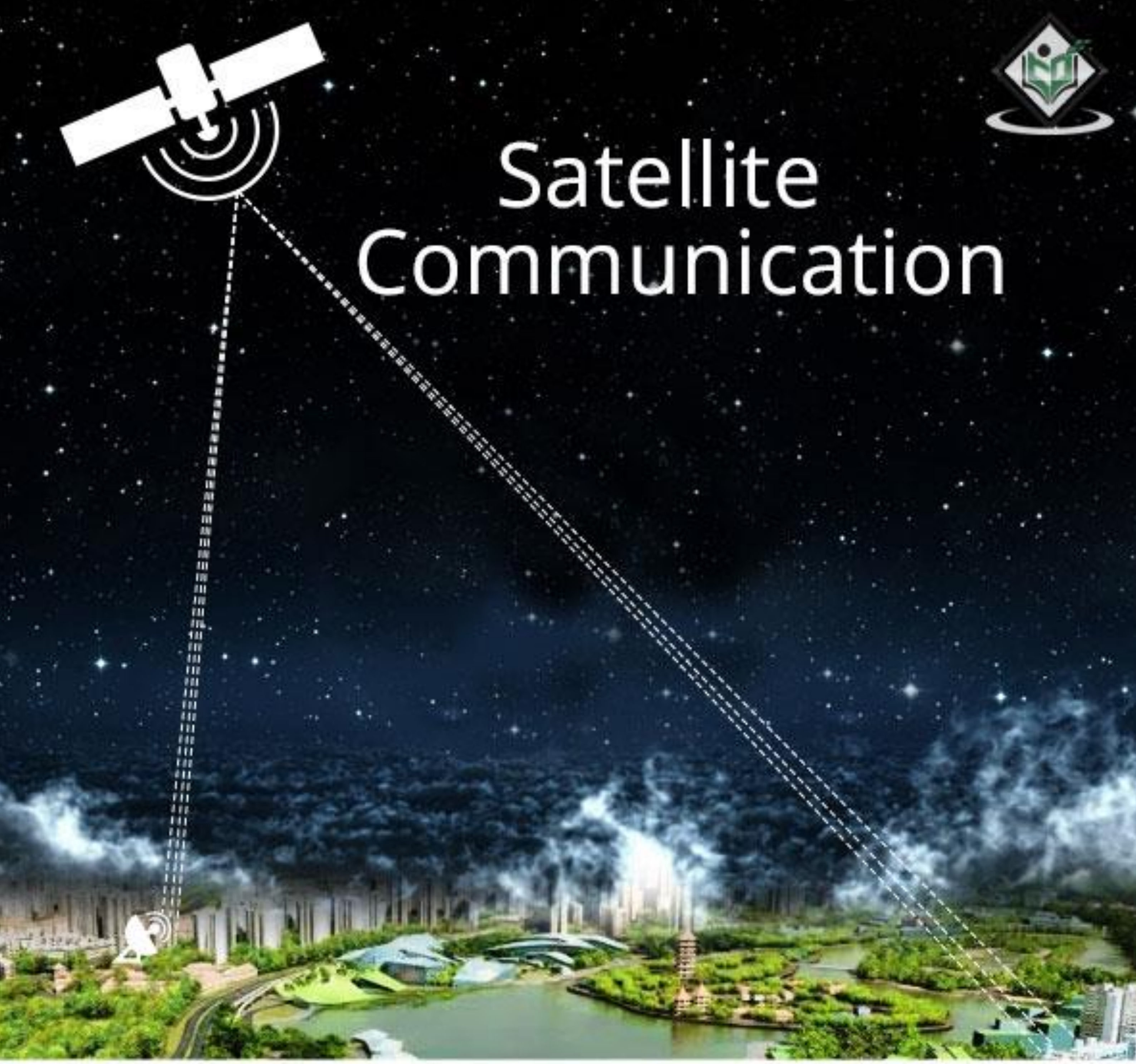
Satellite Communication



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About the Tutorial

If 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.

This tutorial is meant to provide the readers an overview of Satellite Communication and how it works.

Audience

This tutorial will be suitable for all those readers who wish to learn the fundamental concepts of satellite communication. After completing this tutorial, you will be able to learn the significance of satellite communication and its role in present scenario.

Prerequisites

The readers should have prior knowledge on the basic concepts of analog and digital communication systems, in order draw benefit from this tutorial.

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1. Satellite Communication – Introduction

In general terms, a **satellite** is a smaller object that revolves around a larger object in space. For example, moon is a natural satellite of earth.

We know that **Communication** refers to the exchange (sharing) of information between two or more entities, through any medium or channel. In other words, it is nothing but sending, receiving and processing of information.

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. Nearly after 18 years, India also launched the artificial satellite named, Aryabhata in 1975.

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.

