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### 1.1.1 General Background

- A satellite is a physical object which revolves around earth at known height (orbit). Artificial satellites are launched into orbits for various purposes. One of the major application of satellite is in communications. Satellite communication services have become more reliable and affordable now a days. Satellite communication systems offer more flexibility than submarine cables, underground cables, fiber-optic systems. With the satellite to satellite communication, it is possible to communicate with any point on the globe.
- A satellite system basically consists of a satellite in space and many earth stations on the ground which are linked with each other through the satellite. A ground based station controls the overall operations of satellite. A satellite receives the signal transmitted from the earth station, it then processes or amplifies the signal and then it retransmits the signal back to earth in the desired form. This processing is done by a radio repeater which is also called as **transponder**.
- A communication satellite is a microwave repeater station that permits two or more users to deliver or exchange information simultaneously.

### 1.1.2 Frequency Allocation for Satellite Services

- The frequencies to be allocated to various satellites are established by International Telecommunication Union (ITU). This provides the international regulation of frequencies, the maximum radiation levels from space, co-ordination with terrestrial systems and use of satellite locations in the space etc. Table 1.1.1 shows the various frequency bands, the bandwidth of each band and their application areas. The special frequency bands are provided for military and non military applications.
- The fixed point applications include the communication between ground stations on the earth. The broadcast applications are direct broadcast on the wide area. i.e. TV broadcast radio broadcast etc. The mobile applications are related to control of aircraft, ships and vehicles. The inter satellite applications are the direct communication from satellite to satellite. Presently C-Band and X-Bands are widely being used by satellites. As more and more satellites are being launched in the space, the problem which will arise obviously is the congestion in the orbits and the available bandwidth will be completely utilized. This will then create problems of interference among the independent satellite systems and with the terrestrial system.

Sr. No.	Frequency band	Uplink frequency GHz	Downlink frequency GHz	Major applications	Bandwidth
1	UHF-Band (Military)	0.292 - 0.312	0.250 - 0.270	Military applications.	20 MHz
2	C-Band (Commercial)	5.9 - 6.4	3.7 - 4.2	Television Broadcast, fixed point to point ground stations, non-military applications.	500 MHz
3	X-Band (Military)	7.9 - 8.4	7.25 - 7.75	Mobile (ships, aircrafts), radio relay etc.	500 MHz
4	Ku-Band (Commercial)	14 - 14.5	11.7 - 12.2	Broadcast and fixed point service, non-military applications.	500 MHz
5	Ka-Band (Commercial)	27 - 30	17 - 20	Broadcast	3 GHz
6	Ka-Band (Military)	30 - 31	20 - 21	Military	1 GHz
7	V-Band	50 - 51	40 - 41	Fixed point, non-military	1 GHz
8	Q-Band	50 - 51	41 - 43	Broadcast non-military	2 GHz
9	V-Band	54 - 58 59 - 64		Intersatellite Intersatellite	3.9 GHz 5 GHz

**Table 1.1.1 Allocated frequency bands and uplink/downlink frequencies**

The bands of higher frequencies (*Ka*, *Ku* and *V*-bands) are made available with higher bandwidth. The bandwidth available is roughly 10% of the carrier frequency of that band. Thus the advantage of higher carrier frequency is increase in bandwidth.

#### 1.1.2.1 Satellite Uplink

- The transmitter power for earth stations is provided by high power amplifiers. The large power can be supplied to these amplifiers. The transmitting antenna and amplifier units are placed on the ground therefore there is no limitation on size, weight etc. parameters. Therefore high Effective Isotropic Radiated Power (EIRP) levels are possible for satellite uplinks. The power levels of 40-60 dBW are possible even at high frequency bands like K-bands and V-bands. The beam pattern of the satellite decides the power actually sent to the satellite and interference to the neighbouring satellites.
- As the beams becomes narrower from the earth station, the interference is reduced, but it should track the satellite location exactly. Also the gain of the earth station is increased. Therefore as the beam width is narrowed, the satellite pointing should be improved. This allows the satellite to be placed closer in the same orbit. As the uplink carrier frequency goes on increasing, the size of antenna goes on reducing. This reduces the size of complete earth station.

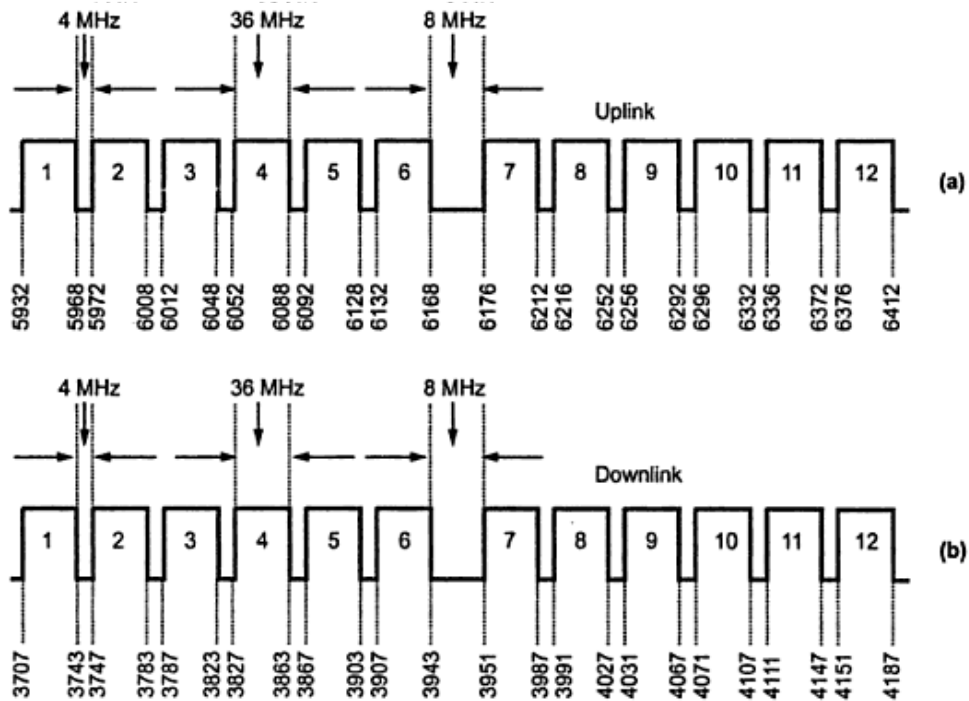
### 1.1.2.2 Satellite Downlink

- The amplifier and transmitting antennas now are placed on the satellite itself for downlink. This limits the size and weight of the transmitting antennas and complete amplifier. The power at the satellite is limited. Therefore small power can be transmitted from the satellite on downlink. The power output from the satellites on the downlink depends on the downlink frequencies. The downlink frequencies are lower than uplink frequencies. The requirements of downlink frequencies are that,
  - i) The attenuation should be less compared to the uplink frequencies because the power available at the satellite transmitter is limited.
  - ii) For the same transmitted power, the low frequencies travel more compared to high frequencies.
- To fulfill these requirements low frequencies are used for downlinks compared to uplink frequencies. The beams of downlink frequencies are designed such that they provide the required coverage area. The EIRP of the satellite or receiver gain does not directly affect the downlink quality. The choice of downlink frequency depends on the maximum power that can be transmitted and atmospheric losses.

►►► **Example 1.1.1 :** *The Intelsat IV satellite operates in the bands 5932-6418 MHz and 3707-4193 MHz. The satellite uses 12 transponders, each of bandwidth 36 MHz. An 8 MHz guard band separate the transponder channels into two groups of six and guard band between transponder channels in each group of six is 4 MHz. Draw the frequencu*

channeling scheme and indicate which are the uplink and which are the downlink assignments.

