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Chapter 1

INTRODUCTION

1.1 The birth of satellite communications

Satellite communications are the outcome of research in the area of communications and space technologies whose objective is to achieve ever increasing ranges and capacities with the lowest possible costs. The Second World War stimulated the expansion of two very distinct technologies—missiles and microwaves. The expertise eventually gained in the combined use of these two techniques opened up the era of satellite communications. The service provided in this way usefully complements that previously provided exclusively by terrestrial networks using radio and cables. The space era started in 1957 with the launching of the first artificial satellite (Sputnik). Subsequent years have been marked by various experiments including the following: Christmas greetings from President Eisenhower broadcast by SCORE (1958), the reflecting satellite ECHO (1960), store-and-forward transmission by the COURIER satellite (1960), powered relay satellites (TELSTAR and RELAY in 1962) and the first geostationary satellite SYNCOM (1963). In 1965, the first commercial geostationary satellite INTELSAT I (or Early Bird) inaugurated the long series of INTELSATs; in the same year, the first Soviet communications satellite of the MOLNYA series was launched.

1.1.1 Satellite

Satellite can be defined as a heavy object which goes around another object in space due to the effect of mutual gravitational forces. the path followed by the orbiting body may be as per the (kepler's law of orbiting bodies) , and the kepler's law is defined the path followed by the satellite of mass(m) around a primary body of mass (M) in space will be an ellipse .

1.1.2 Types of Satellite:

The satellite can be classified into two categories:

1. Active satellite
2. Passive satellite

Active satellite: are used not only for linking but also for processing and transmitting signals .this type of linkage is called bend pipe technology where frequency translation and power amplification take place .some active satellites also use regenerative technology in which modulation, demodulation, processing, frequency translation, switching, power amplification and this units that responsible is called transponder.

Passive satellite: do not have any on-board processing and are just used to link two satellite through space .these are not very useful for regular communication or sensing applications.

1.2 Satellite communication 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). Although we shall deal with the communication aspects, satellite systems are in fact used for many different services as defined by the ITU. The satellite communication services are:

• fixed satellite service (FSS)

• broadcast satellite service (BSS)

• Mobile satellite service (MSS)

Although communications clearly remains a major part of other satellite services as well.

FSS includes all of the current radiocommunication services operated via the major operators such as INTELSAT, EUTELSAT, PANAMSAT etc., and operates essentially to fixed earth stations. BSS covers the area of direct broadcasting satellites (DBS). This consists of much smaller earth stations on domestic premises together with fixed earth stations providing the uplink feeder to the satellite. MSS currently operates in the maritime mobile service (MMS), aeronautical mobile service (AMS), land mobile service (LMS) via INMARSAT, plus a number of regional operators e.g. AMSC, OPTUS etc. These services consist of earth terminals located on the mobiles as well as fixed base stations for connection back into major terrestrial networks. In addition to the previous types of Satellite communication services, there are another types of service which are:

- Earth Exploration Satellite Service (EES);
- Space Research Service (SRS);
- Space Operation Service (SOS);
- Radiodetermination Satellite Service (RSS);
- Inter-Satellite Service (ISS);
- Amateur Satellite Service (ASS).

1.3 Satellite Communication Systems

Figure 1.1 gives an overview of a satellite communication system and illustrates its interfacing with terrestrial entities. The satellite system is composed of a space segment, a control segment and a ground segment:

- **The space segment** contains one or several active and spare satellites organized into a constellation.
- **The control segment** consists of all ground facilities for the control and monitoring of the satellites, also named TTC (tracking, telemetry and command) stations, and for the management of the traffic and the associated resources on-board the satellite.

