 Longitudinal Position of Several Curre Synchronous Satellites Parked in an Equatorial Arc[a]

Satellite	Longitude (°W
Satcom I	135
Satcom II	119
Satcom V	143
Satcom C1	137
Satcom C3	131
Anik 1	104
Anik 2	109
Anik 3	114
Anik C1	109.25
Anik C2	109.15
Anik C3	114.9
Anik E1	111.1
Anik E2	107.3
Westar I	99
Westar II	123.5
Westar III	91
Westar IV	98.5
Westar V	119.5
Mexico	116.5
Galaxy III	93.5
Galaxy IV	99
Galaxy V	125
Galaxy VI	74
Telstar	96
Comstar I	128
Comstar II	95
Comstar D2	76.6
Comstar D4	75.4
Intelsat 501	268.5
Intelsat 601	27.5
Intelsat 701	186

[a]0° latitude.

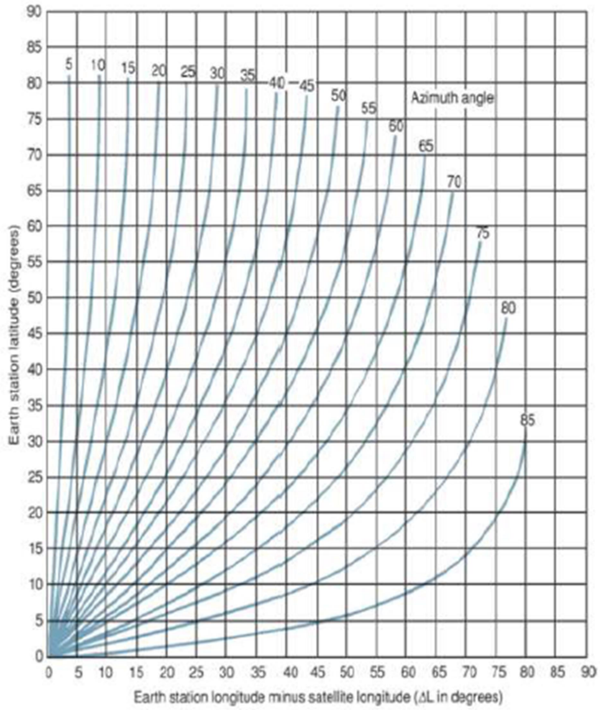


FIGURE 12 Azimuth angles for earth stations located in the northern hemisphere referenced to 180 degrees