**Solution :** Fig. 1.1.1 shows the frequency channeling scheme.

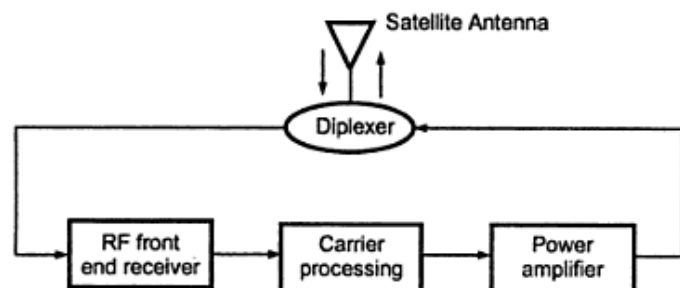


**Fig. 1.1.1 (a) Uplink frequency allocations for 12 transponders of the satellite**

**(b) Downlink frequency allocations for 12 transponders of the satellite**

### 1.1.2.3 Satellite Transponder

- The satellite transponder receives the uplink transmission from the earth station and retransmits the signal on downlink. Fig. 1.1.2 shows the basic block diagram of satellite transponder.



**Fig. 1.1.2 Satellite transponder block diagram**

- The uplink transmission is received by the antenna of the satellite. Through diplexer it is given to the front end receiver.
- The front end receiver increases the signal to noise ratio of the signal received and provides amplification. The power received at the antenna of satellite via uplink is very small. Therefore front end receiver provides amplification to the signal. Carrier processing involves the demodulation of the uplink carrier frequencies and remodulation of the information on downlink frequencies. It can also change the modulation format for downlink.
- Normally uplink and downlink frequencies are separate. This is done so that uplink and downlink frequencies should not mix with each other. Therefore same antenna is used for the transmission of downlink frequencies. The diplexer performs the job of simultaneous transmission and reception through the antenna. Since the uplink and downlink frequency bands are separate, simultaneous reception and transmission has no problem.
- The power amplifier is provided in the transponder to increase the power level of remodulated downlink carrier. The power level is such that it should reach satisfactorily to the earth stations. The gain of the typical transponder is around 80-100 dB.

### 1.1.3 Basic Satellite System

- Fig. 1.1.3 shows basic operation of a communication satellite system. There are three main parts of satellite communication system.

- i) Transmitting earth station
- ii) Transponder

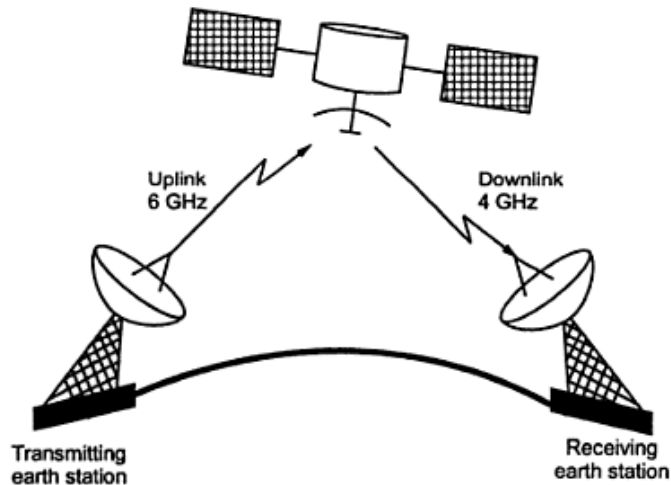


Fig. 1.1.3 Satellite communication system

- iii) Receiving earth station

- The signal to transmit is given to transmitting station which transmits the signal towards satellite. Satellite consists of a receiver which collects the signal, amplifies it and translates it into another frequency. The translated frequency is then retransmitted to the receiving station.
- The signal being transmitted by transmitting earth station is called as **uplink**. The retransmitted signal from satellite transponder is called as **down link**. The uplink frequency is greater than down link frequency. Typically uplink frequency of 6 GHz and down link of 4 GHz is used.
- The receiver and transmitter combination of a satellite is called as **transponder**. The transponder is basically RF-to-RF repeater. The basic function of transponder is frequency translation and amplification. Various transponders are employed for different frequency channels.

### 1.1.4 System Design Consideration

- Technical design factor is a major element of the specification of a satellite system. Factors to be considered for a complete satellite system includes.
  1. Orbital parameters
  2. Coverage
  3. Access Technique
  4. Signal in space
  5. Payload
  6. Ground networks

### **1.1.5 Applications of Satellite**

- Communication satellites are one of the means of telecommunication transmission. But the satellite communication applications have several categories.
  - a) Point-to-point
  - b) Point-to-multipoint
  - c) Multipoint-to-multipoint
- Satellite can provide services at that are distant and insensitive. The satellite services are particularly unique in their capabilities with respect to mobile terminals such as ships, aircrafts, trucks and cars etc. spanning large geographical area.
- Different satellites are designed for different purposes. Major application of satellite is for communication. Other applications includes,
  1. Surveillance
  2. Navigation
  3. TV distribution
  4. Satellite Broadband Internet
  5. Satellite telephone

## 1. Surveillance

- An important application of satellite is surveillance i.e. for observation. Satellites can observe earth and transmits back to earth station.
- In military application, satellites are used for reconnaissance i.e. they take images and send them back to earth; from this information about presence of radar or potential enemies, presence of nuclear weapons.
- Weather satellites takes photographs of cloud and sends back to earth station. From these images can be used to predict the weather.
- Images from geodetic satellites are used to draw accurate maps, also for town planning purpose.
- Satellite images can also be used for locating natural resources like forest, lakes, rivers, mines, crops, mineral resources. Also the source of pollution and intensity of pollution can be predicted.

## 2. Navigation

- An important application of satellite is Global Positioning System (GPS). GPS is a network of 24 Low Earth Orbit (LEO) satellites spaced equally around the world in overlapping patterns.
- GPS is another popular application of spread spectrum. The GPS is now used in ship and aircraft navigation, geological surveys. GPS is used to determine the precise location of any object on the earth within the accuracy of inches. Also it is used for measuring the velocity of moving object.
- Typical applications of GPS are -
  1. To pin-point locate the destination by delivery vehicle.
  2. To guide emergency vehicle through electronic map.
  3. To monitor continuously the movement of cargo or any vehicle.
  4. A GPS assisted navigation systems airlines can fly more direct routes, saving time for passengers and fuel.

### Working of GPS

- The GPS system uses 24 satellites in six orbital planes at 22,200 km height from earth. All the satellites are controlled by earth station. All satellites and earth station have highly precise atomic clock for time synchronization for generating PN code. Satellites continuously transmit this PN code and information about location and time. A GPS receiver on ground generates same PN code. The receiver PN code is delayed by  $\alpha$  seconds (timing bias) compared to PN code of satellites.
- Four satellites are used to determine the exact location of a receiver. Fig. 1.1.4 shows block diagram of a GPS receiver.

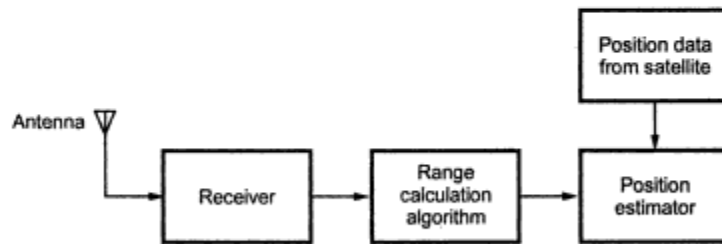


Fig. 1.1.4 GPS receiver

- The data received from satellite and the GPS receiver is given to position estimator. It computes the exact position of receiver.

