Satellite Communication

18EC5DEBSG

Module-1

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Overview of Satellite Communication: Introduction, Advantages of Satellite communication, Frequency Allocations for Satellite Services, Satellite orbits, Kepler laws, Definitions of terms for earth orbiting satellites, Orbital elements, Apogee and perigee heights, Orbit perturbations, Inclined orbits-Calendars, Universal Time, Sidereal Time, Orbital Plane.

Geostationary orbit: Introduction, Antenna look angles, Polar mount antenna, Limits of visibility, Earth eclipse of satellite, Sun transit outage.

Introduction

- Satellites are specifically made for telecommunication purpose.
- They are used for mobile applications such as communication to ships, vehicles, planes, hand -held terminals and for TV and radio broadcasting.
- They are responsible for providing these services to an assigned region (area) on the earth.
- The power and bandwidth of these satellites depend upon the preferred size of the footprint, complexity of the traffic control protocol schemes and the cost of ground stations.
- A satellite works most efficiently when the transmissions are focused with a desired area.
- When the area is focused, then the emissions don’t go outside that designated area and thus minimizing the interference to the other systems which This leads more efficient spectrum usage.
- Satellite’s antenna patterns play an important role and must be designed to best cover the designated geographical area (which is generally irregular in shape).
- Satellites should be designed by keeping in mind its usability for short and long term effects throughout its life time.
- The earth station should be in a position to control the satellite if it drifts from its orbit it is subjected to any kind of drag from the external forces.

Features offered by/Advantages of satellite communications

- **Larger coverage area**: Large areas of the earth are visible from the satellite, thus the satellite can form the star point of a communications net linking together many users simultaneously, users who may be widely separated geographically.
- Provide communications links to **remote communities**.
- Remote sensing detection of pollution, weather conditions, search and rescue operations.

Disadvantages of Satellite Communication

- They don’t consider **political** or **geographical boundaries** which may not be the desirable features.
- The **cost of installation** is high and is insensitive to distance(meaning the cost is approximately same for providing the link between small distance or long distance)

Thus satellite communication is **economical** where system is **in continuous use** and cost can be reasonably distributed over a **large number of users**

Applications Of Satellites:

- Weather Forecasting
- Radio and TV Broadcast
- Military Satellites
- Navigation Satellites
- Global Telephone
- Connecting Remote Area
- Global Mobile Communication

Frequency allocations

International Telecommunication Union (ITU) coordination and planning has divided World into three regions to facilitate proper frequency planning:

Region 1: Europe, Africa, formerly Soviet Union, Mongolia

Region 2: North and South America, Greenland

Region 3: Asia (excluding region 1), Australia, south west Pacific

Within regions, frequency bands are allocated to various satellite services:

- Fixed satellite service (FSS)

  Telephone networks, television signals to cable companies for distribution over systems

- Broadcasting satellite service (BSS)

  Direct broadcast to home referred as direct broadcast satellite (DBS) or direct-to-home satellite television (DTH)

- Mobile satellite service

  Land mobile, maritime mobile, aeronautical mobile

- Navigational satellite service

  Global positioning system

- Meteorological satellite service

  -Provide Search and rescue service

Frequency band designations in common use for satellite service

TABLE 1.1 Frequency Band Designations

Frequency range, GHz	Band designation
0.1–0.3	VHF
0.3–1.0	UHF
1.0–2.0	L
2.0–4.0	S
4.0–8.0	C
8.0–12.0	X
12.0–18.0	Ku
18.0–27.0	K
27.0–40.0	Ka
40.0–75	V
75–110	W
110–300	mm
300–3000	µm

TABLE 1.2 ITU Frequency Band Designations

Band number	Symbols	Frequency range (lower limit exclusive, upper limit inclusive)	Corresponding metric subdivision	Metric abbreviations for the bands
4	VLF	3–30 kHz	Myriametric waves	B.Mam
5	LF	30–300 kHz	Kilometric waves	B.km
6	MF	300–3000 kHz	Hectometric waves	B.hm
7	HF	3–30 MHz	Decametric waves	B.dam
8	VHF	30–300 MHz	Metric waves	B.m
9	UHF	300–3000 MHz	Decimetric waves	B.dm
10	SHF	3–30 GHz	Centimetric waves	B.cm
11	EHF	30–300 GHz	Millimetric waves	B.mm
12		300–3000 GHz	Decimillimetric waves	

SOURCE: ITU Geneva.

- Johannes Kepler(27 December 1571 – 15 November 1630) was a German astronomer, mathematician, and astrologer. He is a key figure in the 17th-century scientific revolution, best known for his laws of planetary motion, and his books Astronomia nova, Harmonices Mundi, and Epitome Astronomiae Copernicanae. These works also provided one of the foundations for Newton's theory of universal gravitation.

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Kepler's laws

- Satellites (spacecraft) orbiting the earth follow the same laws that govern the motion of the planets around the sun.
- 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.***

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 $F1$ and $F2$in Fig.1. The center of mass of the two-body system, termed the *bary center*, is always center of the foci. The semi major axis of the ellipse is denoted by a, and the semi minor axis by b. The eccentricity e(shape of the ellipse, describing how much it is elongated compared to a circle) is given by

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

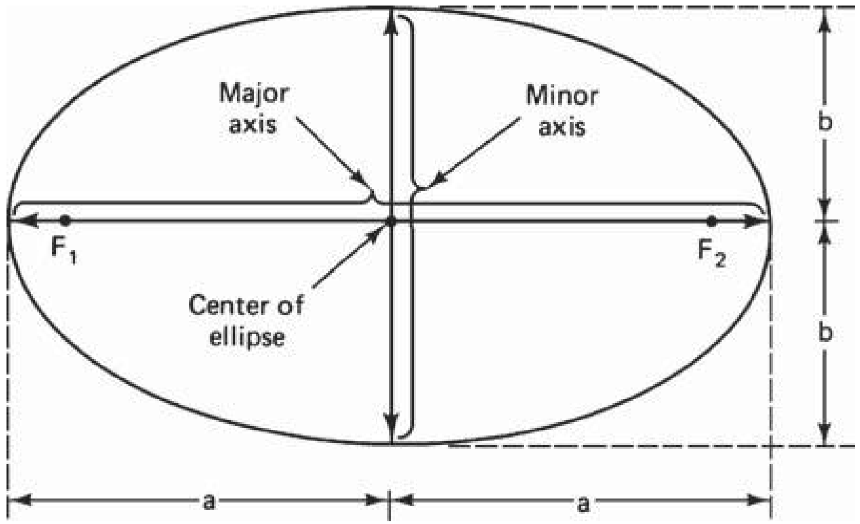


Fig.1. The foci *F1* and *F2*, the semi major axis *a*, and the semi minor axis *b* of an ellipse

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 Fig.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 $S1$.

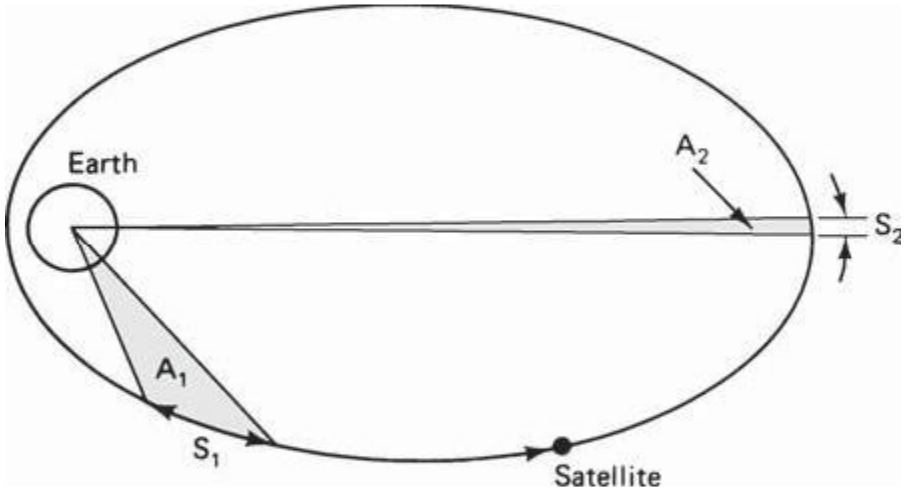


Fig.2. The areas *A*1 and *A*2 swept out in unit time are equal.

Kepler'sThird 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 $\mu = 3.986005 \times 10^{14}\ m^3/s^2$

With mean motion in rad/sec , the orbital period of satellite is given by

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

The importance of 3rd Law is →It shows there is a fixed relation between period and size.

Using above equation we can find radius of a satellite orbit moving with same velocity as that of earth, thus having period of 24 hours as follows

Period=2π/ 1 day=2π/24x60x60=7.2722 x$10^{-5}\,\frac{rad}{sec}$

Therefore $a = \left(\frac{\mu}{n}\right)^{1/3}$

i.e a=42241080 m=42241.08km

Average earth radius=6378 km

Therefore radius of satellite orbit=35863km

Orbital Parameters:

