

# Satellite Communication

## Introduction

The word communication arises from the Latin word *commūnicāre*, which means “to share”. Communication is the basic step for exchange of information. Communication can be defined as the process of exchange of information through means such as words, actions, signs, etc., between two or more individuals. The communication system is a system which describes the information exchange between two points. The process of transmission and reception of information is called communication.

## Need of Satellite Communication

The following two kinds of propagation are used earlier for communication up to some distance.

- **Ground wave propagation** – Ground wave propagation is suitable for frequencies up to 30MHz. This method of communication makes use of the troposphere conditions of the earth.
- **Sky wave propagation** – The suitable bandwidth for this type of communication is broadly between 30–40 MHz and it makes use of the ionosphere properties of the earth.

The maximum hop or the station distance is limited to 1500KM only in both ground wave propagation and sky wave propagation. Satellite communication overcomes this limitation. In this method, satellites provide **communication for long distances**, which is well beyond the line of sight.

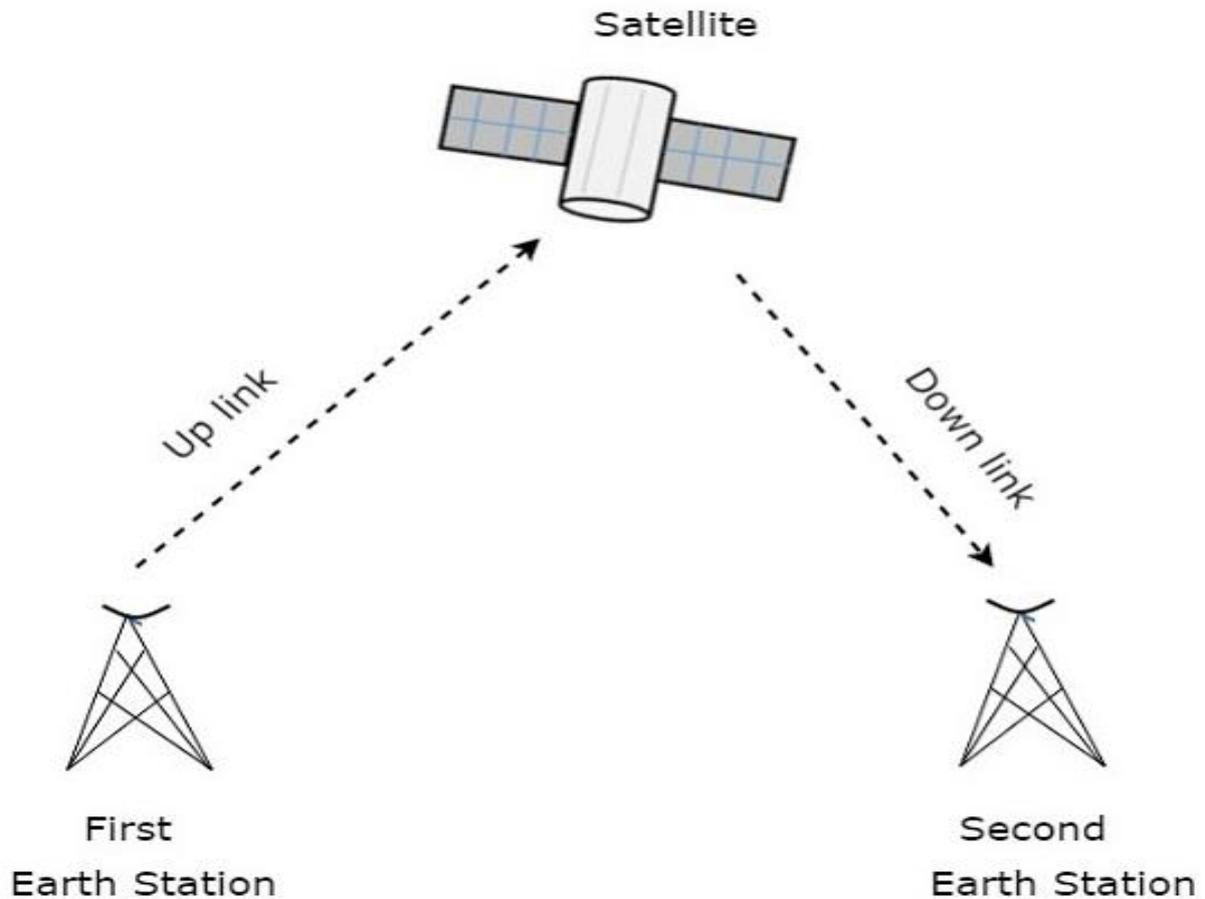
Since the satellites locate at certain height above earth, the communication takes place between any two earth stations easily via satellite. So, it overcomes the limitation of communication between two earth stations due to earth's curvature.

## How a Satellite Works

A **satellite** is a body that moves around another body in a particular path. A communication satellite is nothing but a microwave repeater station in space. It is helpful in telecommunications, radio and television along with internet applications.

A **repeater** is a circuit, which increases the strength of the received signal and then transmits it. But, this repeater works as a **transponder**. That means, it changes the frequency band of the transmitted signal from the received one.

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 also communicate with the first one.

The process of satellite communication begins at an earth station. Here, an installation is designed to transmit and receive signals from a satellite in an orbit around the earth. Earth stations send the information to satellites in the form of high powered, high frequency (GHz range) signals.

The satellites receive and retransmit the signals back to earth where they are received by other earth stations in the coverage area of the satellite. Satellite's **footprint** is the area which receives a signal of useful strength from the satellite.

## Pros and Cons of Satellite Communication

In this section, let us have a look at the advantages and disadvantages of satellite communication.

Following are the **advantages** of using satellite communication:

- Area of coverage is more than that of terrestrial systems
- Each and every corner of the earth can be covered
- Transmission cost is independent of coverage area
- More bandwidth and broadcasting possibilities

Following are the **disadvantages** of using satellite communication –

- Launching of satellites into orbits is a costly process.
- Propagation delay of satellite systems is more than that of conventional terrestrial systems.
- Difficult to provide repairing activities if any problem occurs in a satellite system.
- Free space loss is more
- There can be congestion of frequencies.

## Applications of Satellite Communication

Satellite communication plays a vital role in our daily life. Following are the applications of satellite communication –

- Radio broadcasting and voice communications
- TV broadcasting such as Direct To Home (DTH)
- Internet applications such as providing Internet connection for data transfer, GPS applications, Internet surfing, etc.
- Military applications and navigations
- Remote sensing applications
- Weather condition monitoring & Forecasting

## Orbital Mechanics

We know that the path of satellite revolving around the earth is known as **orbit**. This path can be represented with mathematical notations. Orbital mechanics is the study of the motion of the satellites that are present in orbits. So, we can easily understand the space operations with the knowledge of orbital motion.

## Orbital Elements

Orbital elements are the parameters, which are helpful for describing the orbital motion of satellites. Following are the **orbital elements**.

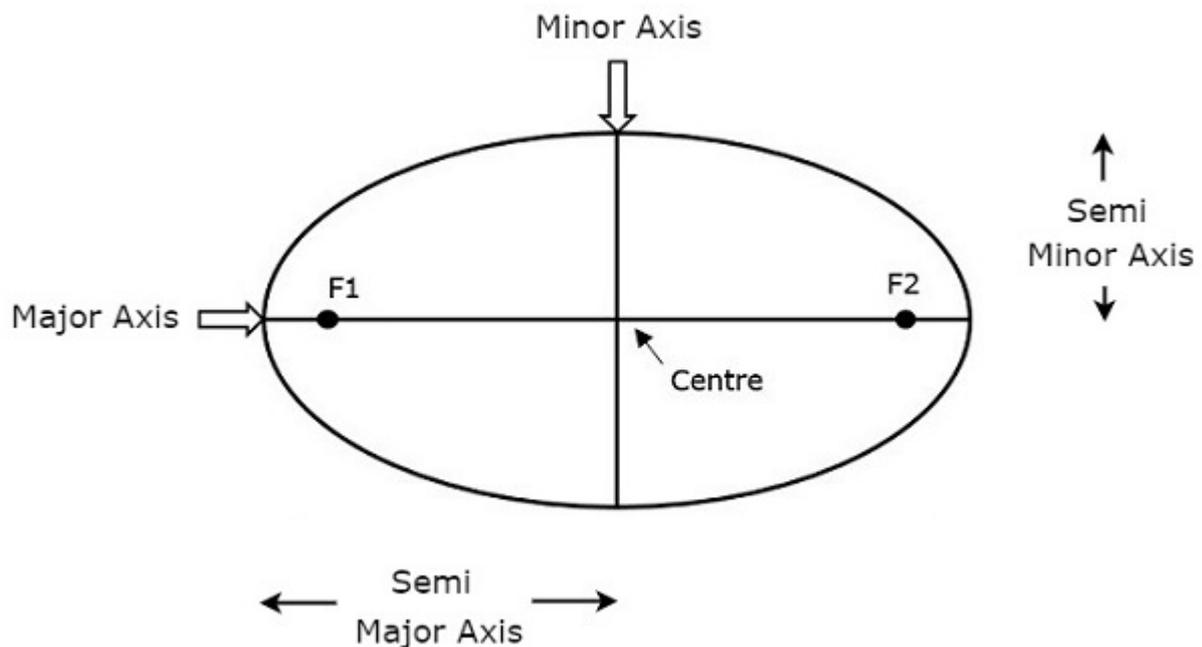
- Semi major axis
- Eccentricity
- Mean anomaly

- Argument of perigee
- Inclination
- Right ascension of ascending node

The above six orbital elements define the orbit of earth satellites. Therefore, it is easy to discriminate one satellite from other satellites based on the values of orbital elements.

### Semi major axis

The length of **Semi-major axis (a)** defines the size of satellite's orbit. It is half of the major axis. This runs from the center through a focus to the edge of the ellipse. So, it is the radius of an orbit at the orbit's two most distant points.



Both semi major axis and semi minor axis are represented in above figure. Length of semi **major axis (a)** not only determines the size of satellite's orbit, but also the time period of revolution.

If circular orbit is considered as a special case, then the length of semi-major axis will be equal to **radius** of that circular orbit.