### 3. TV Distribution

- Direct Broadcast Satellite (DBS) is mainly used for direct home broadcasting of television. Actually operating principle and internal structure of DBS is same as communication satellites. Since large area is covered by the DBS, large power needs to be transmitted from it. Because the DBS receivers are all domestic, they are simple to implement and cheap. The dish size of the DBS receiver is of the order of 0.4 to 0.75 metre.
- The DBS can handle as large as 32 television channels. The TV signals are multiplexed and transmitted to the satellite through earth station. The satellite receives these signals, and transmits them on downlink frequencies. DBS amplifies the signals and its downlink transmission covers the required region. The DBS can also scramble the signals at the program generation facility. This requires descrambles at the consumer terminals. The advantage of this is that the consumer can not receive scrambled channels directly.

- The transmitted power from the satellite is around 100 times that of other communication satellites, therefore DBS reception needs very small dish. Since the antenna size is very small and signal strength is also sufficiently high, the cost of the satellite receiver is affordable to the normal consumer. The DBS receivers at the consumers are all TV receiver only (TVRO). They do not involve any control of satellite.

#### **4. Satellite Broadband Internet**

- The forward link (Internet to link) is a huge pipe divided into number of smaller bandwidths such as 512 kbps, 1024 kbps, 2048 kbps, 4 MBps etc. Depending on the subscription user gets a share of any of these segments.
- The return link (user to Internet) is operated using a time slot system. The data rate from 64 kbps to 1 Mbps is available to share as per the subscription.
- The satellite broadcast system is shared between number of users simultaneously and is known as always on technology.

#### **5. Satellite Telephones**

- Satellite telephones provides global coverage at low cost. Satellites provide a clear Line Of Sight (LOS) that links few ground based antennas.
- Satellite telephone system uses Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) satellites for global communications.

### **1.2 Satellite Orbits**

#### **Definition of Orbit :**

- The satellite can be rotated around the earth through various paths. These paths are called **orbits** of the satellite. These orbits are used to cover the specific application areas.

#### **1.2.1 Orbit Fundamentals**

- When the satellite is moving in the orbits, it stays in position because the **centripetal force** on the satellite balances the gravitational attractive force of the earth. This balance depends on the distance from the earth, the speed of the satellite, earth's radius and gravitational force of the earth. The orbit of the satellite is selected on the basis of coverage area required, transmission path loss, delay time and the period for which satellite is visible from the point on the earth. These orbits are shown in Fig. 1.2.1.

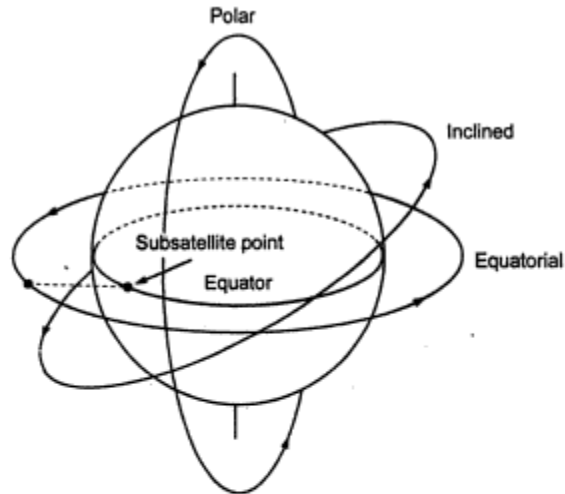


Fig. 1.2.1 Satellite orbits

### 1. Inclined Orbit

- An inclined orbit is used to cover the polar regions. It is not that frequently used. The height of the inclined orbit is set such that it covers the required area of the region of interest. The time for which the satellite is visible to the point on the earth is also controlled. Satellite cannot remain in continuous contact with the point on the earth if rotating in inclined orbit. Sometimes the inclined orbit is also called **elliptical inclined orbit**.

### 2. Polar Orbit

- The Polar orbit shown in Fig. 1.2.1 is not much suitable for communication purposes. It is used for special applications like navigational satellites.

### 3. Geostationary Orbit

- The circular equatorial orbit is exactly in the plane of equator on the earth. All the points on this orbit are at equal distance from earth's surface. The satellites rotating in this orbit are mostly used for communication purposes. If the satellite rotating in this orbit has the angular velocity equal to earth's angular velocity, then the satellite is said to be moving along with the earth. The satellite appears to be stationary to the point on the earth. Therefore this orbit is sometimes called **Geostationary orbit**.

- The revolution period of the earth around its axis is 23 hours and 56 minutes. The satellite in the geostationary orbit should complete its rotation around the earth in the same period of 23 hours and 56 minutes. These satellites are therefore called geostationary satellites.

#### 4. Geosynchronous Orbit

- When the inclination of the orbit is not zero and/or eccentricity is not zero, it is called **geosynchronous orbit**. The period of geosynchronous orbit is equal to period of revolution of earth with itself. This means geostationary orbit and geosynchronous orbit have same period. The similarities and differences between geostationary orbit and geosynchronous orbit are mentioned here :

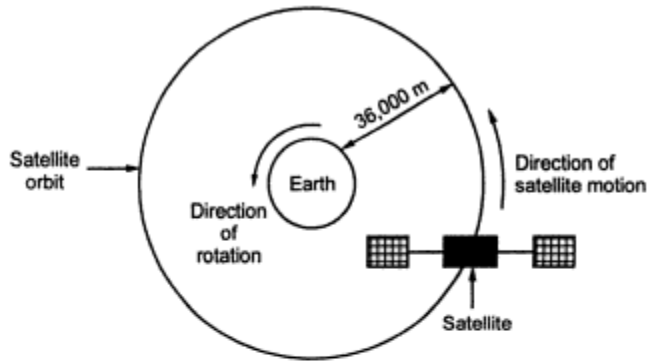
Sr.No.	Geostationary orbit	Geosynchronous orbit
1	This orbit is circular.	This orbit is not circular.
2	This orbit lies in equatorial plane, its inclination is zero.	This orbit is inclined with respect to equatorial plane.
3	A satellite in this orbit appears to be stationary with respect to earth.	A satellite in this orbit appears to oscillate with respect to a point on earth.
4	Period of satellite in this orbit is 23 hr, 56 min and 4.1 sec.	Period of satellite in this orbit is 23 hr, 56 min and 4.1 sec.
5	There is only one geostationary orbit.	There can be many geosynchronous orbits.

**Table 1.2.1 Differences and similarities between geostationary and geosynchronous orbit**

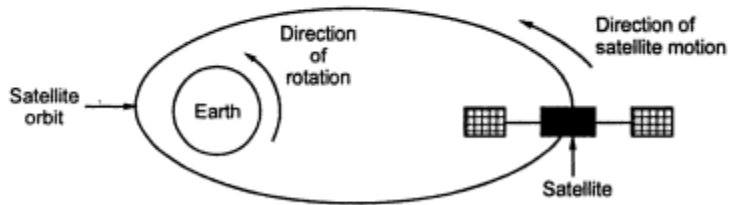
- Geosynchronous satellites are called as geostationary satellites. Exact geostationary orbit cannot be attained in practice. Hence the term geosynchronous satellite is used instead of geostationary satellite.

#### 1.2.2 Orbit Shape

- The orbit path itself can be circular or elliptical as shown in Fig. 1.2.2.