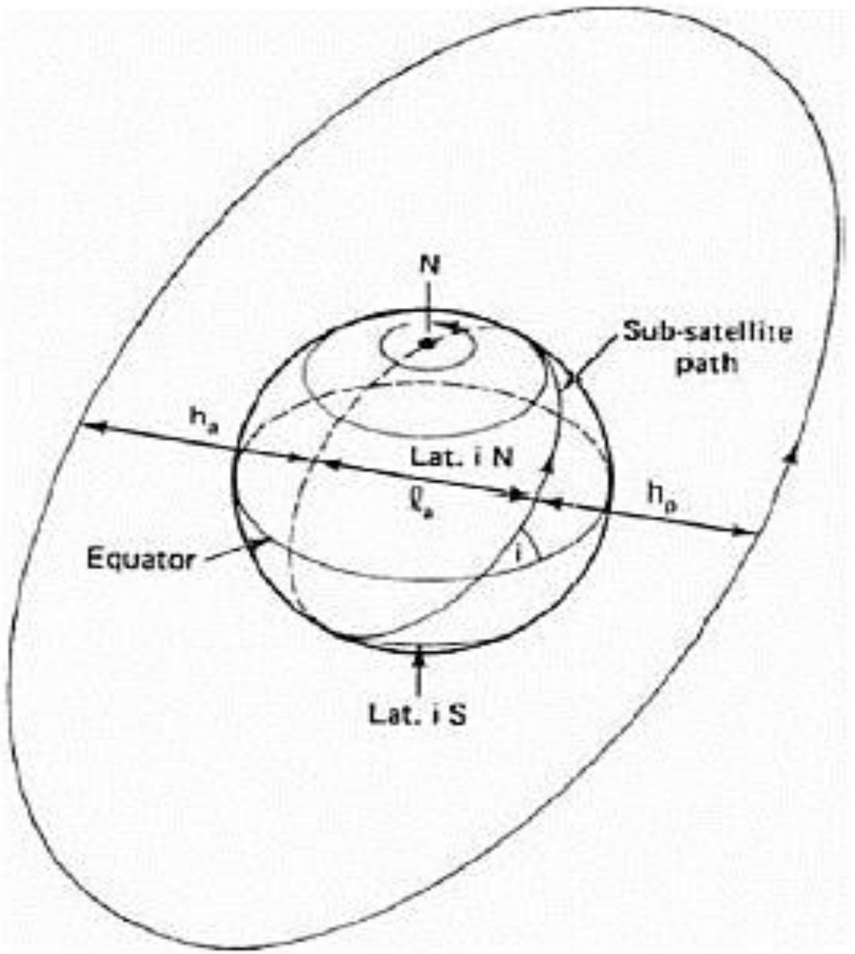


Fig.3a. Apogee height *ha*, perigee height *hp*, and inclination *i*. *La* is the line of apsides

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 equivalent to satellite's mean distance from 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.

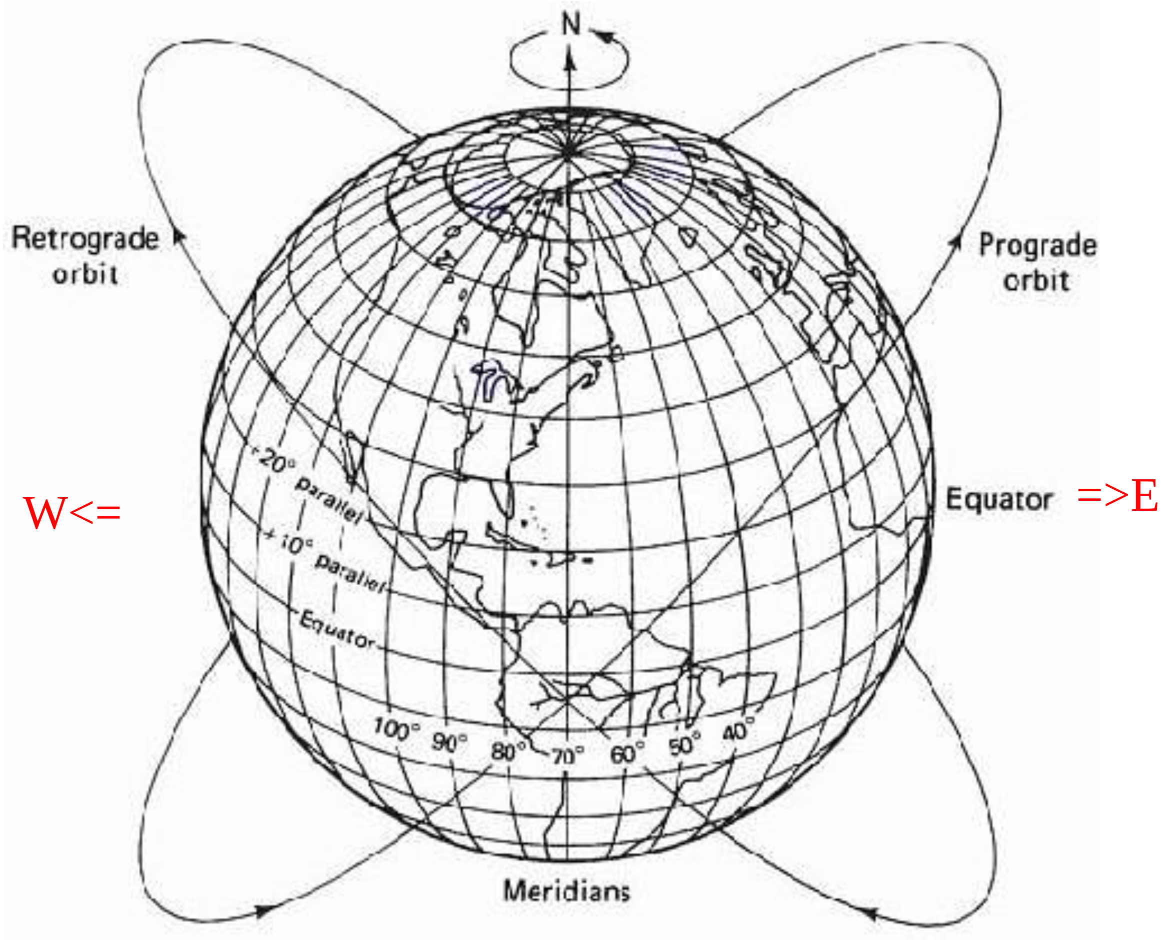


Fig.3b Prograde and retrograde orbits.

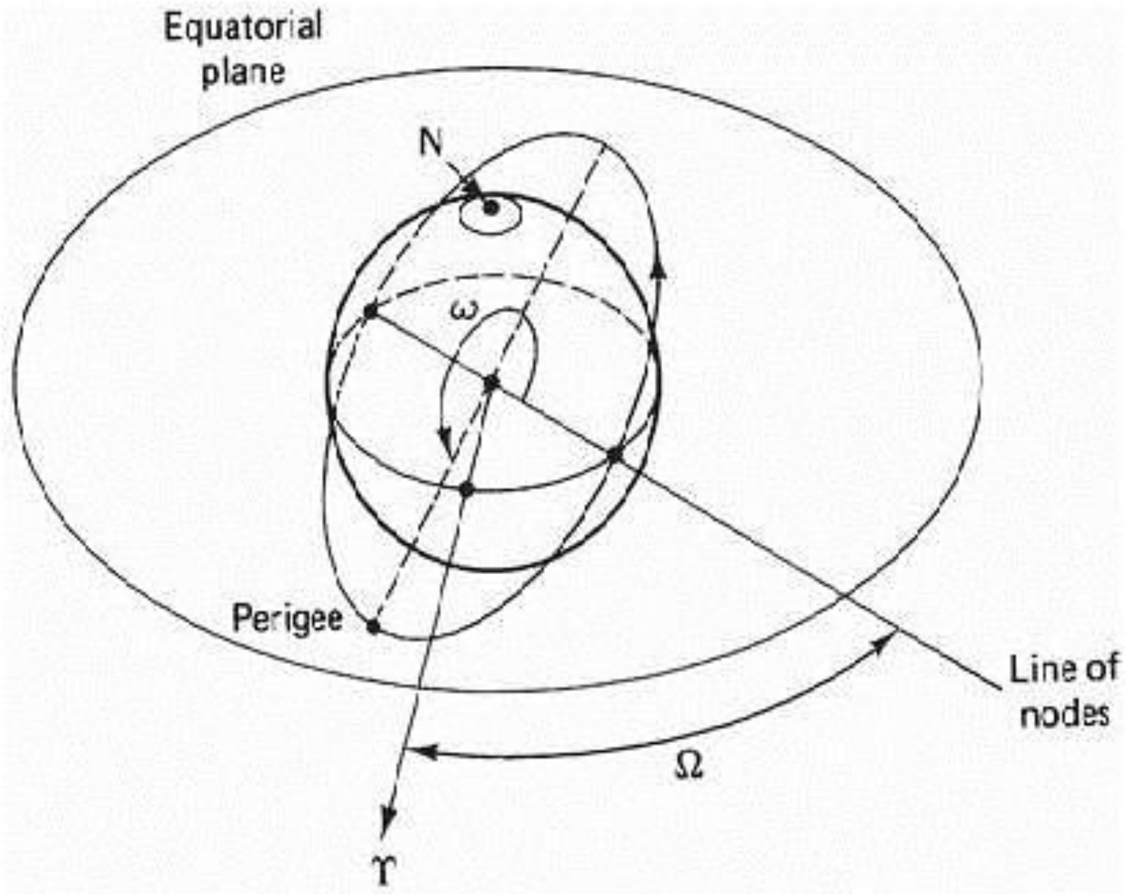
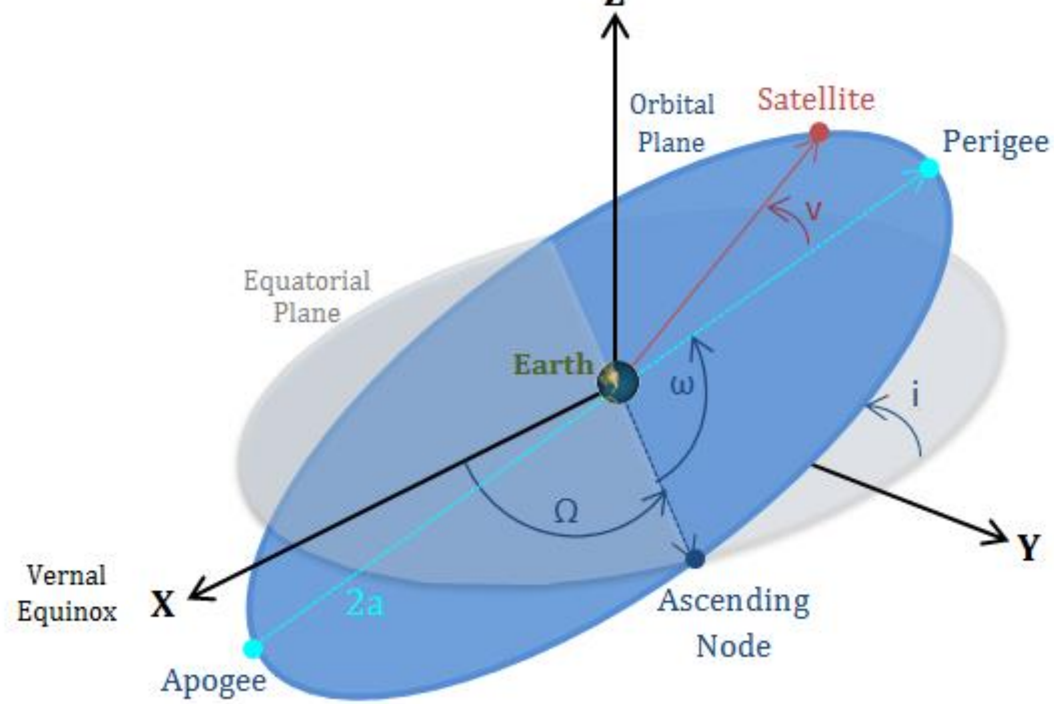


