A Comparative Study of Satellite Orbits as Low Earth Orbit (LEO) and Geostationary Earth Orbit (GEO)

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ABSTRACT

It is known facts that satellites are used to receive the signal at geostationary orbit by remaining stationary above a particular point on the Earth. The orbit that is chosen for a satellite depends upon its application. Those used for direct broadcast television use geostationary orbit. Many communication satellites similarly use geostationary orbit. Other satellite systems used for satellite phones use Low Earth orbiting systems. Similarly, satellite systems used for navigation like Nav-star or Global Positioning (GPS) system occupy a relatively Low Earth Orbit. There are also many other types of satellites : Weather satellites Research satellites and many others. Each will have its own type of orbit depending upon its application.

The actual satellite orbit that is chosen will depend on factors including its function, and the area of serving. At some instances, the satellite orbit may be as low as 100 miles (160 km) for a Low Earth Orbit (LEO), whereas others may be over 22 000 miles (36000 km) high as in the case of a Geostationary Orbit (GEO). The satellite may even has an elliptical rather than a circular orbit.

Keywords : *This paper deals with : LEO, GEO, HEO, constellation, apogee, perigee, Relay, Manoeuvres, Geosynchronous*.

1. INTRODUCTION

The typical satellite communication system comprises of a ground segment, space segment and control segment. The link which transmits radio waves from the ground station to the satellite is called uplink. The satellite in turn transmits to the ground station by the downlink. The function of the ground segment (one or more ground stations) is to receive or transmit the information to the satellite in the most reliable manner while retaining the desired signal quality. The space segment consists of one or more artificial satellites as presented in Fig.1. In case of more satellites, they are organized in a network called constellation[1]. Constellation of satellites is done in orbits. The orbit is the trajectory followed by the satellite.

Several types of orbits are possible, each suitable for a specific application or mission. Generally, the orbits of communication satellites are ellipses within the orbital plane defined by space orbital parameters. Orbits with zero eccentricity are called circular orbits.

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Fig.1. Satellite Elements

The circularity of the orbit simplifies the analysis. The movement of the satellite within its circular orbit is represented by orbital time, radius, altitude and velocity[2]. Circular orbits are categorized and are based on the altitude above Earth's surface as presented in Fig. 2.

- GEO (Geosynchronous Earth Orbits)
- MEO (Medium Earth Orbits) and
- LEO (Low Earth Orbits)

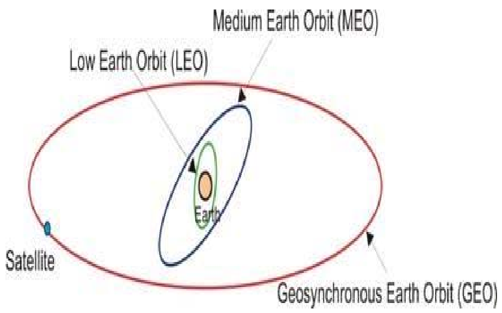

Fig. 2. The Satellite Orbits

2. CIRCULAR AND ELLIPTICAL ORBIT DEFINITIONS

- **Circular satellite orbit:** For a circular orbit, the distance from the Earth remains the same at all times.
- **Elliptical satellite orbit:** The elliptical orbit changes the distance to the Earth as presented in Fig. 3.

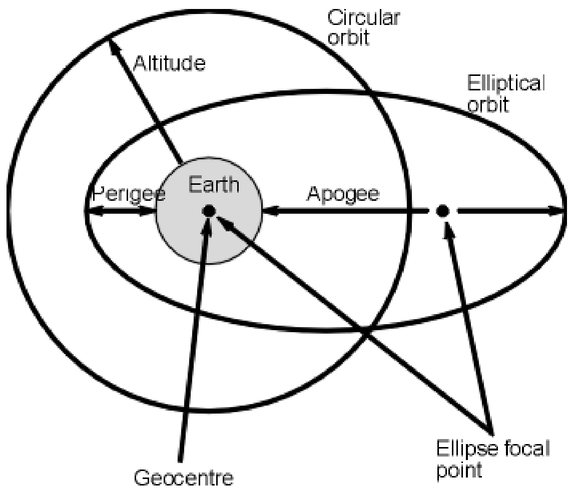

Fig. 3. Circular vs Elliptical Orbit

2.1. Circular Satellite Orbit Definitions

Circular orbits are classified in a number of ways: Such as Low Earth Orbit, Geostationary Orbit and the like detail distinctive elements of the orbit [3]. A summary of circular orbit definitions is given in the table below:

