Subject Name- Satellite Communication **Subject Code**: EC 7002

Unit-I

Overview of satellite systems: Introduction, Frequency allocations for satellite systems. Orbits and launching methods: Kepler's three laws of planetary motion, terms used for earth orbiting satellites, orbital elements, apogee and perigee heights, orbit perturbations, inclined orbits, local mean solar point and sun-synchronous orbits, standard time.

Overview of satellite systems

Introduction

The use of satellites in communications systems is very much a fact of everyday life, as is evidenced by the many homes equipped with antennas, or "dishes," used for reception of satellite television. Satellites form an essential part of telecommunications systems worldwide, carrying large amounts of data and telephone traffic in addition to television signals.

In 1962, the American telecommunications giant AT&T launched the world's first true communications satellite, called Telstar. Since then, countless communications satellites have been placed into earth orbit, and the technology being applied to them is forever growing in sophistication.

Satellites offer a number of features not readily available with other means of communications. Because very large areas of the earth are visible from a satellite, the satellite can form the star point of a communications net, simultaneously linking many users who may be widely separated geographically. The same feature enables satellites to provide communications links to remote communities in sparsely populated areas that are difficult to access by other means. Of course, satellite signals ignore political boundaries as well as geographic ones, which may or may not be a desirable feature.

Satellites are also used for remote sensing, examples being the detection of water pollution and the monitoring and reporting of weather conditions. Some of these remote sensing satellites also form a vital link in search and rescue operations for downed aircraft and the like.

To provide a general overview of satellite systems here, three different types of applications are briefly described in this chapter:

1. the largest international system, Intelsat,
2. the domestic satellite system in the United States, Domsat, and
3. U.S. National Oceanographic and Atmospheric Administration (NOAA) series of polar orbiting satellites used for environmental monitoring and search and rescue.

General Structure of Satellite Communication System:

It is simply the communication of the satellite in space with large number of earth stations on the ground. Users are the ones who generate baseband signals, which is processed at the earth station and then transmitted to the satellite through dish antennas. Now the user is connected to the earth station via some telephone switch or some dedicated link. The satellite receives the uplink frequency and the transponder present inside the satellite does the processing function and frequency down conversion in order to transmit the downlink signal at different frequency. The earth station then receives the signal from the satellite through parabolic dish antenna and processes it to get back the baseband signal.