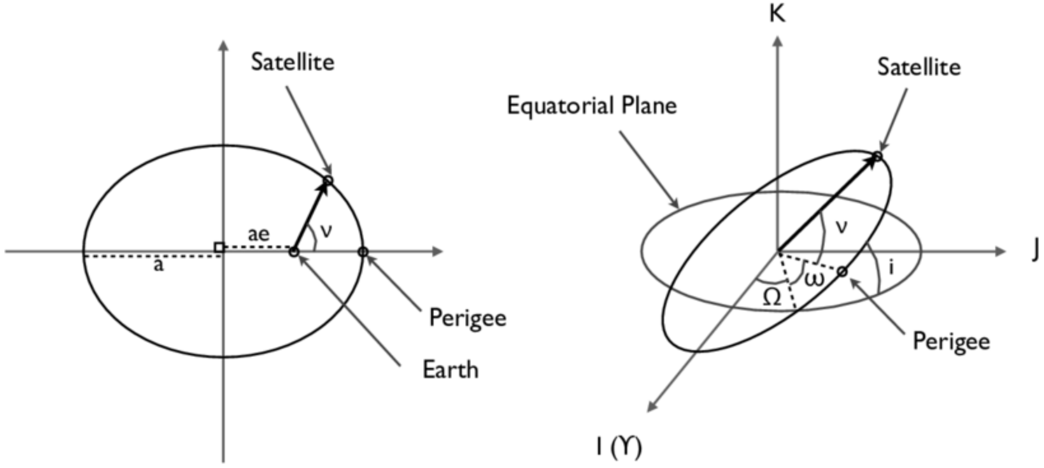
Fig.3c The argument of perigee ω & right ascension of the ascending node Ω.

Inclination: the angle between the orbital plane and the Earth‟s equatorial plane. Its measured at the ascending node from the equator to the orbit, going from East to North. Also, this angle is commonly denoted as i.

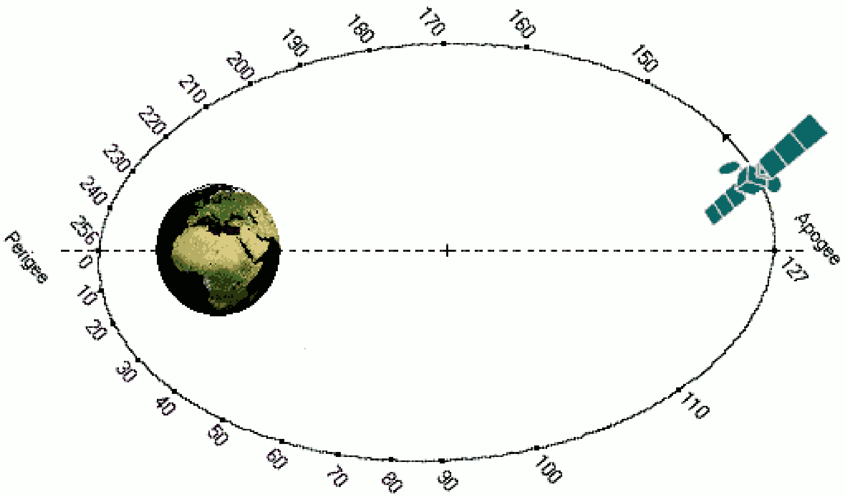
Line of Nodes: the line joining the ascending and descending nodes through the centre of Earth.



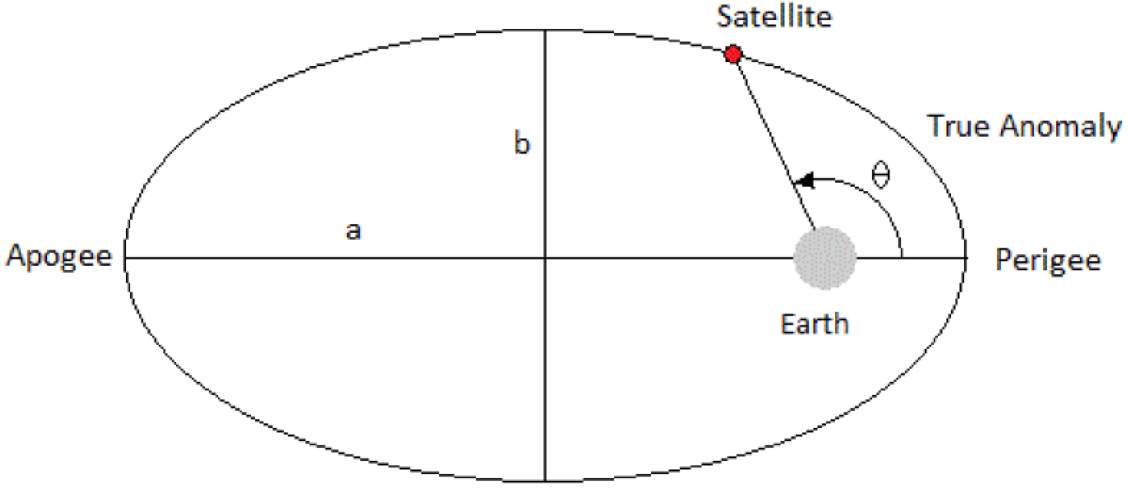
Orbital Plane
Satellite
Perigee
v
Equatorial Plane
Earth
ω
i
Ω
Vernal Equinox
X
Y
2a
Ascending Node
Apogee



Satellite
ae
a
v
Perigee
Earth
K
Satellite
Equatorial Plane
v
J
Ω
ω
i
Perigee
I (ϒ)



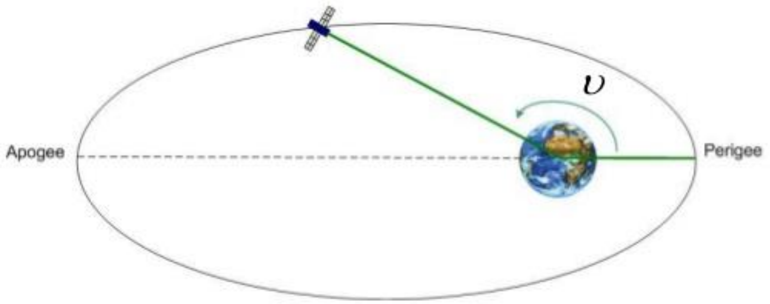
Perigee
Apogee
0
10
20
30
40
50
60
70
80
90
100
110
127
150
160
170
180
190
200
210
220
230
240
256



Satellite
True Anomaly
θ
b
a
Apogee
Perigee
Earth

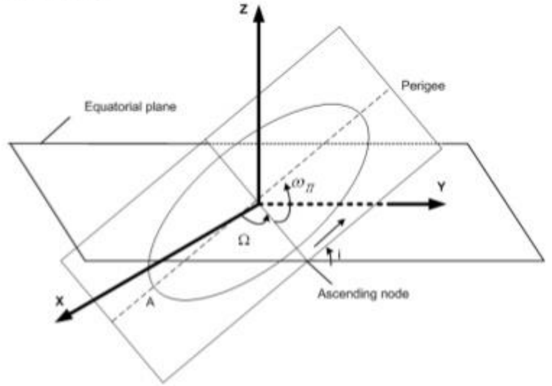
TRUE ANOMALY

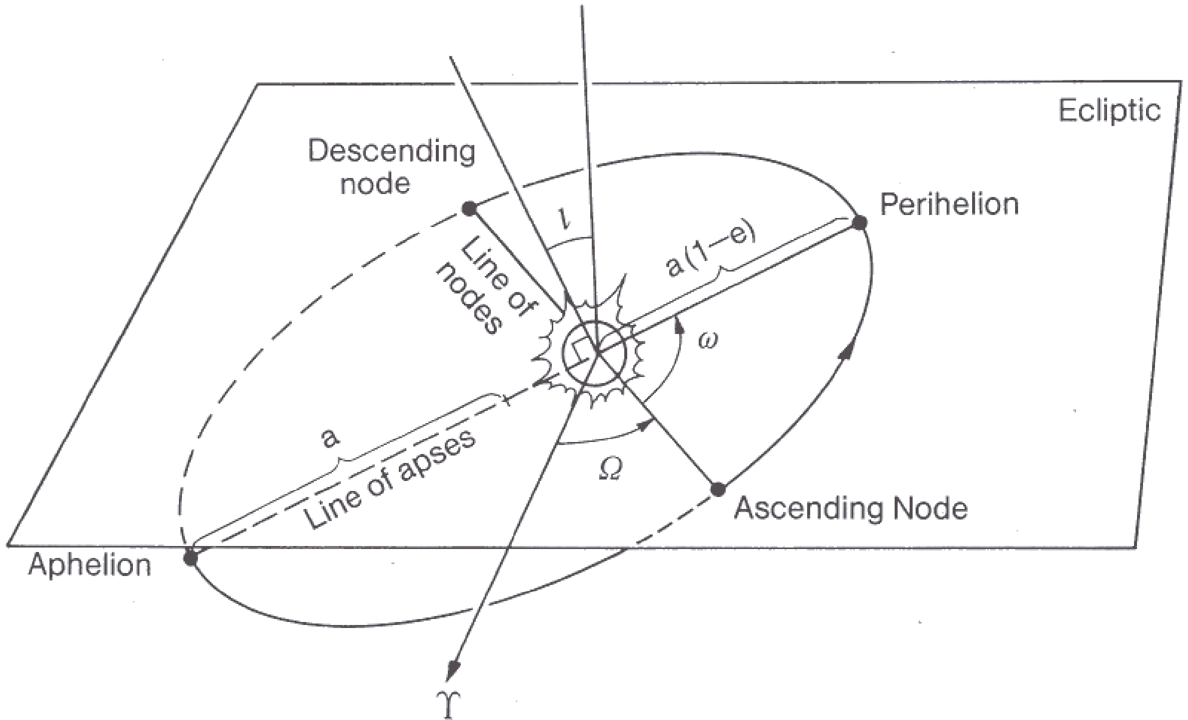
The true anomaly (υ) tells you where the satellite is in its orbital path. True anomaly is the angle measured in the direction of motion from perigee to the satellite's position at epoch time.

