WEEK 2

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.

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

Apogee is the point farthest from earth.

Perigee is the point of closest approach to earth.

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:

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

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

Example: Calculate the apogee and perigee heights for the following orbital parameters:

Mean earth radius of R= 6371 km, e =0.0011501 and a =7192.335 km.

Solution:

Using Eqs. above:

r_a =7192.335(1 + 0.0011501) = 7200.607km

r_p =7192.335(1 - 0.0011501) = 7184.063 km

The corresponding heights are:

$$h_a = r_a - R = 829.6\ Km$$

$$h_p = r_p - R = 813.1\ Km$$

FREQUENTLY USED ORBITS

Geostationary Orbits (GEO)

To an observer on the earth, a satellite in a geostationary orbit appears motionless, in a fixed position in the sky. This is because it revolves around the earth at the earth's own angular velocity (360 degrees every 24 hours, in an equatorial orbit).

A geostationary orbit is useful for communications because ground antennas can be aimed at the satellite without their having to track the satellite's motion. This is relatively inexpensive. In applications that require a large number of ground antennas, such as Direct TV distribution, the savings in ground equipment can more than outweigh the cost and complexity of placing a satellite into orbit.

The main drawback of a geostationary orbit is the height of the orbit, usually which requires more powerful transmitters, larger-than-normal (usually dish) antennas, and higher-sensitivity receivers on the earth. The large distance also introduces a significant delay, of ~0.25 seconds, into communications.

For GEO, $h \approx 36000$ km , $i=0^o$ and $e= 0^o$.

Since i and e cannot be exactly zero in any practical satellite, the more accurate term geosynchronous orbit is frequently used.

For small inclinations $i< 0.5^o$, the satellite appears to move in north-south direction slowly in an oscillating fashion with 1-day period.

For small eccentricities; the satellite appears to oscillate in the East-West direction in 1-day period as well. If both oscillations are combined, a **figure of 8 motion** will appear. Station keeping task is to reduce the amplitude of oscillation to small magnitude.

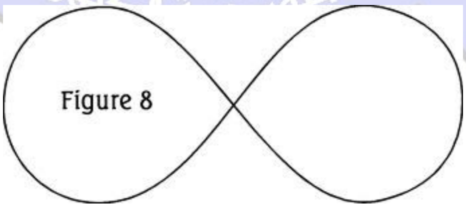


Fig.(3) figure of 8 traced by satellite.

Example

A quasi-GEO satellite is in a circular equatorial orbit close to geosynchronous altitude. The quasi-GEO satellite, however, does not have a period of one sidereal day: its orbital period is exactly 24 h—one solar day. Calculate

(i) the radius of the orbit

(ii) the rate of drift around the equator of the subsatellite point in degrees per (solar) day. An observer on the earth sees that the satellite is drifting across the sky.

(iii) Is the satellite moving toward the east or toward the west?

Sol:

$$T^2 = (4\pi^2 a^3)/\mu$$

Rearranging the equation, the orbital radius a is given by

$$a^3 = T^2\mu/(4\pi^2) = (86{,}400)^2 \times 3.986004418 \times 10^5/4\pi^2$$
$$= 7.5371216 \times 10^{13}\ \text{km}^3$$
$$a = 42{,}241.095\ \text{km}$$

Part (ii) The orbital period of the satellite (one solar day) is longer than a sidereal day by 3 min 55.9 s = 235.9 s. This will cause the subsatellite point to drift at a rate of 360° × 235.9/86400 per day or 0.983° per day.

Part (iii) The earth moves toward the east at a faster rate than the satellite, so the drift will appear to an observer on the earth to be toward the west. ■

Polar Orbiting Satellites

Polar orbiting satellites orbit the earth in such a way as to cover the north and south Polar Regions. (Note that the term polar orbiting does not mean that the satellite orbits around one or the other of the poles).

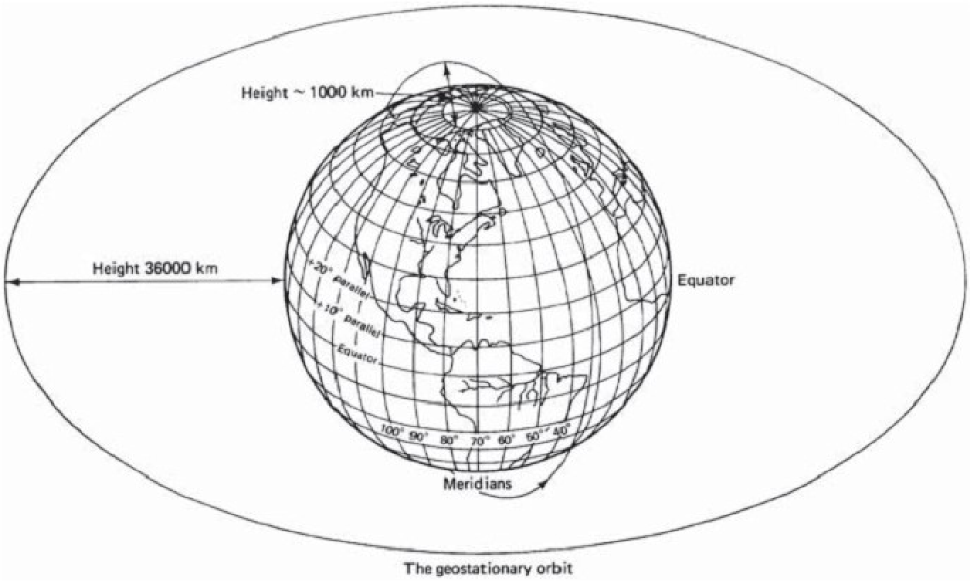


Fig.4 a Geostationary orbit and one possible polar orbit.