### Eccentricity

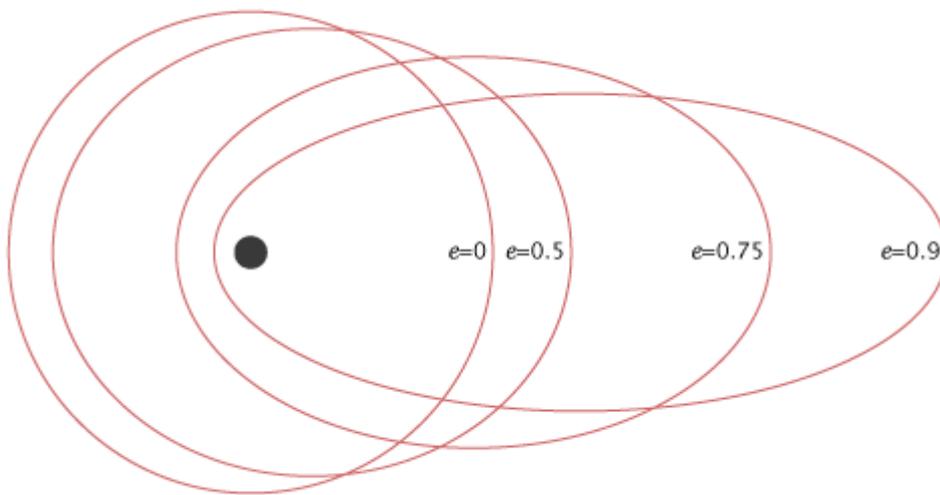
The value of **Eccentricity (e)** fixes the shape of satellite's orbit. This parameter indicates the deviation of the orbit's shape from a perfect circle.

If the lengths of semi major axis and semi minor axis of an elliptical orbit are  $a$  &  $b$ , then the mathematical expression for **eccentricity (e)** will be

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

The value of eccentricity of a circular orbit is **zero**, since both  $a$  &  $b$  are equal. Whereas, the value of eccentricity of an elliptical orbit lies between zero and one.

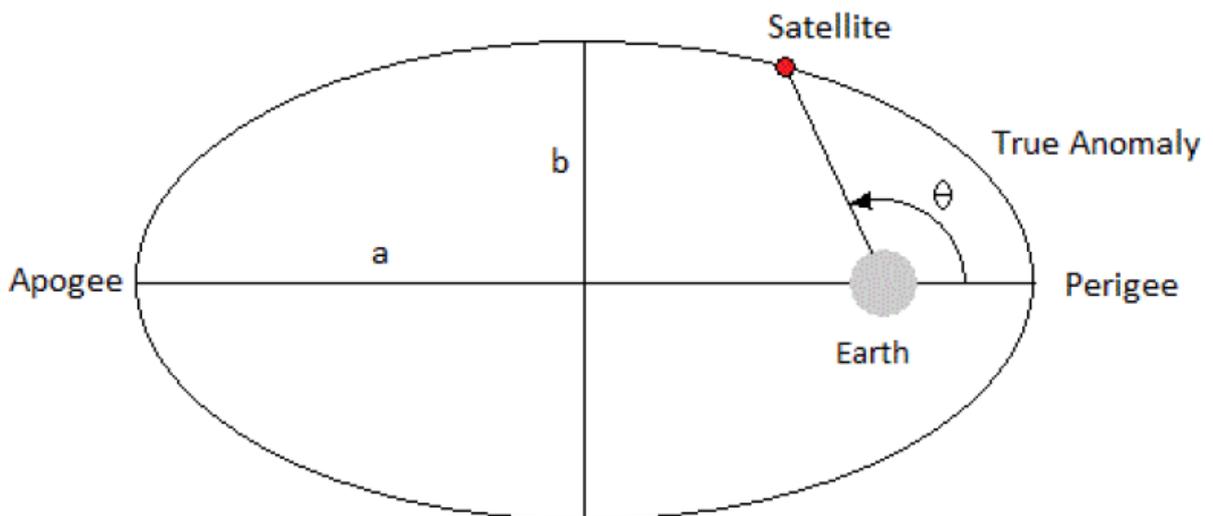
The following **figure** shows the various satellite orbits for different eccentricity ( $e$ ) values



In above figure, the satellite orbit corresponding to eccentricity ( $e$ ) value of zero is a circular orbit. And, the remaining three satellite orbits are of elliptical corresponding to the eccentricity ( $e$ ) values 0.5, 0.75 and 0.9.

### Mean Anomaly

For a satellite, the point which is closest from the Earth is known as Perigee. **Mean anomaly** ( $M$ ) gives the average value of the angular position of the satellite with reference to perigee.



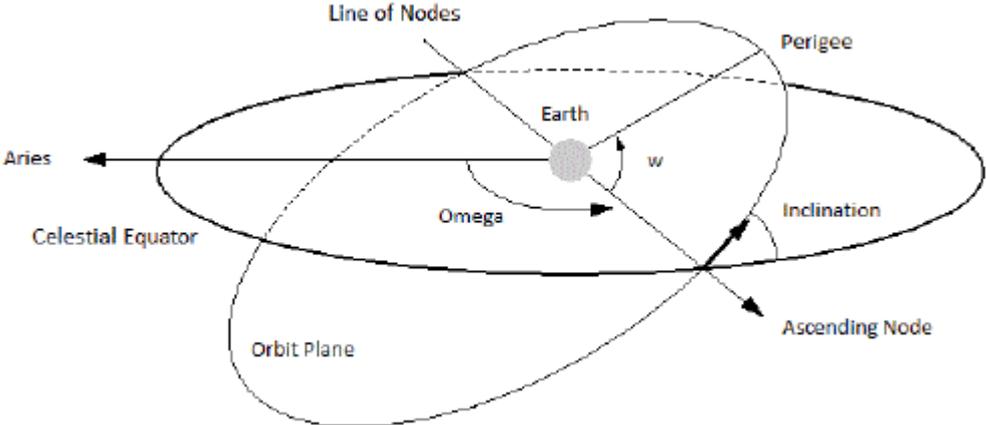
If the orbit is circular, then Mean anomaly gives the angular position of the satellite in the orbit. But, if the orbit is elliptical, then calculation of exact position is very difficult. At that time, Mean anomaly is used as an intermediate step.

### Argument of Perigee

Satellite orbit cuts the equatorial plane at two points. First point is called as **descending node**, where the satellite passes from the northern hemisphere to

the southern hemisphere. Second point is called as **ascending node**, where the satellite passes from the southern hemisphere to the northern hemisphere.

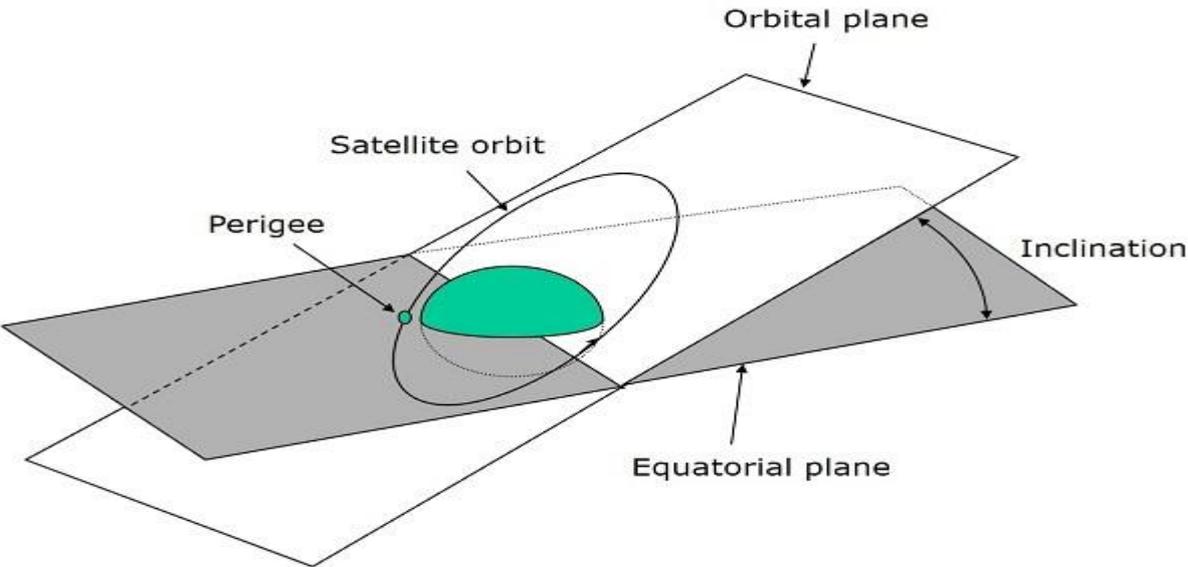
**Argument of perigee ( $\omega$ )** is the angle between ascending node and perigee. If both perigee and ascending node are existing at same point, then the argument of perigee will be zero degrees



Argument of perigee is measured in the orbital plane at earth's center in the direction of satellite motion.

**Inclination**

The angle between orbital plane and earth's equatorial plane is known as **inclination (i)**. It is measured at the ascending node with direction being east to north. So, inclination defines the orientation of the orbit by considering the equator of earth as reference.



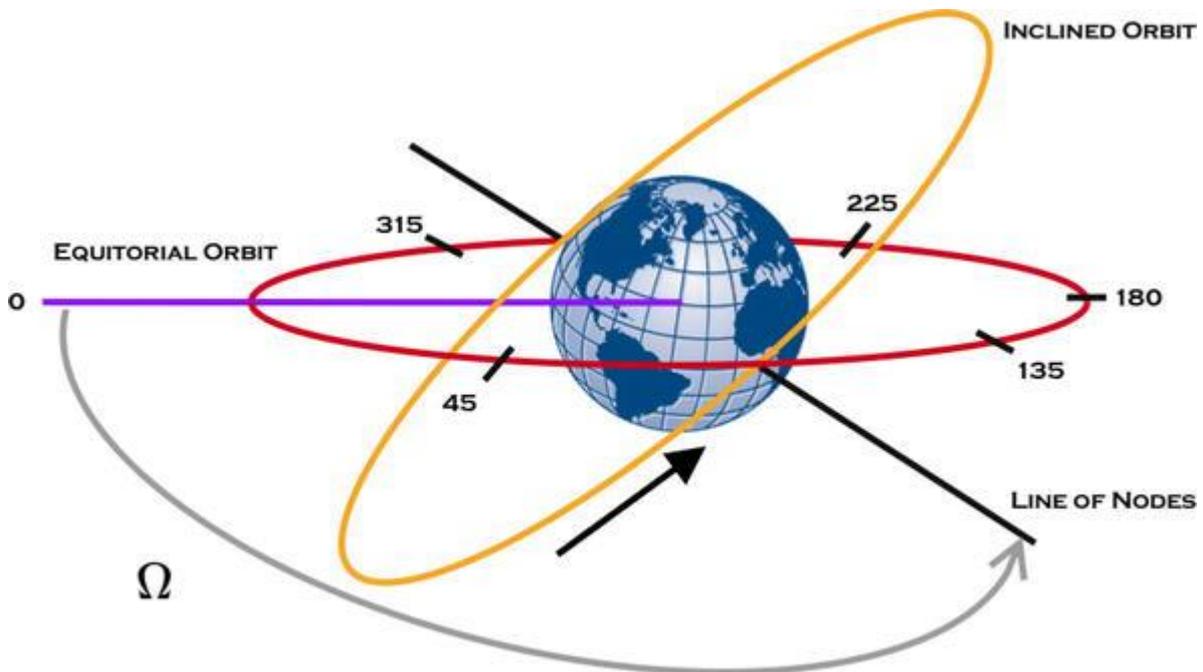
There are four types of orbits based on the angle of inclination.