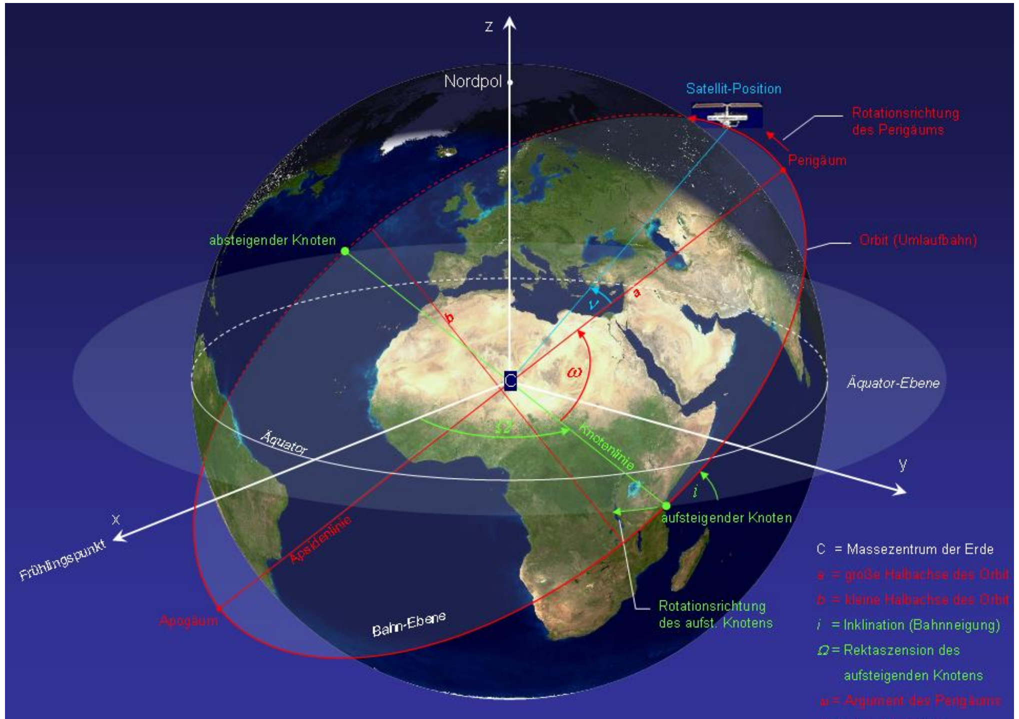


ARGUMENT OF PERIGEE

The argument of perigee (ω) is the angle formed between the two directions to the point of perigee and the point of ascending node. So, if the perigee would occur at the ascending node, the argument of perigee would be 0.







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Prograde Orbit: an orbit in which satellite moves in the same direction as the Earth's rotation. Its inclination is always between 0^o to 90^o. 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 direction counter to the Earth's rotation.

Argument of Perigee (ω): It is an angle from ascending node to perigee measured in the orbital plane at the Earth's centre, in the direction of the satellite motion. It is indicated by **ω.**

Right ascension of ascending node(Ω):

- 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 is 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(also known as First Point of Aries or Spring Equinox) vector to the ascending node(line of nodes) as represented by **Ω** fig.

Mean anamoly(M):

- It gives the average value to the angular position of the satellite with reference to the perigee. It is represented by M.
- For circular orbits M gives the angular position of satellite.
- For Elliptical orbits it if difficult to calculate and M is used as intermediate value in the calculation.

True Anomaly(v):

It gives the angular position of the satellite from perigee measured at earth's centre. It is represented by **v**.
It gives the true angular position of satellite in the orbit as a function of time.

Orbital Elements

Earth orbiting satellites are are defined by 6 orbital elemente known as "**Keplarian Elemental Set**".
They are {**a, e, Mo, ω, i, Ω** }
A,e---→Give shape of the orbit
Mo---→Gives the position of the satellite at a reference time known as epoch
ω ---→Gives rotation of the orbit's perigee point relative to orbit's line of nodes in the earth's equatorial plane**.**
i, Ω---→Relate the orbital plane's position to the earth.

Because equatorial bulge causes slow variations in **ω and Ω the** orbital elements are specified for the reference time or epoch.

Calculate the semi major axis of the satelliterbit if the mean motion of the satellite is given by NN=14.22296917

solution The mean motion is given in Table 2.1 as

$$NN := 14.22296917 \cdot \text{day}^{-1}$$

This can be converted to rad/sec as

$$n_0 := NN \cdot 2 \cdot \pi$$

(Note that Mathcad automatically converts time to the fundamental unit of second.) Equation (2.3) gives

$$\mu := 3.986005 \cdot 10^{14} \cdot m^3 \cdot \sec^{-2}$$

Kepler's 3rd law gives

$$a := \left(\frac{\mu}{n_0^{\,2}}\right)^{1/3}$$

$$a = 7192.3 \cdot \text{km}$$

= = = = = = =

Satellite Orbits

Orbit is a path traversed by the secondary body around primary body.

There different types of orbits in case of artificial satellites

Based on shape of the orbit

elliptical and circular

Based on distance or radius of the orbit

LEO(Low Earth Orbit)

- Satellites in low Earth orbit, or LEO, are the closest devices to Earth. They’re only 500 to 1,000 miles above the Earth’s surface, making them ideal for satellite phone and GPS communication.
- The relatively small distance means there is a minimal delay between the data leaving the satellite and it reaching its target o Earth — usually about 0.05 seconds.
- It takes a lot of LEO satellites to cover the planet, which is why there are so many of them up there.
- Ex.The Iridium Communications Network consist of 66 satellites total, while the Starlink constellation include nearly 12,00 satellites once they’ve all launched, though they won’t all be in LEO.
- The International Space Station(ISS) is also in low Earth orbit.
- LEO is commonly used for communication and remote sensing satellite systems.

MEO(Medium Earth Orbit)

- satellites are a bit of a middle ground between LEO and GEO orbits, circling the planet at an altitude of 8,000 miles.
- These satellites handle high-speed telephone signals and may, in the future, find a place in the military sector as a tool to provide low-latency high-bandwidth internet to military personnel around the globe.

- In spite of a slightly higher signal lag of about 0.1 seconds, depending on the size of the antenna, these MEO satellites can transmit data as quickly as 1.6 gigabits per second(For comparison, the fastest readily available commercial internet, not counting Google Fiber cities, is usually around 100 MB/s — less than a tenth of the speed these MEO satellites will be capable of providing.)

Based on orbital period

Geo stationary and Non Geo-stationary orbits

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.
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 (22,236 miles)from the surface.

A satellite in a geostationary orbit appears to be stationary with respect to the earth.
Three conditions are required for an orbit to be geostationary:

1. The satellite must travel eastward at the same rotational speed as the earth.
   If the satellite is to appear stationary it must rotate at the same speed as the earth, which is constant
2. The orbit must be circular.
   Constant speed means that equal areas must be swept out in equal times, and this can only occur with a circular orbit
3. The inclination of the orbit must be zero.
   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

The first geosynchrous 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.

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.

A geosynchronous orbit(GSO)

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.

Although the terms 'geostationary' and 'geosynchronous' are sometimes used interchangeably, they are not the same technically, geostationary orbit is a subset of all possible geosynchronous orbits.

Both GEO and GSO satellites carry satellite television signals.

GSOs can also forecast the weather and support other types of global communication.

It only takes three GEO or GSO satellites to cover the entire planet because of their altitude. If you’re accessing satellite TV or radio, you don’t have to use the antenna to track the satellite because it’s always going to be in the same place.

Other orbits

Polar Orbit

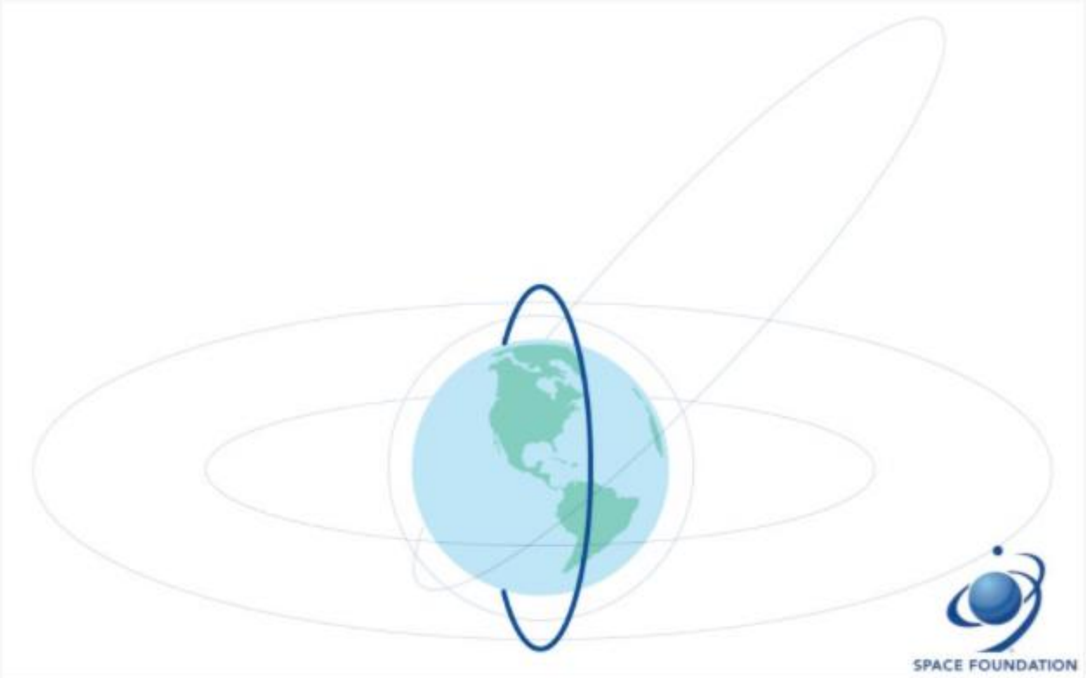
Within 30 degrees of the Earth's poles, the polar orbit is used for satellites providing reconnaissance, weather tracking, measuring atmospheric conditions, and long-term Earth observation.

