Orbital Parameters

Apogee: A point for a satellite farthest from the Earth. It is denoted as **ha. Perigee:** A point for a satellite closest from the Earth. It is denoted as **hp.**

Line of Apsides: Line joining perigee and apogee through centre of the Earth. It is the major axis of the orbit. One-half of this line"s length is the semi-major axis equivalents to satellite's mean distance from the Earth.

Ascending Node: The point where the orbit crosses the equatorial plane going from north to south

Descending Node: The point where the orbit crosses the equatorial plane going from south to north

Inclination: The angle between the orbital plane and the Earth's equatorial plane. It's measured at the ascending node from the equator to the orbit, going from East to North. This angle is commonly denoted as **i.**

Line of Nodes: The line joining the ascending and descending nodes through the centre of Earth

Prograde Orbit: An orbit in which satellite moves in the same direction as the Earth's rotation. Its inclination is always between 00 to 900. Many satellites follow this path as earth's velocity makes it easier to lunch these satellites.

Retrograde Orbit: An orbit in which satellite moves in the same direction counter to the earth's rotation.

Argument of Perigee: An angle from the point of perigee measure in the orbital plane at the earth's centre, in the direction of the satellite motion.

Right ascension of ascending node: The definition of an orbit in space, the position of ascending node is specified. But as the Earth spins, the longitude of ascending node changes and cannot be used for reference. Thus for practical determination of an orbit, the longitude and time of crossing the ascending node are used. For absolute measurement, a fixed reference point in space is required. It could also be defined as "right ascension of the ascending node; right ascension is the angular position measured eastward along the celestial equator from the vernal equinox vector to the hour circle of the object".

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

True anamoly: It is the angle from point of perigee to the satellite's position, measured at the
Earth's centre.

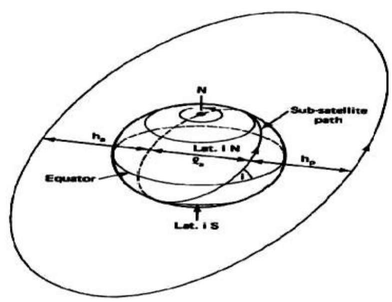

Fig Apogee height *ha*, Perigee height *hp*, and inclination i; *La* is the line of apsides

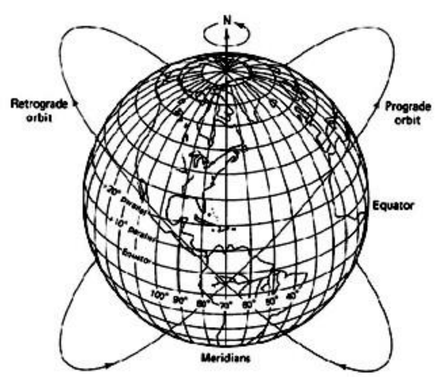

Fig Pro-grade and Retrograde Orbits

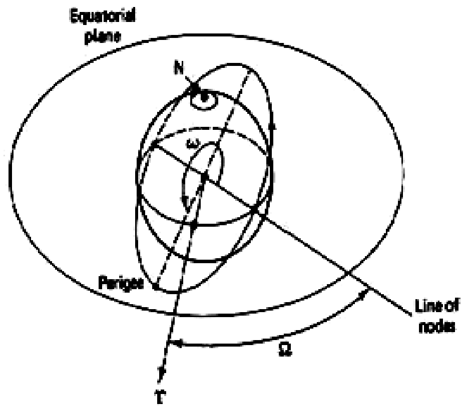

Fig Argument of Perigee 'w' and Right Ascension of the Ascending Node

Orbital Perturbations

An orbit described by Kepler is ideal as Earth, considered to be a perfect sphere and the force acting around the Earth is the centrifugal force. This force is supposed to balance the gravitational pull of the earth. In reality, other forces also play an important role and affect the motion of the satellite. These forces are the gravitational forces of Sun and Moon along with the atmospheric drag. The effect of Sun and Moon is more pronounced on geostationary earth satellites where as the atmospheric drag effect is more pronounced for low earth orbit satellites.