(i) Circular orbit



(ii) Elliptical orbit

**Fig. 1.2.2 Satellite orbit**

- For circular path, the height of satellite is the distance of satellite from earth but for calculation purpose the height is distance between center of earth and satellite.
- Elliptical orbits are inclined at an angle of  $64^\circ$  with respect to equatorial plane. For elliptical path, center of earth is one of the focal point of ellipse. Hence the distance between earth and satellite varies during its revolution. The point in the orbit where the satellite is closest to the earth is called the **perigee** and the point where the satellite is farthest from the earth is called the **apogee**. The perigee and apogee distances are measured from the center of the earth's gravitation force. Therefore apogee and perigee include the radius of earth.
- The elliptical orbit of satellite is shown in Fig. 1.2.3 where the lengths  $a$  and  $b$  are the **semi major** and **semi minor axis**.
- At apogee the satellite is at highest point. Therefore gives the greatest earth coverage region.

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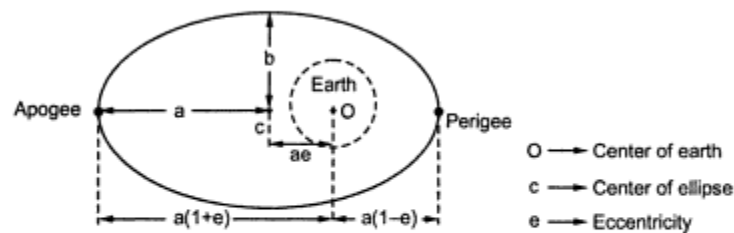
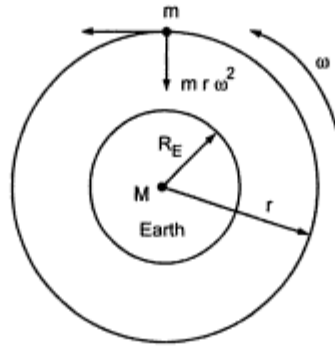


Fig. 1.2.3 Elliptical orbital plane

### 1.2.3 Height of Geostationary Orbit

- At the height of geostationary orbit, the orbital velocity of satellite equals the velocity of the point on earth's equator. Fig. 1.2.4 shows the orbital path of satellite with respect to earth.



**Fig. 1.2.4 Geostationary orbit**

Let

$M$  = Mass of the earth

$m$  = Mass of the satellite

$r$  = Radius of synchronous circular orbit of the satellite

$R_E$  = Radius of earth = 6370 km

$\omega$  = Angular velocity of the satellite

- The centripetal force acting on the satellite will be  $m r \omega^2$ . The gravitational force on the satellite will be  $\frac{G m M}{r^2}$ . Here  $G$  is the gravitational constant. At any point on the geostationary orbit,

Gravitational force = Centripetal force

$$\therefore \frac{G m M}{r^2} = m r \omega^2 \quad \dots (1.2.1)$$

- At the surface of the earth, gravitational force is  $mg$  and  $g$  is acceleration due to gravity.

Therefore

$$\frac{G m M}{R_E^2} = mg \quad \dots (1.2.2)$$

From equation (1.2.1) and (1.2.2)

$$r = \left( \frac{g R_E^2}{\omega^2} \right)^{1/3} = \left( \frac{g R_E^2}{4\pi^2 f^2} \right)^{1/3} \quad \dots (1.2.3)$$

- Here  $\omega = 2\pi f$ ,  $f$  is the rotation rate. If  $f = 1$  revolution per day and  $R_E = 6370$  km,  $g = 9.9 \text{ m / sec}^2$  then,

$$r = 42,208 \text{ km}$$

Therefore height 'h' of the geostationary orbit over the earth's surface will be,

$$h = r - R_E$$

$$\begin{aligned} &= 42,208 \text{ km} - 6370 \text{ km} \\ &= 35,838 \text{ km}. \end{aligned}$$

#### **1.2.4 Laws Governing Satellite Motion**

Orbital mechanics are governed by Kepler's three laws :

### 1.2.4.1 Kepler's First Law

- When small body rotates around large body, it follows elliptical path. One of the foci of this elliptical path is at the center of mass of large body. Fig. 1.2.5 shows such elliptical path. One of the foci is center of mass of earth. This point is denoted by 'E'.
- The Kepler's first law can be stated as -

The planets move in a plane ; the orbit of each satellite is an ellipse with the earth centered at one focus.

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### 1.2.4.2 Kepler's Second Law

- The orbit of smaller body sweeps out equal areas in equal time. Fig. 1.2.5 shows that the satellite (smaller body) sweeps area  $A_{34}$  in time  $t_3$  to  $t_4$ . Similarly it sweeps an area of  $A_{12}$  from time  $t_1$  to  $t_2$ . Then as per Kepler's second law,

if  $t_1 - t_2 = t_3 - t_4$  then  $A_{12} = A_{34}$

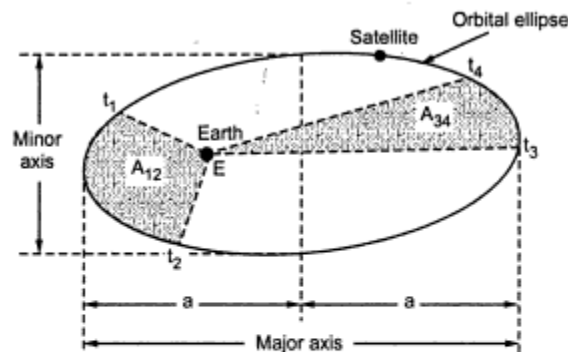


Fig. 1.2.5 Orbital mechanics of satellite are governed by Kepler's laws

- Kepler's second law can be stated as -

The line joining the satellite and the center of the earth sweeps out equal areas in equal times. The area is bounded by the arc segment of the orbit and two lines that extend from the center of the earth.

### 1.2.4.3 Kepler's Third Law

- The square of the period of revolution of satellite about earth is equal to third power of semi major axis of ellipse multiplied by a constant. i.e.,

$$T^2 = \frac{4 \pi^2 a^3}{\mu} \quad \dots (1.2.4)$$

Here T is the period of revolution of satellite about earth.

a is semi major axis of orbital ellipse. This is shown in Fig. 1.2.5.

$\mu$  is Kepler's constant. It's value is  $3.986004418 \times 10^5 \text{ km}^3/\text{s}^2$

### 1.2.4.4 Height of Geosynchronous Orbit using Kepler's Laws

- We know that geostationary satellite follows the geostationary orbit. This orbit is in the plane of the equator. It has no inclination and it is circular. Kepler's 3<sup>rd</sup> law can be used to determine radius of geostationary orbit.

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When the path is circular, the semi major axis (a) becomes radius of the orbit. We know that earth rotates around its polar axis with the period of 23 hr 56 min and 4.09 sec. This is equal to 86164.09 sec. Geostationary satellite must have same period of rotation. That is,

$$T = 86164.09 \text{ sec}$$

- With this period of revolution around earth, the satellite will have same angular motion as that of earth. Hence it will appear stationary with respect to a point on the earth. Putting values of T and  $\mu$  in equation 1.2.4,

$$(86164.09)^2 = \frac{4 \pi^2 \times a^3}{3.986004418 \times 10^5}$$

$$\therefore a^3 = 7.496 \times 10^{13}$$

$$\therefore a = 42164.17 \text{ km}$$

- Note that the radius obtained above is similar to the earlier calculations of height of geostationary orbit.