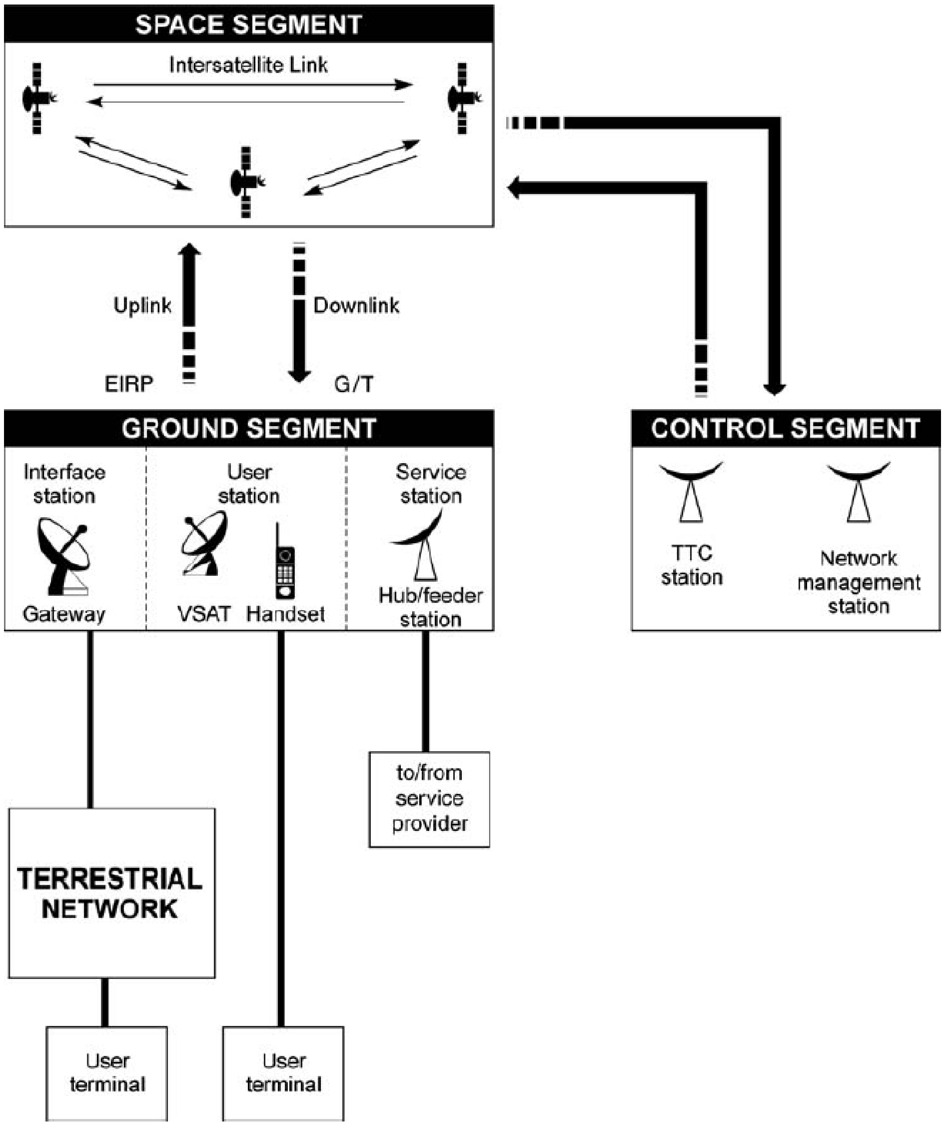

Figure 1.1 Satellite communications system, interfacing with terrestrial entities.

- **The ground segment** consists of all the traffic earth stations. Depending on the type of service considered, these stations can be of different size, from a few centimeters to tens of meters.

Earth stations come in three classes as illustrated in Figure 1.1: user stations, such as handsets, portables, mobile stations and very small aperture terminals (VSATs), which allow the customer direct access to the space segment; interface stations, known as gateways, which interconnect the space segment to a terrestrial network; and service stations, such as hub or feeder stations, which collect or distribute information from and to user stations via the space segment.

Communications between users are set up through user terminals which consist of equipment such as telephone sets, fax machines and computers that are connected to the terrestrial network or to the user stations (e.g. a VSAT), or are part of the user station (e.g. if the terminal is mobile). The path from a source user terminal to a destination user terminal is named a simplex connection. There are two basic schemes: single connection per carrier (SCPC), where the modulated carrier supports one connection only, and multiple connections per carrier (MCPC), where the modulated carrier supports several time or frequency multiplexed connections. Interactivity between two users requires a duplex connection between their respective terminals, i.e. two simplex connections, each along one direction. Each user terminal should then be capable of sending and receiving information. A connection between a service provider and a user goes through a hub (for collecting services) or a feeder station (e.g. for broadcasting services). A connection from a gateway, hub or feeder station to a user terminal is called a forward connection. The reverse connection is the return connection. Both forward and return connections entail an uplink and a downlink, and possibly one or more intersatellite links.