Table-1 : Summary of Circular Orbits

ORBIT NAME	ORBIT INITIALS	ORBIT ALTITUDE (KM ABOVE EARTH'S SURFACE)	DETAILS / COMMENTS
Low Earth Orbit	LEO	200 - 1200	
Medium Earth Orbit	MEO	1200 - 35790	
Geosynchronous Orbit	GSO	35790	Orbits once a day, but not necessarily in the same direction as the rotation of the Earth - not necessarily stationary
Geostationary Orbit	GEO	35790	Orbits once a day and moves in the same direction as the Earth and therefore appears stationary above the same point on the Earth's surface. Can only be above the Equator.
High Earth Orbit	HEO	Above 35790	

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2.2. Highly Elliptical Orbit Definitions

As the name implies, an elliptical orbit or as it is more commonly known as the Highly Elliptical Orbit, HEO, follows the curve of an ellipse. However, one of the key features of an elliptical orbit is that the satellite in an elliptical orbit moves much faster when it is close to Earth than when it is further away.

For any ellipse, there are two focal points, and one of these is the geo-centre of the Earth as presented in Fig5. Another feature of an elliptical orbit is that there are two other major points. One is where the satellite is farthest from the Earth. This point is known as the apogee. This is where the satellite moves at its slowest as the gravitational pull from the earth is lower. The point where it is closest to the Earth is known as the perigee - this is where the satellite moves at its fastest.

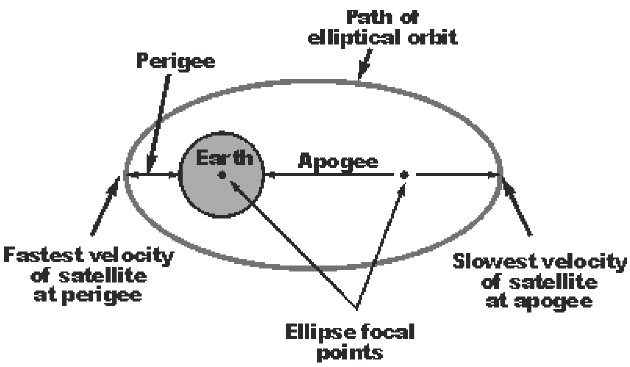

Fig. 4. Highly Elliptical Satellite Orbit, HEO

3. ORBITAL PARAMETERS

The path of the satellite's motion is an orbit. The orbit is a trajectory within an orbital plane and shaped as an ellipse, with a maximum extension from the Earth center at the apogee (r_a) and the minimum at the perigee (r_p) as presented in Fig. 5.

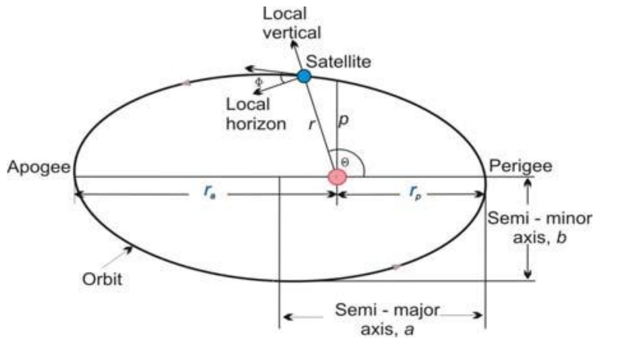

Fig. 5. Major Parameters of an Elliptical Orbit

In order to describe the satellite's movement within its orbit in space, a few parameters are required to be defined. These are known as space orbital parameters schematically presented in Fig. 6 and defined under below items 3.1, 3.2, 3.3 and 3.4 [4].

