Satellite Communication System

Dr Anoop Kumar Mishra
India Meteorological Department
Email: daksha112@gmail.com
Mobile: 8220340854

Satellite Communication: The use of artificial satellites to provide communication links between various points on Earth

Electromagnetic waves are used as carrier signals in Satellite communication (microwave/radio waves).

These signals carry the information such as voice, audio, video or any other data between ground and space and vice-versa.

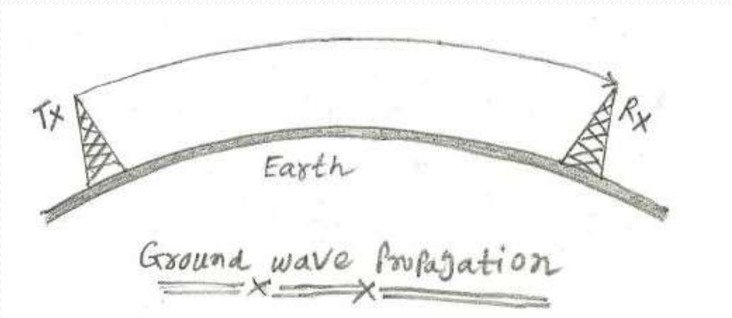
Sputnik 1 in 1957 world's first artificial satellite by Soviet Union

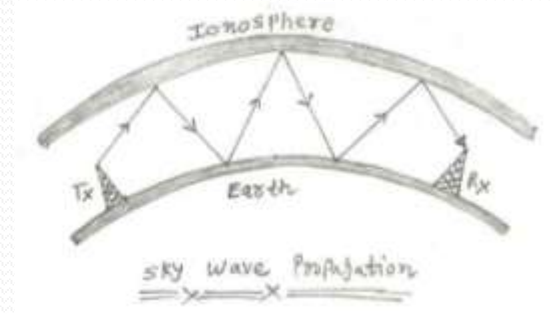
Aryabhata in 1975 (India's first)

Need of Satellite communication

Following two mode of communication in earlier days

1. Ground wave propagation (suitable for frequencies upto 2 MHz (low and medium) and makes use of tropospheric condition of earth), ex- AM, FM, TV broadcast





1. Sky wave propagation (suitable bandwidth for this type of communication is broadly between 2–30 MHz and makes use of the ionosphere properties of the earth) ex-MOBILE COMMUNICATION

Utilizes reflective property of ionosphere available above earth at higher frequencies,

Ionoshere is present FAR/NEAR during night/day time respectively. Due to this, Sky waves can travel longer/smaller distances

Transmitter signal travels multiple hops before reaching the receiver. This reduces signal strength considerably if distances are larger between transmitter and receiver antennas

The length of the antenna is **inversely proportional to the frequency and directly proportional to the wavelength**

Advantages of Ground wave propagation

➡As it uses lower frequencies, interference occurs due to atmospheric noise only. Moreover absorption of EM waves at lower frequencies are less. Hence it can cover longer distances. However the pathloss increases as distance from transmitter increases. Hence distance between Tx and Rx should be optimal.

Disadvantages of Ground wave

➡The distance between two antennas (transmit (Tx) and receive (Rx)) should not be too large, otherwise received signal strength gets reduced too much due to ground and atmospheric absorptions. Hence communication can not be established between two stations. Often this requires use of repeaters in between Tx and Rx. This increases overall cost of the system.

Advantages of sky wave propagation

As it utilizes reflective property of ionosphere available above earth at higher frequencies, it is most simple mode of propagation and provides continuous support in communications.

Disadvantages

Ionosphere is present near or far during night time and day time respectively. Due to this, Sky waves can travel longer or smaller distances.

➡Transmitter signal travels multiple hops before reaching the receiver. This reduces signal strength considerably if distances are larger between transmitter and receiver ant

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

Components of Satellite communication

(a) Ground segment (b) Space segment

Ground segment consists of fixed/mobile transmission, reception and ancillary equipment

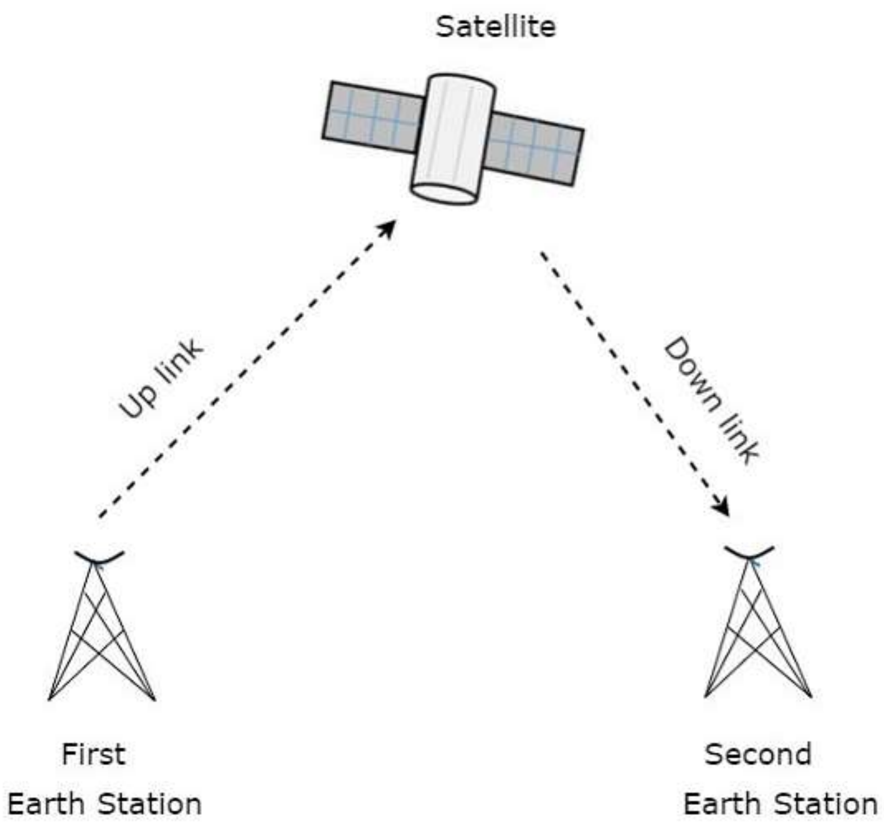
Space segment which primarily is the satellite itself. **Transponder is a crucial component**

Satellite transponder” refers collectively to a transmitter-receiver subsystem on board the satellite that processes, amplifies and retransmits a range of frequencies (the transponder bandwidth) to another location/terminal/antenna on the earth.

A typical satellite link involves the transmission or uplinking of a signal from an Earth station to a satellite. The satellite then receives and amplifies the signal and retransmits it back to Earth, where it is received and reamplified by Earth stations and terminals

Multiple transponders help to have more operating channels

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 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.

The process of satellite communication begins at an Earth station

Advantages of 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

.

Disadvantages of 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

- 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


EVOLUTION
OF
SATELLITE
COMMUNICATION

- During early 1950s, both passive and active satellites were considered for the purpose of communications over a large distance.

- Passive satellites though successfully used in the early years of satellite communications, with the advancement in technology active satellites have completely replaced the passive satellites.

Passive Satellites

- A satellite that only reflects signals from one Earth station to another, or from several Earth stations to several others.
- It reflect the incident electromagnetic radiation without any modification or amplification.
- It can't generate power, they simply reflect the incident power.

Disadvantages

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

Active Satellites

- In active satellites, it amplify or modify and retransmit the signal from the earth.
- Satellites which can transmit power are called active satellite.
- **Have several advantages over the passive satellites.**
  - Require lower power earth station.
  - Less costly.
  - Not open to random use.
  - Directly controlled by operators from ground.

Disadvantages

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

Satellite Communication - Orbital Mechanics

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.