- **Equatorial orbit** – Angle of inclination is either zero degrees or 180 degrees.
- **Polar orbit** – Angle of inclination is 90 degrees.
- **Prograde orbit** – Angle of inclination lies between zero and 90 degrees.
- **Retrograde orbit** – Angle of inclination lies between 90 and 180 degrees.

### Right Ascension of Ascending node

We know that **ascending node** is the point, where the satellite crosses the equatorial plane while going from the southern hemisphere to the northern hemisphere.

Right Ascension of ascending node ( $\Omega$ ) is the angle between line of Aries and ascending node towards east direction in equatorial plane. Aries is also called as vernal and equinox.



Satellite's **ground track** is the path on the surface of the Earth, which lies exactly below its orbit. The ground track of a satellite can take a number of different forms depending on the values of the orbital elements.

## Orbital Equations

In this section, let us discuss about the equations which are related to orbital motion.

### Forces acting on Satellite

A satellite, when it revolves around the earth, it undergoes a pulling force from the earth due to earth's gravitational force. This force is known as **Centripetal force** ( $F_1$ ) because this force tends the satellite towards it.

Mathematically, the **Centripetal force** ( $F_1$ ) acting on satellite due to earth can be written as

$$F_1 = \frac{GMm}{R^2}$$

Where,

- **G** is universal gravitational constant and it is equal to  $6.673 \times 10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$ .
- **M** is mass of the earth and it is equal to  $5.98 \times 10^{24} \text{ Kg}$ .
- **m** is mass of the satellite.
- **R** is the distance from satellite to center of the Earth.

A satellite, when it revolves around the earth, it undergoes a pulling force from the sun and the moon due to their gravitational forces. This force is known as **Centrifugal force** ( $F_2$ ) because this force tends the satellite away from earth.

Mathematically, the **Centrifugal force** ( $F_2$ ) acting on satellite can be written as

$$F_2 = \frac{mv^2}{R}$$

Where, **v** is the orbital velocity of satellite.

### Orbital Velocity

Orbital velocity of satellite is the velocity at which, the satellite revolves around earth. Satellite doesn't deviate from its orbit and moves with certain velocity in that orbit, when both Centripetal and Centrifugal forces are **balance** each other.

So, **equate** Centripetal force ( $F_1$ ) and Centrifugal force ( $F_2$ ).

$$\begin{aligned}\frac{GMm}{R^2} &= \frac{mv^2}{R} \\ \Rightarrow \frac{GM}{R} &= v^2 \\ \Rightarrow v &= \sqrt{\frac{Gm}{R}}\end{aligned}$$

Therefore, the **orbital velocity** of satellite is

$$v = \sqrt{\frac{Gm}{R}}$$

Where,

- **G** is gravitational constant and it is equal to  $6.673 \times 10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$ .
- **M** is mass of the earth and it is equal to  $5.98 \times 10^{24} \text{ Kg}$ .
- **R** is the distance from satellite to center of the Earth.

So, the orbital velocity mainly **depends** on the distance from satellite to center of the Earth (**R**), since **G** & **M** are constants.

# Kepler's Laws

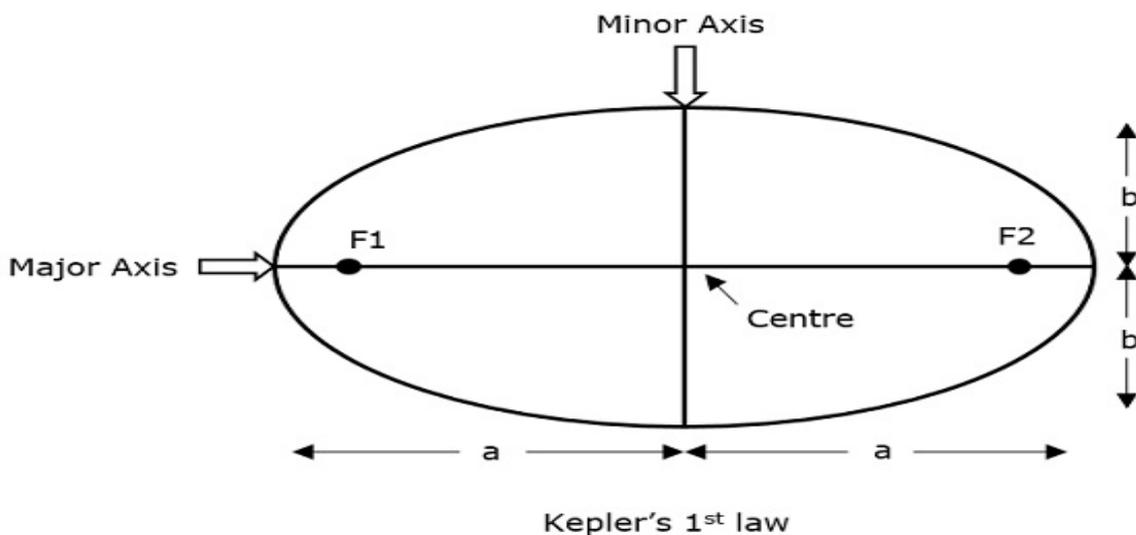
We know that satellite revolves around the earth, which is similar to the earth revolves around the sun. So, the principles which are applied to earth and its movement around the sun are also applicable to satellite and its movement around the earth.

Many scientists have given different types of theories from early times. But, only **Johannes Kepler** (1571-1630) was one of the most accepted scientist in describing the principle of a satellite that moves around the earth.

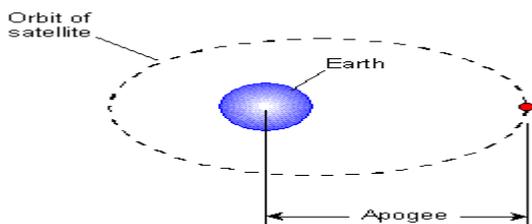
Kepler formulated three laws that changed the whole satellite communication theory and observations. These are popularly known as **Kepler's laws**. These are helpful to visualize the motion through space.

## 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**.



**Eccentricity "e"** of this system can be written as –

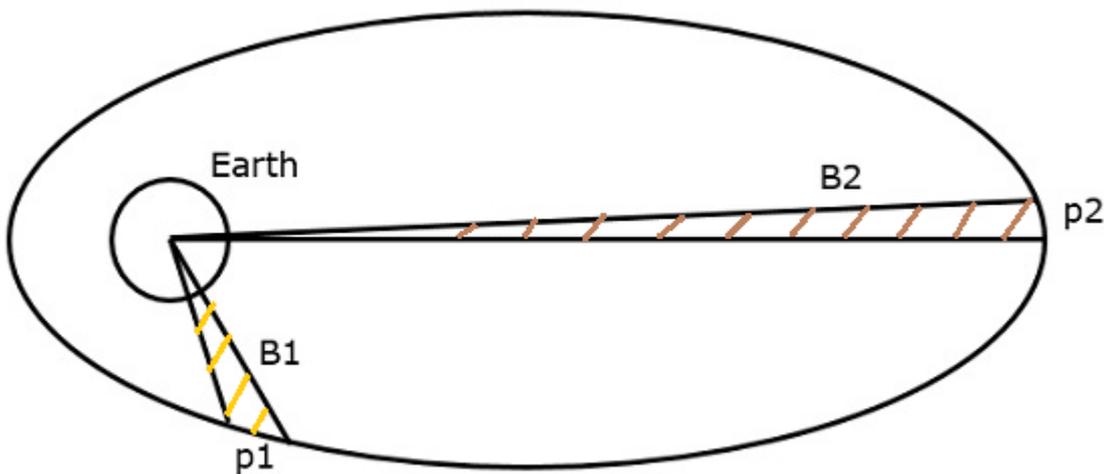
$$e = \frac{\sqrt{a^2 - b^2}}{a}$$

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  $p_1$  and  $p_2$  distances in the same time interval. Then, the areas  $B_1$  and  $B_2$  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 –

$$T^2 \propto a^3$$

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

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

$\mu$  is Kepler's constant and its value is equal to  $3.986005 \times 10^{14} \text{m}^3 / \text{sec}^2$

$$1 = \left(\frac{2\pi}{T}\right)^2 \left(\frac{a^3}{\mu}\right)$$

$$\Rightarrow 1 = n^2 \left( \frac{a^3}{\mu} \right)$$

$$\Rightarrow a^3 = \frac{\mu}{n^2}$$

Where, 'n' is the mean motion of the satellite in radians per second.

**Note** – A satellite, when it revolves around the earth, undergoes a pulling force from the earth, which is gravitational force. Similarly, it experiences another pulling force from the sun and the moon. Therefore, a satellite has to balance these two forces to keep itself in its orbit.

## Earth Orbit Satellites

Satellite should be properly placed in the corresponding orbit after leaving it in the space. It revolves in a particular way and serves its purpose for scientific, military or commercial. The orbits, which are assigned to satellites with respect to earth are called as **Earth Orbits**. The satellites present in those orbits are called as **Earth Orbit Satellites**.

We should choose an orbit properly for a satellite based on the requirement. For example, if the satellite is placed in **lower orbit**, then it takes less time to travel around the earth and there will be better resolution in an onboard camera. Similarly, if the satellite is placed in **higher orbit**, then it takes more time to travel around the earth and it covers more earth's surface at one time.

Following are the three important **types of Earth Orbit satellites** –

- Geosynchronous Earth Orbit Satellites
- Medium Earth Orbit Satellites
- Low Earth Orbit Satellites

Now, let us discuss about each type of earth orbit satellites one by one.

### Geosynchronous Earth Orbit Satellites

A Geo-synchronous Earth Orbit (**GEO**) **Satellite** is one, which is placed at an altitude of **22,300** miles above the Earth. This orbit is synchronized with a side real day (i.e., 23 hours 56 minutes). This orbit can have inclination and eccentricity.

It may not be circular. This orbit can be tilted at the poles of the earth. But, it appears stationary when observed from the Earth. These satellites are used for satellite Television.