1.3.1 Communications links

A link between transmitting equipment and receiving equipment consists of a radio or optical modulated carrier. The performance of the transmitting equipment is measured by its effective isotropic radiated power (EIRP) which is the power fed to the antenna multiplied by the gain of the antenna in the considered direction. The performance of the receiving equipment is measured by G/T, the ratio of the antenna receive gain, G, in the considered direction and the system noise temperature, T; G/T is called the receiver's figure of merit. The types of link shown in Figure 1.1 are:

- The uplinks from the earth stations to the satellites.
- The downlinks from the satellites to the earth stations.
- The intersatellite links, between the satellites.

Uplinks and downlinks consist of radio frequency modulated carriers, while intersatellite links can be either radio frequency or optical. Carriers are modulated by baseband signals conveying information for communications purposes.

The link performance can be measured by the ratio of the received carrier power, C, to the noise power spectral density, N_0, and is denoted as the C/N_0 ratio, expressed in hertz (Hz). The values of C/N_0, for the links which participate in the connection between the end terminals, determine the quality of service, specified in terms of bit error rate (BER) for digital communications.

1.3.2 The space segment

The satellite consists of the payload and the platform. The payload consists of the receiving and transmitting antennas and all the electronic equipment which supports the transmission of the carriers. The two types of payload organization are illustrated in Figure 1.2. Figure 1.2a shows a transparent payload (sometimes called a 'bent pipe' type) where carrier power is amplified and frequency is down converted. Due to technology power limitations, the overall satellite payload bandwidth is split into several sub-bands, the carriers in each sub-band being amplified by a dedicated power amplifier. The amplifying chain associated with each sub-band is called a satellite channel, or transponder. The bandwidth splitting is achieved using a set of filters called the input multiplexer (IMUX). The amplified carriers are recombined in the output multiplexer (OMUX). The transparent payload in Figure 1.2a belongs to a single beam satellite where each transmit and receive antenna generates one beam only. The payload would then have as many inputs/outputs as upbeams/downbeams. Routing of carriers from one upbeam to a given downbeam implies either routing through different satellite channels, transponder hopping, depending on the selected uplink frequency or on-board switching with transparent on-board processing. Figure 1.2b shows a multiple beam regenerative payload where the uplink carriers are demodulated. The availability of the base band signals allows on-board processing and routing of information from upbeam to downbeam through on-board switching at base band. The frequency conversion is achieved by modulating on-board-generated carriers at downlink frequency. The modulated carriers are then amplified and delivered to the destination downbeam.

1.3.3 The ground segment

The ground segment consists of all the earth stations; these are most often connected to the end-user's terminal by a terrestrial network or, in the case of small stations (Very Small Aperture Terminal, VSAT), directly connected to the end-user's terminal. Stations are distinguished by their size which varies according to the volume of traffic to be carried on the satellite link and the type of traffic (telephone, television or data). Figure 1.3 shows the typical architecture of an earth station for both transmission and reception