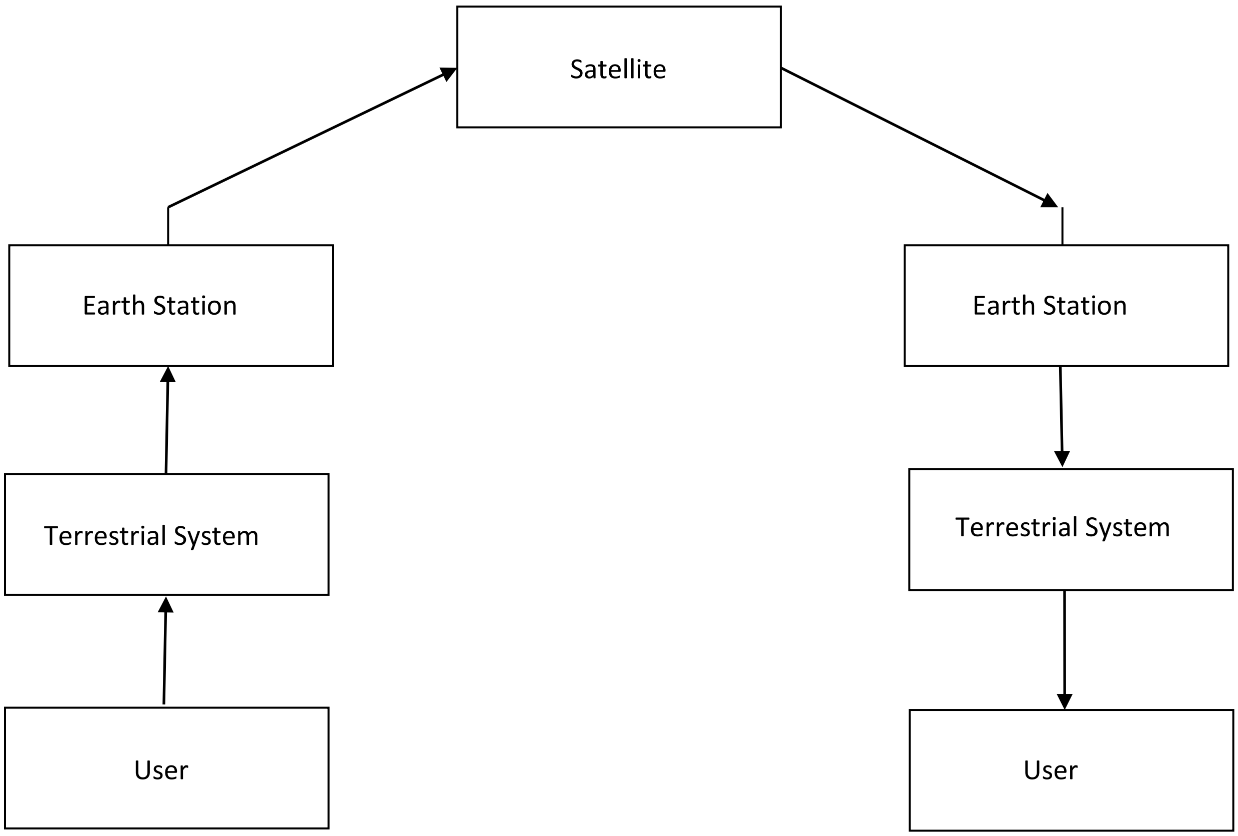


Figure No. 1 – Block diagram of Satellite Communication System

This baseband signal is then transmitted to the respective user via dedicated link or other terrestrial system. Previously satellite communication system used large sized parabolic antennas with diameters around 30 meters because of the very faint and weak signals received. But nowadays satellites have become much stronger, powerful due to which antennas used have become automatically smaller in size. Thus the earth station antennas are now not large in size as the antennas used in olden days.

Earth Station Designing of an Earth station depends not only on the location of earth station but also on some other factors. The location of earth stations could be on land, on ships in sea and on aircraft. The depending factors are type of service providing, frequency bands utilization, transmitter, and receiver and antenna characteristics. We can easily understand the working of earth station from above figure. There are four major **subsystems** that are present in any earth station. Those are transmitter, receiver, antenna and tracking subsystem.

Transmitter- The binary (digital) information enters at base band equipment of earth station from terrestrial network. Encoder includes error correction bits in order to minimize the bit error rate.

In satellite communication, the Intermediate Frequency **(IF)** can be chosen as 70 MHz by using a transponder having bandwidth of 36 MHz. Similarly, the IF can also be chosen as 140 MHz by using a transponder having bandwidth of either 54 MHz or 72 MHz. This signal will be amplified by using High power amplifier. Up converters perform the frequency conversion of modulated signal to higher frequency, there after earth station antenna transmits this signal for Satellite.

Receiver- During reception, the earth station antenna receives downlink signal. This is a low-level modulated RF signal. In general, the received signal will be having less signal strength. So, in order to amplify this signal, Low Noise Amplifier (LNA) is used. Due to this, there is an improvement in Signal to Noise Ratio (SNR) value. RF signal can be down converted to the Intermediate Frequency (IF) value, which is either 70 or 140 MHz. Because, it is easy to demodulate at these intermediate frequencies. The function of the decoder is just opposite to that of encoder. So, the decoder produces error free binary information by removing error correction bits and correcting the bit positions if any. This binary information is given to base band equipment for further processing and then delivers to terrestrial network.