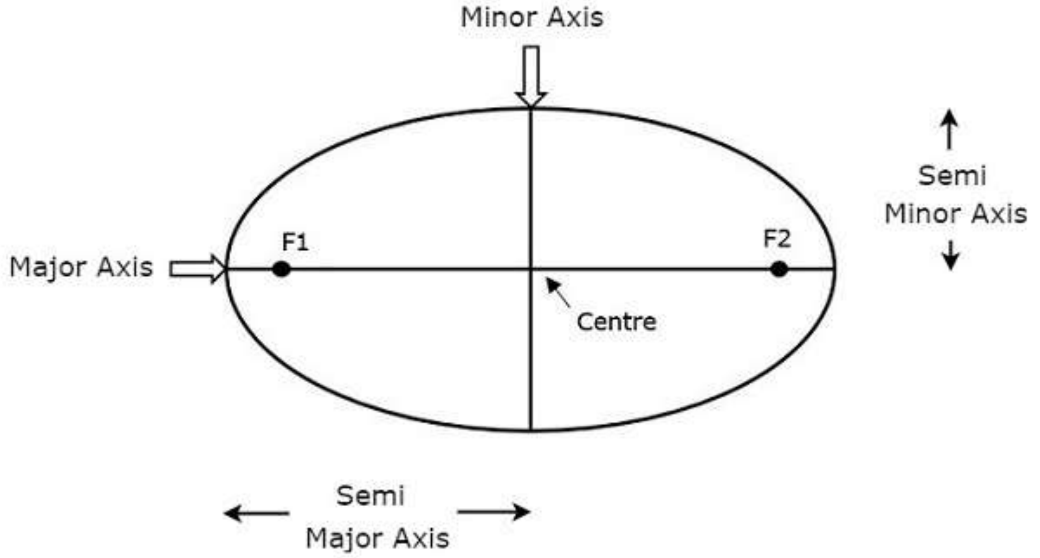
Orbital Elements

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

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

The length of Semi-major axis (a) defines the size of satellite's……………. ***??***

Eccentricity

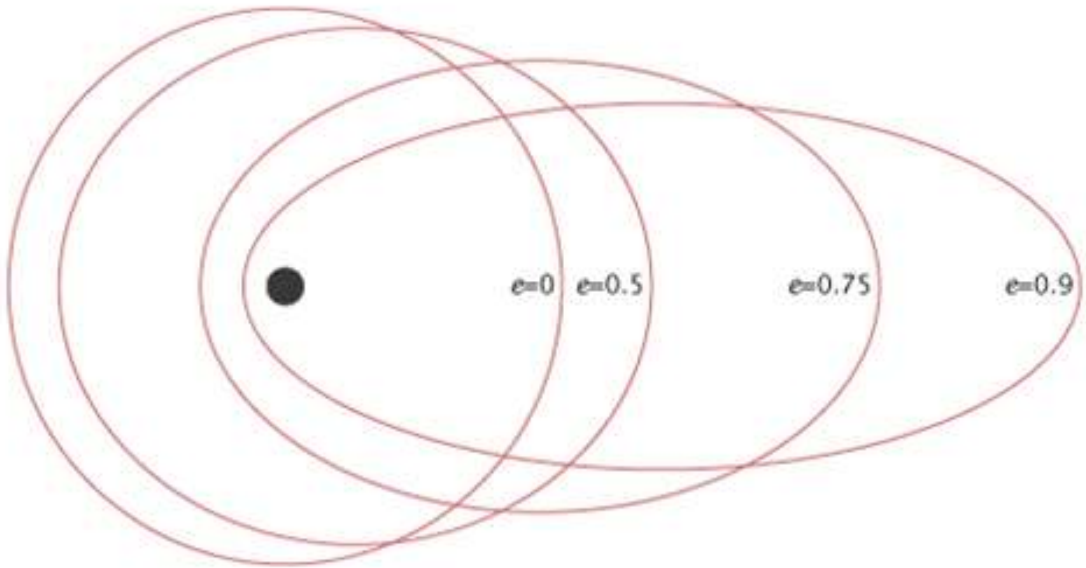
The value of **Eccentricity (e)** fixes the shape of satellite's orbit. This parameter indicates the deviation of the orbit's shape from a perfect circle.

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

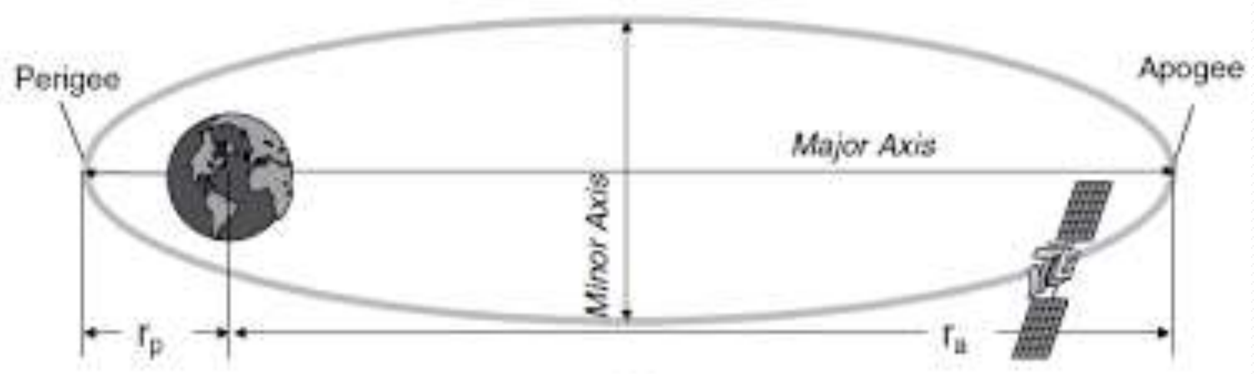


In above figure, the satellite orbit corresponding to eccentricity (e) value of zero is a circular orbit. And, the remaining three satellite orbits are of elliptical corresponding to the eccentricity (e) values 0.5, 0.75 and 0.9.

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.

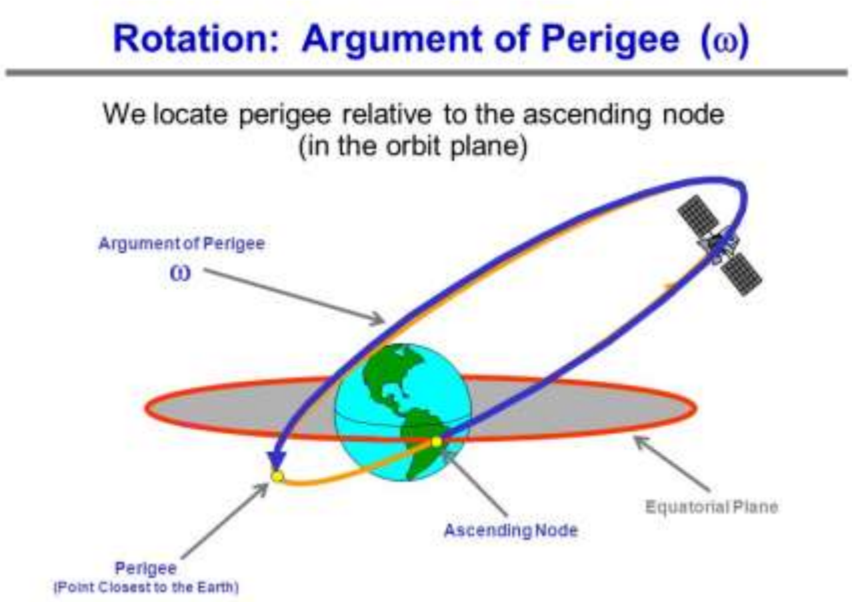


(a)

Argument of Perigee

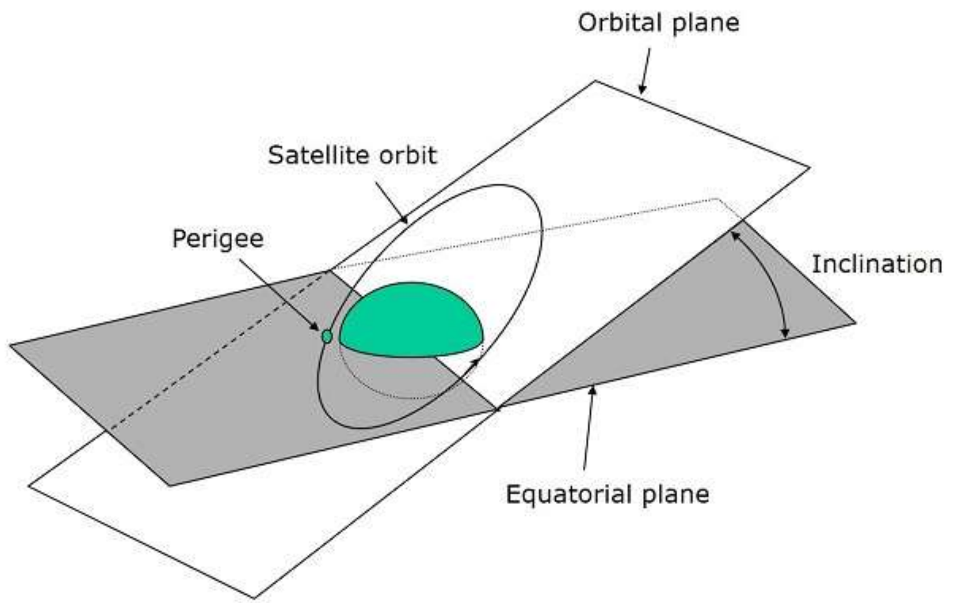
Satellite orbit cuts the equatorial plane at two points. First point is called as **descending node**, where the satellite passes from the northern hemisphere to the southern hemisphere. Second point is called as **ascending node**, where the satellite passes from the southern hemisphere to the northern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