Sun-Synchronous Orbit (SSO)

A type of polar orbit, SSO objects are synchronous with the sun, such that they pass over an Earth region at the same local time every day.

Highly Elliptical Orbit (HEO)

An HEO is oblong, with one end nearer the Earth and other more distant. Satellites in HEO are suited for communications, satellite radio, remote sensing and other applications.



A depiction of a Polar Orbit/SSO. Credit: The Space Foundation

Apogee and perigee heights

Although not specified as orbital elements, the apogee height and perigee height are often required. As shown in App. B, the length of the radius vectors at apogee and perigee can be obtained from the geometry of the ellipse:

$$r_a = a\,(1 + e) \tag{2.5}$$

$$r_p = a\,(1 - e) \tag{2.6}$$

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

Calculate the apogee and perigee heights for the orbital parameters given assuming the radius of earth R=6371 km

Orbital parameters: eccentricity of the orbit e=0.0011501,semimajor axis=7192.3km

$r_a := a \cdot (1 + e)$ ...Eq. (2.5) $r_a = 7200.6 \cdot km$

$r_p := a \cdot (1 - e)$ ...Eq. (2.6) $r_p = 7184.1 \cdot km$

$h_a := r_a - R$ $\underline{\underline{h_a = 829.6 \cdot km}}$

$h_p := r_p - R$ $\underline{\underline{h_p = 813.1 \cdot km}}$

Orbital Perturbations:

- The orbit described by Keplarian element set so far is elliptical and known as Keplarian orbit.
- Theoretically, an orbit described by Kepler is ideal as Earth is 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.
- Effect of Sun and Moon is more pronounced on geostationary and don't effect low earth orbiting satellites much.
- Where as the atmospheric drag effect is more pronounced for low earth orbit satellites below 1000km and do not effect Geostationary satellites.

Effects of non-Spherical Earth :

- As the shape of Earth is not a perfect sphere(Oblate sphere), it causes some variations in the path followed by the satellites around the primary.
- As the Earth is bulging from the equatorial belt, and keeping in mind that an orbit is not a physical entity, and 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 (point closest to the Earth).
- 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 seen.
- A **graveyard orbit**, also called a **junk orbit** or **disposal orbit**, is an orbit that lies away from common operational orbits. One significant graveyard orbit is a super synchronous orbit well above geosynchronous orbit. Some satellites are moved into such orbits at the end of their operational life to reduce the probability of colliding with operational spacecraft and generating space debris.
- The non-spherical shape leads to the small value of eccentricity (10^{-5}) 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 pronounces.
- The impact of this drag is maximum at the point of perigee.
- Drag (pull towards the Earth) has an effect on velocity of Satellite (velocity reduces).

- This causes the satellite to not 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.

Effect of Non spherical Earth

For a spherical earth of uniform mass, Kepler's third law (Eq. 2.2) gives the nominal mean motion n_0 as

$$n_0 = \sqrt{\frac{\mu}{a^3}} \tag{2.7}$$

The 0 subscript is included as a reminder that this result applies for a perfectly spherical earth of uniform mass. However, it is known that the earth is not perfectly spherical, there being an equatorial bulge and a flattening at the poles, a shape described as an *oblate spheroid*. When the earth's oblateness is taken into account, the mean motion, denoted in this case by symbol n, is modified to (Wertz, 1984).

$$n = n_0 \left[\frac{1 + K_1 (1 - 1.5 \sin^2 i)}{a^2 (1 - e^2)^{1.5}} \right] \tag{2.8}$$

K_1 is a constant which evaluates to 66,063.1704 km². The earth's oblateness has negligible effect on the semimajor axis a, and if a is known, the mean motion is readily calculated. The orbital period taking into account the earth's oblateness is termed the *anomalistic period* (e.g., from perigee to perigee). The mean motion specified in the NASA bulletins is the reciprocal of the anomalistic period. The anomalistic period is

$$P_A = \frac{2\pi}{n} \text{ sec} \tag{2.9}$$

where n is in radians per second.

Calendar

Calendar->Months->Days-> hours

- Calendar Day->based on earth’s motion relative to sun
- Mean sun-Motion of mean sun around earth->Tropical year
- Mean solar day->a day measured with mean sun ->mean solar day
- A tropical year contains365.2422 mean solar days
- Civil calendar -> contains 365 days
- Additional 0.2422 day adds 24.22 days over 100 years and
- Approximately 0.2422*4= 1 day every 4 years
- Therefore there would be a difference of 24 days between calendar year ant tropical year every 100 years
- Julius Ceaser made first attempt to compensate this discrepancy by adding concept of leap year, in which an extra day is added in the month of February whenever the year is divisible by 4->this gave Julian Calendar
- According to which one civil year is 365.25 days on average a reasonable approximation to the tropical year
- But this again created discrepancy after 400 years between civilian and tropical calendar
- To compensate this Pope Gregory created new calendar concept by adding an extra day every 400 years to match civilian and tropical calendar

- Hence a year ending with two zeros and divisible by 400 also considered as leap year to add 3 missed out days every 400 years
- This calendar is known as Gregorian calendar which is the on in use today which has 365.2425 days in an year

In calculations requiring satellite predictions, it is necessary to determine whether a year is a leap year or not, and the simple rule is: If the year number ends in two zeros and is divisible by 400, it is a leap year. Otherwise, if the year number is divisible by 4, it is a leap year.

Example 2.8 Determine which of the following years are leap years: (a) 1987, (b) 1988, (c) 2000, (d) 2100.

solution

a) 1987/4 = 496.75 (therefore, 1987 is not a leap year)

b) 1988/4 = 497 (therefore, 1988 is a leap year)

(c) 2000/400 = 5 (therefore, 2000 is a leap year)

(d) 2100/400 = 5.25 (therefore, 2100 is not a leap year)

Universal Time

Universal time coordinated (UTC) is the time used for all civil timekeeping 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* [see App. J in Wertz (1984)]. In terms of "clock time," the mean solar day is divided into 24 hours, an hour into 60 minutes, and a minute into 60 seconds. Thus there are 86,400 "clock seconds" in a mean solar day. Satellite-orbit epoch time is given in terms of UTC.

Calculate the time in days, hours , minutes and seconds for the epoch day 324.95616765

solution This represents the 324th day of the year plus 0.95616765 mean solar day. The decimal fraction in hours is $24 \times 0.95616765 = 22.948022$; the decimal fraction of this, 0.948022, in minutes is $60 \times 0.948022 = 56.881344$; the decimal fraction of this in seconds is $60 \times 0.881344 = 52.88064$. The epoch is at 22 h, 56 min, 52.88 s on the 324th day of the year.

- UTC is similar to GMT(Greenwich Mean Time and there are many other time reference systems with same mean solar day.
- To avoid confusion a standard representation known as Universal Time (UT) is used

For computations, UT will be required in two forms: as a fraction of a day and in degrees. Given UT in the normal form of hours, minutes, and seconds, it is converted to fractional days as

$$\mathrm{UT}_{\mathrm{day}} = \frac{1}{24}\left(\mathrm{hours} + \frac{\mathrm{minutes}}{60} + \frac{\mathrm{seconds}}{3600}\right) \tag{2.18}$$

In turn, this may be converted to degrees as

$$\mathrm{UT}^{\circ} = 360 \times \mathrm{UT}_{\mathrm{day}} \tag{2.19}$$

Sidereal Time

Sidereal Time is the time measured relative to the fixed stars. It is seen that one complete rotation of earth relative to fixed stars is not a complete rotation relative sun, as earth moves in its orbit around the sun. Measurement of longitude on earth's surface require the use of sidereal time

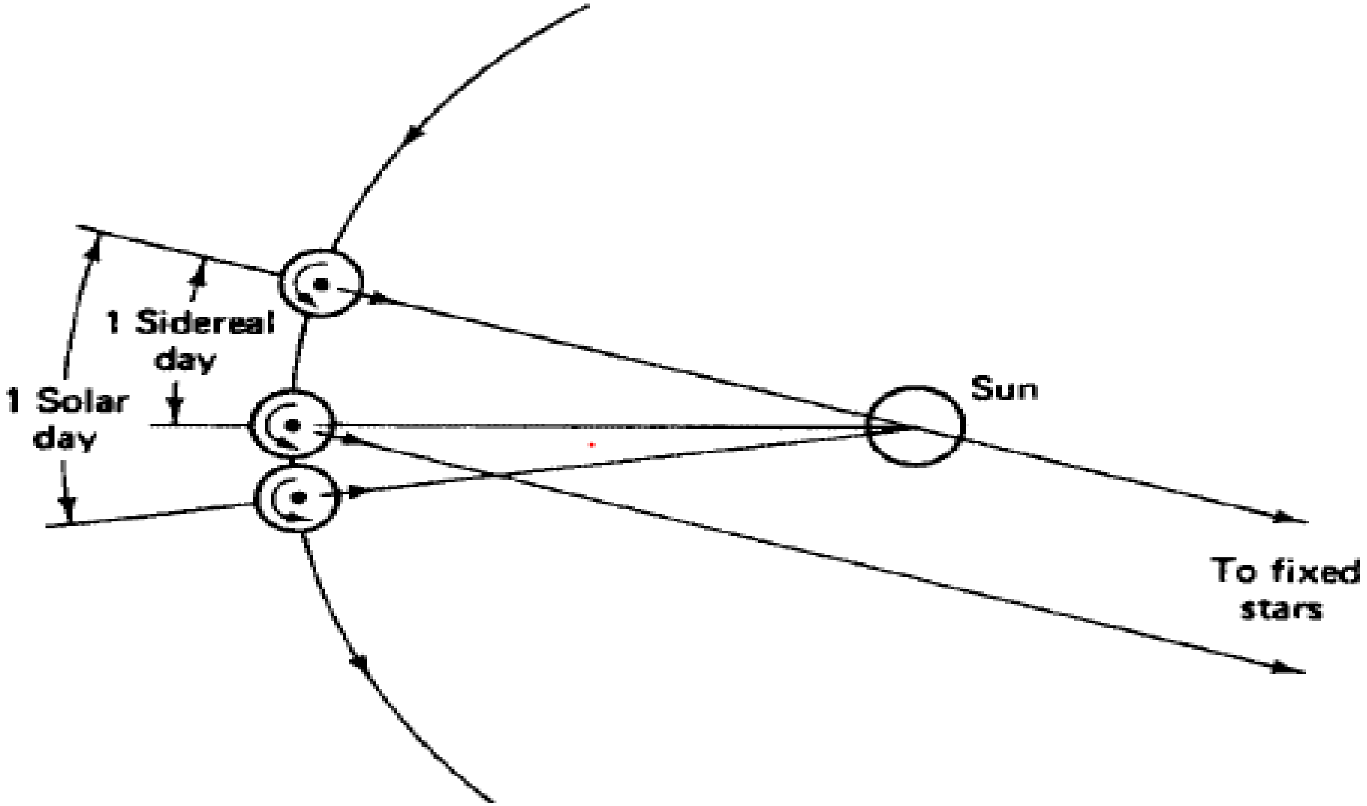


Figure 2.7 A sidereal day, or one rotation of the earth relative to fixed stars, is shorter than a solar day.