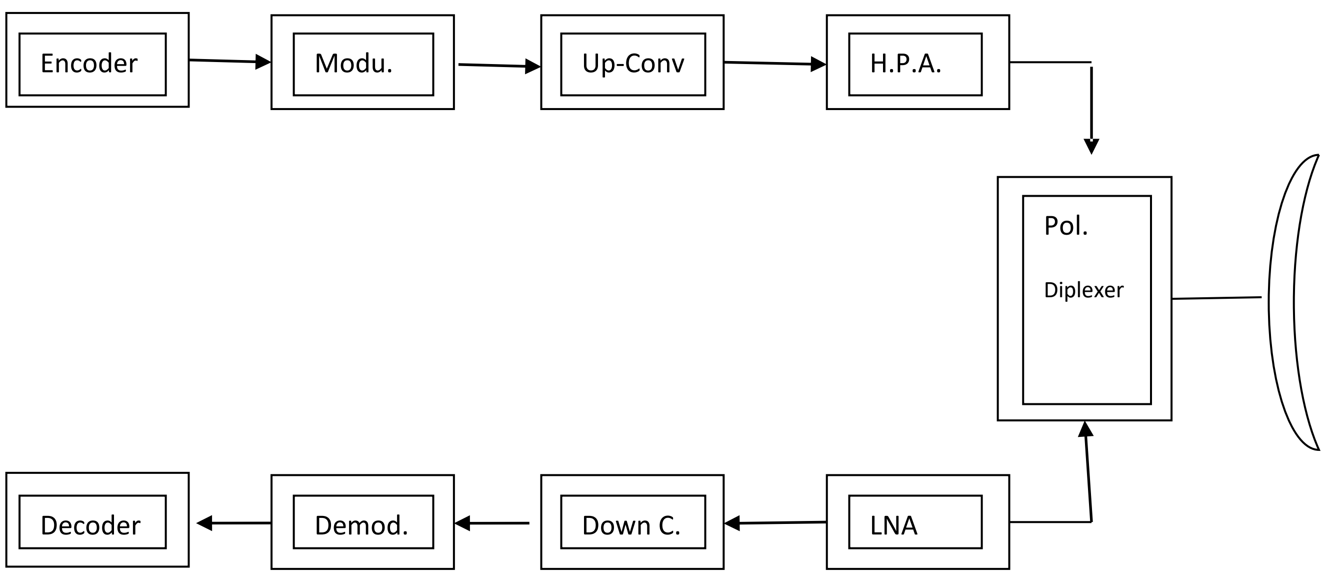


Figure No. 2 – Block diagram of an Earth Station

Now a days the spacing allowed between two adjacent satellites in space is 2^0 along the equatorial arc instead of 4^0. The closer spacing has allowed twice as many satellites to occupy the same orbital arc and therefore now all the earth station antennas are designed to accommodate this spacing of 2^0.

Frequency Allocations for Satellite Services - Allocating frequencies to satellite services is a complicated process which requires international coordination and planning. This is carried out under the auspices of the International Telecommunication Union (ITU).

To facilitate frequency planning, the world is divided into three regions:

Region 1: Europe, Africa, what was formerly the Soviet Union, and Mongolia

Region 2: North and South America and Greenland

Region 3: Asia (excluding region 1 areas), Australia, and the southwest Pacific

Within these regions, frequency bands are allocated to various satellite services, although a given service may be allocated different frequency bands in different regions. Some of the services provided by satellites are:-

1. Fixed satellite service (FSS):- the FSS provides links for existing telephone networks as well as for transmitting television signals to cable companies for distribution over cable systems.
2. Broadcasting satellite service (BSS):- Broadcasting satellite services are intended mainly for direct broadcast to the home, sometimes referred to as direct broadcast satellite (DBS) service [in Europe it may be known as direct-to-home (DTH) service].
3. Mobile satellite services:-Mobile satellite services would include land mobile, maritime mobile, and aeronautical mobile.
4. Navigational satellite service: Navigational satellite services include global positioning systems (GPS)
5. Meteorological satellite services: satellites intended for the meteorological services often provide a search and rescue service.

Satellite communication systems started in C band, with an allocation of 500 MHz shared with terrestrial microwave links. As the GEO orbit filled up with satellites operating at C band, satellites were built for the next available frequency band, Ku band. There is a continuing demand for ever more spectrums to allow satellites to provide new services, with high speed access to the Internet forcing a move to ka band and even higher frequencies.

Table No. 1

Band	Downward bands MHz	Uplink Bands MHz
Uhf- Military	250-270 (Approx)	292-312
C Band-Commercial	3700-4200	5925-6425
X Band-Military	7250-7750	7900-8400
Ku Band-Commercial	11700-12200	14000-14500
Ka Band-Commercial	17700-21200	27500-30000
Ka Band-Military	20200-21200	43500-45500

Orbits and launching methods:

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 moves 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-

$$F1 = \frac{\mathrm{GMm}}{R^2}$$

Where G is Universal Gravitational constant G= 6.673×10^{-11} N-m^2/Kg^2.

M mass of the earth, M= 5.98×10^{24} Kg, m is the mass of the satellite; R is the distance of satellite from center of the Earth.

The satellite when it revolves around the earth, it undergoes a pulling force from the sun and the moon due to their gravitational force. This force is known as Centrifugal force, because this force tends the satellite away from the earth. Mathematically we can write as –

$$F_2 \quad = \frac{mv^2}{R}$$

Where, v is the orbital velocity of satellite.

Orbital Velocity – Orbital velocity is the velocity at which, revolves around the earth. Satellite doesn't deviates from its orbit and moves with certain velocity in that orbit, when both Centripetal and Centrifugal forces balanced each other.