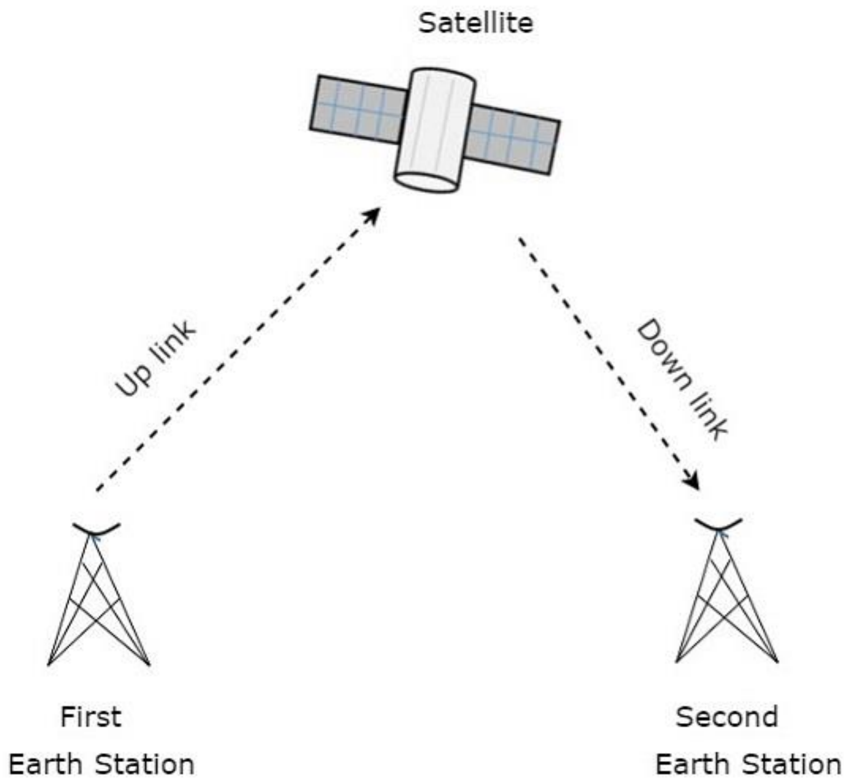
Since the satellites locate at certain height above earth, the communication takes place between any two earth stations easily via satellite. So, it overcomes the limitation of communication between two earth stations due to earth's curvature.

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 possibilites

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

2. Satellite Communication – 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

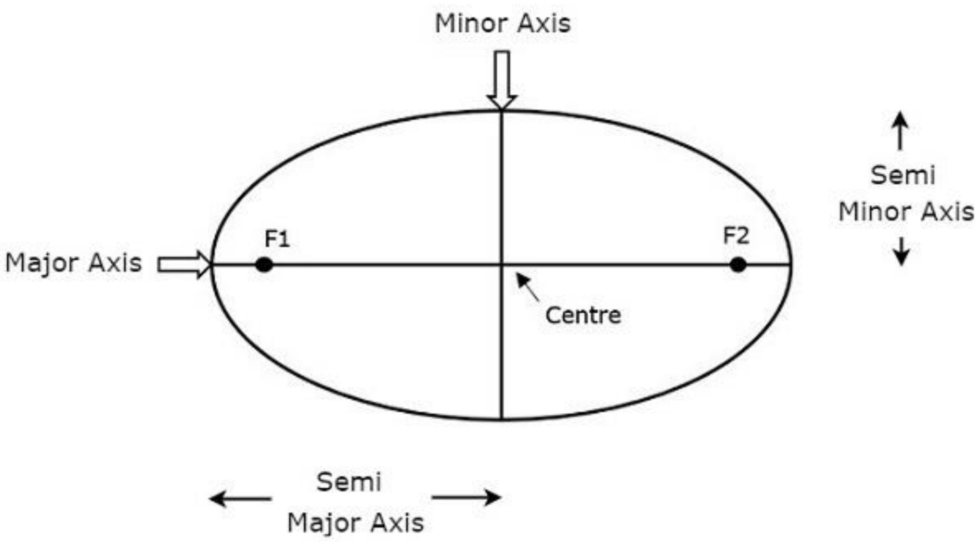
Orbital elements are the parameters, which are helpful for describing the orbital motion of satellites. Following are the **orbital elements**.

- 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

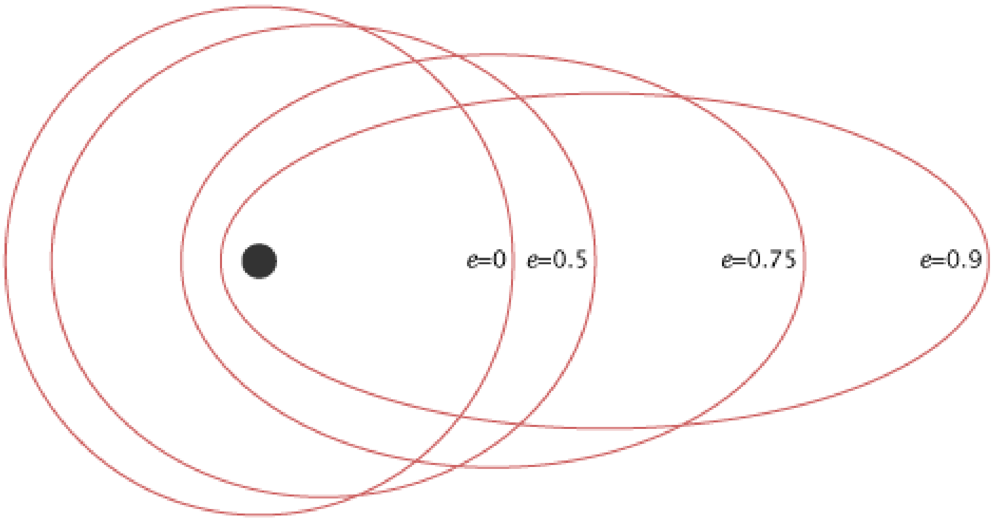
The value of **Eccentricity (e)** fixes the shape of satellite's orbit. This parameter indicates the deviation of the orbit's shape from a perfect circle.