The *sidereal day* is defined as one complete rotation of the earth relative to the fixed stars. One sidereal day has 24 sidereal hours, one sidereal hour has 60 sidereal minutes, and one sidereal minute has 60 sidereal seconds. Care must be taken to distinguish between sidereal times and mean solar times which use the same basic subdivisions. The relationships between the two systems, given in Bate

$$
\begin{aligned}
1 \text{ mean solar day} &= 1.0027379093 \text{ mean sidereal days} \\
&= 24^{\mathrm{h}}\ 3^{\mathrm{m}}\ 56^{\mathrm{s}}.55536 \text{ sidereal time} \\
&= 86{,}636.55536 \text{ mean sidereal seconds}
\end{aligned}
$$

$$
\begin{aligned}
1 \text{ mean sidereal day} &= 0.9972695664 \text{ mean solar days} \\
&= 23^{\mathrm{h}}\ 56^{\mathrm{m}}\ 04^{\mathrm{s}}.09054 \text{ mean solar time} \\
&= 86{,}164.09054 \text{ mean solar seconds}
\end{aligned}
$$

The Orbital Plane

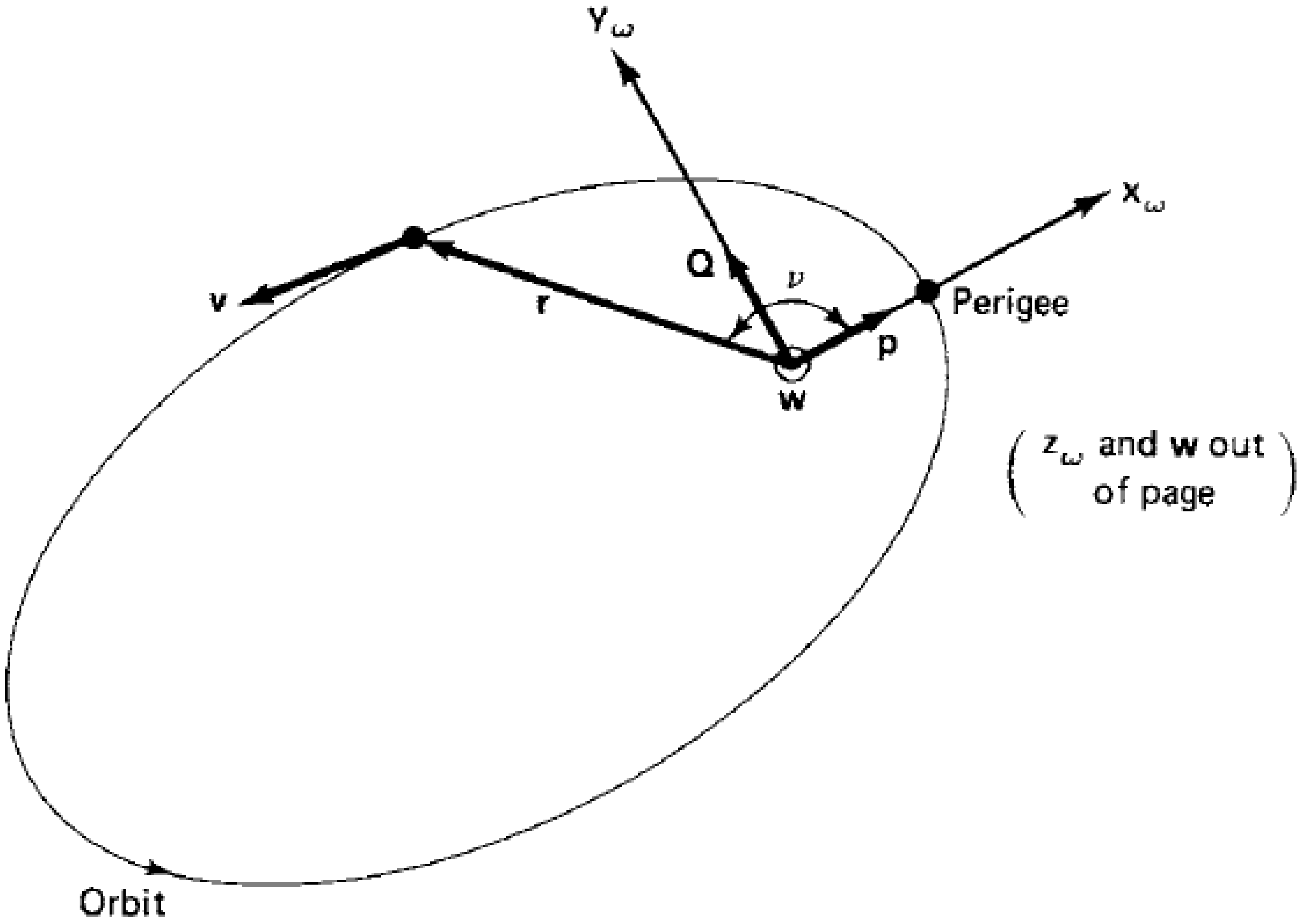


Figure 2.8 Perifocal coordinate system (**PQW** frame).

In the orbital plane, the position vector **r** and the velocity vector **v** specify the motion of the satellite, as shown in Fig. 2.8. For present purposes, only the magnitude of the position vector is required. From the geometry of the ellipse (see App. B), this is found to be

$$r = \frac{a\,(1 - e^2)}{1 + e \cos \nu} \tag{2.23}$$

The true anomaly ν is a function of time, and determining it is one of the more difficult steps in the calculations.

The usual approach to determining ν proceeds in two stages. First, the mean anomaly M at time t is found. This is a simple calculation:

$$M = n\,(t - T) \tag{2.24}$$

Here, n is the mean motion, as previously defined in Eq. (2.8), and T is the time of perigee passage.

The time of perigee passage T can be eliminated from Eq. (2.24) if one is working from the elements specified by NASA. For the NASA elements,

$$M_0 = n\,(t_0 - T)$$

Therefore,

$$T = t_0 - \frac{M_0}{n} \tag{2.25}$$

Hence, substituting this in Eq. (2.24) gives

$$M = M_0 + n\,(t - t_0) \tag{2.26}$$

Consistent units must be used throughout. For example, with n in degrees/day, time $(t - t_0)$ must be in days and M_0 in degrees, and M will then be in degrees.

Once the mean anomaly M is known, the next step is to solve an equation known as *Kepler's equation*. Kepler's equation is formulated in terms of an intermediate variable E, known as the *eccentric anomaly*, and is usually stated as

$$M = E - e \sin E \tag{2.27}$$

This rather innocent looking equation requires an iterative solution, preferably by computer. The following example in Mathcad shows how to solve for E as the root of the equation

$$M - (E - e \sin E) = 0 \tag{2.28}$$

Once E is found, ν can be found from an equation known as *Gauss' equation*, which is

$$\tan\frac{\nu}{2} = \sqrt{\frac{1+e}{1-e}}\tan\frac{E}{2} \tag{2.29}$$

It may be noted that r, the magnitude of the radius vector, also can be obtained as a function of E and is

$$r = a\,(1 - e\cos E) \tag{2.30}$$

For near-circular orbits where the eccentricity is small, an approximation for ν directly in terms of M is

$$\nu \cong M + 2e\sin M + \frac{5}{4}e^2\sin 2M \tag{2.31}$$

Note that the first M term on the right-hand side must be in radians, and ν will be in radians.

The magnitude r of the position vector $\mathbf{r}$ may be calculated by either Eq. (2.23) or Eq. (2.30). It may be expressed in vector form in the *perifocal coordinate system*. Here, the orbital plane is the fundamental plane, and the origin is at the center of the earth (only earth-orbiting satellites are being considered). The positive x axis lies in the orbital plane and passes through the perigee. Unit vector $\mathbf{P}$ points along the positive x axis as shown in Fig. 2.8. The positive y axis is rotated 90° from the x axis in the orbital plane, in the direction of satellite motion, and the unit vector is shown as $\mathbf{Q}$. The positive z axis is normal to the orbital plane such that coordinates xyz form a right-hand set, and the unit vector is shown as $\mathbf{W}$. The subscript ω is used to distinguish the xyz coordinates in this system, as shown in Fig. 2.8. The position vector in this coordinate system, which will be referred to as the **PQW** *frame*, is given by

$$\mathbf{r} = (r \cos \nu)\,\mathbf{P} + (r \sin \nu)\,\mathbf{Q} \tag{2.32}$$

For example Calculate the time of perigee passage for a satellite with Mean motion n= 14.23304826 rev/day, Mean Anomaly M_0 =246.6853 degrees and t_0 =223.79688452 days

Solution: wkt $M_0 = n(t_0 - T)$

i.e $T = t_0 - \frac{M_0}{n}$

Substitute M_0 in degrees , n in degrees/sec

n=n*360

T= 223.79604425

Caculate the position vector 5 seconds after the epoch, for near circular orbit defined by eccentricity e=9.5981 10 ^-3 and mean anamoly at epoch as 204.9779 degrees . The mean motion is n= 14.23304826 rev/day. The semi major axis is given by a=7194.9km

$$n = \frac{14.2171404 \times 2\pi}{86400} \cong 0.001 \text{ rad/s}$$

$$M = 204.9779 + 0.001 \times \frac{180}{\pi} \times 5$$

$$= 205.27^\circ \quad \text{or} \quad 3.583 \text{ rad}$$

Since the orbit is near-circular (small eccentricity), Eq. (2.26) may be used to calculate the true anomaly ν as

$$\nu \cong 3.583 + 2 \times 9.5981 \times 10^{-3} \times \sin 205.27 + {}^5\!/_4 \times 9.5981^2 \times 10^{-6} \sin (2 \times 205.27)$$

$$= 3.575 \text{ rad}$$

$$= 204.81^\circ$$

Applying Eq. (2.23) gives r as

$$r = \frac{7194.9 \times (1 - 9.5981^2 \times 10^{-6})}{1 + (9.5981 \times 10^{-3}) \times \cos 204.81} \underline{\underline{\cong 7257 \text{ km}}}$$

The perifocal system is very convenient for describing the motion of the satellite. If the earth were uniformly spherical, the perifocal coordinates would be fixed in space, i.e., inertial. However, the equatorial bulge causes rotations of the perifocal coordinate system, as described in Sec. 2.8.1. These rotations are taken into account when the satellite position is transferred from perifocal coordinates to *geocentric-equatorial coordinates*, described in the next section.