So on balancing both the forces, we can write-

Centripetal force = Centrifugal force

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

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

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

Kepler's First Law

Kepler's first law states that the path followed by a satellite around the primary will be an ellipse. An ellipse has two focal points shown as F_1 and F_2 in below figure. The center of mass of the two-body system, termed the barycenter, is always centered on one of the foci. In our specific case, because of the enormous difference between the masses of the earth and the satellite, the center of mass coincides with the center of the earth, which is therefore always at one of the foci. The semi major axis of the ellipse is denoted by a, and the semi minor axis, by b. The eccentricity e is given by

$$e = \frac{\sqrt{a^2 - b^2}}{a}$$

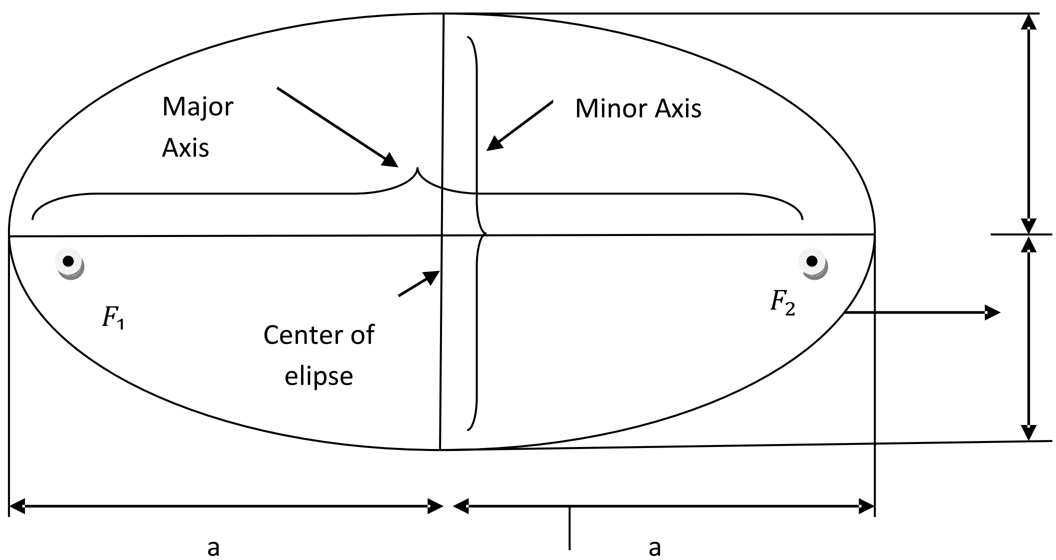


Figure No. 3 – The foci F_1 and F_2, the semi major axis a; and the semi minor axis b of an ellipse.

The eccentricity and the semi major axis are two of the orbital parameters specified for satellites (space craft) orbiting the earth.

For an elliptical orbit, $0 < e < 1$

When $e < 0$, the orbit becomes circular.

The geometrical significance of eccentricity, along with some of the other geometrical properties of the ellipse, is developed in App. B.

Kepler's Second Law

Kepler's second law states that, for equal time intervals, a satellite will sweep out equal areas in its orbital plane, focused at the barycenter . Referring to below figure, assuming the satellite travels distances S_1 andS_2 meters in 1 s, then the areas A_1 and A_2 will be equal. The average velocity in each case is S_1 and S_2 m/s, and because of the equal area law, it follows that the velocity at S_2 is less than that at S_1. An important consequence of this is that the satellite takes longer to travel a given distance when it is farther away from earth. Use is made of this property to increase the length of time a satellite can be seen from particular geographic regions of the earth.

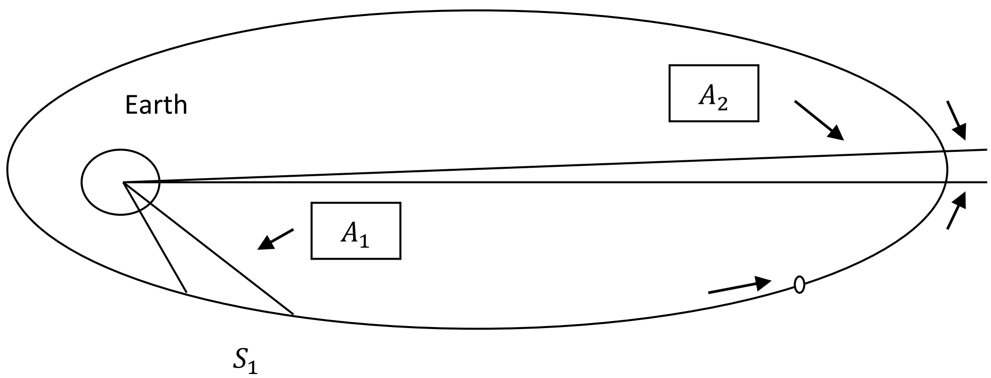


Figure No. 4 – Kepler's second law. The areas A_1 and A_2 swept out in unit time are equal.