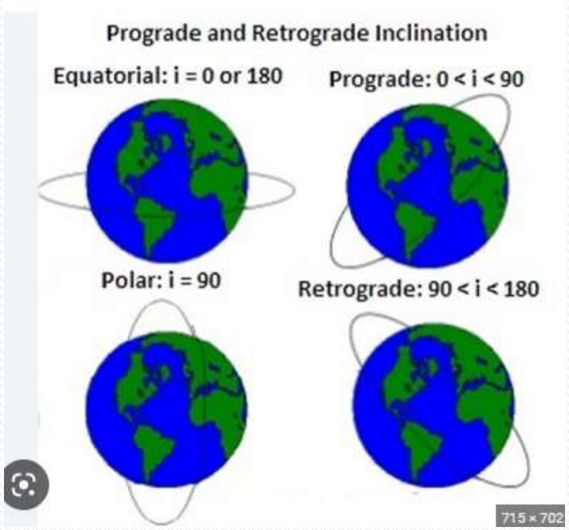
Inclination

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.



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·m²/kg².
- ***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.

Centrifugal force

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

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

As the height of a satellite orbit gets lower, the speed of the satellite ???

Satellite doesn’t deviate from its orbit and moves with certain velocity in that orbit, when Centripetal force is half of the Centrifugal forces.

True or false??

RECAP.....

1. **The transmitter-receiver combination in the satellite is known as a ________**

   a) Relay
   b) Repeater
   c) Transponder
   d) Duplexer

2. **What is the reason for carrying multiple transponders in a satellite?**

   a) More number of operating channel
   b) Better reception
   c) More gain
   d) Redundancy

3. **A satellite link uses different frequencies for receiving and transmitting in order to**

   a) avoid interference from terrestrial microwave links
   b)avoid interference between its powerful transmitted signal and weak in coming signal
   c) minimise free-space losses
   d) maximise antenna gain

4. The point farthest from the earth is defined as ______

A. Apogee

B. perigee

C. line of apsides

D. none of the above

5. The point where the orbit crosses the equatorial plane going from south to north is known as ________

A. Ascending node

B. Descending node

C. Inclination

D. none of the above

6. Which of the following are the advantages of using satellite communication?

A. Area of coverage is more than that of terrestrial systems

B. Transmission cost is independent of coverage area

C. More bandwidth and broadcasting possibilities

D. All of the above

7. As the height of a satellite orbit gets lower, the speed of the satellite................

8. Eccentricity of a …………………orbit is zero.

9. .... are used as carrier signals in Satellite communication.

10. Transmission cost is independent of coverage area in .... (Satellite communication/conventional terrestrial systems)

11. ………. gives the average value of the angular position of the satellite with reference to perigee (mean anomaly/inclination/argument of perigee).

12. . If both perigee and ascending node are existing at same point, then the argument of perigee will be ……… degrees

13. Large size of antenna is required for X band communication as compared to Ka band (true/false)

14. The frequency with which, the signal is sent into the space is called as …… frequency.

15. **……….. force** tends the satellite towards earth while …… force tends the satellite away from the earth

Satellite Communication - Kepler's Laws

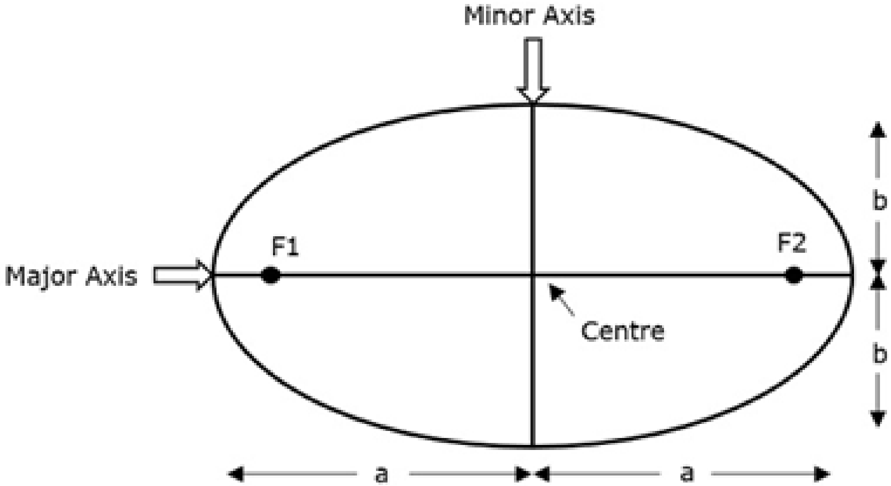
Satellite revolves around the earth, which is similar to the earth revolves around the sun. So, the principles which are applied to earth and its movement around the sun are also applicable to satellite and its movement around the earth.

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.

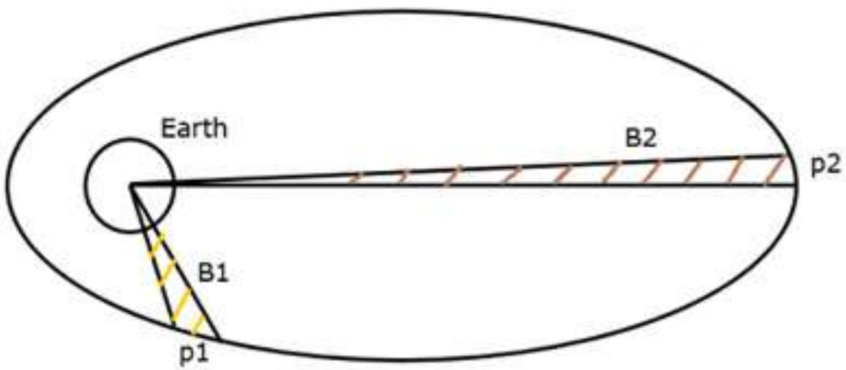


Kepler's 1st law

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**.

Kepler’s second law

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



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

Kepler’s Third Law

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

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

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

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

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.

Satellite orbits

Orbit is selected based on the requirement.

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

Orbital period and distance from Earth:

Polar Satellites, for example, requires about less time (90-100 minutes) to orbit the Earth at about 705-800 kilometers up, while a Geostationary Satellite (weather satellite) about 36,000 kilometers from Earth’s surface takes 23 hours, 56 minutes, and 4 seconds to complete an orbit.

Orbit Consideration for good communication

To ensure that communication is possible for the maximum amount of time there are a number of options that can be employed:

1. The first is to use an elliptical orbit where the apogee is above the planned Earth station so that the satellite remains visible for the maximum amount of time.

2. Another option is to launch a number of satellites with the same orbit so that when one disappears from view, and communications are lost, another one appears.

3. Generally three satellites are required to maintain almost uninterrupted communication. However the handover from one satellite to the next introduces additional complexity into the system, as well as having a requirement for at least three satellites.