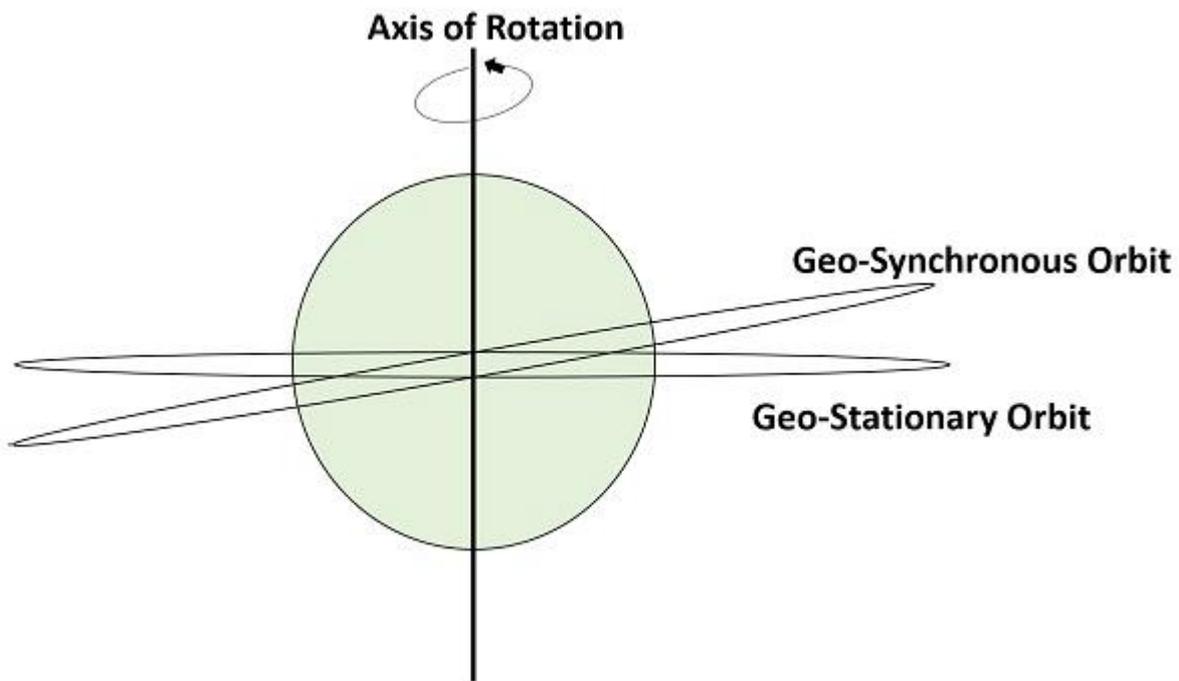
The same geo-synchronous orbit, if it is circular and in the plane of equator, then it is called as **Geostationary orbit**. These Satellites are placed at 35,900kms (same as Geosynchronous) above the Earth's Equator and they keep on rotating with respect to earth's direction (west to east).

The satellites present in these orbits have the angular velocity same as that of earth. Hence, these satellites are considered as **stationary** with respect to earth since, these are in synchronous with the Earth's rotation.

The **advantage** of Geostationary orbit is that no need to track the antennas in order to find the position of satellites.

Geostationary Earth Orbit Satellites are used for weather forecasting, satellite TV, satellite radio and other types of global communications.

The following figure shows the difference between Geo-synchronous and Geo-stationary orbits. The axis of rotation indicates the movement of Earth.



**Note** – Every Geostationary orbit is a Geo-synchronous orbit. But, the converse need not be true.

## Medium Earth Orbit Satellites

Medium Earth Orbit (**MEO**) satellites will orbit at distances of about **8000 miles** from earth's surface. Signals transmitted from a MEO satellite travel a shorter distance. Due to this, the signal strength at the receiving end gets improved. This shows that smaller and light weight receiving terminals can be used at the receiving end.

**Transmission delay** can be defined as the time it takes for a signal to travel up to a satellite and back down to a receiving station. In this case, there is less transmission delay. Because, the signal travels for a shorter distance to and from the MEO satellite.

For **real-time communications**, the shorter the transmission delay, the better will be the communication system. As an example, if a GEO satellite requires 0.25 seconds for a round trip, then MEO satellite requires less than 0.1 seconds to complete the same trip. MEOs operate in the frequency range of 2 GHz and above.

These satellites are used for High speed telephone signals. Ten or more MEO satellites are required in order to cover entire earth.

## Low Earth Orbit Satellites

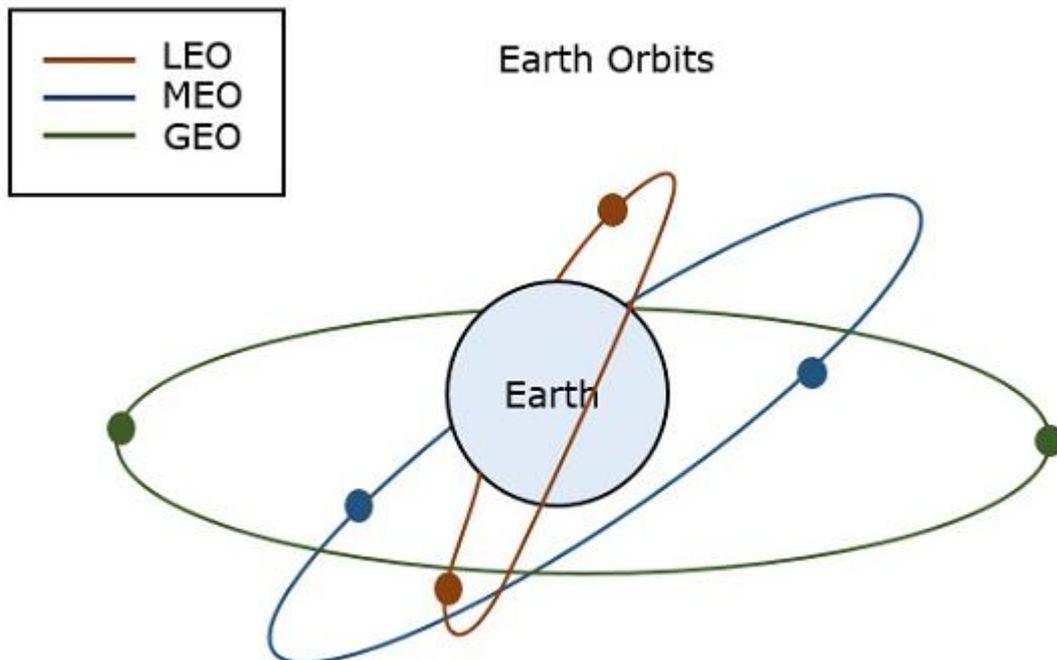
Low Earth Orbit **LEO** satellites are mainly classified into three categories. Those are little LEOs, big LEOs, and Mega-LEOs. LEOs will orbit at a distance of **500 to 1000 miles** above the earth's surface. These satellites are used for satellite phones and GPS.

This relatively short distance reduces transmission delay to only 0.05 seconds. This further reduces the need for sensitive and bulky receiving equipment. Twenty or more LEO satellites are required to cover entire earth.

Little LEOs will operate in the 800 MHz (0.8 GHz) range. Big LEOs will operate in the 2 GHz or above range, and Mega-LEOs operates in the 20-30 GHz range.

The higher frequencies associated with **Mega-LEOs** translates into more information carrying capacity and yields to the capability of real-time, low delay video transmission scheme.

The following **figure** depicts the paths of LEO, MEO and GEO



## Orbital Slots

Here, a question may arise that with more than **200 satellites** that are in geosynchronous orbit, how do we keep them from running into each other or from attempting to use the same location in space?

To answer this problem (question), international regulatory bodies like the International Telecommunications Union (**ITU**) and national government organizations like the Federal Communications Commission (**FCC**) designate the locations on the geosynchronous orbit, where the communications satellites can be located.

These locations are specified in degrees of longitude and are called as **orbital slots**. The FCC and ITU have progressively reduced the required spacing down to only 2 degrees for C-band and Ku-band satellites due to the huge demand for orbital slots.

## Look Angles & Orbital Perturbations

Earth station will receive the maximum signal level, if it is located directly under the satellite. Otherwise, it won't receive maximum signal level and that signal level decreases as the difference between the latitude and longitude of earth station increases.

So, based on the requirement we can place the satellite in a particular orbit. Now, let us discuss about the look angles.

### Look Angles

The following two angles of earth station antenna combined together are called as **look angles**.

- Azimuth Angle
- Elevation Angle

Generally, the values of these angles change for non-geostationary orbits. Whereas, the values of these angles don't change for geostationary orbits. Because, the satellites present in geostationary orbits appear stationary with respect to earth.

These two angles are helpful in order to point at the satellite directly from the earth station antenna. So, the **maximum gain** of the earth station antenna can be directed at satellite.

We can **calculate** the look angles of geostationary orbit by using longitude & latitude of earth station and position of satellite orbit.

#### Azimuth Angle

The angle between local horizontal plane and the plane passing through earth station, satellite and center of earth is called as **azimuth angle**.

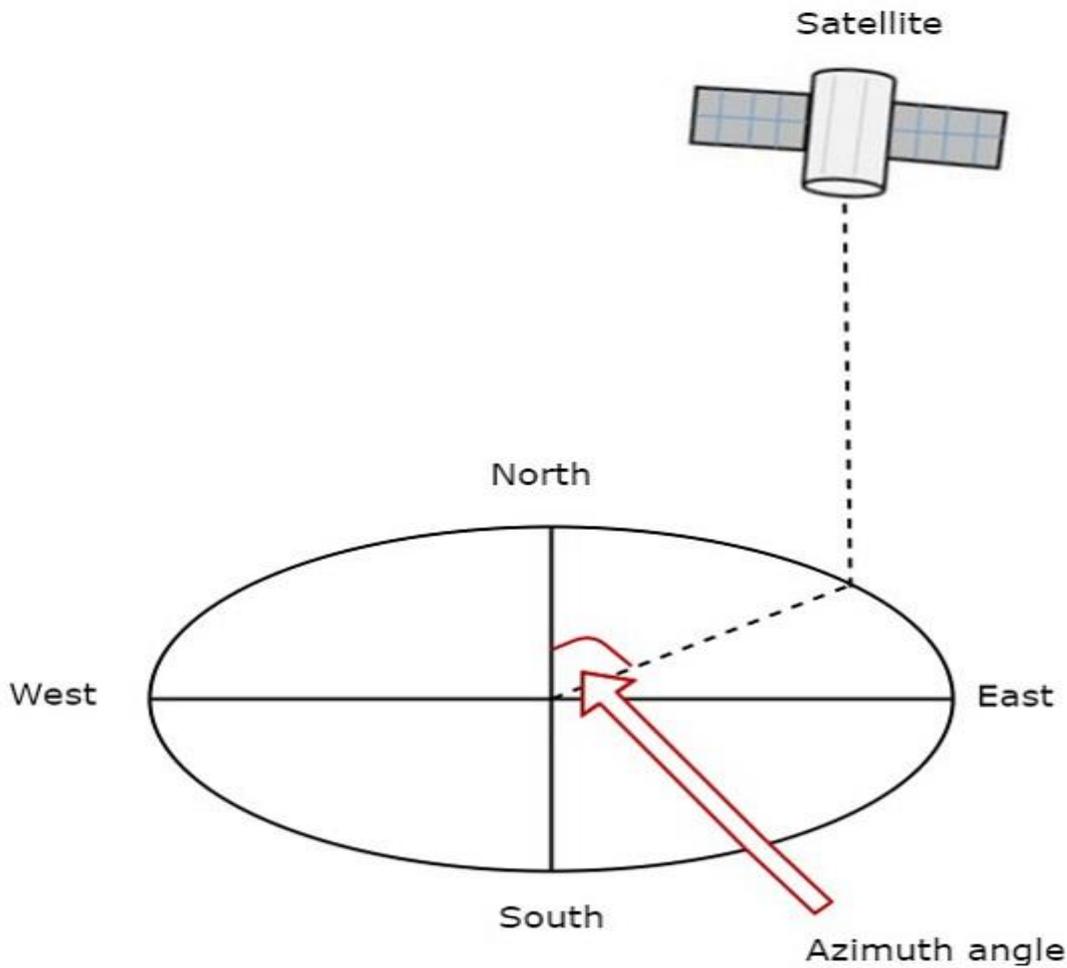
The **formula** for Azimuth angle ( $\alpha$ ) is

$$\alpha = 180^\circ + \tan^{-1} \left( \frac{\tan G}{\tan L} \right)$$

Where,

- $L$  is Latitude of earth station antenna.
- $G$  is the difference between position of satellite orbit and earth station antenna.