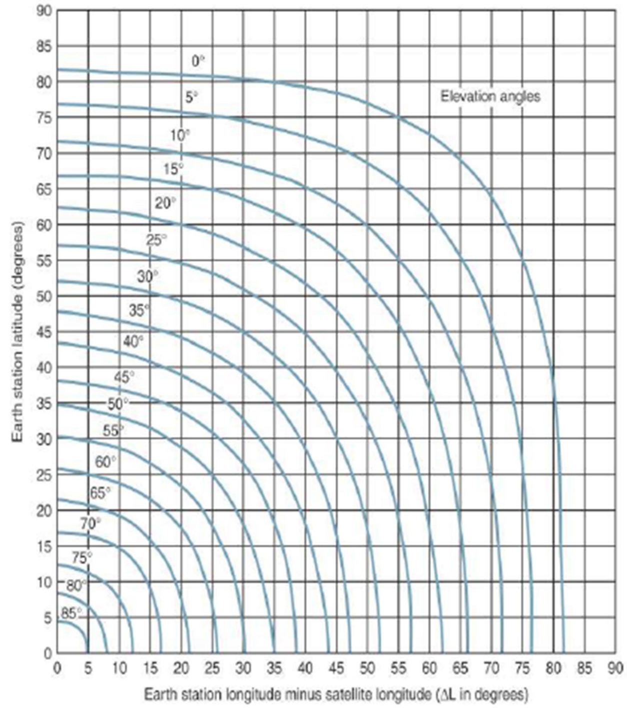


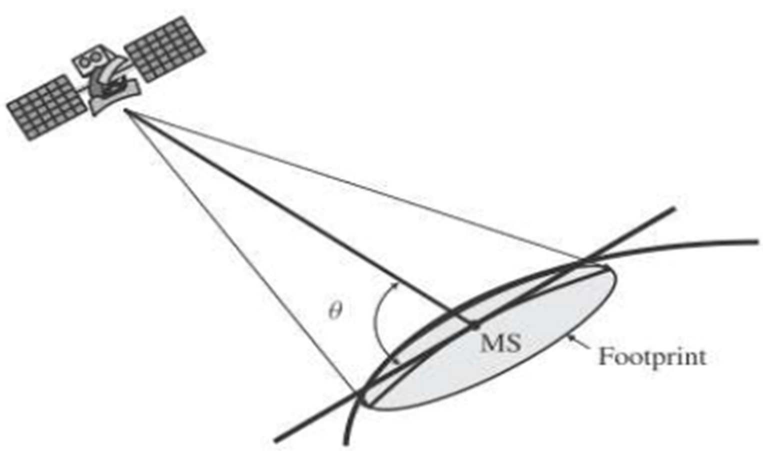
FIGURE 13 Elevation angles for earth stations located in the Northern Hemisphere

Footprint with Elevation Angle

The elevation angle between the satellite beam and the surface of the earth has an impact on the illuminated area (known as the footprint)

The elevation angle θ of the satellite beam governs the distance of the satellite with respect to the MS.

The satellite beam footprint (highlighted circle with 0 dB intensity) is considered to be an isoflux region



The area of Earth covered by a satellite depends on:

1. The location of the satellite in its geosynchronous orbit,

2. The carrier frequency and

3. The gain of its antennas.

The radiation pattern from a satellite antenna may be categorized as either spot, zonal or earth.

1. Earth Coverage: The radiation patterns covers approximately one-third of Earth's surface.

2. Zonal coverage: covers an area less than one-third of Earth's surface.

3. Spot coverage: beams concentrate the radiated power in a very small geographic area.

Orbital Control

Orbital control, often called **station keeping**, is the process required to maintain a satellite in its proper orbit location. It is similar to, although not functionally the same as, attitude control.

GSO satellites will undergo forces that would cause the satellite to drift in the east-west (longitude) and north-south (latitude) directions, as well as in altitude, if not compensated for with active orbital control jets. Orbital control is usually maintained with the thruster system.

The non-spherical (oblate) properties of the earth, primarily exhibited as an equatorial bulge, cause the satellite to drift slowly in longitude along the equatorial plane. Control jets are pulsed to impart an opposite velocity component to the satellite, which causes the satellite to drift back to its nominal position. These corrections are referred to as **east-west station keeping** maneuvers, which are accomplished periodically every two to three weeks.

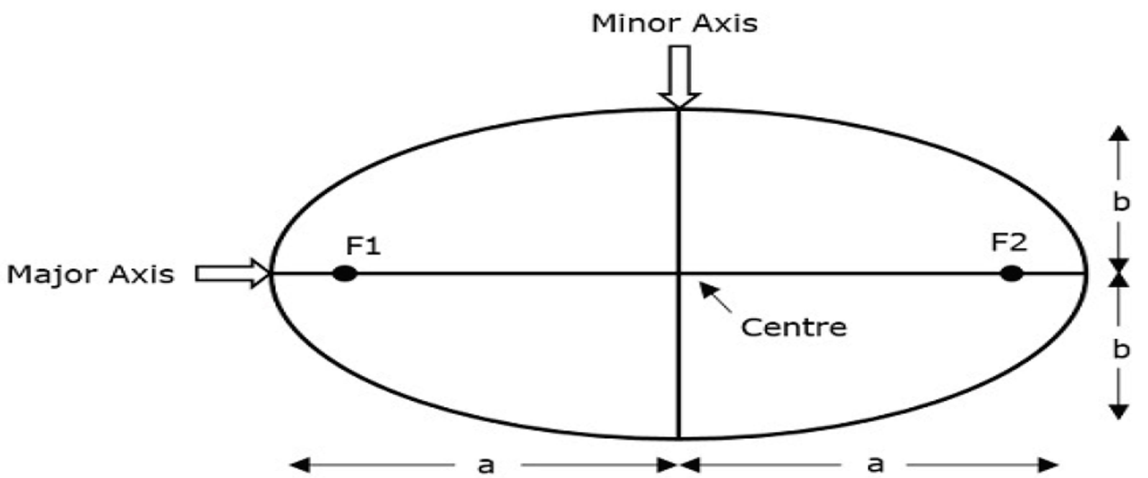
Latitude drift will be induced primarily by gravitational forces from the sun and the moon. These forces cause the satellite inclination to change about 0.075◦ per month if left uncorrected. Periodic pulsing to compensate for these forces, called **north-south station keeping** maneuvers, must also be accomplished periodically to maintain the nominal satellite orbit location.