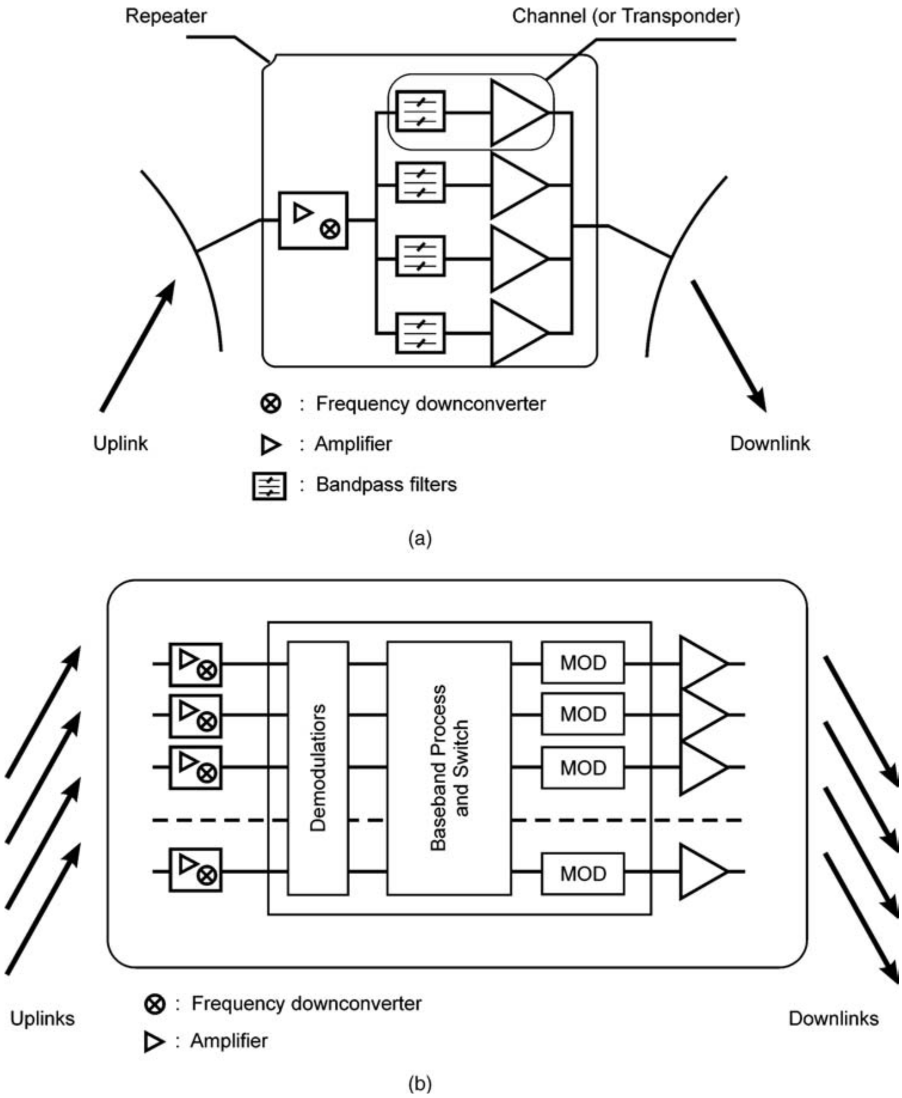

Figure 1.2 Payload organization: (a) transparent and (b) regenerative

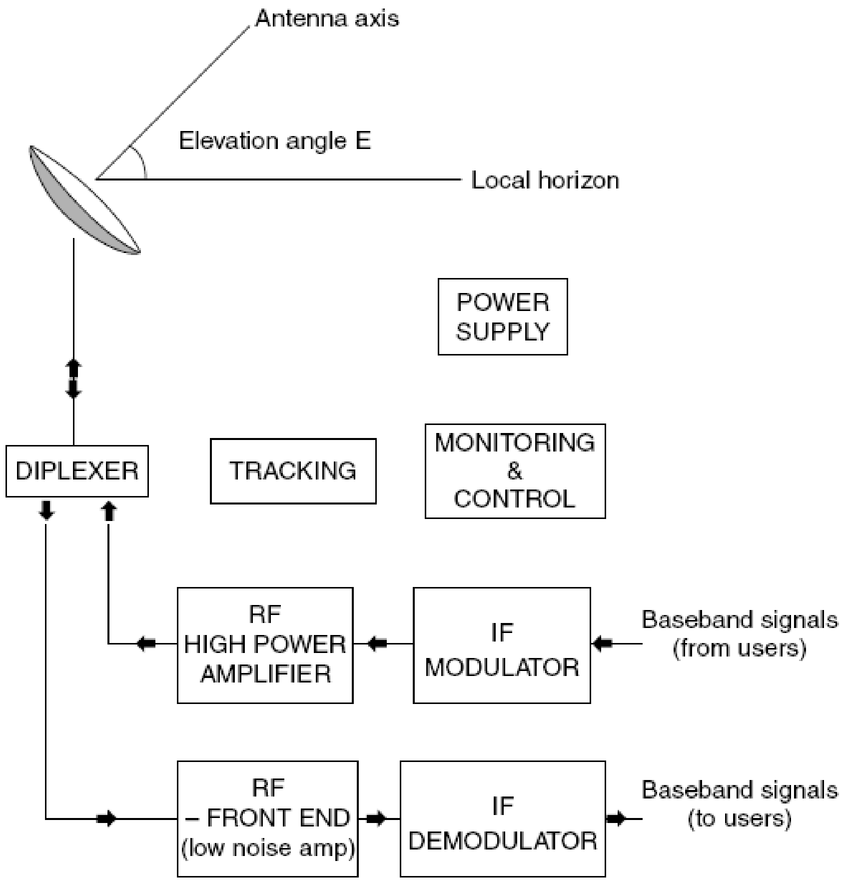

Figure 1.3 The organization of an earth station. RF= radio frequency, IF= intermediate frequency.

1.4 Types of orbits

The orbit is the trajectory followed by the satellite. The trajectory is within a plane and shaped as an ellipse with a maximum extension at the apogee and a minimum at the perigee. The satellite moves more slowly in its trajectory as the distance from the earth increases. Chapter 2 provides a definition of the orbital parameters.

The most favourable orbits are as follows:

1. Elliptical orbits inclined at an angle of 64^O with respect to the equatorial plane. This type of orbit is particularly stable with respect to irregularities in terrestrial gravitational potential and, owing to its inclination, enables the satellite to cover regions of high latitude for a large fraction of the orbital period as it passes to the apogee. The satellite remains above the regions located under the apogee for a time interval of the order of 8 hours.

Continuous coverage can be ensured with three phased satellites on different orbits.

2. Circular low earth orbits (LEO) The altitude of the satellite is constant and equal to several hundreds of kilometers. The period is of the order of one and a half hours. With near 90^O inclination, this type of orbit guarantees worldwide long term coverage as a result of the combined motion of the satellite and earth rotation. circular orbits can provide worldwide real-time communication. Non-polar orbits with less than 90^O inclination, can also be envisaged.
3. Circular medium earth orbits (MEO), also called intermediate circular orbits (ICO), have an altitude of about 10 000km and an inclination of about 50^0. The period is 6 hours. With constellations of about 10 to 15 satellites, continuous coverage of the world is guaranteed, allowing worldwide real-time communications.
