Satellite Communication

Introduction

If the communication takes place between any two earth stations through a satellite, then it is called as **satellite communication**. In this communication, electromagnetic waves are used as carrier signals. These signals carry the information such as voice, audio, video or any other data between ground and space and vice-versa.

Soviet Union had launched the world's first artificial satellite named, Sputnik 1 in 1957.

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.

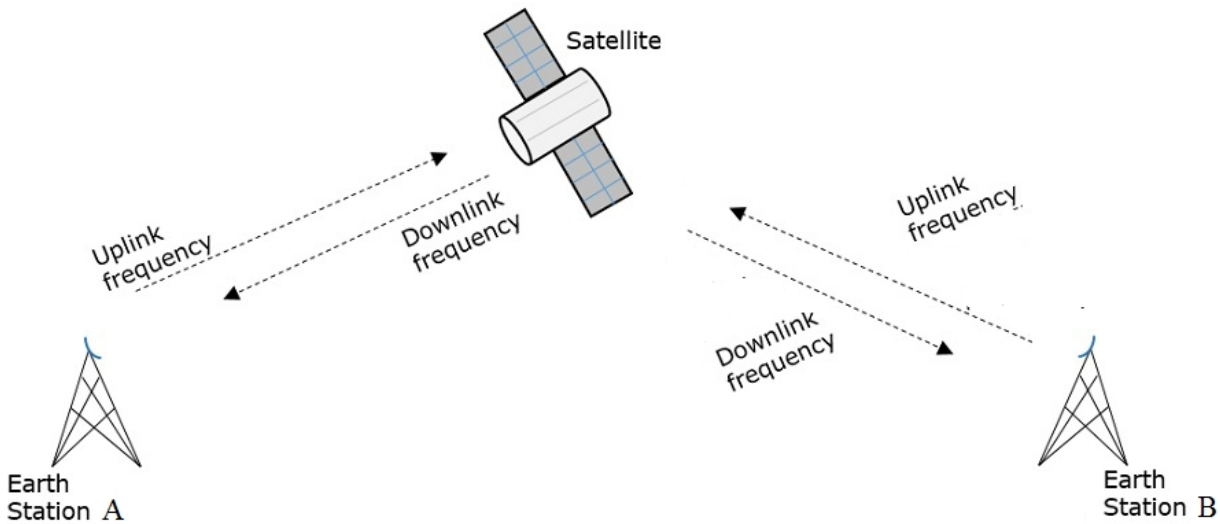
How a Satellite Works

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 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 following figure illustrates this concept clearly.



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 re-transmit 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

(a) 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. These satellites are exceptionally useful in predicting disasters like hurricanes, and for monitor the changes in the Earth's vegetation, sea state, ocean color, and ice fields.

(b) 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.

(c) 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.

(d) 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 for fleet management of trucks or for vehicle localization in case of theft.

(e) 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.

(f) 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.

(g) 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 do not cover all parts of a country. Areas that are not covered usually have lowhttps://www.google.com/ 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).

Orbital Elements

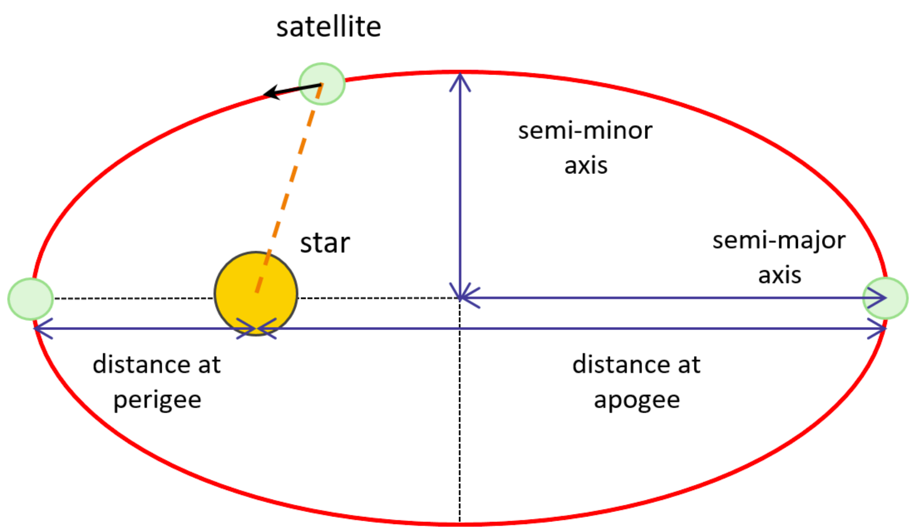
Orbital elements are the parameters, which are helpful for describing the orbital motion of satellites. Following are the **orbital elements**.