Effects of Non-Spherical Earth

As the shape of Earth is not a perfect sphere, it causes some variations in the path followed by the satellites around the primary. As the Earth is bulging from the equatorial belt, it is the forces resulting from an oblate Earth which act on the satellite produce a change in the orbital parameters. This causes the satellite to drift as a result of regression of the nodes and the latitude of the point of perigee. This leads to rotation of the line of apsides. As the orbit itself is moving with respect to the Earth, the resultant changes are seen in the values of argument of perigee and right ascension of ascending node.

Due to the non-spherical shape of Earth, one more effect called as the “Satellite Graveyard” is observed. The non-spherical shape leads to the small value of eccentricity at the equatorial plane. This causes a gravity gradient on GEO satellite and makes them drift to one of the two stable points which coincide with minor axis of the equatorial ellipse.

Atmospheric Drag

For Low Earth orbiting satellites, the effect of atmospheric drag is more pronouncing. The impact of this drag is maximum at the point of perigee. The drag (pull towards the Earth) has an effect on velocity of Satellite. This causes the satellite not to reach the apogee height successive revolutions. This leads to a change in value of semi-major axis and eccentricity. Satellites in service are maneuvered by the earth station back to their original orbital position.

Station Keeping

In addition to having its attitude controlled, it is important that a geo-stationary satellite be kept in its correct orbital slot. The equatorial ellipticity of the earth causes geostationary satellites to drift slowly along the orbit, to one of two stable points, at 75°E and 105°W. To counter this drift, an oppositely directed velocity component is imparted to the satellite by means of jets, which are pulsed once every 2 or 3 weeks. These maneuvers are called as *east-west station-keeping maneuvers*.

Satellites in the 6/4-GHz band must be kept within 0.1° of the designated longitude and in the 14/12-GHz band, within 0.05°.

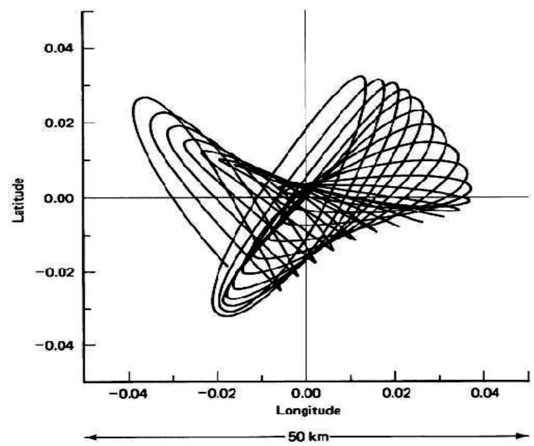

Fig 1.5 Typical Satellite Motion

Geo stationary and Non Geo-stationary orbits

Geo stationary Orbit

A **geostationary** orbit is one in which a satellite orbits the earth at exactly the same speed as the earth turns and at the same latitude, specifically zero, the latitude of the equator. A satellite orbiting in a geostationary orbit appears to be hovering in the same spot in the sky, and is directly over the same patch of ground at all times.

A **geosynchronous** orbit is one in which the satellite is synchronized with the earth's rotation, but the orbit is tilted with respect to the plane of the equator. A satellite in a geosynchronous orbit will wander up and down in latitude, although it will stay over the same line of longitude. A geostationary orbit is a subset of all possible geosynchronous orbits.

The person most widely credited with developing the concept of geostationary orbits is noted science fiction author Arthur C. Clarke (Islands in the Sky, Childhood's End, Rendezvous with Rama, and the movie 2001: a Space Odyssey). Others had earlier pointed out that bodies traveling a certain distance above the earth on the equatorial plane would remain motionless with respect to the earth's surface. But Clarke published an article in 1945's Wireless World that made the leap from the Germans' rocket research to suggest permanent manmade satellites that could serve as communication relays.

Geostationary objects in orbit must be at a certain distance above the earth; any closer and the orbit would decay, and farther out they would escape the earth's gravity altogether. This distance is 35,786 kilometers from the surface. The first geo-synchrous satellite was orbited in 1963, and the first geostationary one the following year. Since the only geostationary orbit is in a plane with the equator at 35,786 kilometers, there is only one circle around the world where these conditions obtain.

This means that geostationary 'real estate' is finite. While satellites are in no danger of bumping in to one another yet, they must be spaced around the circle so that their frequencies do not interfere with the functioning of their nearest neighbors.