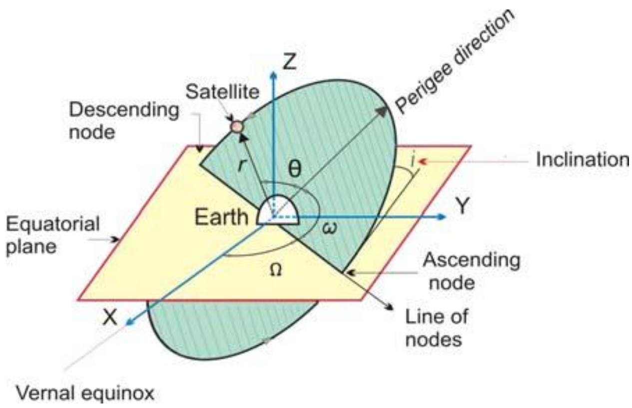

Fig. 6. Space Orbital Parameters

3.1 The Position of The Orbital Plane in Space

This is specified by means of two parameters - The inclination i and the right ascension of the ascending node Ω. Inclination i represents the angle of the orbital plane with respect to the Earth's equator. The right ascension of the ascending node Ω defines the location of the ascending and descending orbital crossing nodes (these two nodes make a line of nodes) with respect to a fixed direction in space. The fixed direction is Vernal equinox. Vernal equinox is direction of line joining the Earth's center and the Sun on the first day of spring [5].

3.2 Location of The Orbit in Orbital Plane

Normally an infinite number of orbits can be laid within an orbital plane. So, the orientation of the orbit in its plane is defined by the argument of perigee ω. This is the angle, taken positively from 0º to 360º in the direction of the satellite's motion, between the direction of the ascending node and the direction of perigee.

3.3 Position of The Satellite in The Orbit

The position of the satellite in orbit is determined by the angle θ called the true anomaly, which is the angle measured positively in the direction of satellite's movement from 0º to 360º, between the direction of perigee and the position of the satellite.

3.4 The Shape of Orbit

The shape of orbit is presented by the semi-major axis a (Fig. 3) which defines the size of orbit and the eccentricity e which defines the shape of the orbit. The eccentricity is the ratio of difference to the sum of apogee (r_a) and perigee (r_p) radii as in Eqn. 1.

$$e = \frac{r_a - r_p}{r_a + r_p} \tag{1}$$

Applying geometrical ellipse features yield out the relations between semi major axis, apogee and perigee as:

$$r_p = a\,(1 - e) \tag{2}$$

$$r_a = a\,(1 + e) \tag{3}$$

both r_p and r_a are considered from the Earth's centre. Earth's radius is $r_E = 6378$ km.

Then, the heights of perigee and apogee are:

$$h_p = r_p - r_E \tag{4}$$

$$h_a = r_a - r_E \tag{5}$$

For orbits with zero eccentricity, yields:

$$e = 0 \Rightarrow r_a = r_p = a \tag{6}$$

4. LOW EARTH ORBIT (LEO)

The Low Earth Orbit, LEO is used for the vast majority of satellites.

As the names imply, Low Earth Orbit is relatively low in altitude; the definition of LEO stating that the altitude range is between 200 and 1200 km above the Earth's surface. LEO is very close to the Earth, especially when compared to other forms of satellite orbit including geostationary orbit.

The low orbit altitude of LEO leads to a number of characteristics:

- Orbit time is much less than for many other forms of orbit. The lower altitude means higher velocities and is required to balance the earth's gravitational field. Typical velocities are approximately around 8 km/s, with orbit time sometimes of the order of 90 minutes. Although these figures vary considerably with the exact details of the orbit.
- The lower orbit means the satellite and user are closer together and therefore path losses is less than for other orbits such as GEO
- The round trip time, RTT for the radio signals is considerably less than that experienced by geostationary orbit satellites. The actual time will depend upon factors such as the orbit altitude and the position of the user relative to the satellite.
- Radiation levels are lower than experienced at higher altitudes.
- Less energy is expanded placing the satellites in LEO than higher orbits.
- Some speed reduction may be experienced as a result of friction from the low, but measurable levels of gasses, especially at lower altitudes. An altitude of 300 km is normally accepted as the minimum for an orbit as a result of the increasing drag from the presence of gasses at low altitudes.