The following **figure** illustrates the azimuth angle.



Measure the **horizontal angle** at earth station antenna to north pole as shown in figure. It represents azimuth angle. It is used to track the satellite horizontally.

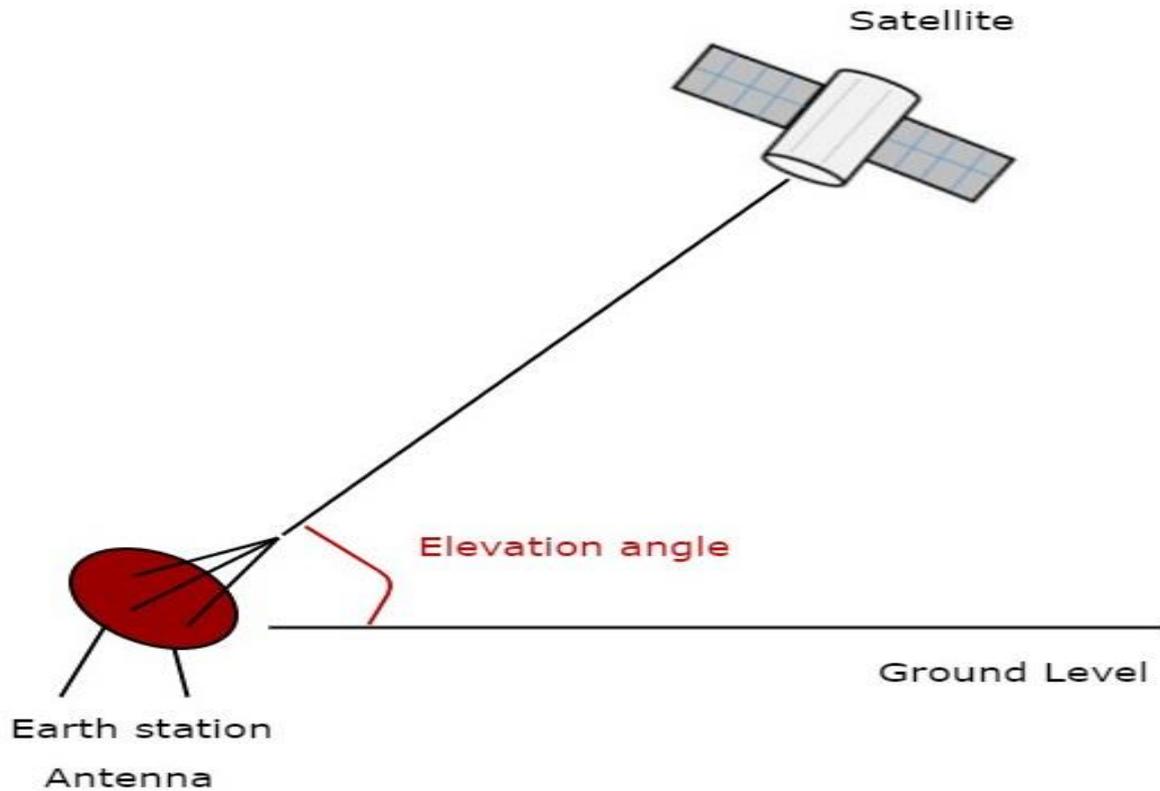
### Elevation Angle

The angle between vertical plane and line pointing to satellite is known as Elevation angle. Vertical plane is nothing but the plane, which is perpendicular to horizontal plane.

The **formula** for Elevation angle ( $\beta$ ) is

$$\beta = \tan^{-1} \left( \frac{\cos G \cdot \cos L - 0.15}{\sqrt{1 - \cos^2 G \cos^2 L}} \right)$$

We can calculate the elevation angle by using above formula. The following **figure** illustrates the elevation angle.



Measure the **vertical angle** at earth station antenna from ground to satellite as shown in the figure. It represents elevation angle.

## Orbital Perturbations

Following are the orbital perturbations due to gravitational and non-gravitational forces or parameters.

- Irregular gravitational force around the Earth due to non-uniform mass distribution. Earth's magnetic field too causes orbital perturbations.
- Main external perturbations come from Sun and Moon. When a satellite is near to these external bodies, it receives a stronger gravitational pull.
- Low-orbit satellites get affected due to friction caused by collision with atoms and ions.
- Solar radiation pressure affects large GEO satellites, which use large solar arrays.
- Self-generated torques and pressures caused by RF radiation from the antenna.

Most satellites use a **propulsion subsystem** in order to maintain a proper spin axis direction and control the altitude of the satellite against perturbation forces.

# Launching

Satellites stay in space for most of their life time. We know that the environment of weightlessness is present in the space. That's why satellites don't require additional strong frames in space. But, those are required during launching process. Because in that process satellite shakes violently, till the satellite has been placed in a proper orbit.

The **design of satellites** should be compatible with one or more launch vehicles in order to place the satellite in an orbit.

We know that the period of revolution will be more for higher **apogee** altitude according to Kepler's second law. The period of geostationary transfer orbit is nearly equal to 16 hours. If **perigee** is increased to GEO altitude (around 36,000 km), then the period of revolution will increase to 24 hours.

## Launching of Satellites

The process of placing the satellite in a proper orbit is known as **launching process**. During this process, from earth stations we can control the operation of satellite. Mainly, there are four stages in launching a satellite.

- **First Stage** – The first stage of launch vehicle contains rockets and fuel for lifting the satellite along with launch vehicle from ground.
- **Second Stage** – The second stage of launch vehicle contains smaller rockets. These are ignited after completion of first stage. They have their own fuel tanks in order to send the satellite into space.
- **Third Stage** – The third (upper) stage of the launch vehicle is connected to the satellite fairing. This fairing is a metal shield, which contains the satellite and it protects the satellite.
- **Fourth Stage** – Satellite gets separated from the upper stage of launch vehicle, when it has been reached to out of Earth's atmosphere. Then, the satellite will go to a "transfer orbit". This orbit sends the satellite higher into space.

When the satellite reached to the desired height of the orbit, its subsystems like solar panels and communication antennas gets unfurled. Then the satellite takes its position in the orbit with other satellites. Now, the satellite is ready to provide **services** to the public.

## Satellite Launch Vehicles

Satellite launch vehicles launch the satellites into a particular orbit based on the requirement. Satellite launch vehicles are nothing but multi stage rockets. Following are the **two types** of satellite launch vehicles.

- Expendable Launch Vehicles (ELV)
- Reusable Launch Vehicles (RLV)

## Expendable Launch Vehicles

Expendable launch vehicles (ELV) get destroyed after leaving the satellites in space. The following image shows how an ELV looks.



The ELV contains three stages. First and second stages of ELV raise the satellite to an about 50 miles and 100 miles. Third stage of ELV places the satellite in transfer orbit. The task of **ELV** will be completed and its spare parts will be fallen to earth, when the satellite reached to transfer orbit.

## Reusable Launch Vehicles

Reusable launch vehicles (RLV) can be used **multiple times** for launching satellites. Generally, this type of launch vehicles will return back to earth after leaving the satellite in space.

The following image shows a reusable launch vehicle. It is also known as **space shuttle**.



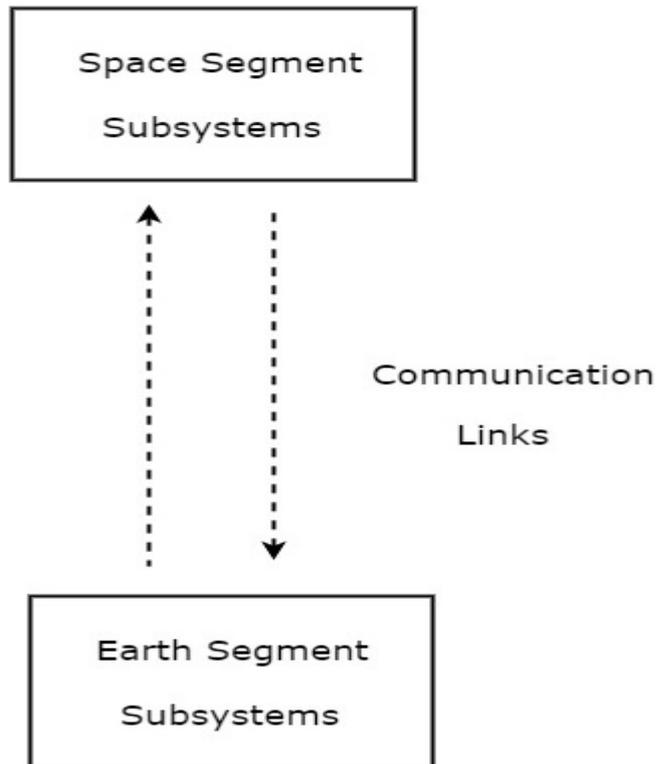
The functions of **space shuttle** are similar to the functions of first and second stages of ELV. Satellite along with the third stage of space shuttle are mounted in the cargo bay. It is ejected from the cargo bay when the space shuttle reaches to an elevation of 150 to 200 miles.

Then, the third stage of space shuttle gets fired and places the satellite into a transfer orbit. After this, the space shuttle will return back to earth for **reuse**.