Geostationary Satellites

There are 2 kinds of manmade satellites - One kind of satellite ORBITS the earth once or twice a day and the other kind is called a communications satellite and it is PARKED in a STATIONARY position 35,900 km above the equator of the STATIONARY earth. A type of the orbiting satellite includes the space shuttle and the international space station which keep a low earth orbit (LEO) to avoid the Van Allen radiation belts.

The most prominent satellites in medium earth orbit (MEO) are the satellites which comprise the GLOBAL POSITIONING SYSTEM (GPS).

Global Positioning System

The global positioning system was developed by the U.S. military and then opened to civilian use. It is used today to track planes, ships, trains, cars or anything that moves. Anyone can buy a receiver and track their exact location by using a GPS receiver.

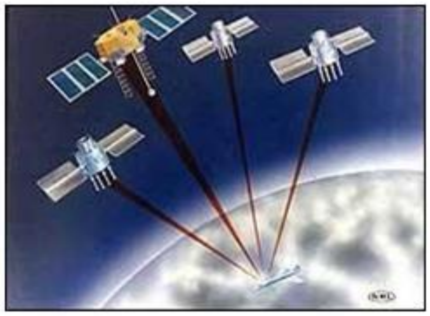

Fig 1.6 GPS satellites orbit at a height of about 19,300 km and orbit the earth once every 12 hours

These satellites are traveling around the earth at speeds of about 7,000 mph. GPS satellites are powered by solar energy. They have backup batteries onboard to keep them running when there's no solar power. Small rocket boosters on each satellite keep them flying in the correct path. The satellites have a lifetime of about 10 years until all their fuel runs out.

At exactly 35,900 km above the equator, the force of gravity is cancelled by the centrifugal force of the rotating universe. This is the ideal spot to park a stationary satellite.

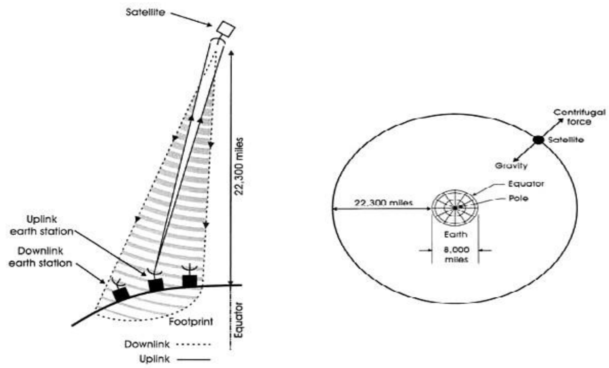

Fig At exactly 35,900 km above the equator, the earth's force of gravity is canceled by the centrifugal force of the rotating universe

Non Geo-Stationary Orbit

For the geo-stationary case, the most important of these are the gravitational fields of the moon and the sun and the non-spherical shape of the earth. Other significant forces are solar radiation pressure and reaction of the satellite to motor movement within the satellite. As a result, station- keeping maneuvers must be carried out to maintain the satellite within limits of its nominal geostationary position.

An exact geostationary orbit is not attainable in practice, and the orbital parameters vary with time. The two-line orbital elements are published at regular intervals. The period for a geostationary satellite is 23 h, 56 min, 4 s, or 86,164 s. The reciprocal of this is 1.00273896 rev/day, which is about the value tabulated for most of the satellites as in Figure 1.7. Thus these satellites are *geo-synchronous,* in that they rotate in synchronism with the rotation of the earth. However, they are not geostationary. The term *geosynchronous satellite* is used in many cases instead of *geostationary* to describe these near-geostationary satellites.

In general a geosynchronous satellite does not have to be near-geostationary, and there are a number of geosynchronous satellites that are in highly elliptical orbits with comparatively large inclinations. The small inclination makes it difficult to locate the position of the ascending node, and the small eccentricity makes it difficult to locate the position of the perigee. However, because of small inclination, the angles *w* and Ω can be assumed to be in the same plane. The longitude of the sub-satellite point is the east early rotation from the Greenwich meridian.

$$\phi_{SS} = \omega + \Omega + v - \mathrm{GST}$$

The *Greenwich sidereal time* (GST) gives the eastward position of the Greenwich meridian relative to the line of Aries, and hence the sub-satellite point is at longitudeand the mean longitude of the satellite is given by

$$\phi_{SSmean} = \omega + \Omega + M - \mathrm{GST}$$

The above equation can be used to calculate the true anomaly and because of the small eccentricity, this can be approximated as $v = M + 2e\sin M$.