- Semi major axis (a)
- Eccentricity (e)
- Mean anomaly (M_o)
- 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 (a)

The length of **Semi-major axis (a)** defines the size of satellite’s orbit. It is half of the major axis. It is the longest diameter, a line that runs through the center and both foci, its ends being at the widest points of the shapes. Semi-Minor axis (b) is the the line joining the points of perigee.



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.

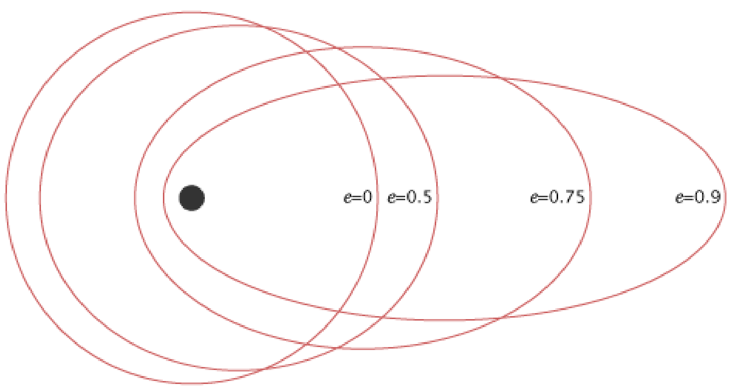
Eccentricity

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 **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.

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) F_1 and F_2 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.

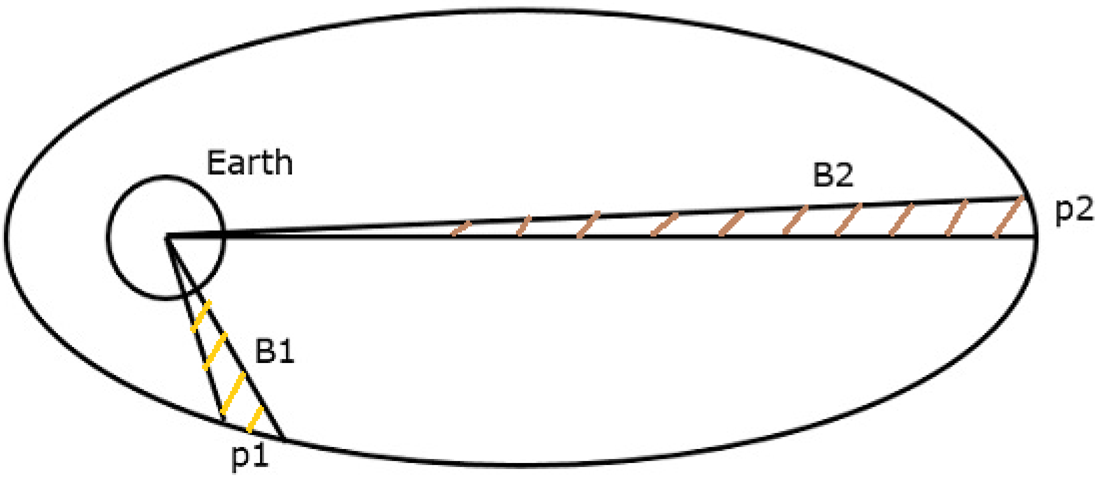
For an **elliptical path**, the value of eccentricity (e) is always lie in between 0 and 1, i.e.

$$0 < e < 1$$

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 −

$$\mathrm{T}^2 \alpha a^3$$

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

Where, $4\pi^2 \frac{}{\mu}$ is a proportional constant

μ is Kepler's constant and its value is equal to 3.986005 x $10^{14}m^3$ /sec^2

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

$$1 = (\mathrm{n})^2 \frac{a^3}{\mu}$$

$$\mathrm{a}^3 = \frac{\mu}{(n)^2}$$

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.

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 (ω) 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.