## Subsystems

In satellite communication system, various operations take place. Among which, the main operations are orbit controlling, altitude of satellite, monitoring and controlling of other subsystems.

A satellite communication consists of mainly two **segments**. Those are space segment and earth segment. So, accordingly there will be two types of subsystems namely, space segment subsystems and earth segment subsystems. The following **figure** illustrates this concept.



As shown in the figure, the **communication** takes place between space segment subsystems and earth segment subsystems through communication links.

## Space Segment Subsystems

The subsystems present in space segment are called as space segment subsystems. Following are the **space segment subsystems**.

- AOC Subsystem
- TTCM Subsystem
- Power and Antenna Subsystems
- Transponders

## Earth Segment Subsystems

The subsystems present in the ground segment have the ability to access the satellite repeater in order to provide the communication between the users. **Earth segment** is also called as ground segment.

Earth segment performs mainly two functions. Those are transmission of a signal to the satellite and reception of signal from the satellite. **Earth stations** are the major subsystems that are present in earth segment.

We will discuss about all these subsystems of space segment and earth segment in following chapters.

# AOC Subsystem

We know that satellite may deviates from its orbit due to the gravitational forces from sun, moon and other planets. These forces change cyclically over a 24-hour period, since the satellite moves around the earth.

Altitude and Orbit Control (**AOC**) subsystem consists of rocket motors, which are capable of placing the satellite into the right orbit, whenever it is deviated from the respective orbit. AOC subsystem is helpful in order to make the antennas, which are of narrow beam type points towards earth.

We can make this AOC subsystem into the following **two parts**.

- Altitude Control Subsystem
- Orbit Control Subsystem

Now, let us discuss about these two subsystems one by one.

## Altitude Control Subsystem

Altitude control subsystem takes care of the orientation of satellite in its respective orbit. Following are the **two methods** to make the satellite that is present in an orbit as stable.

- Spinning the satellite
- Three axes method

### Spinning the satellite

In this method, the body of the satellite rotates around its **spin axis**. In general, it can be rotated at 30 to 100 rpm in order to produce a force, which is of gyroscopic type. Due to this, the spin axis gets stabilized and the satellite will point in the same direction. Satellites are of this type are called as **spinnners**.

Spinner contains a drum, which is of cylindrical shape. This drum is covered with solar cells. Power systems and rockets are present in this drum.

Communication subsystem is placed on top of the drum. An electric motor drives this communication system. The direction of this motor will be opposite to the rotation of satellite body, so that the antennas point towards earth. The satellites, which perform this kind of operation are called as **de-spin**.

During launching phase, the satellite **spins** when the small radial gas jets are operated. After this, the **de-spin** system operates in order to make the TTCM subsystem antennas point towards earth station.

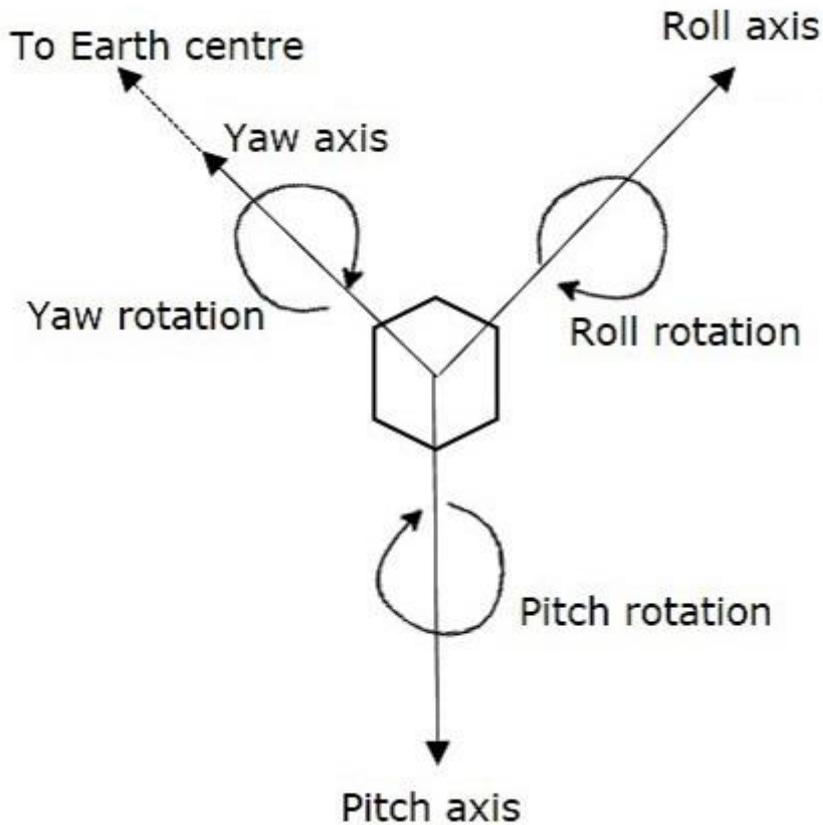
### Three Axis Method

In this method, we can stabilize the satellite by using one or more momentum wheels. This method is called as **three-axis method**. The advantage of this method is that the orientation of the satellite in three axes will be controlled and no need of rotating satellite's main body.

In this method, the following **three axes** are considered.

- **Roll axis** is considered in the direction in which the satellite moves in orbital plane.
- **Yaw axis** is considered in the direction towards earth.
- **Pitch axis** is considered in the direction, which is perpendicular to orbital plane.

These three axes are shown in below **figure**.



Let  $X_R$ ,  $Y_R$  and  $Z_R$  are the roll axis, yaw axis and pitch axis respectively. These three axis are defined by considering the satellite's position as **reference**. These three axes define the altitude of satellite.

Let  $X$ ,  $Y$  and  $Z$  are another set of Cartesian axes. This set of three axis provides the information about orientation of the satellite with respect to reference axes. If there is a change in altitude of the satellite, then the angles between the respective axes will be changed.

In this method, each axis contains two gas jets. They will provide the rotation in both directions of the three axes.

- The **first gas jet** will be operated for some period of time, when there is a requirement of satellite's motion in a particular axis direction.
- The **second gas jet** will be operated for same period of time, when the satellite reaches to the desired position. So, the second gas jet will stop the motion of satellite in that axis direction.

## Orbit Control Subsystem

Orbit control subsystem is useful in order to bring the satellite into its correct orbit, whenever the satellite gets deviated from its orbit.

The TTCM subsystem present at earth station monitors the position of satellite. If there is any change in satellite orbit, then it sends a signal regarding the correction to Orbit control subsystem. Then, it will resolve that issue by bringing the satellite into the correct orbit.

In this way, the **AOC subsystem** takes care of the satellite position in the right orbit and at right altitude during entire life span of the satellite in space.

## TTCM Subsystem

Telemetry, Tracking, Commanding and Monitoring (**TTCM**) subsystem is present in both satellite and earth station. In general, satellite gets data through sensors. So, Telemetry subsystem present in the satellite sends this data to earth station(s). Therefore, TTCM subsystem is very much necessary for any communication satellite in order to operate it successfully.

It is the responsibility of satellite operator in order to control the satellite in its life time, after placing it in the proper orbit. This can be done with the help of **TTCM subsystem**.

We can make this TTCM subsystem into the following **three parts**.

- Telemetry and Monitoring Subsystem
- Tracking Subsystem
- Commanding Subsystem

## Telemetry and Monitoring Subsystem

The word '**Telemetry**' means measurement at a distance. Mainly, the following operations take place in 'Telemetry'.

- Generation of an electrical signal, which is proportional to the quantity to be measured.
- Encoding the electrical signal.
- Transmitting this code to a far distance.

**Telemetry subsystem** present in the satellite performs mainly two functions –

- receiving data from sensors, and
- transmitting that data to an earth station.

Satellites have quite a few sensors to monitor different parameters such as pressure, temperature, status and etc., of various subsystems. In general, the telemetry data is transmitted as FSK or PSK.

Telemetry subsystem is a remote controlled system. It sends monitoring data from satellite to earth station. Generally, the **telemetry signals** carry the information related altitude, environment and satellite.

## Tracking Subsystem

Tracking subsystem is useful to know the position of the satellite and its current orbit. Satellite Control Center (**SCC**) monitors the working and status of space segment subsystems with the help of telemetry downlink. And, it controls those subsystems using command uplink.

We know that the **tracking subsystem** is also present in an earth station. It mainly focusses on range and look angles of satellite. Number of techniques that are using in order to track the satellite. For **example**, change in the orbital position of satellite can be identified by using the data obtained from velocity and acceleration sensors that are present on satellite.

The **tracking subsystem** that is present in an earth station keeps tracking of satellite, when it is released from last stage of Launch vehicle. It performs the functions like, locating of satellite in initial orbit and transfer orbit.

## Commanding Subsystem

Commanding subsystem is necessary in order to launch the satellite in an orbit and its working in that orbit. This subsystem adjusts the altitude and orbit of satellite, whenever there is a deviation in those values. It also controls the communication subsystem. This **commanding subsystem** is responsible for turning ON / OFF of other subsystems present in the satellite based on the data getting from telemetry and tracking subsystems.

In general, control codes are converted into command words. These command words are used to send in the form of **TDM frames**. Initially, the validity of command words is checked in the satellite. After this, these command words can be sent back to earth station. Here, these command words are checked once again.

If the earth station also receives the same (correct) command word, then it sends an execute instruction to satellite. So, it executes that command.

Functionality wise, the Telemetry subsystem and commanding subsystem are opposite to each other. Since, the first one transmits the satellite's information to earth station and second one receives command signals from earth station.

## Power & Antenna Subsystems

In this chapter, let us discuss about **Power systems** from which various subsystems of satellite gets power and **Antenna subsystems** one by one.

# Power Systems

We know that the satellite present in an orbit should be operated continuously during its life span. So, the satellite requires internal power in order to operate various electronic systems and communications payload that are present in it.

**Power system** is a vital subsystem, which provides the power required for working of a satellite. Mainly, the solar cells (or panels) and rechargeable batteries are used in these systems.

## Solar Cells

Basically, the **solar cells** produce electrical power (current) from incident sunlight. Therefore, solar cells are used primarily in order to provide power to other subsystems of satellite.

We know that individual solar cells generate very less power. So, in order to generate more power, group of cells that are present in an array form can be used.

## Solar Arrays

There are two **types of solar arrays** that are used in satellites. Those are cylindrical solar arrays and rectangular solar arrays or solar sail.

- **Cylindrical solar arrays** are used in spinning satellites. Only part of the cylindrical array will be covered under sunshine at any given time. Due to this, electric power gets generated from the partial solar array. This is the drawback of this type.
- The drawback of cylindrical solar arrays is overcome with **Solar sail**. This one produce more power because all solar cells of solar sail are exposed to sun light.