### 1.2.5 Antenna Look Angles

**Definition :**

- Earth station antenna is pointed towards satellite for communication. The earth station antenna is pointed as per some co-ordinates. These co-ordinates are called *look angles*. For geostationary orbit to calculate the look angles following parameters are required.
  - a) The earth station latitude ( $\lambda_E$ )
  - b) The earth station longitude ( $\phi_E$ ) ,
  - c) Satellite longitude ( $\phi_{SS}$ )

Two important look angles are - azimuth angle and elevation angle.

## 1. Azimuth Angle (Az) :

- Fig. 1.2.6 shows how azimuth angle is calculated. A local horizontal plane is formed by north and east axes. Third axis is local vertical direction. An earth station is considered to be located at the center of this co-ordinate system. A projection of satellite path is taken on local horizontal plane.
- *Azimuth angle* is an angle made by projected satellite path with respect to geographic north. This angle is calculated in clockwise direction.
- Azimuth angle varies between 0 and 360 degrees as a function of the relative positions of the satellite and the point considered.

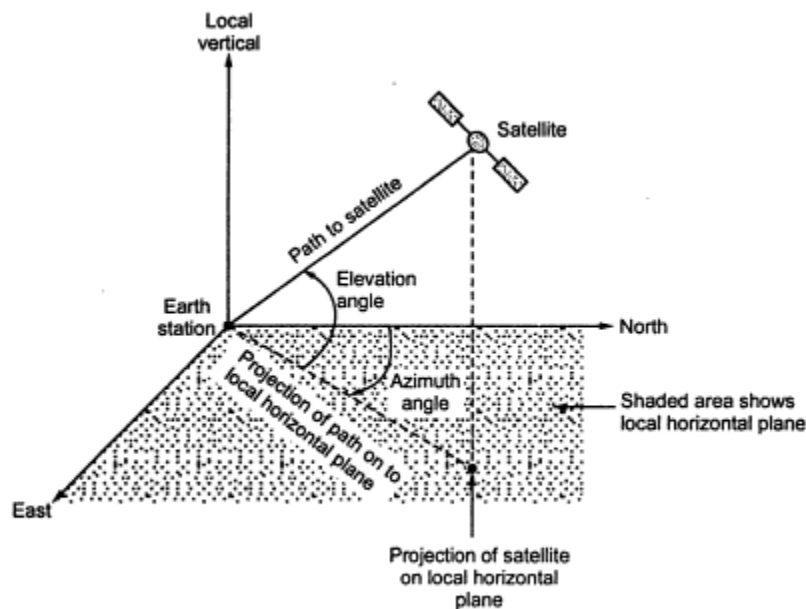


Fig. 1.2.6 Look angles

## 2. Elevation :

- Elevation angle is an angle made by satellite path with respect to local horizontal plane. This angle determines the height of the satellite from horizontal plane.

### 1.2.6 Geostationary Satellite

- Geostationary or geosynchronous satellites orbit the earth around the equator in a circular pattern with an angular velocity equal to that of earth. Geostationary satellite travels in the same direction as the earth's rotation. Since satellite revolves in exact synchronism with the earth's rotation, it appears fixed or stationary to an observer on earth therefore such satellites are called as **geostationary** or **geosynchronous satellites**.
- Geostationary satellite remains apparently fixed i.e. satellite is continually visible from a point on earth, therefore no special tracking antenna and associated circuitry is required. The fixed antenna pointed towards satellite can be used hence keeping track of a geostationary satellite is relatively easy.

- The effect of **Doppler shift** of frequency is negligible. Doppler shift in frequency results due to change in relative movement between source and receiver.

For a geostationary satellite, the angular velocity  $v$ , is given by –

$$v = r \sqrt{\frac{g}{r+h}}$$

where  $r$  = Average radius of earth = 6371 km

$g$  = Gravitational acceleration = 9.81 m/sec

$h$  = Height of satellite above ground

#### 1.2.6.1 Advantages of Geostationary Satellite

1. Keeping track of geostationary satellite is relatively easy as the satellite remains almost stationary in respect to a given earth station.
2. The relative positions of satellite and earth station are fixed hence continuous communication is possible by one satellite only i.e. no need to switch from one satellite to another.
3. There is no break in communication as only one satellite is to track.
4. The coverage area on the earth is very large because the height of satellite is more.
5. Very small energy storage is required as at very high altitude of satellite, it is coming under high intensity solar radiations most of the time.
6. The effect of Doppler shift frequency is negligible.

#### 1.2.6.2 Disadvantages of Geostationary Satellite

1. Because of higher altitude of satellite the propagation time for signal is much longer.
2. Signal has to travel longer distance, greater path loss and attenuation takes place. Therefore highly sensitive receivers are required.
3. There is practical inability to service a satellite in geosynchronous orbit and replace consummables such as solar battery cells and degraded (failure) components.
4. Satellite launching mechanism must be powerful and most accurate.
5. Highly precised spacemanship required for launching satellite at such altitudes.

#### 1.2.6.3 Applications of Geostationary Satellite

- Most communications satellites today are geostationary satellites. Various application specific areas of geostationary satellites are discussed below -
  - Television broadcasting.
  - Regional, national and international global communications.
  - Telephone and data circuits.
  - Mobile telephone services.
  - Private networks for corporations, government agencies.
  - Military applications

### 1.2.7 Station Keeping

- A geostationary orbit must lie in the equator plane, be circular and have correct altitude. Once the satellite is placed in geosynchronous orbit, several forces tend to deviate it from its required orbit. This drift in orbit position is undesirable for reliable continuous communications to be established and maintained.
- Actually the satellite is subject to forces other than the earth's gravitational force such as gravitational forces of Sun and Moon. Also the gravitational force of earth is not uniform at all points on the earth. Because the earth is not a perfect sphere instead it is flattened at both poles. It is necessary to adjust the orbit of satellite periodically.
- Accurate prediction of satellite position one or two weeks ahead requires skilled spacemanship. An **orbit control system** is employed to return the satellite to its correct orbit. The task of correcting deviation is referred to as **station keeping**.
- The principle task of station keeping is to sense satellite positioning parameters and provide corrective action if necessary. Various sensing devices such as – radiation sensory device, gyroscope sensory device and infrared sensors are installed on satellite board.

### 1.2.8 Orbital Perturbation

- The movement of the satellite in its orbit is determined by the forces acting on the centre of mass. The orbital parameters can be obtained from the position and velocity vectors of the satellite by a geometric transformation. In the case of a perturbed orbit, the orbital parameters are no longer constant but are a function of the date for which the transformation is applied.
- Perturbations of the orbit are the result of various forces which are exerted on the satellite other than the forces of attraction of the central, spherical and homogeneous body. These forces mainly consists of -
  - a) Non-spherical components of terrestrial attraction.
  - b) The attraction of the Sun and the Moon.
  - c) Solar radiation pressure.
  - d) Aerodynamic drag.
  - e) Atmospheric drag.
- The first two contributions are gravitational forces, other forces do not depend on the mass of the satellite.

### 1.2.8.1 Effects of Nonspherical Earth

- The earth is not a perfect spherical homogeneous body. The earth is flattened at the poles and there is non uniform mass distribution, this is known as earth's **oblateness**. The orbital period considering earth's oblateness is called as **anomalistic period**.

The anomalistic period is given by

$$P_{anomalistic} = \frac{2\pi}{n} \text{ sec}$$

where n is in radians per sec.

- The mean motion of satellite is given by Kepler's third law by relation -

$$n = \sqrt{\frac{\mu}{a^3}}$$

where a is semi-major axis.

This semi major axis a, is affected by earth's oblateness.