Types of Earth orbit satellites

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

Geosynchronous Earth Orbit Satellites

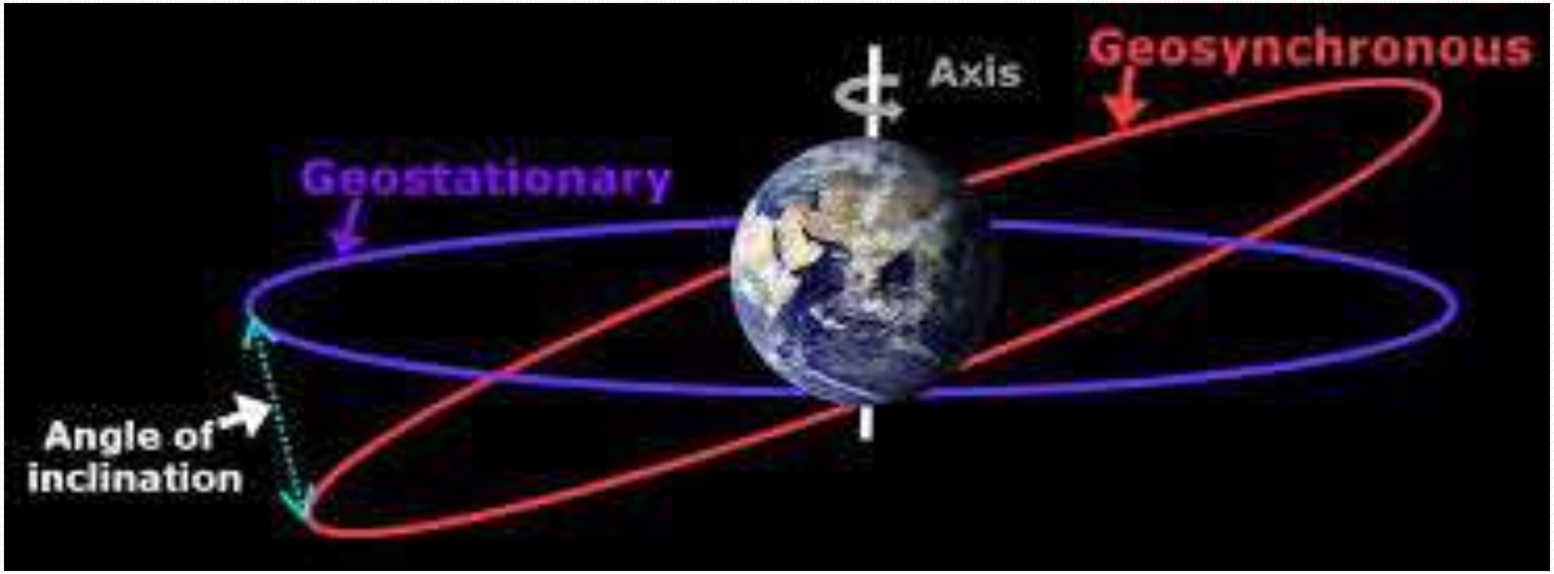
A Geo-synchronous Earth Orbit **(GEO) Satellite** is one, which is placed at an altitude of 35,900kms above the Earth (42000 km from Earth centre). This orbit is synchronized with a side real day (i.e., 23 hours 56 minutes). This orbit can have inclination and eccentricity.

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.

While geosynchronous satellites can have any inclination, the key difference to geostationary orbit is the fact that **they lie on the same plane as the equator**. Geostationary orbits fall in the same category as geosynchronous orbits, but it's parked over the equator.



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

GEO Satellites have a very poor coverage over Poles.

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

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.

The choice of the satellite orbit will depend on its applications.

While geostationary orbits are popular for applications such as direct broadcasting or satellite television and for communications satellites

Others such as GPS and even those satellites used for mobile phones are much lower.

RECAP

1. 2 LEO satellites are sufficient to cover entire globe (true/false)

2. Transmission delay is least in GEO Satellite communication system (true/false)

3. 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/semi minor axis)

4. GEO satellites are good for polar coverage (true/false)

5. Polar Satellites require less time as compared to GEO satellite for orbiting around the earth (true/false)

6. If the satellite is placed in higher orbit then the camera onboard the satellite gives better resolution (true/false)

7. Every Geostationary orbit is a Geo-synchronous orbit. But, the converse need not be true (True or false)

8. Angle between orbital and equatorial plane is ……….. For geostationary orbits

9. Signal loss is less in MEO orbits as compared to ……… orbits

10. MEO gives global coverage as compared to LEO (True/false)

Launching of Satellites

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.

Launch Vehicle

ELV (Expendable Launch Vehicle)

RLV (Reusable Launch Vehicle)

Orbital Slots

More than **200 satellites** in geosynchronous orbit,

How do we keep them from running into each other??

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**.

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.

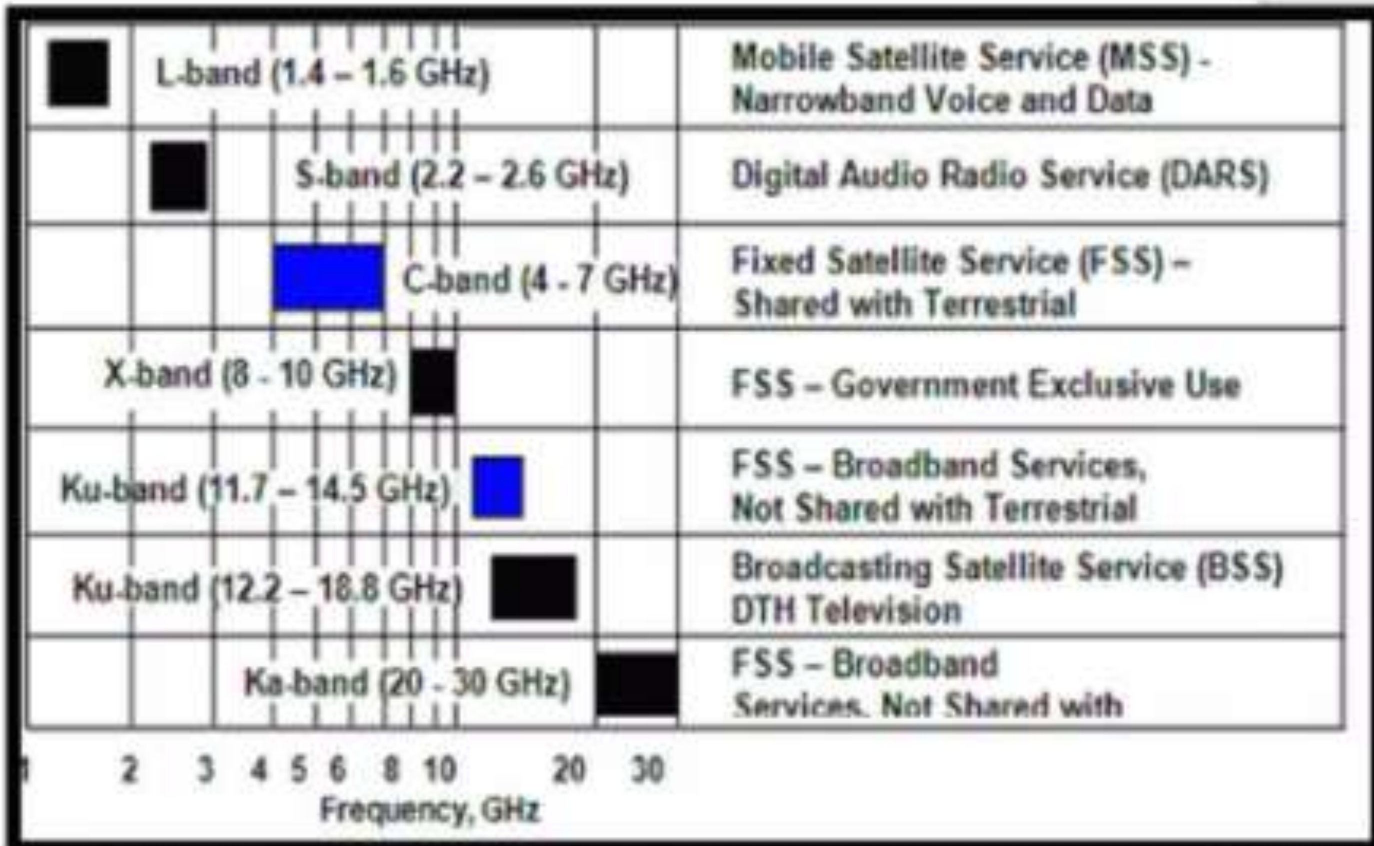
- Solar radiation pressure affects large GEO satellites, which use large solar arrays.

Self-generated torques and pressures caused by RF radiation from the antenna

Frequency considerations for communication:

Satellite communications use the very high-frequency range of 1–50 gigahertz (GHz; 1 gigahertz = 1,000,000,000 hertz) to transmit and receive signals. The frequency ranges or bands are identified by letters: (in order from low to high frequency) L-, S-, C, X-, Ku-, Ka- and V-bands. Signals in the lower range (L-, S-, and C-bands) of the satellite frequency spectrum are transmitted with low power, and thus larger antennas are needed to receive these signals. Signals in the higher end (X-, Ku-, Ka-, and V-bands) of this spectrum have more power; therefore, dishes as small as 45 cm (18 inches) in diameter can receive them. This makes the Ku-band and Ka-band spectrum ideal for direct-to-home (DTH) broadcasting, Broadband data communications, and mobile telephony and data applications.

Where used frequency bands:



The future of satellite communication

Future communication satellites will have more onboard processing capabilities, more power, and larger-aperture antennas that will enable satellites to handle more bandwidth

Further improvements in satellites’ propulsion and power systems will increase their service life to 20–30 years from the current 10–15 years.

In addition, other technical innovation such as low-cost reusable launch vehicles are in development.