4. The Geostationary Orbit, a satellite in a geostationary orbit appears to be stationary with respect to the earth, hence the name geostationary. Three conditions are required for an orbit to be geostationary:

A. The satellite must travel eastward at the same rotational speed as the earth or a satellite which moves with the same angular velocity (in the orbit path) as the revolution of earth around its axis of rotation (pitch axis) these called a geosynchronous.

B. The orbit must be circular.

C. The inclination of the orbit must be zero.

The first condition is obvious. If the satellite is to appear stationary, it must rotate at the same speed as the earth, which is constant. The second condition follows from this and from Kepler's second law. Constant speed means that equal areas must be swept out in equal times, and this can only occur with a circular orbit. The third condition, that the inclination must be zero, follows from the fact that any inclination would have the satellite moving north and south, and hence it would not be geostationary. Movement north and south can be avoided only with zero inclination, which means that the orbit lies in the earth's equatorial plane.

Chapter 2

LINK ANALYSIS

2.1 Introduction

Satellites (spacecraft) orbiting the earth follow the same laws that govern the motion of the planets around the sun. From early times much has been learned about planetary motion through careful observations. Johannes Kepler (1571–1630) was able to derive empirically three laws describing planetary motion. Kepler's laws apply quite generally to any two bodies in space which interact through gravitation. The more massive of the two bodies is referred to as the *primary,* the other, the *secondary* or *satellite*.

2.2 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 Fig. 2.1.