## Rechargeable Batteries

During eclipses time, it is difficult to get the power from sun light. So, in that situation the other subsystems get the power from **rechargeable batteries**. These batteries produce power to other subsystems during launching of satellite also.

In general, these batteries charge due to excess current, which is generated by solar cells in the presence of sun light.

# Antenna Subsystems

Antennas are present in both satellite and earth station. Now, let us discuss about the satellite antennas.

Satellite antennas perform **two types** of functions. Those are receiving of signals, which are coming from earth station and transmitting signals to one or more earth stations based on the requirement. In other words, the satellite antennas receive uplink signals and transmit downlink signals.

We know that the length of satellite antennas is inversely proportional to the operating frequency. The operating frequency has to be increased in order to reduce the length

of satellite antennas. Therefore, satellite antennas operate in the order of **GHz** frequencies.

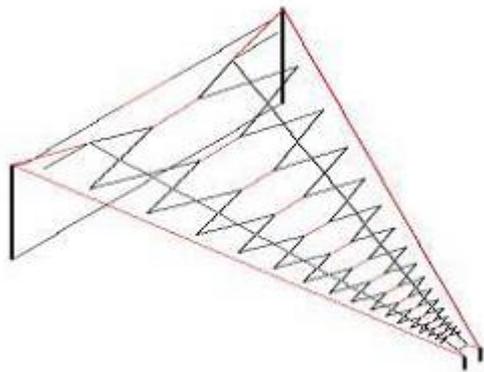
## Satellite Antennas

The antennas, which are used in satellite are known as satellite antennas. There are mainly four **types of Antennas**. They are:

- Wire Antennas
- Horn Antennas
- Array Antennas
- Reflector Antennas

Now, let us discuss about these antennas one by one.

### Wire Antennas



Wire antennas are the basic antennas. **Mono pole** and **dipole antennas** come under this category. These are used in very high frequencies in order to provide the communication for TTCM subsystem.

The length of the total wire, which is being used as a dipole, if equals half of the wave length (i.e.,  $l = \lambda/2$ ), such an antenna is called as **half-wave dipole antenna**.

**Wire antennas** are suitable for covering its range of access and to provide signal strength in all directions. That means, wire antennas are Omni-directional antennas.

### Horn Antennas



An Antenna with an aperture at the end can be termed as an **Aperture antenna**. The edge of a transmission line when terminated with an opening, radiates energy. This opening which is an aperture, makes it as an aperture antenna.

**Horn antenna** is an example of aperture antenna. It is used in satellites in order to cover more area on earth.

Horn antennas are used in **microwave** frequency range. The same feed horn can be used for both transmitting and receiving the signals. A device named duplexer, which separates these two signals.

### Array Antennas

An antenna when individually can radiate an amount of energy, in a particular direction, resulting in better transmission, how it would be if few more elements are added it, to produce more efficient output. It is exactly this idea, which lead to the invention of **Array Antennas** or Antenna arrays. Array antennas are used in satellites to form multiple beams from single aperture.



### Reflector Antennas



Reflector antennas are suitable for producing beams, which have more signal strength in one particular direction. That means, these are highly directional antennas. So, **Parabolic reflectors** increase the gain of antennas in satellite communication system. Hence, these are used in telecommunications and broadcasting.

If a Parabolic Reflector antenna is used for **transmitting** a signal, the signal from the feed, comes out of a dipole or a horn antenna, to focus the wave on to the parabola. It means that, the waves come out of the focal point and strikes the Paraboloidal reflector. This wave now gets reflected as collimated wave front.

If the same antenna is used as a **receiver**, the electromagnetic wave when hits the shape of the parabola, the wave gets reflected onto the feed point. The dipole or the horn antenna, which acts as the receiver antenna at its feed, receives this signal, to convert it into electric signal and forwards it to the receiver circuitry.

## Transponders

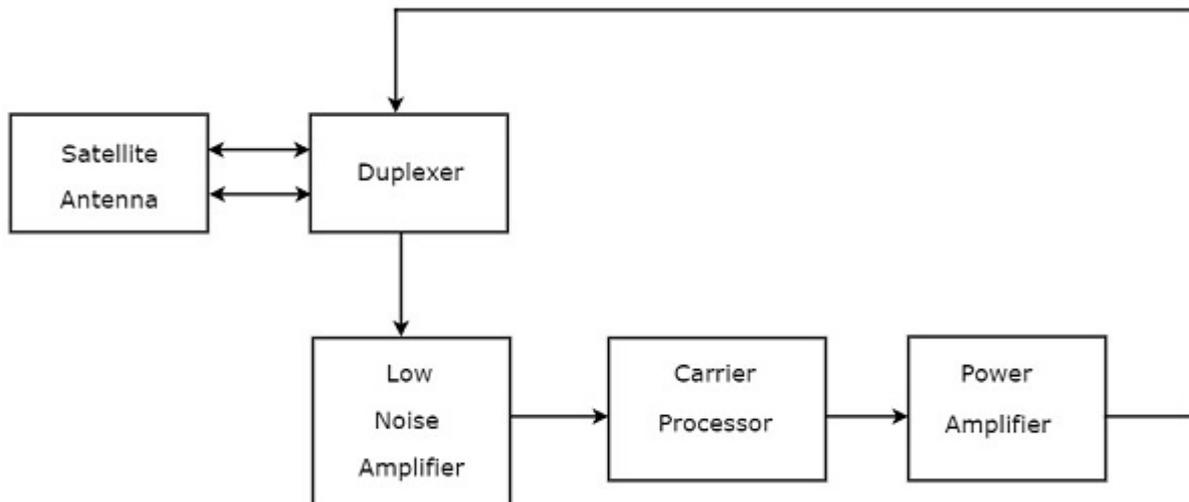
The subsystem, which provides the connecting link between transmitting and receiving antennas of a satellite is known as **Transponder**. It is one of the most important subsystem of space segment subsystems.

Transponder performs the functions of both transmitter and receiver (Responder) in a satellite. Hence, the word 'Transponder' is obtained by the combining few letters of two words, Transmitter (**Trans**) and Responder (**ponder**).

### Block diagram of Transponder

Transponder performs mainly **two functions**. Those are amplifying the received input signal and translates the frequency of it. In general, different frequency values are chosen for both uplink and down link in order to avoid the interference between the transmitted and received signals.

The **block diagram** of transponder is shown in below figure.



We can easily understand the operation of Transponder from the block diagram itself. The function of each block is mentioned below.

- **Duplexer** is a two-way microwave gate. It receives uplink signal from the satellite antenna and transmits downlink signal to the satellite antenna.
- **Low Noise Amplifier (LNA)** amplifies the weak received signal.
- **Carrier Processor** performs the frequency down conversion of received signal (uplink). This block determines the type of transponder.
- **Power Amplifier** amplifies the power of frequency down converted signal (down link) to the required level.

## Types of Transponders

Basically, there are **two types** of transponders. Those are Bent pipe transponders and Regenerative transponders.

### Bent Pipe Transponders

Bent pipe transponder receives microwave frequency signal. It converts the frequency of input signal to RF frequency and then amplifies it.

Bent pipe transponder is also called as repeater and **conventional transponder**. It is suitable for both analog and digital signals.

### Regenerative Transponders

Regenerative transponder performs the functions of Bent pipe transponder. i.e., frequency translation and amplification. In addition to these two functions, Regenerative transponder also performs the demodulation of RF carrier to baseband, regeneration of signals and modulation.

Regenerative transponder is also called as Processing transponder. It is suitable only for digital signals. The main **advantages** of Regenerative transponders are improvement in Signal to Noise Ratio (SNR) and have more flexibility in implementation.

## Earth Segment Subsystems

The **earth segment** of satellite communication system mainly consists of two earth stations. Those are transmitting earth station and receiving earth station.

The transmitting **earth station** transmits the information signals to satellite. Whereas, the receiving earth station receives the information signals from satellite. Sometimes, the same earth station can be used for both transmitting and receiving purposes.

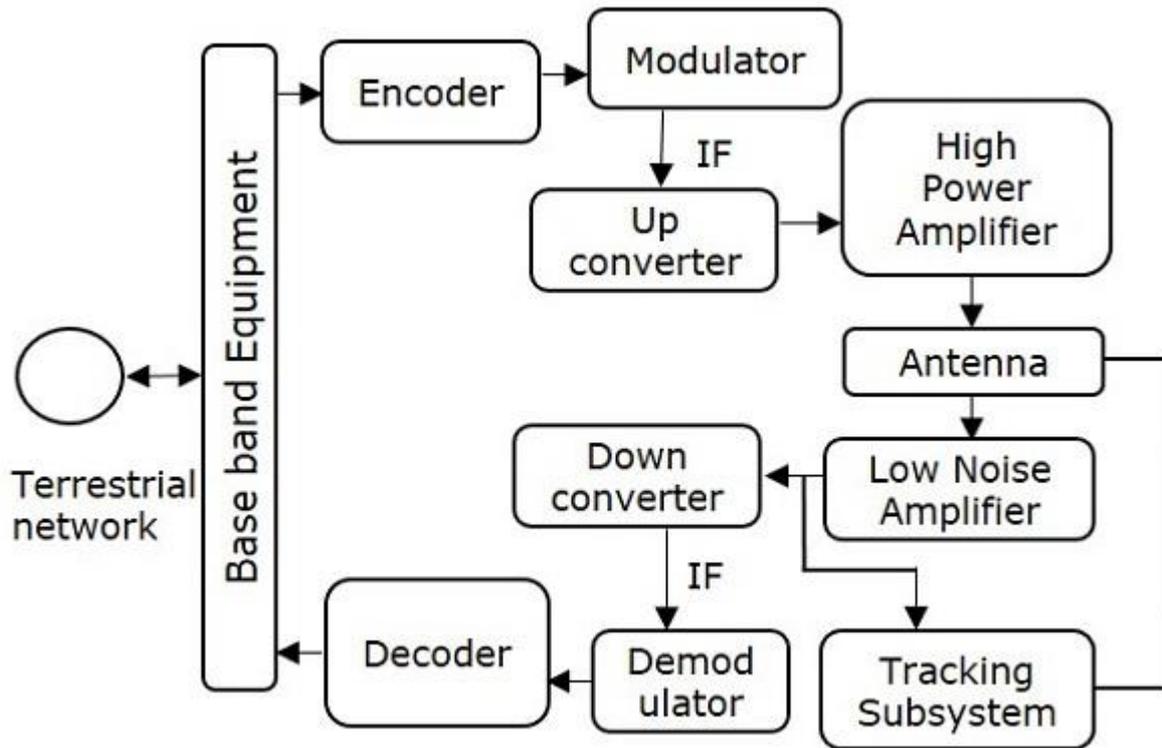
In general, earth stations receive the baseband signals in one of the following forms. Voice signals and video signals either in analog form or digital form.