### 1.2.8.2 Attraction of the Moon and Sun

- The Moon and the Sun each create a gravitational potential. The gravitation pulls Sun and Moon have negligible effect on low orbiting satellites but they affect satellites in geostationary orbit.
- The satellite is perturbed mainly because of variation in the inclination of the Moon and Sun. The net effect of these two forces is to change in inclination of geostationary satellite between 0.75° to 0.94° per year. The inclination must be corrected regularly by firing thrusters on satellite in the orbit.

### 1.2.8.3 Solar Radiation Pressure

- The solar panels constitute practically the whole of the apparent surface of the satellite with communication satellites of low power (1 kW), the solar panel are not extensive and the ratio  $\frac{S_a}{m}$  is of the order of  $2 \times 10^{-2} \text{ m}^2 / \text{kg}$  where

$S_a$  = satellite surface in the direction of sun

$m$  = mass of satellite

- For satellites of high electrical power on which very extensive solar panels are mounted, the ratio  $\frac{S_a}{m}$  is of the order of  $10^{-1}$ , the acceleration due to radiation pressure must then be taken into account in calculating perturbations. The main effect of solar radiation pressure is to modify the eccentricity of the orbit which evolves with a period of 1 year.
- For satellites in low orbit, it is also necessary to take account of the radiation pressure of the solar flux reradiated from the surface of the earth whose effect can be significant with respect to that of the direct solar flux.

#### 1.2.8.4 Aerodynamic and Atmospheric Drag

- The aerodynamic drag are very significant at low altitude (200-400 km). It is due to the very high velocity, the aerodynamic force is exerted on the satellite in the opposite direction to its velocity. Mostly the satellites in lower earth orbit suffers the largest atmospheric drag. At this level the friction is too high causing excessive heat on a satellite's surface and the satellite may burn out. The atmospheric drag is directly related to the surface area and mass of satellite. The orbital life time of a satellite is a complex function of orbit plane mass of satellite and ionospheric conditions.

- The aerodynamic force in the opposite direction to the velocity is given by -

$$F_{AD} = -0.5 \rho_A C_D A_e v^2$$

where,  $\rho_A$  is density of the atmosphere

$C_D$  is coefficient of atmospheric drag

$A_e$  is equivalent surface area of the satellite perpendicular to velocity

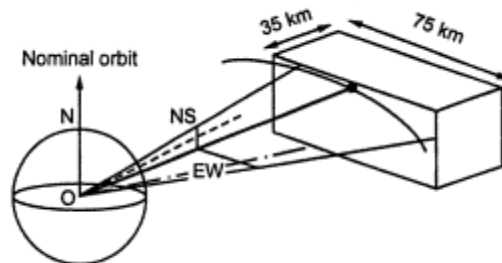
$v$  is velocity of satellite with respect to atmosphere

- The actual movement of the satellite is obtained from the fact that the satellite is in equilibrium between inertial force and various forces which are exerted on it.

#### 2.9 Orbit Correction

- Because of perturbations, the orbit parameters of geostationary satellites gets deviated from the nominal parameters. The parameters by which an orbit is characterized are -
  - i) Inclination  $i$ ,
  - ii) Eccentricity  $e$ ,
  - iii) Longitude drift  $d\lambda / dt$
- In order to keep satellite stationary with respect to earth and to stay in a well defined position on the equator orbit correction is needed. An orbit control system is employed to return the satellite to its correct orbit. The task of correcting deviation is referred to as **station keeping**. Accurate prediction of satellite position is required one or two weeks before and this requires skilled spacemanship.
- The principle task of station keeping is to sense satellite positioning parameters and provide corrective action if necessary. Various sensing devices such as radiation sensory device, gyroscope sensory device and infrared sensors are installed on satellite board. But it is impossible to maintain the satellite absolutely immobile with respect to the earth hence a station keeping box is defined.
- The **station keeping box** represent the maximum permitted values of the excursions of the satellite in longitude ( $\lambda$ ) and latitude ( $\phi$ ). The station keeping box can be considered as pyramidal solid angle, whose vertex is at centre of earth. The station keeping box is defined by the two half angles of vertex, one within plane of equator E-W width and other in the plane of

satellite meridian N-S width as shown in Fig. 1.2.7.



**Fig. 1.2.7 Station keeping rectangular box**

- The rectangular box indicates the positional limits for a satellite in geostationary orbit with respect to its original central position.
- The objective of station keeping is to control the progression of the orbital parameters under the effect of perturbations by applying periodic orbit

corrections so that the satellite remain within the rectangular region. The dimensions of this rectangular box (region) is decided by the mission and purpose of satellite.

#### **1.2.9.1 East West Station Keeping**

- The control of movement of satellite in plane of orbit i.e. tangentially to orbit is termed as **east-west station keeping maneuvers**. It is done by means of jets or actuators which are pulsed once every 2 or 3 weeks. Satellites in the C band must be kept within  $\pm 0.1^\circ$  of longitude and for Ku band it should be within  $\pm 0.05^\circ$ .

#### **1.2.9.2 North-South Station Keeping**

- North-South station keeping is achieved by thrusts acting perpendicularly to the plane of the orbit thereby modifying its inclination. To keep the inclination within limits, jets are pulsed at a specified time to return to zero. This maneuvers is called as **north-south station keeping maneuver**. The tolerance limits for north-south station keeping are same as in east-west station keeping.

### 1.2.9.3 Correction Cycles

- The controls employed for satellite station have several constraints imposed by operation aspects and security. Hence repetitive correction cycles lasting for multiple weeks are usually suited.
- A typical organization of correction cycle is shown in Fig. 1.2.8.

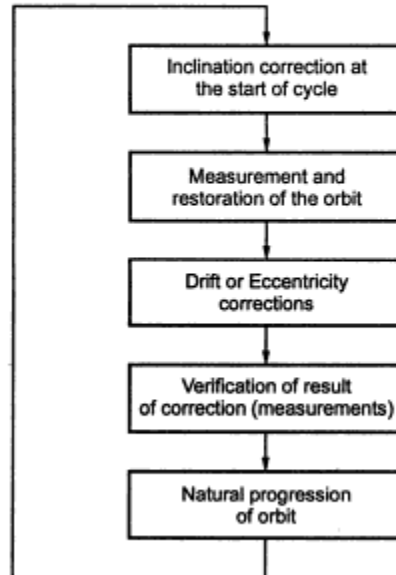
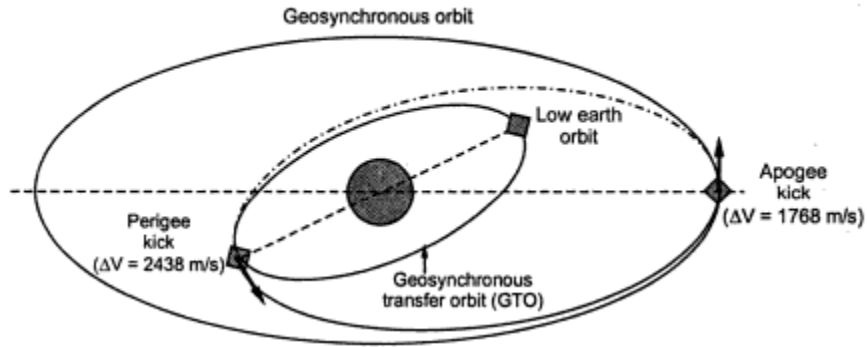


Fig. 1.2.8

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### 1.2.10 Launching of Geostationary satellite

- A satellite is installed into orbit with the help of a launching vehicle. Installation into orbit consists of positioning the satellite in its nominal orbit from a launching site on the surface of the earth. A launch vehicle injects the satellite into an intermediate orbit called the **transfer orbit**. The satellite is then moved from low altitude circular orbit to a higher altitude circular orbit using Hohmann transfer process. Kepler's second law states that the orbital scales as the  $3/2$  power of the semimajor axis. Therefore, the higher the apogee altitude, the larger the period of revolution. e.g. geostationary transfer orbit (GTO) which has a period of approximately 16 hours. After perigee is raised to GEO altitude (about 36,000 km), the period increases to the prescribed 24 hours. Fig. 1.2.9 shows this procedure of a geostationary satellite.