Kepler's Third Law

Kepler's third law states that the square of the periodic time of orbit is proportional to the cube of the mean distance between the two bodies. The mean distance is equal to the semi major axis a. For the artificial satellites orbiting the earth, Kepler's third law can be written in the form

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

where n is the mean motion of the satellite in radians per second and μ is the earth's geocentric gravitational constant. Its value is

$$\mu = 3.986055 \times 10^{14}\, m^2/s^2$$

Equation applies only to the ideal situation of a satellite orbiting a perfectly spherical earth of uniform mass, with no perturbing forces acting, such as atmospheric drag. Later, the effects of the earth's and atmospheric drag will be taken into account. With n in radians per second, the orbital period in seconds is given by

$$P = \frac{2\pi}{n}$$

The importance of Kepler's third law is that it shows there is a fixed relationship between period and semi-major axis. One very important orbit in particular, known as the geostationary orbit, is determined by the rotational period of the earth.

Definitions of Terms for Earth-Orbiting Satellites

Sub-satellite path: This is the path traced out on the earth's surface directly below the satellite.

Apogee: The point farthest from earth.

Perigee: The point of closest approach to earth.

Line of Apsides: The line joining the perigee and apogee through the center of the earth.

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

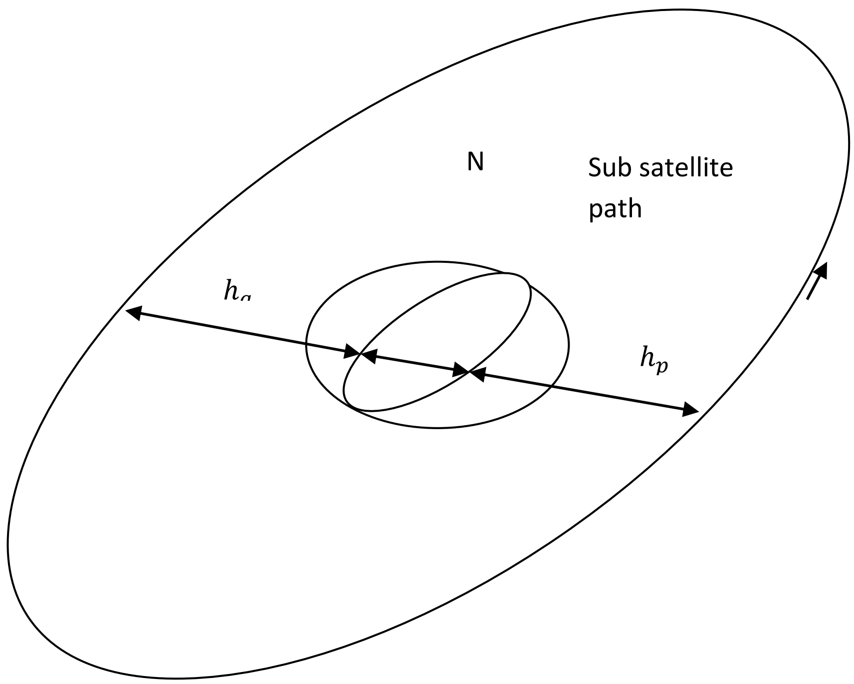


Figure No. 5 – Apogee height h_a and perigee height h_b

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

Line of nodes. The line joining the ascending and descending nodes through the center of the earth.

Inclination: The angle between the orbital plane and the earth's equatorial plane. It is measured at the ascending node from the equator to the orbit, going from east to north. It will be seen that the greatest latitude, north or south, reached by the sub-satellite path is equal to the inclination.

Prograde orbit: An orbit in which the satellite moves in the same direction as the earth's rotation. The prograde orbit is also known as a direct orbit. The inclination of a prograde orbit always lies between 0º and 90º. Most satellites are launched in a prograde orbit because the earth's rotational velocity provides part of the orbital velocity with a consequent saving in launch energy.

Retrograde orbit: An orbit in which the satellite moves in a direction counter to the earth's rotation. The inclination of a retrograde orbit always lies between 90ºand 180º.

True anomaly: The true anomaly is the angle from perigee to the satellite position, measured at the earth's center. This gives the true angular position of the satellite in the orbit as a function of time.

Orbital Elements

Orbital elements are the parameters, which are helpful for defining the orbital motion of satellites. Orbital elements are as follows -