Geostationary Orbits

Refer previous sections for defn, to fine radius and explanation

An important point to grasp is that there is only one geostationary orbit because there is only one value of a that satisfies Eq. (2.3) for a periodic time of 23 h, 56 min, 4 s. Communications authorities throughout the world regard the geostationary orbit as a natural resource, and its use is carefully regulated through national and international agreements.

Antenna Look angles

- Antenna Look angles for ground station antenna are the Azimuth and Elevation angles required at the antenna so that it points directly at the satellite.
  - In case of elliptical orbits the look angles have to change to track satellites
  - In case of Geostationary Orbits the situation is simpler as satellite is stationary relative to earth.
- In case of Commercial communications involving narrow beam width antennas tracking is needed to compensate movement of satellite about geostationary position.
- In applications such as satellite reception where beam width is quite large no tracking is necessary

The three pieces of information that are needed to determine the look angles for the geostationary orbit are

1. The earth station latitude, denoted here by λ_E
2. The earth station longitude, denoted here by ϕ_E
3. The longitude of the subsatellite point, denoted here by ϕ_{SS} (often this is just referred to as the satellite longitude)

- Points to be considered while calculating look angles.

→ latitudes north will be taken as positive angles, and latitudes south, as negative angles.

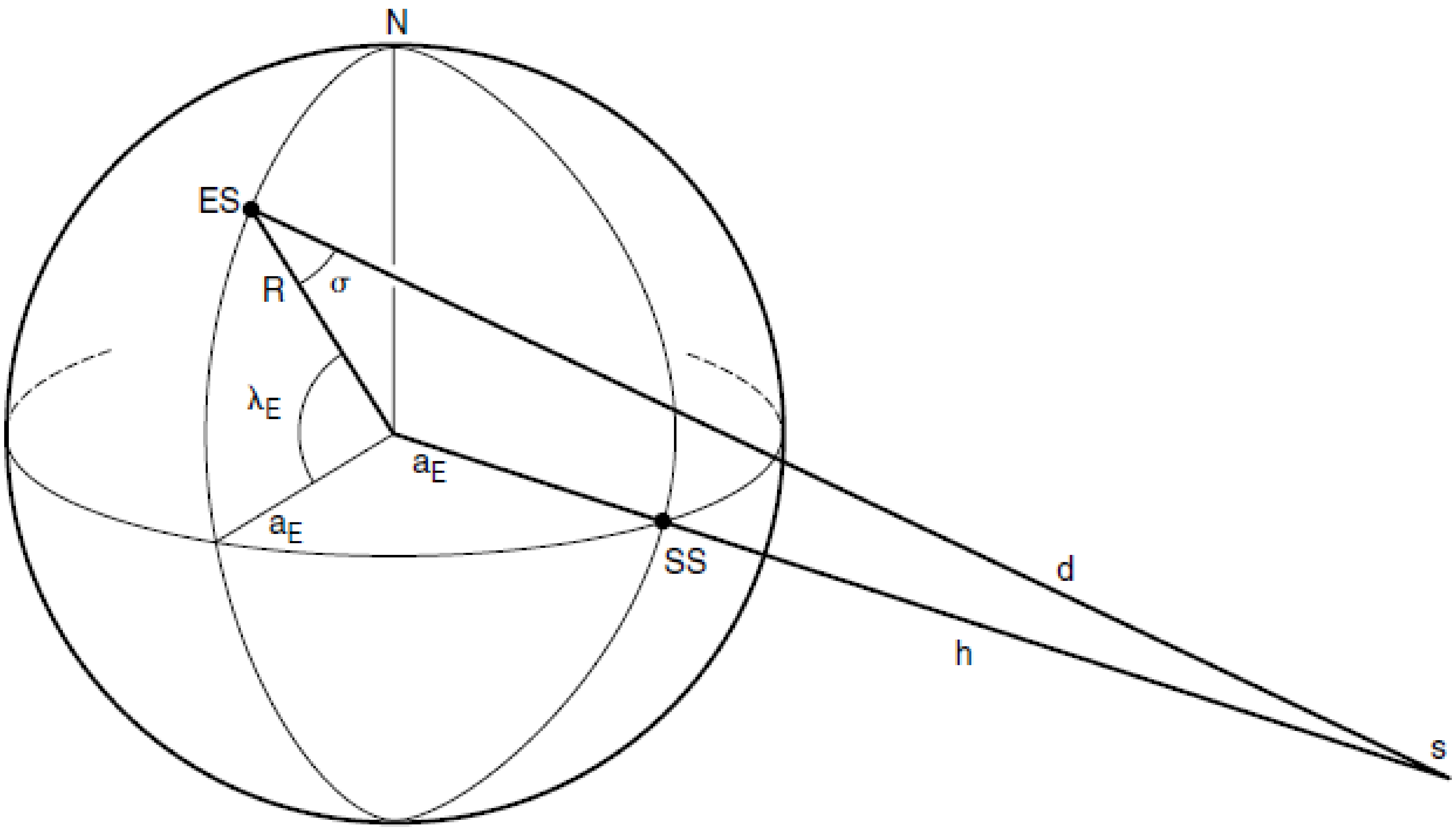
→ Longitudes east of the Greenwich meridian will be taken as positive angles, and longitudes west, as negative angles.

For example, if a latitude of 40°S is specified, this will be taken as −40°, and if a longitude of 35°W is specified, this will be taken as −35°.

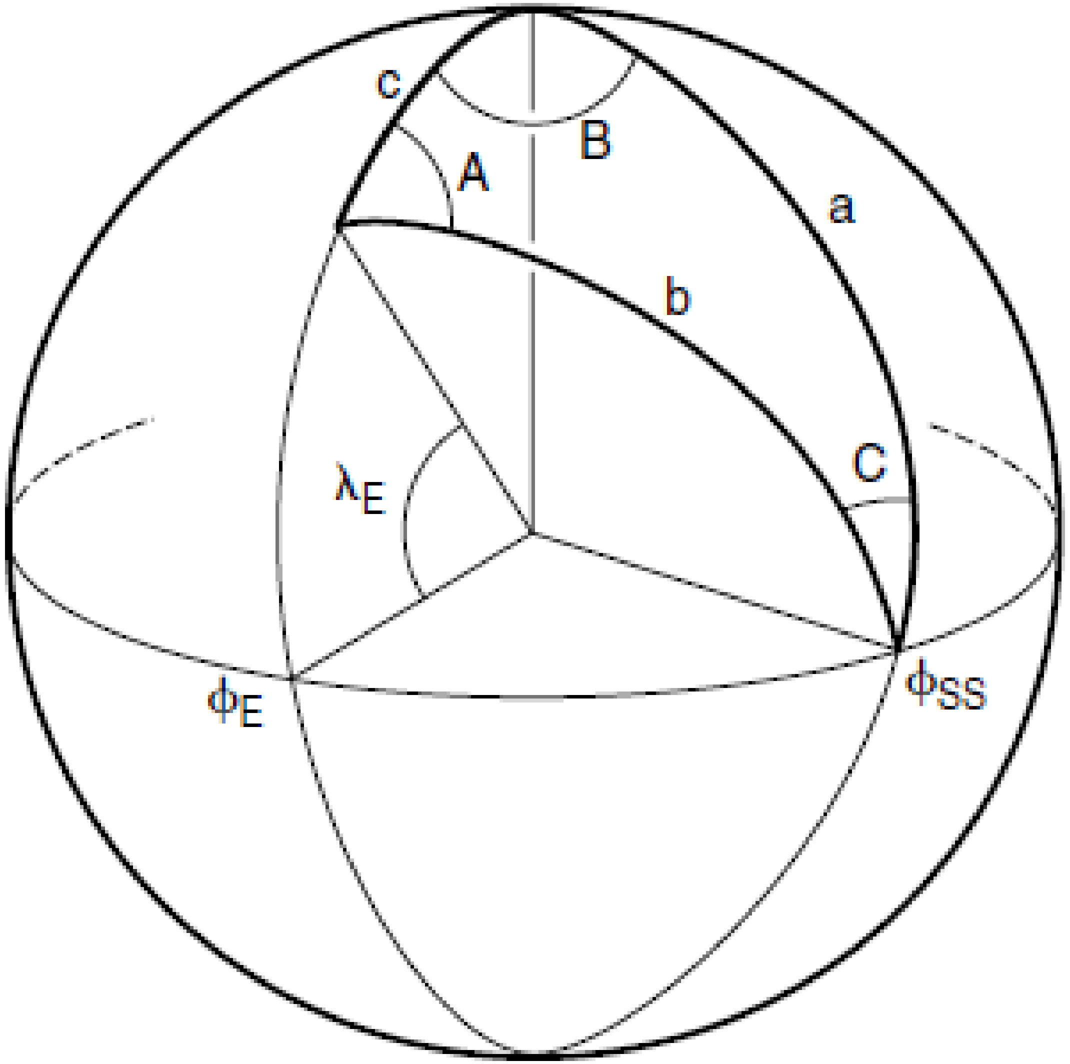
→ when calculating the look angles for lower-earth-orbit (LEO) satellites, it was necessary to take into account the variation in earth's radius.