With increasing video, voice, and data traffic requiring larger amounts of bandwidth, there is no dearth of emerging applications that will drive demand for the satellite services in the years to come.

Frequency spectrum and interference:

The radio frequency (RF) spectrum is a critical component of space activities. Nearly every satellite uses some portion of the RF spectrum to communicate with the ground or other satellites. As the RF spectrum is a limited natural resource, the increase in the number of terrestrial and space users leads to RF congestion that could result in unintentional radio frequency interference (RFI).

Natural events such as space weather can also create RFI, as can intentional activities such as jamming. Management of the RF spectrum is a complicated policy issue, with various entities at the national and international level providing oversight and coordination. With a growing number of space users and reliance on space, RFI is a significant challenge for ensuring space sustainability and security.

Unintentional and Natural Radio Frequency Interference (RFI)

Various ways in which other RF sources or natural events can interfere with or disrupt RF communications

In the active GEO region if a transmitting satellite drifts past another transmitting satellite or a satellite has its transponders misconfigured

Unintentional RFI can also occur if a uplink antenna on the ground is pointed at the wrong satellite in orbit

Transmissions in certain frequencies such as Ku and Ka bands can experience interference from heavy rain or snow.

Energetic particles and radiation from the Sun, especially during solar storms, can create periodic outages or even permanently damage satellites.

Intentional RFI and Jamming

Radio jamming is the deliberate jamming, blocking or interference with wireless communications In some cases jammers work by the transmission of radio signals that disrupt communications by decreasing the signal-to-noise ratio

Jamming is usually distinguished from interference that can occur due to device malfunctions

Earth Station

An **earth station** is a collection of equipment installed on the earth's surface that enables communications over one or more satellites (is a part of ground segment).

Earth stations consist of a reflector antenna (or parabolic dish), a feed system to send and receive the RF carrier, data handling equipment and mechanical tracking equipment to keep the satellite within the antenna's data send/receive area.

Earth stations are typically owned by the company receiving the data from the satellite network, thus must operate within certain specified parameters to maintain the network's stability.

INSAT SYSTEM:

INSAT or the Indian National Satellite System is a series of multipurpose geo-stationary satellites launched by ISRO to satisfy the telecommunications, broadcasting, meteorology, and search and rescue operations. ***Commissioned in 1983, INSAT is the largest domestic communication system in the Asia Pacific Region.*** It is a joint venture of the Department of Space, Department of Telecommunications, India Meteorological Department, All India Radio and Doordarshan. The overall coordination and management of INSAT system rests with the Secretary-level INSAT Coordination Committee. INSAT satellites provide transponders in various bands (C, S, Extended C and Ku) to serve the television and communication needs of India. Some of the satellites also have the Very High Resolution Radiometer (VHRR), CCD cameras for metrological imaging.

List of Indian Communication Satellites:

Serial No.	Satellite	Date of Launch	Launch Vehicle	Status
1	INSAT-1A	10 April 1982	Delta	Failed in orbit
2	INSAT-1B	30 August 1983	Shuttle PAM-D	Mission Completed
3	INSAT-1C	22 July 1988	Ariane-3	Partial failure in orbit
4	INSAT-1D	12 June 1990	Delta	Mission Completed
5	INSAT-2A	10 July 1992	Ariane-4	Mission Completed
6	INSAT-2B	23 July 1993	Ariane-4	Mission Completed
7	INSAT-2C	07 December 1995	Ariane-4	Mission Completed
8	INSAT-2D	04 June 1997	Ariane-4	Failed in Orbit
9	INSAT-2E	03 April 1999	Ariane-4	Mission Completed
10	INSAT-3B	22 March 2020	Ariane-5	Mission Completed
11	GSAT-1	18 April 2001	GSLV	Mission Completed
12	INSAT-3C	24 January 2002	Ariane-5	Mission Completed
13	KALPANA-1	12 September 2002	PSLV	Mission Completed
14	INSAT-3A	10 April 2003	Ariane-5	
15	GSAT-2	08 May 2003	GSLV	
16	INSAT-3E	28 September 2003	Ariane-5	
17	EDUSAT	20 September 2004	GSLV	Mission Completed

18	HAMSAT	05 May 2005	PSLV	
19	INSAT-4A	22 December 2005	Ariane-5	
20	INSAT-4C	10 July 2006	GSLV	Launch unsuccessful
21	INSAT-4B	12 March 2007	Ariane-5	
22	INSAT-4CR	02 September 2007	GSLV	
23	GSAT-4	15 April 2010	GSLV	Launch unsuccessful
24	GSAT-5P	25 December 2010	GSLV-F06	Launch unsuccessful
25	GSAT-8	21 May 2011	Ariane-5	
26	GSAT-12	15 July 2011	PSLV-C17	
27	GSAT-10	29 September 2012	Ariane-5	
28	GSAT-7	30 August 2013	Ariane-5	
29	GSAT-14	05 January 2014	GSLV-D5	
30	GSAT-16	07 December 2014	Ariane-5	
31	GSAT-6	27 August 2015	GSLV-D6	
32	GSAT-15	11 November 2015	Ariane-5	
33	GSAT-18	06 October 2016	Ariane-5	
34	GSAT-9	05 May 2017	GSLV-F09	
35	GSAT-19	05 June 2017	GSLV MkIII - D1	
36	GSAT-17	29 June 2017	Ariane-5	

37	GSAT-6A	29 March 2018	GSLV-F08	
38	GSAT-29	14 November 2018	GSLV MkIII-D2	
39	GSAT-11	05 December 2018	Ariane-5	
40	GSAT-7A	19 December 2018	GSLV-F11	
41	GSAT-31	06 February 2019	Ariane-5 VA-247	
42	GSAT-30	17 January 2020	Ariane-5 VA-251	
43	CMS-01	17 December 2020	PSLV-C50	

Few important weather satellites of INSAT Series:

1. **Kalpana-1** was the first dedicated meteorological satellite launched by Indian Space Research Organisation using Polar Satellite Launch Vehicle on 12 September 2002.

2. Originally known as MetSat-1, On February 5, 2003 it was renamed to Kalpana-1 by the Indian Prime Minister Atal Bihari Vajpayee in memory of Kalpana Chawla—a NASA astronaut who perished in the Space Shuttle *Columbia* disaster.

3. The satellite features a Very High Resolution scanning Radiometer (VHRR), for three-band images (visible, infrared, and thermal infrared) with a resolution of 2 km × 2 km, and a Data Relay Transponder (DRT) payload to provide data to weather terrestrial platforms.
Kalpana-1 went out of service in mid-2018

Payload refers to equipment onboard the satellite to provide the service for which a satellite is launched

At present we have INSAT 3D/3DR working in staggered mode for providing weather information

RECAP

1. Orbital slots are allocated to the Satellite operator by ....
2. Main external perturbations come from ………. And ………….
3. Low-orbit satellites get affected due to friction caused by collision with …………. and ……………….

4 Large size of antenna is required for X band communication as compared to Ka band (true/false)

5. Radio jammer works by the transmission of radio signals that disrupt communications by …………the signal-to-noise ratio (decreasing/increasing)

6. Transmissions in certain frequencies such as ………. bands can experience interference from heavy rain or snow (Ka/Ku or S/C)

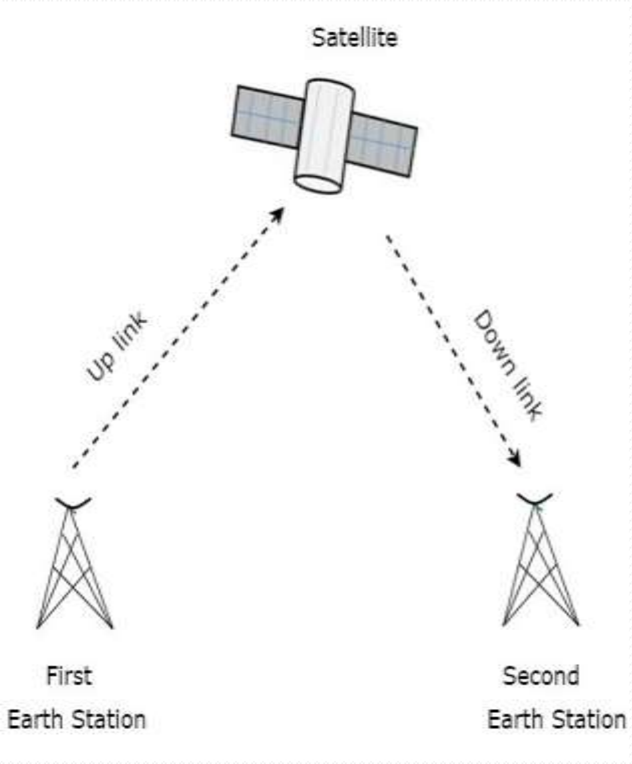
7. Write a short note on **future of satellite communication**

Satellite Communication - Services

- One-way satellite communication link service
- Two-way satellite communication link service

One-way Satellite Communication Link Service

In **one-way** satellite communication link service, the information can be transferred from one earth station to one or more earth stations through a satellite. That means, it provides both point to point connectivity and point to multi point connectivity.