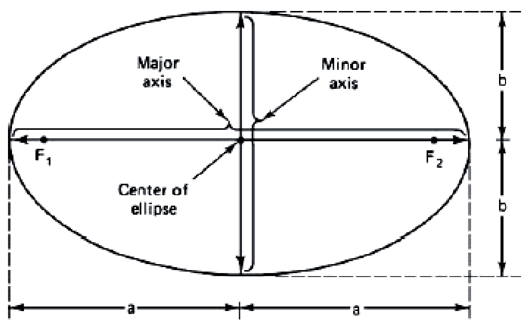

Figure 2.1 The foci *F*1 and *F*2, the semimajor axis *a*, and the semiminor axis *b* of an ellipse.

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 semimajor axis of the ellipse is denoted by *a*, and the semiminor axis, by *b*. The eccentricity *e* is given by:

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

The eccentricity and the semimajor axis are two of the orbital parameters specified for satellites (spacecraft) orbiting the earth. For an elliptical orbit $0 < e < 1$. When $e = 0$, the orbit becomes circular.

2.3 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 bar center. Referring to Fig. 2.2, assuming the satellite travels distances $S1$ and $S2$ meters in 1 s, then the areas $A1$ and $A2$ will be equal. The average velocity in each case is $S1$ and $S2$ m/s, and because of the equal area law, it follows that the velocity at $S2$ is less than that at $S1$. 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.

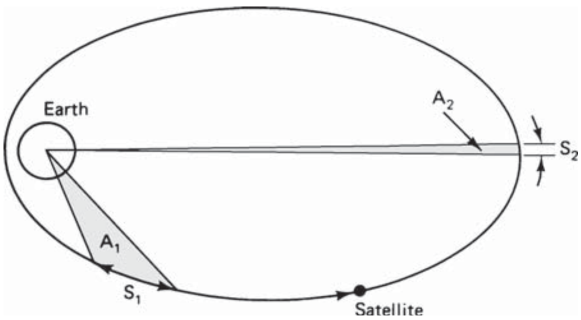

Figure 2.2 Kepler's second law. The areas *A*1 and *A*2 swept out in unit time are equal

2.4 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 semimajor 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. μ= 3.986005x1o^{14} m^3/s^2

Equation above applies only to the ideal situation of a satellite orbiting a perfectly spherical earth of uniform mass. 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 semimajor axis. One very important orbit in particular, known as the *geostationary orbit,* is determined by the rotational period of the earth.

Example 2.1 Calculate the radius of a circular orbit for which the period is 1 day.

Solution: There are 86,400 seconds in 1 day, and therefore the mean motion is

$$n = \frac{2\Pi}{86400} = 7.272 \times 10^{-5} rad/s$$

From Kepler's third law:

$$a = \left[\frac{3.986005 \times 10^{14}}{(7.272 \times 10^{-5})^2}\right]^{1/3}$$

= 42.241 km

Since the orbit is circular the semimajor axis is also the radius.

2.5 Definitions of Terms for Earth-Orbiting Satellites

As mentioned previously, Kepler's laws apply in general to satellite motion around a primary body. For the particular case of earth-orbiting satellites, certain terms are used to describe the position of the orbit with respect to the earth.

Subsatellite path. This is the path traced out on the earth's surface directly below the satellite.

Apogee. The point farthest from earth. Apogee height is shown as h_a in Fig. 2.3.

Perigee. The point of closest approach to earth. The perigee height is shown as h_p in Fig. 2.3.

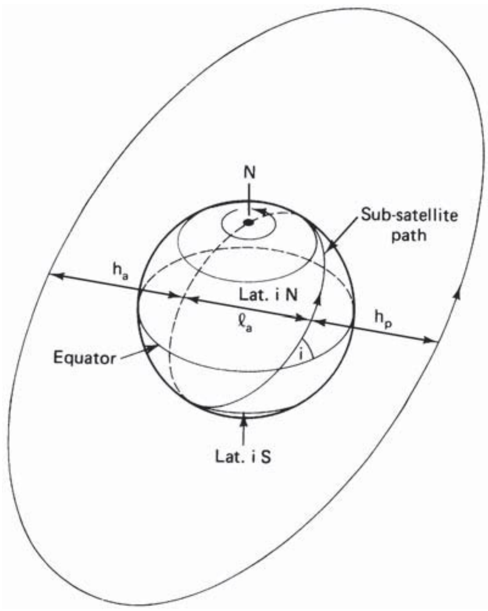

Figure 2.3 Apogee height *ha*, perigee height *hp*, and inclination *i*. *la* is the line of apsides.