**Fig. 1.2.9 Orbit changes from GTO to Geosynchronous orbit**

- The first velocity increment changes the low altitude circular orbit into the transfer orbit which is an elliptical one whose perigee altitude is that of circular orbit. A second velocity increment at the apogee of the transfer orbit enables a circular orbit to be obtained at the altitude of the apogee.
- The Launch Vehicle (LV) can be either a rocket or the space shuttle. When the space craft and LV leave the launch platform the satellite must undergo steps in sequence to achieve geosynchronous orbit. The steps are -
  1. Ascent
  2. Placement into parking orbit
  3. Transfer orbit
  4. Placement into permanent geosynchronous orbit.

#### 1.2.10.1 Launch Vehicles in India

- India in 1970 under the administration of Indian Space Research Organization (ISRO) initiated the development of launchers for national scientific requirements. In 1980, a satellite is launched using a four stage solid propellant SLV-3 launcher and India became the sixth country to have launched a satellite by its own means.
- The next improved performance Augmented Satellite Launch Vehicle (ASLV) which has a capacity of 150 kg is developed for low earth orbit. The launch base was Sriharikota in the north of chennai.
- The Polar SLV (PSLV) is capable of placing 2900 kg in sun synchronous polar orbit at 400 km altitude. A cryogenic motor development programme enables the production of the Geostationary Satellite Launch Vehicle (GSLV).

#### Launch Vehicle Development in India

- The realization of launch vehicle involves many branches of science and engineering, sophisticated infrastructure and innovative management techniques. Even today, only a few countries possess the technology of launch vehicles. The subsystems in a launch vehicle should withstand hostile flight environment should be of lightweight, cost effective and should be realizable within reasonable time, Years of developmental efforts are put to test in a few minutes of flight requiring performances with practically no margin for error.

- In India, rocket development began with the establishment of Thumba Equatorial Rocket Launching Station near Thiruvananthapuram in 1963 for carrying out scientific experiments in aeronomy and astronomy using rockets brought from outside. India's first sounding rocket was a small 75 mm diameter Rohini, RH-75. Today, India operates a family of sounding rockets of diameter ranging from 200 to 560 mm and capable of carrying upto 200 kg payloads to an altitude of 300 - 400 km to conduct scientific experiments.

#### 1.2.10.2 SLV - 3

- SLV-3 India's first experimental satellite launch vehicle. It was first successfully launched on July 18, 1980 from Satish Dhawan Centre, SHAR, Sriharikota when a Rohini satellite, RS-1 was placed in orbit. The first experimental flight of SLV-3 had taken place in July 1979 but the mission was only partially successful due to a jammed valve in the second stage control system resulting in the leak of oxidizer. After the successful second

flight, two more flights of SLV-3 were conducted in May 1981 and April 1983 to place Rohini satellites carrying remote sensing sensors on board.

- SLV - 3 gave valuable inputs for the vehicle and mission design, materials, hardware fabrication, realization of solid propellant technology, control power plants, staging systems inertial sensors, electronics, testing integration and checkout and launch complex establishment at Sriharikota with associated ground instrumentation. Sriharikota Island, located at 13 degree N latitude, was selected as the launch site for SLV-3 and for all subsequent launch vehicles, to take advantage of the earth's rotation and other advantages.

#### 1.2.10.3 ASLV

- Keeping in view the long term goal for realizing polar and geosynchronous launch capability for operational class of satellites, development of Augmented Satellite Launch Vehicle (ASLV), was undertaken to act as a low cost intermediate vehicle, for demonstrating critical technologies. ASLV was configured as a five stage solid propellant vehicle, weighing about 40 tonne and having a length of about 23.8m. The strap-on stage consisted of two identical 1m diameter solid propellant motors similar to SLV-3 first stage, other stages being the same as in SLV-3. Closed loop guidance, active from the ignition of the second stage motor to the separation of the third stage was employed in ASLV while SLV-3 has used an open loop system.
- The first developmental flight test of ASLV took place in March 1987 but the mission did not succeed due to non-ignition of the first stage motor after the strap-on stage burn out. The second, ASLV-D2, was launched on July 1988. This mission also did not succeed. After a detailed failure analysis, a number of corrective actions were taken, many of them relating to the transition between the strap-on stage and the first stage. They also included better characterization of vehicle, improved stability, introduction of on-board detection of flight events and extensive simulations.

- With the incorporation of all the above modifications, the third developmental flight, ASLV-D3, was successfully conducted on May 20, 1992 when SROSS-C satellite, carrying a Gammarray burst detector and an aeronomy payload was placed in the intended orbit. Another launch of ASLV (ASLV-D4) was conducted on May-4, 1994 when a 113 kg SROSS-C2 satellite was put into a low earth orbit. ASLV provided valuable inputs to the development of PSLV.

#### 1.2.10.4 PSLV

- The Polar Satellite Launch Vehicle (PSLV) project was initiated in 1982. In the present configuration (PSLV-C1), the 44.4 meter tall, 294 tonne PSLV, has four stages using solid and liquid propulsion systems alternately. While the first developmental launch of PSLV (PSLV-D1), on September 20, 1993 did not fulfill the mission of injecting the IRS-1E satellite into orbit, most of the PSLV systems performed normally. The failure of this flight was primarily due to a software error in the pitch control loop of the on-board guidance and control processor, and the failure of two small retro rockets leading to a contact between second and third stages during the separation of the second stage. The second developmental flight, PSLV-D2, on October 15, 1994, was successful when the vehicle injected the 804 kg remote sensing satellite, IRS-P2 into the desired orbits. During the third developmental test flight, on March 21, 1996, PSLV could place a 922 kg IRS-P3 satellite, in the intended 817 km polar orbit. With these two consecutive successes, PSLV became an operational vehicle.
- Several improvements were incorporated in the first operational flight of PSLV (PSLV-C1) to increase its payload capability to 1,200 kg. The major improvements included : increasing the solid propellant in the first core stage from 128 tone to 138 tonne by stretching the stage tankages; replacing the metallic payload adopter by a CFROP adopter and; effecting weight reduction in the vehicle equipment bay. Besides, in the PSLV-C1 mission, four of the six strap-on motors were ignited on the ground and the remaining a few seconds after lift-off. This revised sequence gave a substantial payload advantage.
- In its first operational flight, PSLV successfully placed the Indian Remote Sensing Satellite, IRS-1D, into polar orbit. In its second operational flight on May 26, 1999, PSLV, placed the Indian remote sensing satellite, IRS-P4 along with two satellites the KITSAT of Korea and DLR-TUBSAT of Germany into the precise sun synchronous polar orbit.
- PSLV has thus become a work horse launch vehicle for polar satellites and it is now offered for carrying satellites of other space agencies also. PSLV has proved several systems that are now employed in GSLV. Several facilities established for PSLV, are also used by GSLV, with modifications where required.

#### 1.2.10.5 Launch Complex

- Sriharikota range is the launch station for GSLV. The SHAR complex is located at 82 km north east of Chennai (latitude :13 degree north, longitude : 18 degree east and is ideally located at east coast of India.