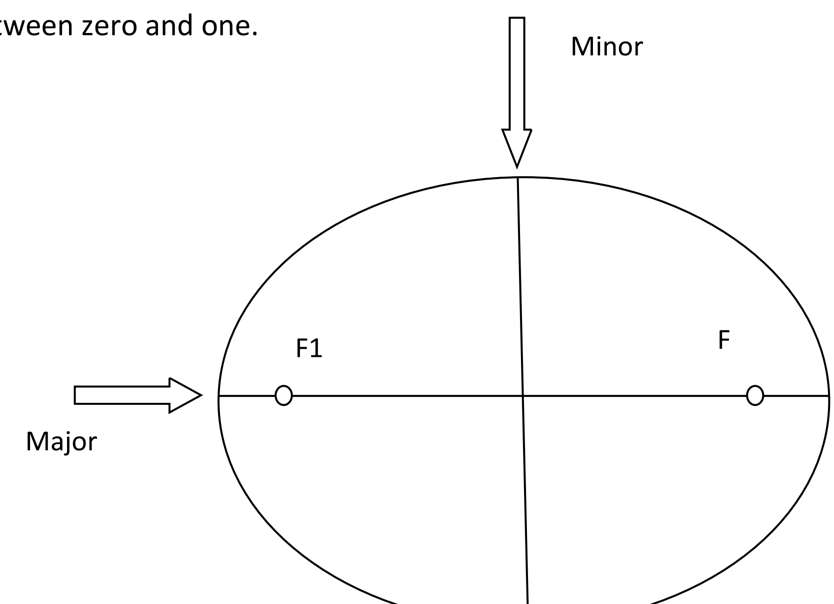
- Semi major axis
- Eccentricity
- Mean anomaly
- Argument of perigee
- Inclination
- Right ascension of ascending node

The above six orbital elements define the orbit of earth satellites. Therefore, it is easy to differentiate one satellite from other satellites based on the values of orbital elements.

- **Semi major axis -** The length of Semi-major axis (a) defines the size of satellite's orbit. It is half of the major axis. This runs from the center through a focus to the edge of the ellipse. So, it is the radius of an orbit at the orbit's two most distant points. Both semi major axis and semi minor axis are represented in figure. Length of semi **major axis (a)** not only determines the size of satellite's orbit, but also the time period of revolution. If circular orbit is considered as a special case, then the length of semi-major axis will be equal to **radius** of that circular orbit.
- **Eccentricity -** The value of **Eccentricity (e)** fixes the shape of satellite's orbit. This parameter indicates the deviation of the orbit's shape from a perfect circle. If the lengths of semi major axis and semi minor axis of an elliptical orbit are **a & b**, then the mathematical expression for **eccentricity (e)** will be-

$$e = \frac{\sqrt{a^2 - b^2}}{a}$$

The value of a circular orbit is Zero, sice both **a & b** are equal. Whereas, the value of eccentricity of an elliptical orbit lies between zero and one.



- **Mean Anomaly -** For a satellite, the point which is closest from the Earth is known as Perigee. Mean anomaly (M) gives the average value of the angular position of the satellite with reference to perigee. If the orbit is circular, then Mean anomaly gives the angular position of the satellite in the orbit. But, if the orbit is elliptical, then calculation of exact position is very difficult. At that time, Mean anomaly is used as an intermediate step.
- **Argument of Perigee-** Satellite orbit cuts the equatorial plane at two points. First point is called as descending node, where the satellite passes from the northern hemisphere to the southern hemisphere. Second point is called as ascending node, where the satellite passes from the southern hemisphere to the northern hemisphere.

  Argument of perigee (ω) is the angle between ascending node and perigee. If both perigee and ascending node are existing at same point, then the argument of perigee will be zero degrees. Argument of perigee is measured in the orbital plane at earth's center in the direction of satellite motion.
- **Inclination -** The angle of inclination can be defined as "angle between orbital plane and earth's equatorial plane". It is measured at the ascending node with direction being east to north. So, inclination can defines as the orientation of the orbit by considering the equator of earth as reference.
- **Right Ascension of Ascending node - Ascending node** is the point, where the satellite intersect the equatorial plane while moving from the southern hemisphere to the northern hemisphere.

  Right Ascension of ascending node **(Ω)** is the angle between "line of Aries and ascending node towards east direction in equatorial plane". Satellite's **ground rack** is the path on the surface of the Earth, which lies exactly below its orbit. The ground track of a satellite can take a number of different forms depending on the values of the orbital elements.

Apogee and Perigee Heights

Although not specified as orbital elements, the apogee height and perigee height are often required.

The length of the radius vectors at apogee and perigee can be obtained from the geometry of the ellipse:

$$r_a = a(1+e)$$

$$r_p = a(1-e)$$

In order to find the apogee and perigee heights, the radius of the earth must be subtracted from the radii lengths as shown in below figure.