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

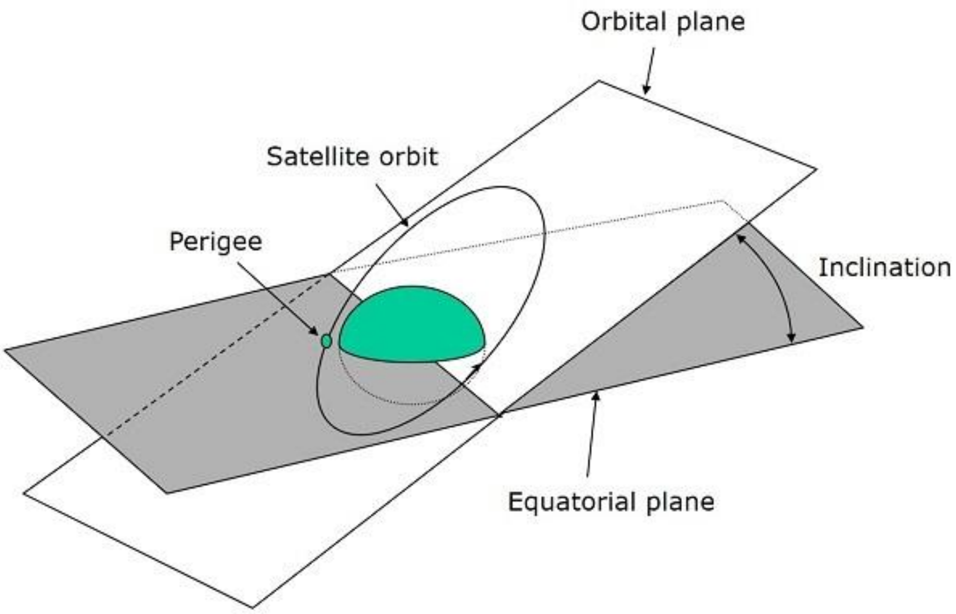
Satellite orbit cuts the equatorial plane at two points. First point is called as **descending node**, where the satellite passes from the northern hemisphere to the southern hemisphere. Second point is called as **ascending node**, where the satellite passes from the southern hemisphere to the northern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

Argument of perigee (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.

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 (**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.

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 x 10^{-11} N·m^2/kg^2.
- ***M*** is mass of the earth and it is equal to 5.98 x 10^{24} 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).

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

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

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

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

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

Where,

- ***G*** is gravitational constant and it is equal to 6.673×10^{-11} N·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.

3. Satellite Communication – Kepler's Laws

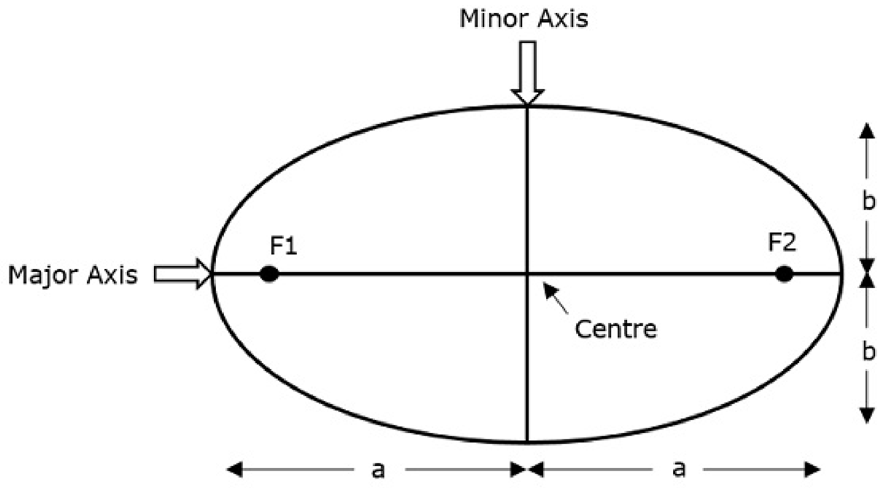
We know that satellite revolves around the earth, which is similar to the earth revolves around the sun. So, the principles which are applied to earth and its movement around the sun are also applicable to satellite and its movement around the earth.

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.



Kepler's 1st law

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. $\mathbf{0} < \boldsymbol{e} < \mathbf{1}$, 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.