Kepler's laws:-

Kepler formulated three laws that changed the whole satellite communication theory and observations. These are popularly known as Kepler's laws. These are helpful to visualize the motion through space.

Kepler's First Law:-

Kepler's first law states that the path followed by a satellite around its primary (the earth) will be an ellipse. This ellipse has two focal points (foci) F1 and F2 as shown in the figure below. Center of mass of the earth will always present at one of the two foci of the ellipse.



If the distance from the center of the object to a point on its elliptical path is considered, then the farthest point of an ellipse from the center is called as **apogee** and the shortest point of an ellipse from the center is called as **perigee.**

Apogee: A point for a satellite farthest from the Earth.

Perigee: A point for a satellite closest from the Earth.

Eccentricity "e" of this system can be written as −

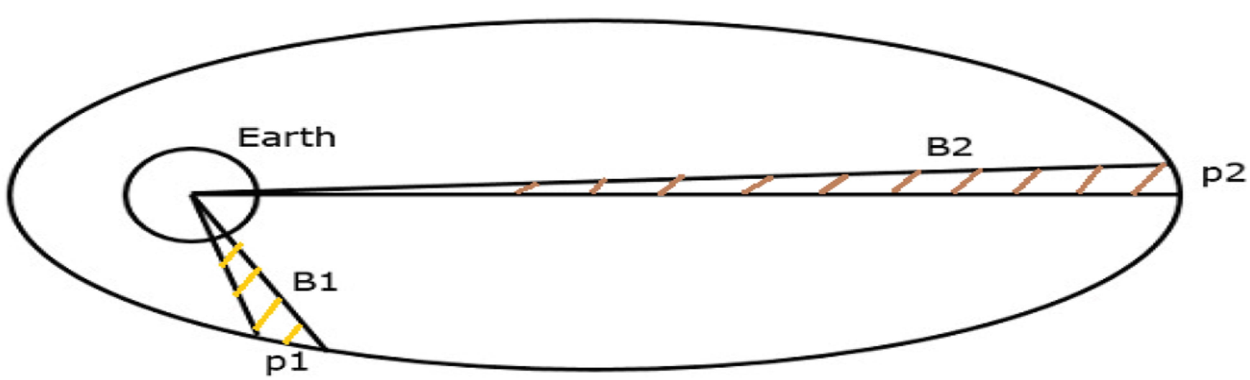
$$e = \frac{\sqrt{a^2 - b^2}}{a}$$

Where, a & b are the lengths of semi major axis and semi minor axis of the ellipse respectively.

For an elliptical path the value of eccentricity (e) is always lie in between 0 and 1, i.e.0 < e < 1, since a is greater than b. Suppose, if the value of eccentricity (e) is zero, then the path will be no more in elliptical shape, rather it will be converted into a circular shape.

Kepler's Second Law:-

Kepler's second law states that for equal intervals of time, the area covered by the satellite will be same with respect to center of mass of the earth. This can be understood by taking a look at the following figure.



Assume, the satellite covers p1 and p2 distances in the same time interval. Then, the areas B1 and B2 covered by the satellite at those two instances are equal.

Kepler's Third Law

Kepler's third law states that, the square of the periodic time of an elliptical orbit is proportional to the cube of its semi major axis length. Mathematically, it can be written as follows −

$$T^2 \, \alpha \, a^3$$

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

Where, $\frac{4\pi^2}{\mu}$ is the proportionality constant.

μ is Kepler's constant and its value is equal to 3.986005 x10^{14} m^3/sec^2

ORBITAL PERTURBATIONS

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

Atmospheric Drag

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

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.