Initially, the analog modulation technique, named **FM modulation** is used for transmitting both voice and video signals, which are in analog form. Later, digital modulation techniques, namely Frequency Shift Keying (**FSK**) and Phase Shift Keying (**PSK**) are used for transmitting those signals. Because, both voice and video signals are used to represent in digital by converting them from analog.

## Block Diagram of Earth Station

Designing of an **Earth station** depends not only on the location of earth station but also on some other factors. The location of earth stations could be on land, on ships in sea and on aircraft. The depending factors are type of service providing, frequency bands utilization, transmitter, receiver and antenna characteristics.

The **block diagram** of digital earth station is shown in below figure.



We can easily understand the working of earth station from above figure. There are four major **subsystems** that are present in any earth station. Those are transmitter, receiver, antenna and tracking subsystem.

### Transmitter

The binary (digital) information enters at base band equipment of earth station from terrestrial network. **Encoder** includes error correction bits in order to minimize the bit error rate.

In satellite communication, the Intermediate Frequency (**IF**) can be chosen as 70 MHz by using a transponder having bandwidth of 36 MHz. Similarly, the IF can also be chosen as 140 MHz by using a transponder having bandwidth of either 54 MHz or 72 MHz.

Up converter performs the frequency conversion of modulated signal to higher frequency. This signal will be amplified by using High power amplifier. The earth station antenna transmits this signal.

### Receiver

During **reception**, the earth station antenna receives downlink signal. This is a low-level modulated RF signal. In general, the received signal will be having less signal strength. So, in order to amplify this signal, Low Noise Amplifier (**LNA**) is used. Due to this, there is an improvement in Signal to Noise Ratio (SNR) value.

RF signal can be **down converted** to the Intermediate Frequency (IF) value, which is either 70 or 140 MHz. Because, it is easy to demodulate at these intermediate frequencies.

The function of the **decoder** is just opposite to that of encoder. So, the decoder produces an error free binary information by removing error correction bits and correcting the bit positions if any.

This binary information is given to base band equipment for further processing and then delivers to terrestrial network.

### Earth Station Antenna

The major parts of **Earth station Antenna** are feed system and Antenna reflector. These two parts combined together radiates or receives electromagnetic waves. Since the feed system obeys reciprocity theorem, the earth station antennas are suitable for both transmitting and receiving electromagnetic waves.

**Parabolic reflectors** are used as the main antenna in earth stations. The gain of these reflectors is high. They have the ability of focusing a parallel beam into a point at the focus, where the feed system is located.

### Tracking Subsystem

The **Tracking subsystem** keeps track with the satellite and make sure that the beam comes towards it in order to establish the communication. The Tracking system present in the earth station performs mainly **two functions**. Those are satellite acquisition and tracking of satellite. This tracking can be done in one of the following ways. Those are automatic tracking, manual tracking & program tracking.

## Examples of Earth Stations

In this chapter, let us discuss about two examples of earth stations: **Receive-only Home TV system** and **Community Antenna TV system**.

### Receive Only Home TV System

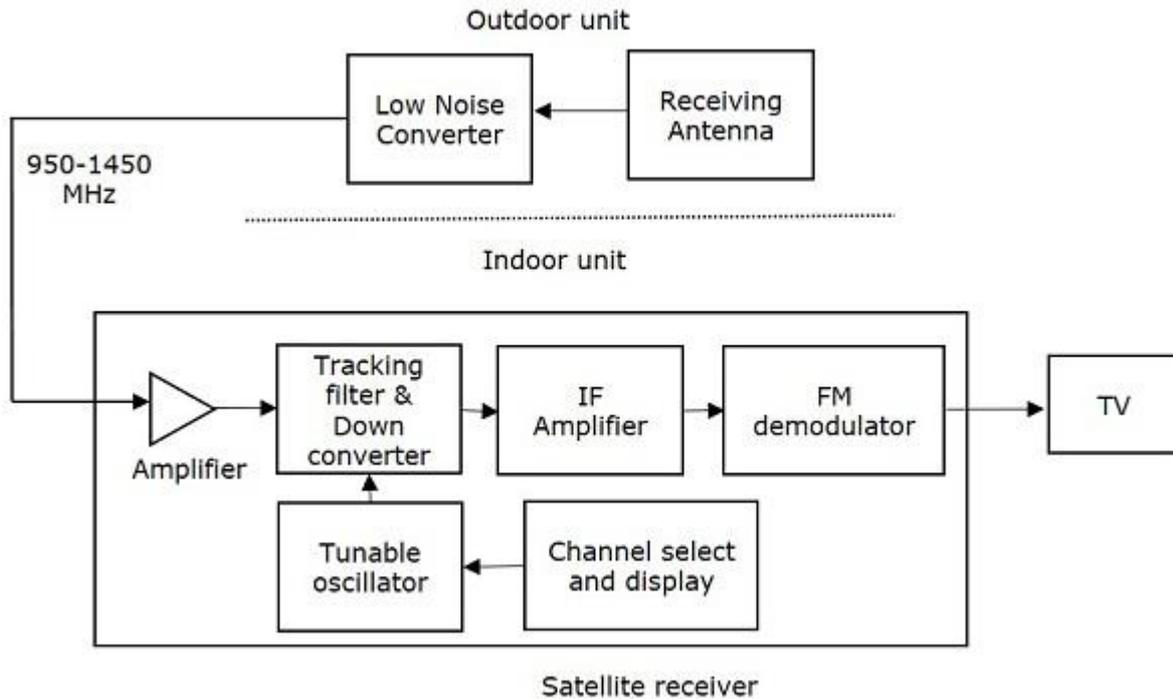
If broadcasting takes place directly to home TV receivers, then that type of service is called as Direct Broadcast Satellite (**DBS**) service.

A mesh type reflector can be used for focusing the signals into a **dual feed-horn**. It is having two separate outputs. From one output will get C-band signals and from other output will get Ku-band signals.

Television programming mostly originates as first generation signals. These signals are transmitted through satellite to network main end stations in C band. These signals are compressed and transmitted in digital form to cable and DBS providers.

C-band users can subscribe to pay TV channels. These subscription services are **cheaper** when compared to cable because of the availability of multiple-source programming.

The **block diagram** of DBS TV receiver is shown in below figure.



### Outdoor Unit

Outdoor unit mainly consists of **receiving antenna** and Low Noise Converter (**LNC**). Low Noise Converter (LNC) is nothing but the combination of Low Noise Amplifier (LNA) followed by a converter. The receiving antenna is directly fed into LNC.

In general, the **parabolic reflector** is also used with the receiving horn antenna for more focusing of the beam.

### Indoor Unit

In general, the signal fed to the indoor unit is a wideband signal. The frequency of this signal lies between 950 MHz and 1450 MHz. In indoor unit, this signal gets amplified by using an **amplifier**.

The amplified signal is applied to a tracking filter and down converter. It selects the desired channel and converts its frequency to an **Intermediate Frequency (IF)** of 70 MHz.

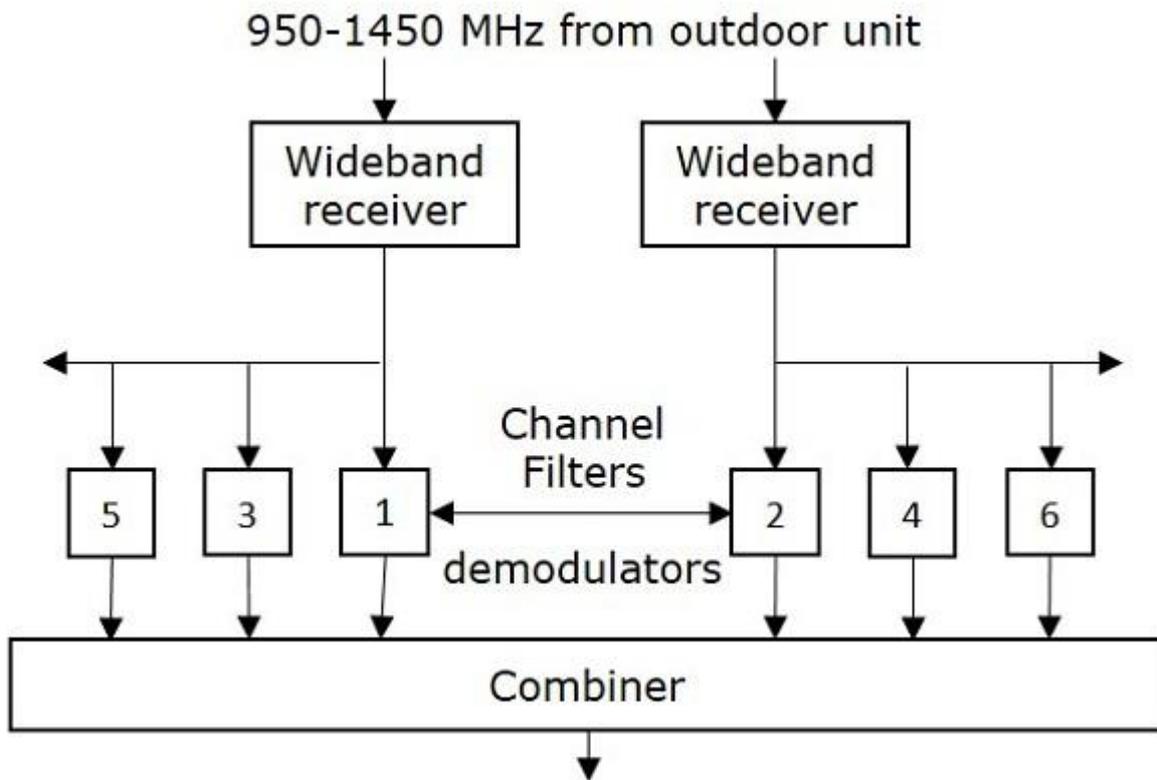
**IF amplifier** amplifies the signal strength in order to demodulate it properly. The baseband (demodulated) signal is used to generate a Vestigial Single Side Band (VSSB) signal. This signal is fed into one of VHF/UHF channels of a standard TV set.

Frequency Modulation (FM) is used in DBS TV. Whereas, Amplitude Modulation (AM) in the form of VSSB is used in conventional TV. This is the **major difference** between DBS TV and conventional TV.

## Community Antenna TV System

The Community Antenna TV (**CATV**) system uses a single outdoor unit and multiple feeds. These feeds are available separately for each sense of polarization. Due to this, all channels will be available at the indoor receiver, simultaneously.

The **block diagram** of indoor unit of CATV system is shown in below figure.



In this case, there is no need of separate receiver to each user. Because, all the carriers are demodulated in a common receiver-filter system. After that, the channels are combined into a multiplexed signal. This signal is then transmitted through a cable to the subscribers (users).