Figure 4 shows a polar orbit in relation to the geostationary orbit. Whereas there is only one geostationary orbit, there are, in theory, an infinite number of polar orbits. The U.S. experience with weather satellites has led to the use of relatively low orbits, ranging in altitude between 800 and 900 km, compared with 36,000 km for the geostationary orbit.

Low-Earth-orbit (LEO)

A Low Earth Orbit (LEO) typically is a circular orbit stretch approximately 160 to 1600 km above the earth's surface. In addition, satellites in low earth orbit change their position relative to the ground position quickly. So even for local applications, a large number of satellites are needed if the mission requires uninterrupted connectivity.

Low earth orbiting satellites are less expensive to launch into orbit than geostationary satellites and, due to proximity to the ground, do not require as high signal strength (Recall that signal strength falls off as the square of the distance from the source, so the effect is dramatic). Thus there is a trade-off between the number of satellites and their cost. In addition, there are important differences in the onboard and ground equipment needed to support the two types of missions.

LEOs are subject to aerodynamic drag caused by resistance of the earth's atmosphere to the satellite passage. The exact value of the force caused by the drag depends on atmospheric density, the shape of the satellite, and the satellite's velocity. This force may be expressed in the form:

$$F_d = -0.5\rho_a C_d A_{eq} v^2 \quad kg \cdot m/sec^2$$

where

p_a: atmospheric density. This density is altitude-dependent, and its variation is exponential.
C_d : coefficient of aerodynamic drag.
A_{eq} : equivalent surface area of the satellite that is perpendicular to the velocity,
v : velocity of the satellite.

If the mass ms of the satellite is known, the acceleration a_d due to aerodynamic drag can be expressed as:

$$a_d = \frac{F_d}{m_s} \quad m/sec^2$$

The effect of the drag is a decrease of the orbit's semi-major axis due to the decrease in its energy. A circular orbit remains as such, but its altitude decreases whereas its velocity increases. Due to drag, the apogee in the elliptical orbit becomes lower and, as a consequence, the orbit gradually becomes circular.

The longer the influence on the orbit, the slower the satellite becomes, and it eventually falls from orbit. Aerodynamic drag is more significant at low altitudes (200 to 400 km) and negligible only about 3000 km because, in spite of the low value of atmospheric density encountered at the altitudes of satellites, their high orbital velocity implies that perturbations due to drag are very significant.

- Aerodynamic drag tends to reduce orbital height & eccentricity. It does not affect inclination and it is negligible in geosynchronous satellite.

- The effect is to remove kinetic energy from spacecraft & causing it to fall toward the earth, which in turn increases the orbital velocity resulting in higher drag & faster orbital decay.

Medium and High Earth orbit (MEO) & (HEO)

Medium Earth orbit (MEO), sometimes called intermediate circular orbit (ICO), is the region of space around the Earth above low Earth orbit (altitude of 2,000 kilometers) and below geostationary orbit (altitude of 35,786 kilometers).

The most common use for satellites in this region is for navigation, communication, and geodetic/space environment science. The most common altitude is approximately 20,200 kilometers, which yields an orbital period of 12 hours, as used, for example, by the Global Positioning System (GPS). Other satellites in Medium Earth Orbit include Glonass (with an altitude of 19,100 kilometers) and Galileo (with an altitude of 23,222 kilometers). Communications satellites that cover the North and South Pole are also put in MEO.

The orbital periods of MEO satellites range from about 2 to nearly 24 hours.

- A high Earth orbit (HEO) is a geocentric orbit with an altitude above that of a geosynchronous orbit.
- A highly elliptical orbit (HEO) is an elliptic orbit with a low-altitude (about 1,000 kilometers) perigee and a high-altitude (over 35,786 kilometers) apogee.

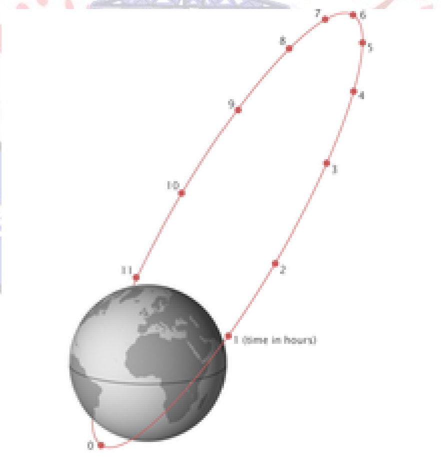
Such extremely elongated orbits have the advantage of long dwell times at a point in the sky during the approach to, and descent from, apogee. Visibility near apogee can exceed twelve hours of dwell at apogee with a much shorter and faster-moving perigee phase. Bodies moving through the long apogee dwell can appear still in the sky to the ground.

Examples of HEO orbits offering visibility over Earth's Polar Regions, Molniya orbits, named after the Molniya Soviet communication satellites which used them.

Molniya Orbit

For areas close to the North (and South) Pole, a geostationary satellite may appear below the horizon. Therefore Molniya orbit satellite has been launched, mainly in Russia, to alleviate this problem. The first satellite of the Molniya series was launched on 1965 and was used for experimental transmission of TV signal from Moscow uplink station to downlink station located in Siberia and the Russian far east.

Molniya (meaning "lightning") was a military communications satellite system used by the Soviet Union. The satellites were placed into highly eccentric elliptical orbits (HEO) known as Molniya orbits, characterized by an inclination of +63.4 degrees and a period of around 12 hours. Such orbits allowed them to remain visible to sites in Polar Regions for extended periods.



The Molniya orbit is designed so that the satellite spends the great majority of its time over the far northern latitudes. Its period is one half day, so that the satellite is available for operation over the targeted region for six to nine hours every revolution. In this way a constellation of three Molniya satellites (plus in-orbit spares) can provide uninterrupted coverage.