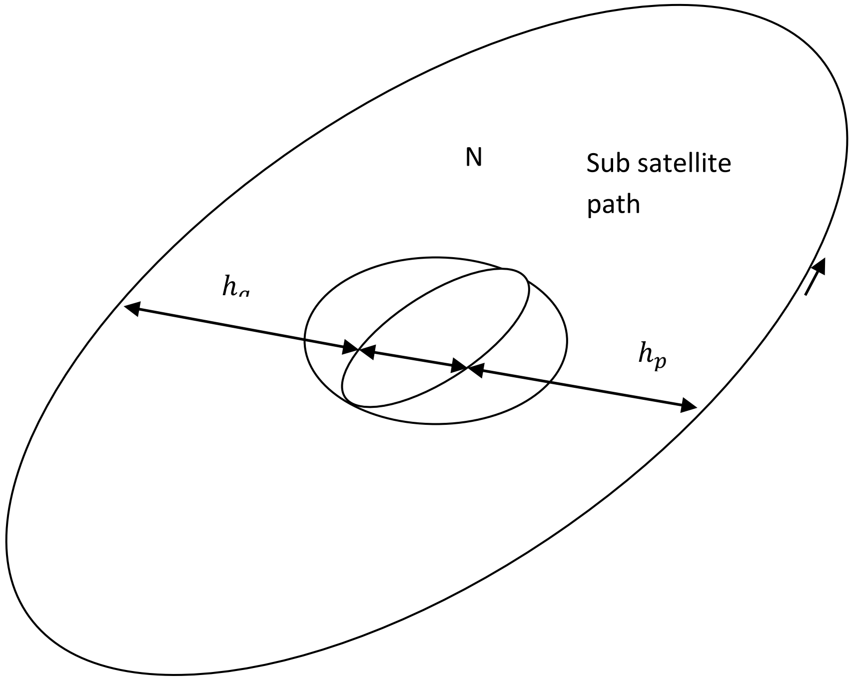


Figure No. 6 – Apogee height $h_{a,}$ perigee height h_b

Orbit Perturbations

The Keplerian orbit described so far is ideal in the sense that it assumes that the earth is a uniform spherical mass and that the only force acting is the centrifugal force resulting from satellite motion balancing the gravitational pull of the earth. In practice, other forces which can be significant are the gravitational forces of the sun and the moon and atmospheric drag. The gravitational pulls of sun and moon have negligible effect on low-orbiting satellites, but they do affect satellites in the geostationary orbit. Atmospheric drag, on the other hand, has negligible effect on geostationary satellites but does affect low orbiting earth satellites below about 1000 km. Following are the Orbital Perturbations due to gravitational & Non gravitational force or parameters

1. The irregular gravitational force around the Earth due to non-uniform distribution of mass. Earth's magnetic field too causes orbital perturbations.
2. Main external perturbations come from Sun and Moon. When a satellite is near to these external bodies, it receives a stronger gravitational pull.
3. Due to friction caused by collision with atoms and ions Low-orbit satellites get affected.
4.

Inclined Orbits

A study of the general situation of a satellite in an inclined elliptical orbit is complicated by the fact that different parameters relate to different reference frames. The orbital elements are known with reference to the plane of the orbit, the position of which is fixed (or slowly varying) in space, while the location of the earth station is usually given in terms of the local geographic coordinates which rotate with the earth. Rectangular coordinate systems are generally used in calculations of satellite position and velocity in space, while the earth station quantities of interest may be the azimuth and elevation angles and range. Transformations between coordinate systems are therefore required. Here, in order to illustrate the method of calculation for elliptical inclined orbits, the problem of finding the earth station look angles and range will be considered. It should be kept in mind that with inclined orbits the satellites are not geostationary, and therefore, the required look angles and range will change with time.

Determination of the look angles and range involves the following quantities and concepts:

1. Various measures of time

2. The peri-focal coordinate system, which is based on the orbital plane.

3. The geocentric-equatorial coordinate system, which is based on the earth's equatorial plane.

The two major coordinate transformations needed are:

1. The satellite position measured in the peri-focal system is transformed to the geocentric-horizon system in which the earth's rotation is measured, thus enabling the satellite position and the earth station location to be coordinated.

2. The satellite-to-earth station position vector is transformed to the topo-centric-horizon system, which enables the look angles and range to be calculated.

Local Mean Solar Time and Sun-Synchronous Orbits

The celestial sphere is an imaginary sphere of infinite radius, where the points on the surface of the sphere represent stars or other celestial objects. The points represent directions, and distance has no significance for the sphere. The orientation and center of the sphere can be selected to suit the conditions being studied, and below figure the sphere is centered on the geocentric-equatorial coordinate system.

What this means is that the celestial equatorial plane coincides with the earth's equatorial plane, and the direction of the north celestial pole coincides with the earth's polar axis. The angular distance along the celestial equator, measured eastward from the point of Aries to the sun's meridian is the right ascension of the sun, denoted by α_s. In general, the right ascension of a point P, is the angle, measured eastward along the celestial equator from the point of Aries to the meridian passing through P. This is shown as α_p. The hour angle of a star is the angle measured westward along the celestial equator from the meridian to meridian of the star. Thus for point P the hour angle of the sun is $(\alpha_p - \alpha_s)$ measured westward (the hour angle is measured in the opposite direction to the right ascension).