Look Angle Determination

The look angles for the ground station antenna are Azimuth and Elevation angles. They are required at the antenna so that it points directly at the satellite. Look angles are calculated by considering the elliptical orbit. These angles change in order to track the satellite. For geostationary orbit, these angle values do not change as the satellites are stationary with respect to earth. Thus large earth stations are used for commercial communications.

For home antennas, antenna beam-width is quite broad and hence no tracking is essential.

This leads to a fixed position for these antennas.

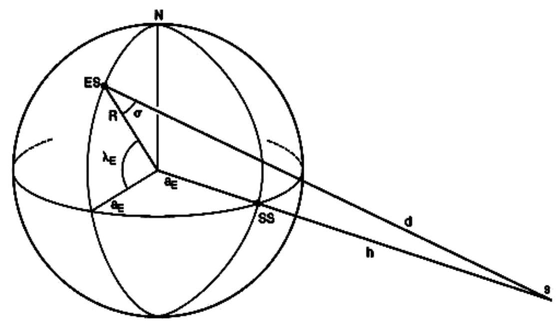

Fig Geometry used in determining the look angles for Geostationary Satellites

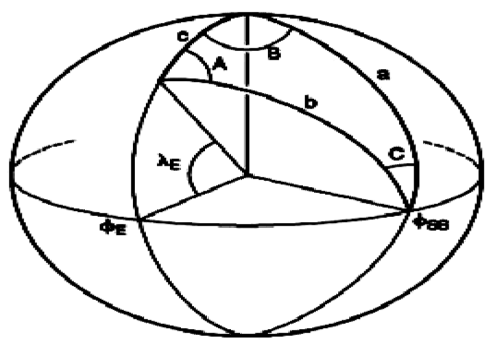

Fig Spherical Geometry related to Figure

With respect to the figure 1.8 and 1.9, the following information is needed to determine the look angles of geostationary orbit.

- Earth Station Latitude: λE
- Earth Station Longitude: ΦE
- Sub-Satellite Point's Longitude: ΦSS
- ES: Position of Earth Station
- SS: Sub-Satellite Point
- S: Satellite
- d: Range from ES to S
- ζ: angle to be determined

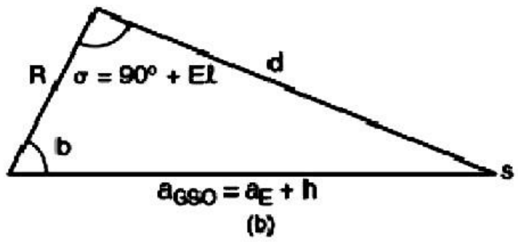

Fig Plane triangle obtained from Figure

Considering Figure , it's a spherical triangle. All sides are the arcs of a great circle. Three sides of this triangle are defined by the angles subtended by the centre of the earth.

- Side a: angle between North Pole and radius of the sub-satellite point.
- Side b: angle between radius of Earth and radius of the sub-satellite point.
- Side c: angle between radius of Earth and the North Pole.
- a $=90^0$ and such a spherical triangle is called quadrantal triangle. c = $90^0 - \lambda$
- Angle B is the angle between the plane containing c and the plane containing a.

Thus, B = ΦE-ΦSS

- Angle A is the angle between the plane containing b and the plane containing c.
- Angle C is the angle between the plane containing a and the plane containing b.

Thus, a = 90^0 c = 90^0 - λE B = ΦE-ΦSS

Thus, b = arcos (cos B cos λE)

And A = arcsin (sin |B| / sin b)

Applying the cosine rule for plane triangle to the triangle of F i g u r e,

$$d = \sqrt{R^2 + a_{GSO}{}^2 - 2Ra_{GSO} \cos b}$$

Applying the sine rule for plane triangles to the triangle of Figure, allows the angle of elevation to be found:

$$El = \arccos\left(\frac{a_{GSO}}{d} \sin b\right)$$

Limits of Visibility

The east and west limits of geostationary are visible from any given Earth station. These limits are set by the geographic coordinates of the Earth station and antenna elevation. The lowest elevation is zero but in practice, to avoid reception of excess noise from Earth. Some finite minimum value of elevation is issued. The earth station can see a satellite over a geostationary arc bounded by **+- (81.30)** about the earth station's longitude.