- The launch complex at Satish Dhawan Space Centre, SHAR has facilities for storage, testing and integration of the various stage elements. The launch complex houses a 75 m tall Mobile Service Tower inside which the vehicle is integrated. In addition, the launch complex has extensive network of tracking Radars, the launch and mission control center, the facilities for spacecraft check out and integration.
- The launch facilities at Satish Dhawan Space Centre, SHAR have been suitably modified to launch both PSLV and GSLV under construction to enable more frequency launches.

The facilities at SHAR complex include :

- Mobile service tower, Umbilical tower and launch pedestal.
- Solid motor preparation facility
- Subsystem preparation facility
- Hardware storage facility
- Industrial service facility
- Safety and fire fighting systems
- Liquid/cryogenic propellant storage and transfer facility
- Stage preparation facility for cryogenic stage
- Launch control center and mission control center
- Satellite preparation facility.

#### 1.2.10.6 Indian Launch Vehicle at a Glance

Vehicle	Launch Dates	Result
SLV-3 E1	August 10, 1979	Partially successful. A jammed valve in the second stage control system resulted in the leak of oxidizer.
SLV-3 E2	July 18, 1980	Successful
SLV-3 D1	May 31, 1981	Successful
SLV-3 D2	April 17, 1983	Successful
ASLV D1	March 24, 1987	Unsuccessful due to non-ignition of first stage
ASLV D2	July 13, 1988	Unsuccessful. The flight was normal only up to 46 seconds after lift off
ASLV D3	May 20, 1992	Successful

ASLV D4	May 4, 1994	Successful
PSLV - D1	September 20, 1993	Unsuccessful due to software error in on board guidance and control processor
PSLV - D2	October 15, 1994	Successful
PSLV - D3	March 21, 1996	Successful
PSLV - C1	September 29, 1997	Successful
PSLV - C2	May 26, 1999	Successful

► **Example 1.2.1** : An earth observation satellite is in an inclined retrograde orbit and has the following orbital parameters.

Semimajor axis ( $d$ ) = 7830 kms

Eccentricity ( $e$ ) = 0.01

Argument of perigee ( $\omega$ ) = 180

Time of ascending node = 10 hrs 30 min LT

Determine -

- i) Radius of Apogee
- ii) Radius of perigee
- iii) Orbital period
- iv) Mean angular velocity
- v) Velocity at apogee.

**Solution :**

Solution :

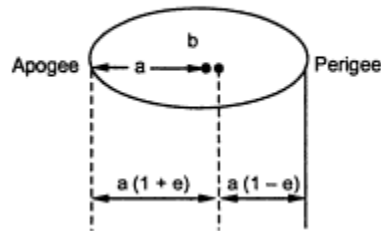


Fig. 1.2.10

i) Radius of apogee :

$$r_A = a(1 + e) = 7830 (1 + 0.01) = 7908.3 \text{ km}$$

...Ans.

ii) Radius of perigee :

$$r_P = a(1 - e) = 7830 (1 - 0.01) = 7751.7 \text{ km.}$$

...Ans.

iii) Orbital period

$$T = \frac{2\pi a^{3/2}}{\mu^{1/2}} = \mu = \text{Kepler's constant.}$$

$$T^2 = \frac{4\pi^2 a^3}{\mu} = 3.9861 \times 10^5 \text{ km}^3/\text{s}^2.$$

$$T^2 = 47497060.68$$

$$T = 6891.81 \text{ sec.}$$

...Ans.

iv) Mean angular velocity ( $\eta$ )

$$\eta = \frac{1}{a} \left( \frac{\mu}{a} \right)^{1/2} = 9.11 \times 10^{-4} \text{ rad/sec.}$$

...Ans.

v) Velocity at apogee ( $S_A$ )

$$S_C = \sqrt{\frac{\mu}{a}} = 0.124 \text{ rad/sec.}$$

$$S_A = S_C \sqrt{\frac{r_P}{r_A}} = 0.124 \sqrt{\frac{7751.7}{7908.3}}$$

$$= 2.14 \times 10^{-3} \text{ rad/sec.}$$

...Ans.

►► **Example 1.2.2 :** Orbital measurements for SIR IO semimajor axis = 42,167.911 km  
Eccentricity = 0.00033 mean anomaly = 28.3866.

Determine

- i) Orbital periods in Hrs. min. sec.
- ii) Mean orbital angular velocity
- iii) Min. & max. distance of space craft from the centre of the earth
- iv) Time of next perigee after 00 : 00 : 00 on March 26, 1979.

**Solution :** Given

$$a = 42,167.911 \text{ km}$$

$$e = 0.00033$$

$$m = 28.3866$$

$$i) \quad T^2 = \frac{4\pi^2 a^3}{\mu} \mu = 398,600.5 \text{ km}^3/\text{sec}^2$$

$$T = 86131.86 \text{ sec.}$$

$$T = 23 \text{ Hrs. } 55 \text{ min } 31.86 \text{ sec.}$$

...Ans.

$$ii) \quad \eta = \frac{1}{a} \left[ \frac{\mu}{a} \right]^{1/2} \text{ Angular Velocity}$$

$$\eta = 7.29 \times 10^{-5} \text{ rad/sec.}$$

$$iii) \text{ Max. distance} = \text{Apogee} = r_A = a(1 + e)$$

$$= 42181.82 \text{ km.}$$

...Ans.

$$\text{Min. distance} = \text{Perigee} = r_P = a(1 - e)$$

$$= 42153.99 \text{ km}$$

...Ans.

$$iv) \quad \eta = 7.29 \times 10^{-5} \text{ rad/sec.}$$

$$m = \eta (t - t_p)$$

m – mean anomaly (arc length in rad) or satellite traversed since perigee passed.

$$t_p = \text{time of perigee.}$$

$$(t - t_p) = \frac{m}{\eta}$$

$$= \frac{28.3866}{7.29 \times 10^{-5}}$$

$$= 389390.9465 \text{ sec.}$$

...Ans.

### Points to Remember

1. Satellite is a physical object revolving in any orbit above earth.
2. A satellite remains in orbit due to balance of centripetal force and gravitational force.
3. Satellite communication system consists of a receiver, a transmitter, earth stations and a transponder.
4. Most satellites operate in upper UHF and microwave frequency region.
5. Signal from transmitting earth station to transponder is called as uplink.

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6. Signal from transponder to receiving station is called as downlink.
7. The most widely used frequency band for satellite communications is C-band (300 MHz - 3000 MHz).
8. The three important functions of a transponder are signal amplification, frequency translation and power amplification.
9. Main application areas of satellite are in communications, surveillance navigation, TV distribution, mobile communications.
10. A circular orbit around the equator with 24 hour period is called as geostationary orbit.
11. The bandwidth of a satellite frequency band is typically 500 MHz.

### Review Questions

#### Introduction to Satellite Communications

1. Explain various frequency bands used for satellite transmission.
2. Explain the term satellite transponder in relation to satellite communication.
3. What do you mean by
  - a) Satellite uplink
  - b) Satellite downlink
4. Explain the requirements of downlink frequency.
5. Discuss important applications of satellite.

#### Satellite Orbits

1. Explain orbital perturbation. Elaborate the causes of orbital perturbation.
2. Explain orbit corrections. How it can be achieved ?
3. What is station keeping ? Explain East-West station keeping and North-South station keeping.
4. With a neat sketch show the correction cycle of satellite station keeping.
5. Explain in brief satellite launching.
6. Write a note on - Launch vehicles in India.
7. Explain the meaning of attitude control. What are attitude control functions ?