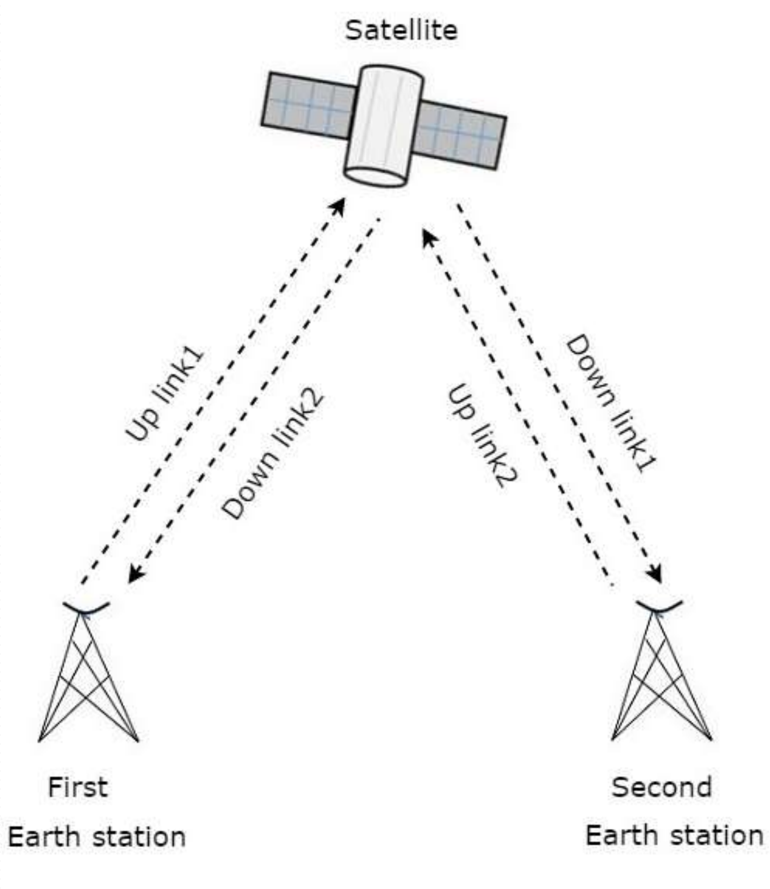
Here, the communication takes place between first earth station (transmitter) and second earth station (receiver) on earth's surface through a satellite in **one direction**.

Examples:

- Broadcasting satellite services like Radio, TV and Internet services.
- Space operations services like Telemetry, Tracking and Commanding services.
- Radio determination satellite service like Position location service.

Two-way Satellite Communication Link Service

In **two-way** satellite communication link, the information can be exchanged between any two earth stations through a satellite. That means, it provides only point to point connectivity.



Here, the communication takes place between first earth station (transmitter) and second earth station (receiver) on earth's surface through a satellite
in **two** (both) **directions**.

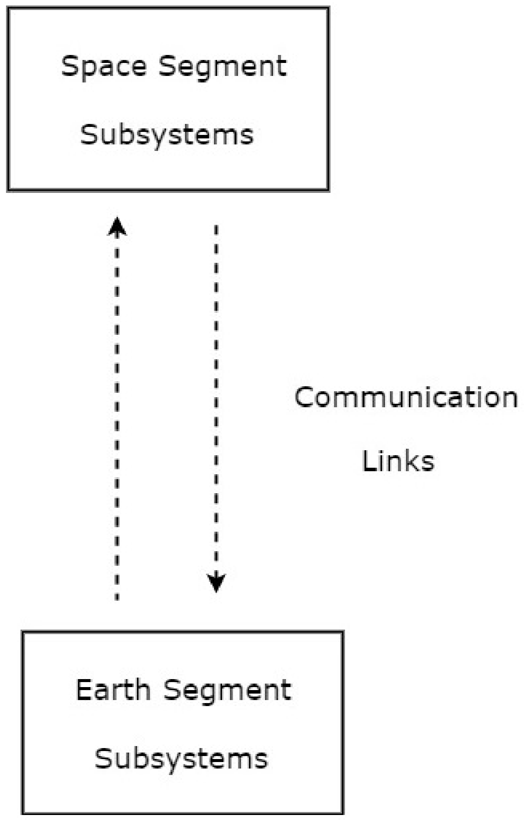
Examples:

- Fixed satellite services like Telephone, Fax and Data of high bit rate services.
- Mobile satellite services like Land mobile, Maritime and Aero mobile communication services.

Satellite Communication - 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**.

- Attitude and Orbit Control (AOC) Subsystem
- Telemetry, Tracking, Commanding and Monitoring(TTCM) Subsystem
- Power and Antenna Subsystems
- Transponders

Earth Segment Subsystems

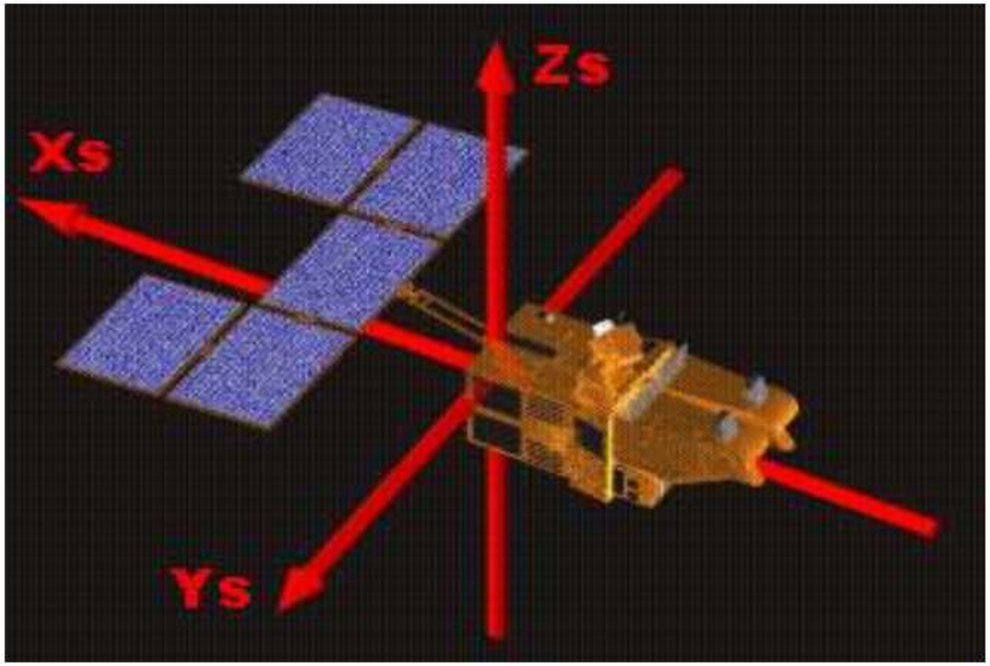
The subsystems present in the ground segment have the ability to access the satellite repeater in order to provide the communication between the users. **Earth segment** is also called as ground segment.

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.

.

SATELLITE'S ATTITUDE

Orientation of satellite as perceived in a certain frame of Reference



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.

Attitude 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 divide this AOC subsystem into the following **two parts**.

- **Attitude Control Subsystem**
- **Orbit Control Subsystem**

Attitude Control Subsystem

Attitude 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 of this type are called as **spinners.**

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.

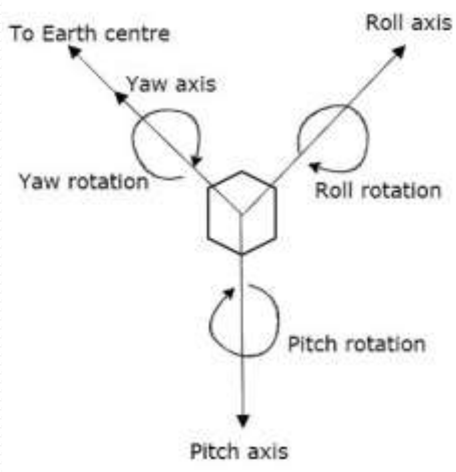
In this method, the following **three axes** are considered.