Now the apparent solar time of point P is the local hour angle of the sun, expressed in hours, plus 12hour. The 12 hour is added because zero hour angle corresponds to midday, when the P meridian coincides with the sun's meridian. Because the earth's path around the sun is elliptical rather than circular, and also because the plane containing the path of the earth's orbit around the sun (the ecliptic plane) is inclined at an angle of approximately 23.44^0 the apparent solar time does not measure out uniform intervals along the celestial equator, in other words, the length of a solar day depends on the position of the earth relative to the sun. To overcome this difficulty a fictitious mean sun is introduced, which travels in uniform circular motion around the sun (this is similar in many ways to the mean anomaly). The time determined in this way is the mean solar time. Tables are available in various almanacs which give the relationship between mean solar time and apparent solar time through the equation of time.

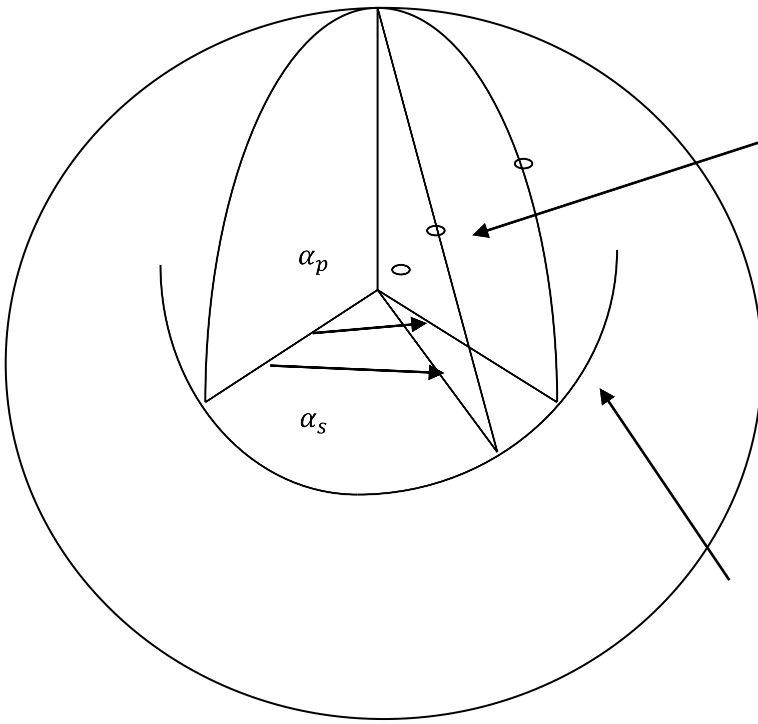


Figure No. 7 – Apogee height $h_{a,}$ perigee height h_b

Standard Time

Local mean time is not suitable for civil time–keeping purposes because it changes with longitude (and latitude), which would make it difficult to order day-to-day affairs. The approach taken internationally is to divide the world into 1-hour time zones, the zonal meridians being 15^0 apart at the equator. The Greenwich meridian is used as zero reference and in the time zone that is $\pm 7.5^0$ about the Greenwich meridian the civil time is the same as the GMT. Care must be taken, however, since in the spring the clocks are advanced by 1 hour, leading to British summer time (BST), also known as daylight saving time. Thus BST is equal to GMT plus 1 hour. In the first zone east of the GMT zone, the basic civil time is GMT + 1 hour, and in the first zone west of the GMT zone, the basic civil time is GMT−1 hour. One hour is added or subtracted for each additional zone east or west. Again, care must be taken to allow for summer time if it is in force (not all regions have the same summer time adjustment, and some regions may not use it at all). Also, in some instances the zonal meridians are adjusted where necessary to suit regional or country boundaries. Orbital elements are normally specified in relation to GMT (or as noted in UTC), but results (such as times of equatorial crossings) usually need to be known in the standard time for the zone where observations are being made. Care must be taken therefore to allow for the zone change, and for daylight saving time if in force.

Universal time

Universal time coordinated (UTC) is the time used for all civil time–keeping purposes, and it is the time reference which is broadcast by the National Bureau of Standards as a standard for setting clocks. It is based on an atomic time-frequency standard. The fundamental unit for UTC is the mean solar day. In terms of “clock time,” the mean solar day is divided into 24 hour, an hour into 60 min, and a minute into 60 s. Thus there are 86,400 “clock seconds” in a mean solar day. Satellite-orbit epoch time is given in terms of UTC.