4.1. Applications for LEO Satellites

Applications of LEO satellites include:

- Communications satellites - some communications satellites including the Iridium phone system use LEO.
- Earth monitoring satellites use LEO as they are able to see the surface of the Earth more clearly as they are not so far away. They are also able to traverse the surface of the Earth.
- The International Space Station is in LEO that varies between 320 km (199 miles) and 400 km (249 miles) above the Earth's surface. It can often be seen from the Earth's surface with naked eyes.

5. GEOSTATIONARY SATELLITE ORBIT (GEO)

One very popular orbit format is the geostationary satellite orbit. The geostationary orbit is used by many applications including direct broadcast as well as communications or relay systems. The geostationary orbit has the advantage that the satellite remains in the same position throughout the day, and antennas can be directed towards the satellite and remain on track. This factor is of particular importance for applications such as direct broadcast TV where changing directions for the antenna would not be practicable [6].

5.1. Idea of Geostationary Orbit

The idea of a geostationary orbit has been postulated for many years. One of the possible originators of the basic idea was a Russian theorist and science fiction writer, Konstantin Tsiolkovsky. However, it was Herman Oberth and Herman Potocnik who wrote about orbiting stations at an altitude of 35 900 km above the Earth that had a rotational period of 24 hours making it to appear hover over a fixed point on the equator.

The next major step towards this occurred when *Arthur C Clarke*, the science fiction writer, published a serious article in Wireless World, a major UK electronics and radio publication, in October 1945. The article was entitled *"Extra-Terrestrial Relays: Can Rocket Stations Give World Coverage?"*

Clarke extrapolated what could be done with the German rocket technology of the day and looked at what might be possible in the future. He postulated that it would be possible to provide complete global coverage with just three geostationary satellites as presented in Fig.7.

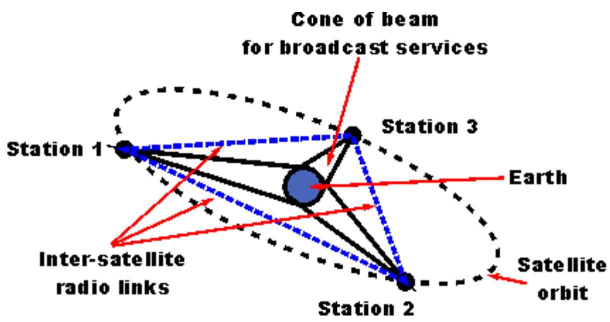

Fig.7. Arthur C Clarke's Geostationary Orbiting Satellites Concept

In the article, Clarke determined the orbital characteristics required as well as the transmitter power levels, the generation by solar power, even calculated the impact of solar eclipses.

Clarke's article was well ahead of its time. It took until 1963 before NASA was able to start launching satellites that could test the theory. The first serviceable satellite able to start testing the theory was Syncom 2 which was launched on 26 July 1963. [Syncom 1 failed as it was unable to reach its correct geostationary orbit]

5.2. Basics of Geostationary Orbit

As the height of a satellite increases, so the time for the satellite to orbit increases. At a height of 35790 km, it takes 24 hours for the satellite to orbit. This type of orbit is known as a geosynchronous orbit, i.e. it is synchronized with the Earth.

One particular form of geosynchronous orbit is known as a geostationary orbit. In this type of orbit the satellite rotates in the same direction as the rotation of the Earth and has an approximate 24 hours period. This means that it revolves at the same angular velocity as the Earth and in the same direction and therefore remains in the same position relative to the Earth.

5.3. Geostationary Satellite Drift

Even when satellites are placed into a geostationary orbit, there are several forces that can act on it to change its position slowly over time.