•**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**.



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.

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.

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 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**).

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.

Recap

1. In **two-way** satellite communication link, the information can be exchanged between only point to multiple point. (True/False)

2. Attitude control subsystem takes care of the ……….. of satellite in its respective orbit

3. …………subsystem consists of rocket motors, which are capable of placing the satellite into the right orbit, whenever it is deviated from the respective orbit.

4. Orbit control subsystem is useful in order to bring the satellite into its ………… orbit

5. **Yaw** is considered in the direction in which the satellite moves in orbital plane (true/false)

6. Spinner contains a drum, which is of ……….. Shape

7. ……… subsystem into the following **three parts**.

Telemetry and Monitoring Subsystem

•Tracking Subsystem

•Commanding Subsystem

8. Spinners can be rotated at 30 to 100 rpm in order to produce a force, which is of gravitational type (true/false).

9. In ……….. method, each axis contains two gas jets for providing the rotation.

10. Pitch axis is considered in the direction, which is parallel to orbital plane (true/false)

Antenna Subsystems (**to transmit and receive clear signals between multiple wireless points**)

Antennas are present in both satellite and earth station

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.

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: 4 **types of Antennas**

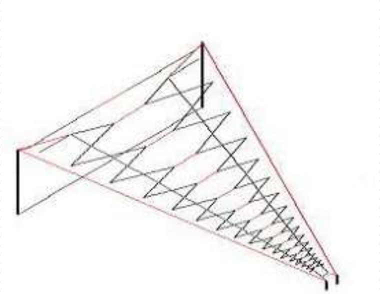
- Wire Antennas
- Horn Antennas
- Array Antennas
- Reflector Antennas

Wire 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

Array antennas are used in satellites to form multiple beams from single aperture for better transmission.

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.

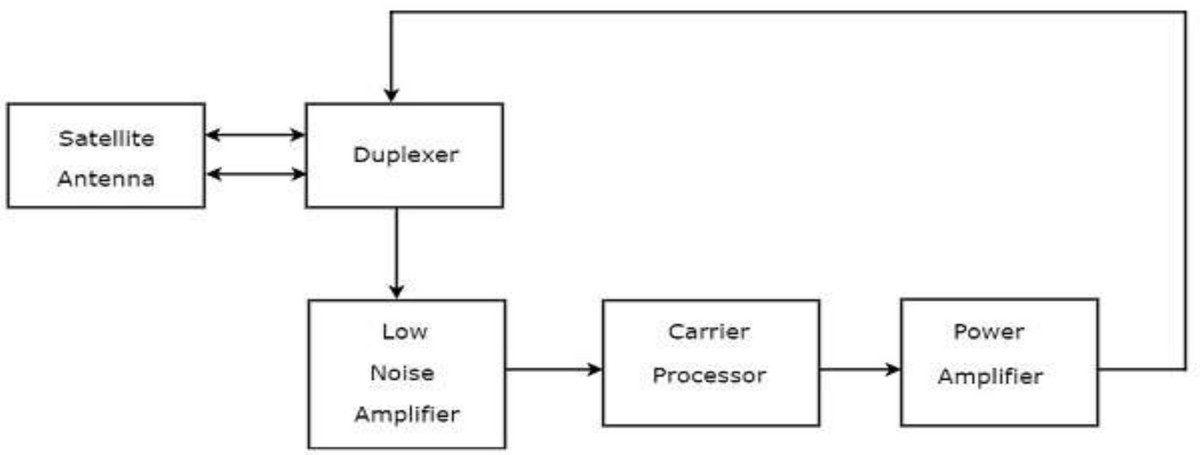
So, **Parabolic reflectors** increase the gain of antennas in satellite communication system. Hence, these are used in telecommunications and broadcasting.

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.

Satellite Communication - Transponders

Transponder performs the functions of both transmitter and receiver (Responder) in a satellite.

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.



- **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.

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.

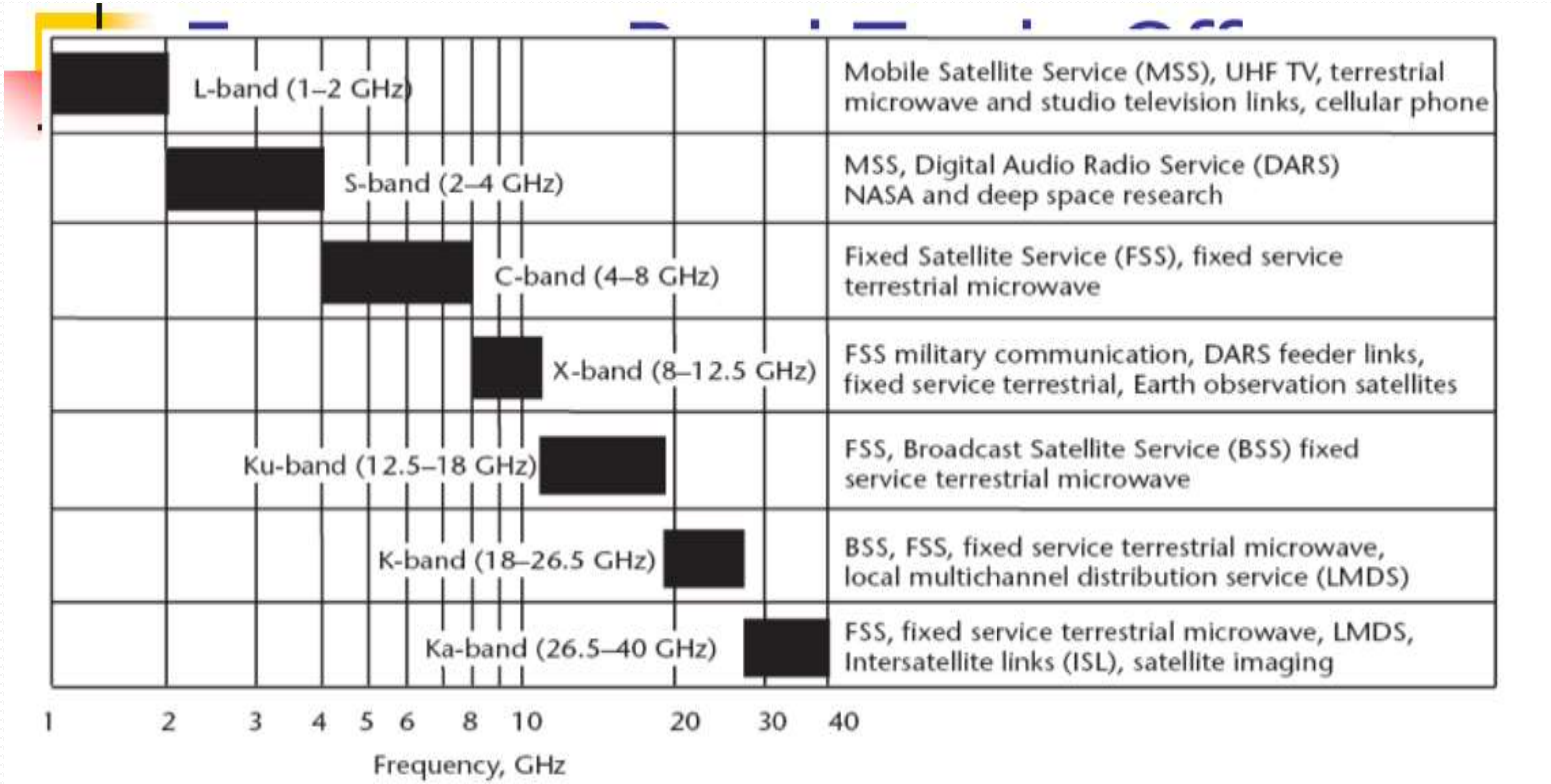
Initially, the analog modulation technique, named **FM modulation** is used for transmitting both voice and video signals, which are in analog form.

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.

Frequency Band Trade-offs

- Satellite communication is a form of radio or wireless communication and therefore must compete with other existing and potential uses of the radio spectrum.
- During the initial 10 years of development of these applications, there appeared to be more or less ample bandwidth, limited only by what was physically or economically justified by the rather small and low powered satellites of the time.
- In later years, as satellites grew in capability, the allocation of spectrum has become a domestic and international battlefield as service providers fight among themselves, joined by their respective governments when the battle extends across borders.
- So, we must consider all of the factors when selecting a band for a particular application.