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.

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. The inclination is shown as *i* in Fig. 2.3. It will be seen that the greatest latitude, north or south, reached by the subsatellite path is equal to the inclination.

Prograde orbit. An orbit in which the satellite moves in the same direction as the earth's rotation, as shown in Fig. 2.4. The prograde orbit is also known as a *direct orbit.* The inclination of a prograde orbit always lies between $0^0$and 90^0. 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.

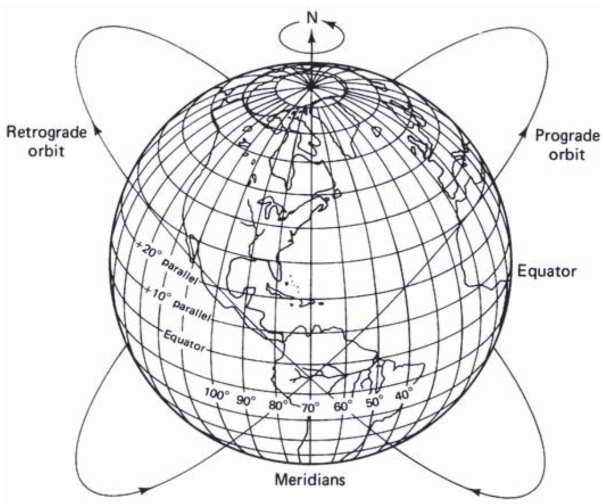

Figure 2.4 Prograde and retrograde orbits

Retrograde orbit. An orbit in which the satellite moves in a direction counter to the earth's rotation, as shown in Fig. 2.4. The inclination of a retrograde orbit always lies between 90^0 and 180^0.

Argument of perigee. The angle from ascending node to perigee, measured in the orbital plane at the earth's center, in the direction of satellite motion. The argument of perigee is shown as *w* in Fig. 2.5.

Right ascension of the ascending node. To define completely the position of the orbit in space, the position of the ascending node is specified. However, because the earth spins, while the orbital plane remains stationary (slow drifts that do occur are discussed later), the longitude of the ascending node is not fixed, and it cannot be used as an absolute reference. For the practical determination of an orbit, the longitude and time of crossing of the ascending node are frequently used. However, for an absolute measurement, a fixed reference in space is required.

The reference chosen is the *first point of Aries,* otherwise known as the vernal, or spring, equinox. The vernal equinox occurs when the sun crosses the equator going from south to north, and an imaginary line drawn from this equatorial crossing through the center of the sun points to the first point of Aries (symbol ϒ). This is the *line of Aries.* The right ascension of the ascending node is then the angle measured eastward, in the equatorial plane, from the ϒ line to the ascending node, shown as Ω in Fig. 2.5.

Mean anomaly. Mean anomaly M gives an average value of the angular position of the satellite with reference to the perigee. For a circular orbit, M gives the angular position of the satellite in the orbit. For elliptical orbit, the position is much more difficult to calculate, and M is used as an intermediate step in the calculation.

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.

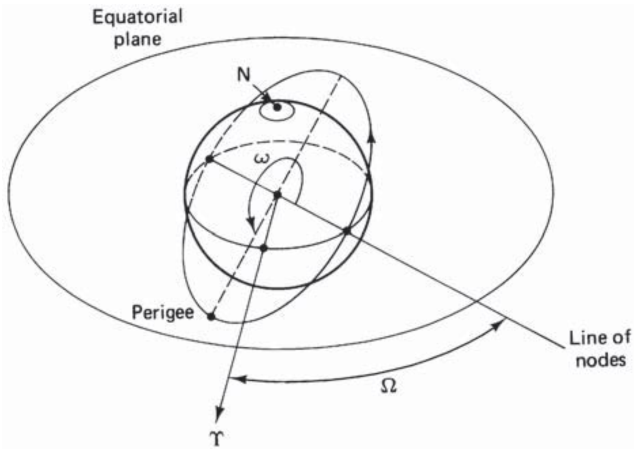

Figure 2.5 The argument of perigee *ω* and the right ascension of the ascending node Ω.