Factors including the earth's elliptical shape, the pull of the Sun and Moon and others act to increase the satellite orbital inclination. In particular the non-circular shape of the of the Earth around the Equator tends to draw the satellites towards two stable equilibrium points, one above the Indian Ocean and the other very roughly around the other side of the World. This results in what is termed as an east-west libration or movement back and forth.

To overcome these movements, fuel is carried by the satellites to enable them to carry out "station-keeping" where the satellite is returned to its desired position. The period between station-keeping manoeuvres is determined by the allowable tolerance on the satellite which is mainly determined by the ground antenna beam width. This will mean that no re-adjustment of the antennas is required.

Often the useful life of a satellite is determined by the time for which fuel will allow the station-keeping to be undertaken. Often this will be several years. After this the satellite can drift towards one of the two equilibrium points, and possibly re-enter the Earth's atmosphere. The preferred option is for the satellites to utilise some last fuel to lift them into a higher and increasing orbit to prevent them from interfering with other satellites.

5.4. Advantages and Disadvantages of Geostationary orbit Satellites

While the geostationary orbit is widely used for many satellite applications it is not suitable for all situations. There are several advantages and disadvantages to be taken into consideration:

5.4.1 Advantages :

Satellite always in same position relative to earth - antennas do not need re-orientation.

5.4.2 Disadvantages :

- Long path length, and hence losses when compared to LEO, or MEO.
- Satellites more costly to install in GEO in view of greater altitude.
- Long path length introduces delays. Geostationary satellite orbits can only be above the equator and therefore polar regions cannot be covered.

Despite the disadvantages of using satellites in geostationary orbit, they are still widely used because of the overriding advantage of the satellite always being in the same position relative to a given place on the Earth.

6. FREQUENCY BANDS AVAILABLE FOR SATELLITE COMMUNICATIONS

Satellite technology is developing fast, and the applications for satellite technology are increasing all the time. Not only can satellites be used for radio communications, but they are also used for astronomy, weather forecasting, broadcasting, mapping and many more applications.

With the variety of satellite frequency bands that can be used, designations have been developed so that they can be referred to easily.

The higher frequency bands typically give access to wider bandwidths, but are also more susceptible

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to signal degradation due to 'rain fade' (the absorption of radio signals by atmospheric rain, snow or ice).

Some of the useful frequency bands for satellite communications are designated as Fig.8. [7].

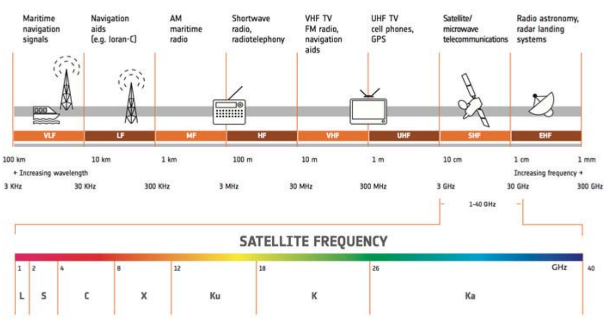

Fig.8. Satellite Frequency Bands

7. CONCLUSION

LEO Satellites are best suited for small distance applications where synchronization never matter and these are cost effective also. 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 as discussed in brief in paper. These orbits are very useful for scientific observations and small scale communications. An organization working with their many branches at different locations can install their own LEO satellite to monitor and share there workings. Where as GEO satellites are synchronous with respect to earth. Looking from a fixed point from Earth, these satellites appear to be stationary. These satellites are placed in the space in such a way that only three satellites are sufficient to provide connection throughout the surface of the Earth (that is; their footprint is covering almost 1/3rd of the Earth). Lifetime expectancy of these satellites is 15 years. Geostationary satellite in practical is termed as geosynchronous as there are multiple factors which make these satellites shift from the ideal geostationary condition. These satellites are used for TV and radio broadcast, weather forecast and also, these satellites are operating as backbones for the telephone networks. Disadvantages of GEO satellites lies in the matters such as transferring a GEO into orbit is very expensive and these satellites cannot be used for small mobile phones.

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