Orbital Equations

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

$$\mathrm{F}_1 = \frac{GMm}{r^2}$$

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

$$\mathrm{F}_2 = \frac{mv^2}{r}$$

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

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

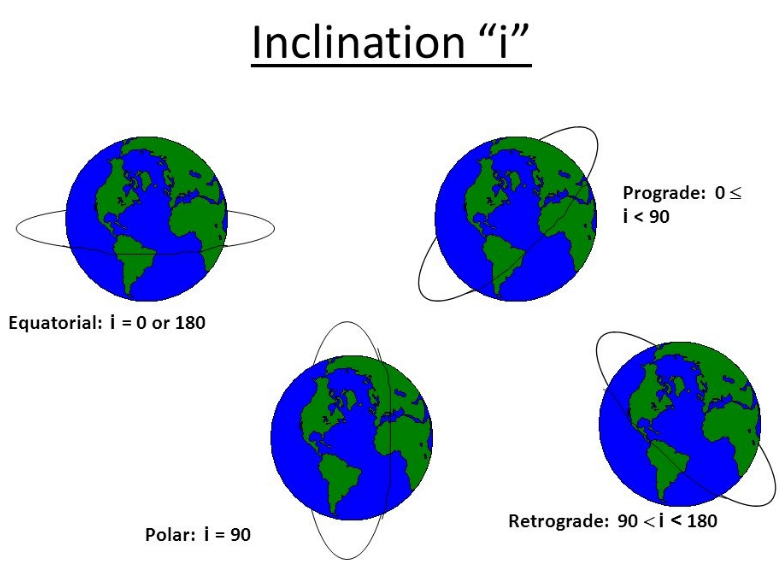
$$=> \frac{GM}{R} = v^2$$

$$=> v = \sqrt{\frac{GM}{R}}$$

Where,

- ***G*** is gravitational constant and it is equal to 6.673×10^{-11} $N \cdot m^2/kg^2$.
- ***M*** is mass of the earth and it is equal to 5.98×10^{24} 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.

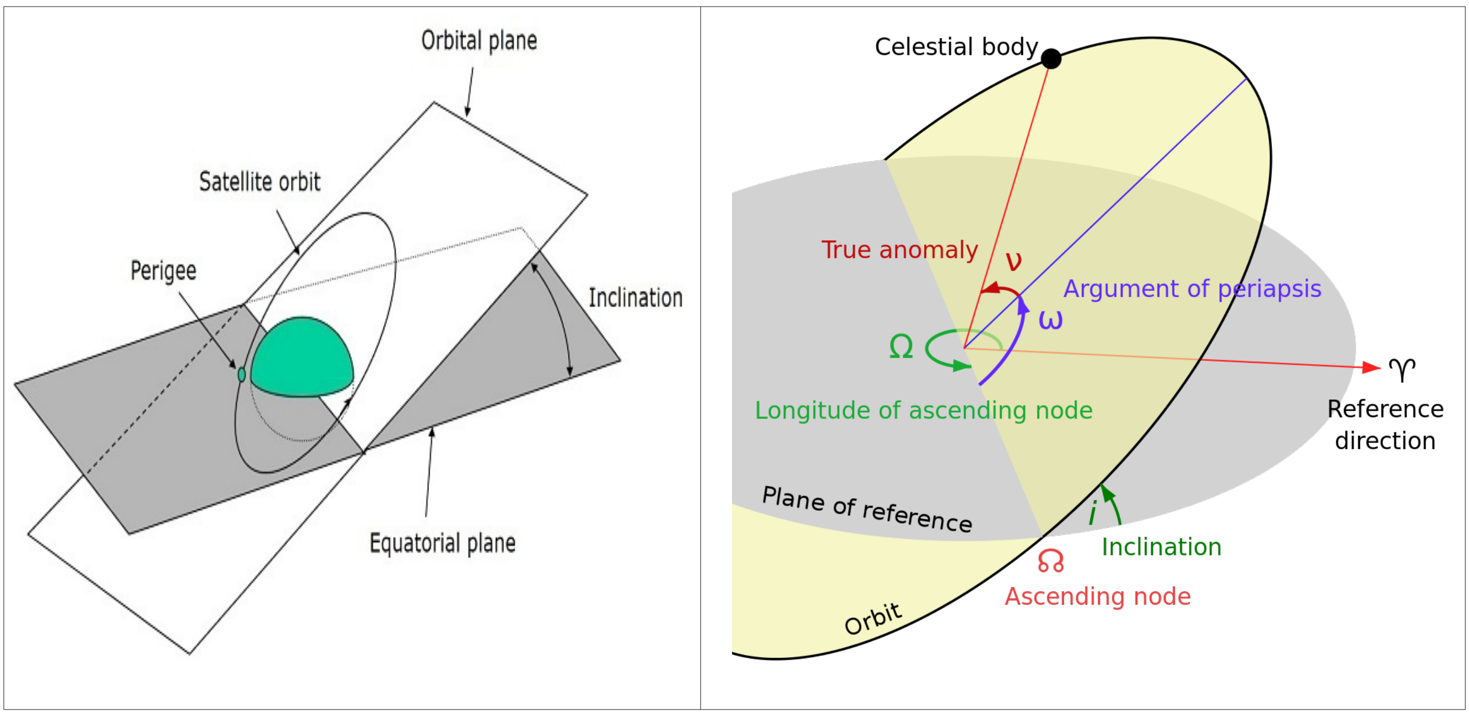


Inclination

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.
- Pro-grade 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 **(Ω)** 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.

Summary

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

Perigee: A point for a satellite closest from the Earth. It is denoted as h_p .

Line of Apsides: Line joining perigee and apogee through center 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 center 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.

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

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