- The most attractive portion of the radio spectrum for satellite communication lies between 1 and 30 GHz.
- The relationship of frequency, bandwidth, and application are shown



- The use of letters probably dates back to World War II as a form of shorthand and simple code for developers of early microwave hardware.
- Two band designation systems are in use: adjectival (meaning the bands are identified by the following adjectives) and letter (which are codes to distinguish bands commonly used in space communications and radar).

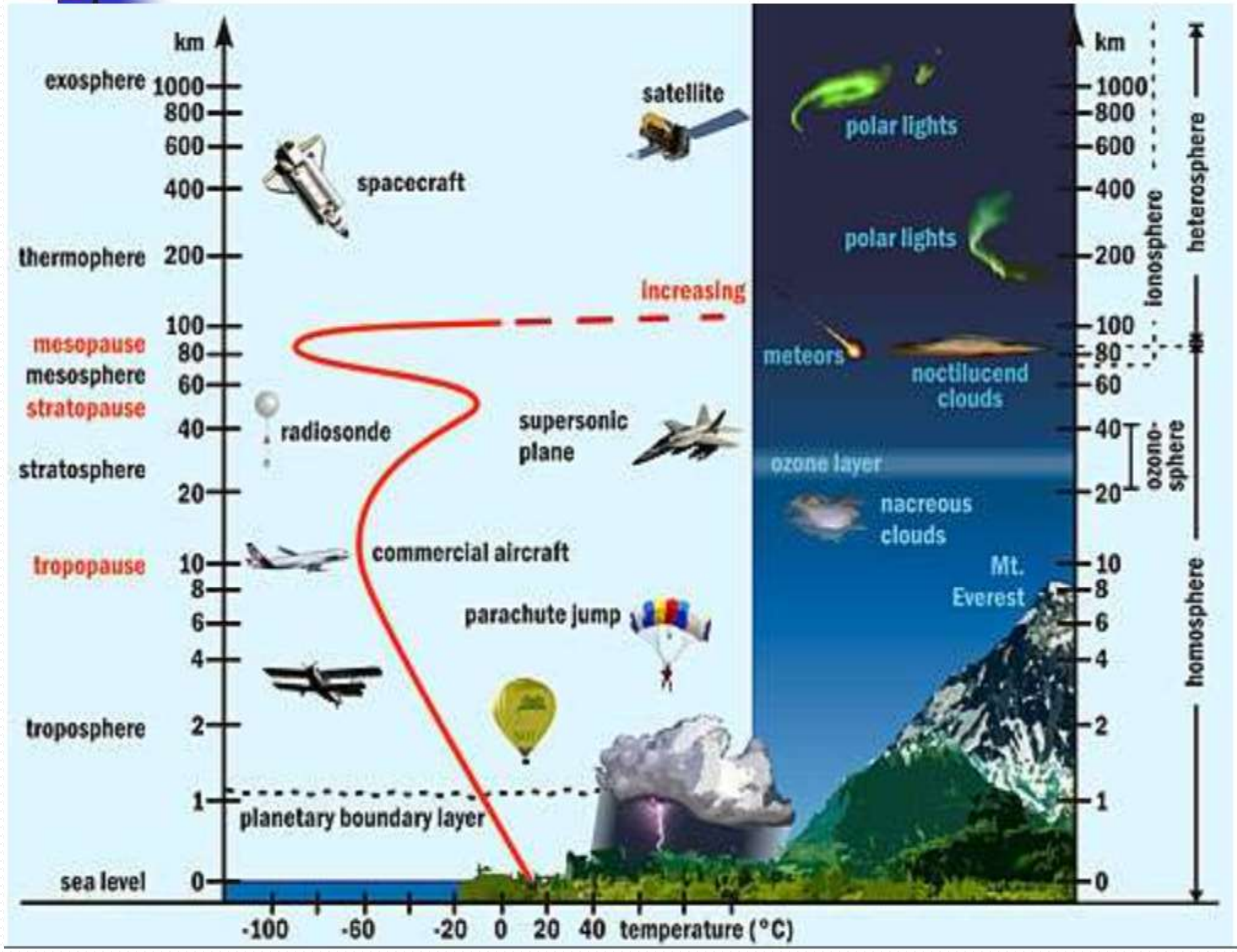
Adjectival band designations, frequency in Gigahertz:

- Very high frequency (VHF): 0.03–0.3;
- Ultra high frequency (UHF): 0.3–3;
- Super high frequency (SHF): 3–30;
- Extremely high frequency (EHF): 30–300.

Letter band designations, frequency in Gigahertz:

- L: 1.0–2.0;
- S: 2.0–4.0;
- C: 4.0–8.0;
- X: 8–12;
- Ku: 12–18;
- Ka: 18–40;
- Q: 40–60;
- V: 60–75;
- W: 75–110.

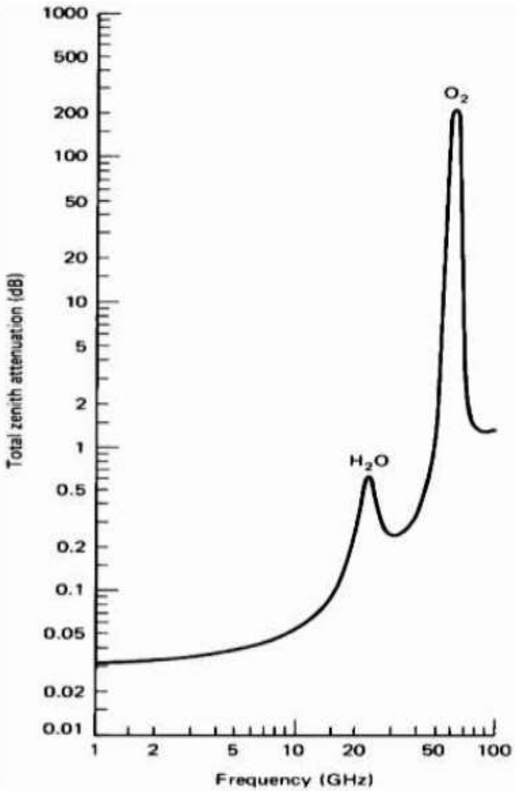
Earth' s atmosphere



Atmospheric Losses

- Different types of atmospheric losses can disturb radio wave transmission in satellite systems:
  - Atmospheric absorption
  - Atmospheric attenuation
  - Traveling ionospheric disturbances

Atmospheric Absorption



- Energy absorption by atmospheric gases, which varies with the frequency of the radio waves.
- Two absorption peaks are observed (for 90º elevation angle):
  - 22.3 GHz from resonance absorption in water vapour (H2O)
  - 60 GHz from resonance absorption in oxygen (O2)
- For other elevation angles:
  - $[AA] = [AA]90 \text{ cosec } \theta$

Atmospheric Attenuation

- Rain is the main cause of atmospheric attenuation (hail, ice and snow have little effect on attenuation because of their low water content).
- Total attenuation from rain can be determined by:
  - $A = \alpha L$ [dB]
  - where α [dB/km] is called the specific attenuation, and can be calculated from specific attenuation coefficients in tabular form that can be found in a number of publications
  - where L [km] is the effective path length of the signal through the rain; note that this differs from the geometric path length due to fluctuations in the rain density.

Traveling Ionospheric Disturbances

- Traveling ionospheric disturbances are clouds of electrons in the ionosphere that provoke radio signal fluctuations which can only be determined on a statistical basis.
- The disturbances of major concern are:
  - Scintillation;
  - Polarisation rotation.
- Scintillations are variations in the amplitude, phase, polarisation, or angle of arrival of radio waves, caused by irregularities in the ionosphere which change over time.
- The main effect of scintillations is fading of the signal.

Recap:

1. The length of satellite antennas is directly proportional to the operating frequency (true/false)
2. Reflector antennas are omni directional (true/false)
3. Atmospheric attenuation is most in ……………. Band (L/KA band)
4. ………… reflectors increase the gain of antennas in satellite communication system
5. For horn antennas of same feed horn, a device named **……….** separates transmitting and receiving signals.
6. ……………. And ……………….. Are used as digital modulation techniques for transmitting signal from earth segment of satellite communication unit

7. Atmospheric loss of radio wave transmission in GHz frequencies happen due to absorption bands of ………….. And …………
8. Rain has more atmospheric attenuation of transmission signal as compared to snow (true/false)
9. Main impact of scintillation is improving the transmission signal (true/false)
10. ………. performs the frequency down conversion of received signal

Satellite Link Budget

Satellite link budget or simply link budget in satellite communication is nothing but the calculation of various factors so as to have an estimation of power that is transmitted from Earth Station to satellite and satellite to earth station in order to have a reasonable amount of power reception at the ends.