→ With the geostationary orbit, this variation has negligible effect on the look angles, and the average radius of the earth will be used and this is denoted by R and $\mathbf{R} = 6371$ km

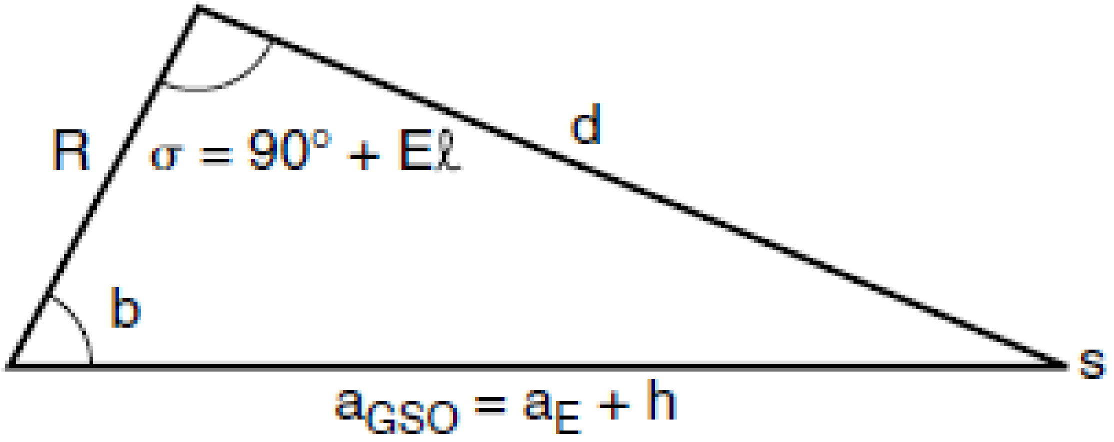
The geometry involving these quantities is shown in the figure below



The Geometry used to determine the look angles for a Geostationary satellite.



The Spherical geometry related to above figure



The plane triangle obtained from figure

Here, ES denotes the position of the earth station

SS the subsatellite point

S the satellite

d is the range from the earth station to the satel lite.

The angle σ is an angle to be determined

Two types of triangles involved in the geometry

The spherical triangle shown in heavy outline in Fig

The plane triangle

In spherical triangle, the sides are all arcs of great circles, defined by the angles subtended by them at the center of the earth

these sides are

Side a is the angle between the radius to the north pole and the radius to the sub satellite point

it is seen that $a = 90°$.

A spherical triangle in which one side is 90° is called a *quadrantal triangle*

Angle b is the angle between the radius to the earth station and the radius to the subsatellite point.

Angle c is the angle between the radius to the earth station and the radius to the north pole.

it is seen that $c = 90° - \lambda_E$.

Six angle viz A, B, C and the angles between the planes as shown in Fig.

Angle A is the angle between the plane containing c and the plane containing b

Angle B is the angle between the plane containing c and the plane con taining a

From Fig. $B = \phi_E - \phi_{SS}$. It will be shown that the maximum value of B is 81.3°

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

To summarize the information known about the spher ical triangle

$$a = 90°$$

$$c = 90° - \lambda_E$$

$$B = \phi_E - \phi_{SS}$$

when the earth station is west of the subsatellite point, B is negative, and when east, B is positive

When the earth station lati tude is north, c is less than 90°, and when south, c is greater than 90°

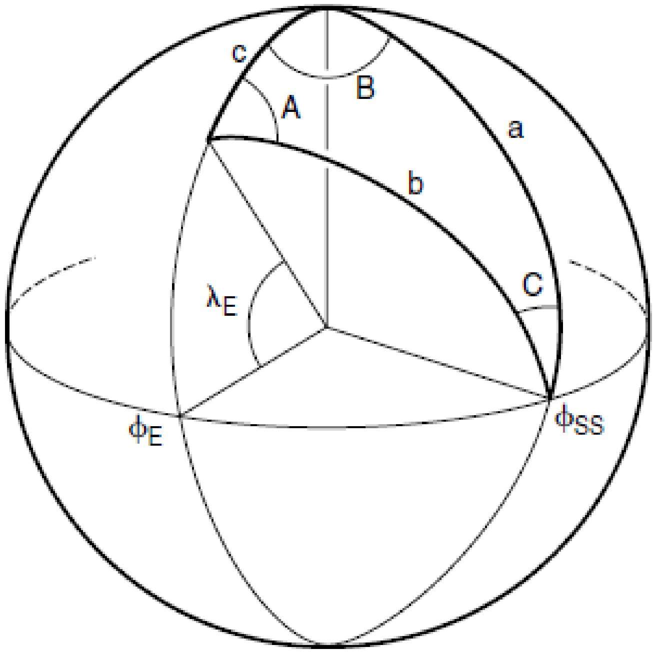
Special rules, known as *Napier's rules,* are used to solve the spherical triangle

Napier's rules gives angle b as

$$b = \arccos(\cos B \cos \lambda_E)$$

and angle A as

$$A = \arcsin\left(\frac{\sin|B|}{\sin b}\right)$$



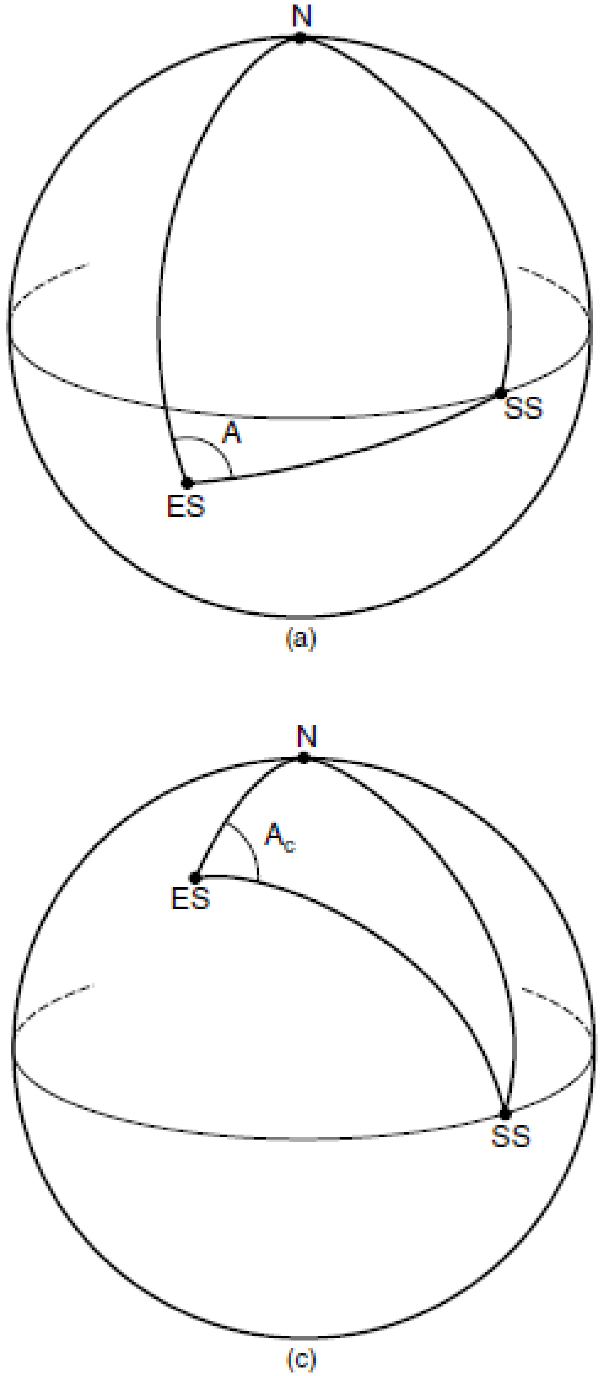


TABLE 3.1 Azimuth Angles A_z from Fig. 3.3

Fig. 3.3	λ_E	B	A_z, degrees
a	<0	<0	A
b	<0	>0	$360° - A$
c	>0	<0	$180° - A$
d	>0	>0	$180° + A$

Two values will satisfy Eq. for A and those are A and $180^\circ - A$,

and these must be determined by inspection

These are shown in Fig.

In Fig. a, angle A is acute (less than 90°), and the azimuth angle is $A_z = A$.

In Fig. b, angle A is acute, and the azimuth is, by inspection, $A_z = 360^\circ - A$.

In Fig. c, angle A_c is obtuse and is given by $A_c = 180^\circ - A$, where A is the acute value

Again, by inspection, $A_z = A_c = 180^\circ - A$.

In Fig. d, angle $\dot{A}_d$ is obtuse and is given by $180^\circ - A$, where A is the acute value

By inspection, $A_z = 360^\circ - A_d = 180^\circ + A$.

In all cases, A is the acute angle returned

These conditions are summarized in Table 3.1.

TABLE 3.1 Azimuth Angles A_z from Fig. 3.3

Fig. 3.3	λ_E	B	A_z, degrees
a	<0	<0	A
b	<0	>0	$360^\circ - A$
c	>0	<0	$180^\circ - A$
d	>0	>0	$180^\circ + A$

Applying the cosine rule for plane triangle
the range d is found to a close approximation:

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

Applying the sine rule for plane triangle
the angle of elevation El is found

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

In summary given Earth satation Lat. ,(   ) Long. (   ), and satellite long. (   )

Step 1) Find angles B, b and A using

$$B := \phi_E - \phi_{SS} \qquad b := \operatorname{acos}(\cos(B)\cdot\cos(\lambda_E)) \qquad A := \operatorname{asin}\left(\frac{\sin(|B|)}{\sin(b)}\right)$$

Step 2) Find Az using the table below and A

TABLE to find **Azimuth Angles A_z**

Fig. 3.3	λ_E	B	A_z, degrees
a	<0	<0	A
b	<0	>0	$360° - A$
c	>0	<0	$180° - A$
d	>0	>0	$180° + A$

Step 3) Find Elevation angle El by finding d

using Radius of earth R=6371 km

and radius of GSO orbit (a_{GSO}) as 42164 km

$$d = \sqrt{R^2 + a_{GSO}{}^2 - 2Ra_{GSO}\cos b} \qquad El = \arccos\left(\frac{a_{GSO}}{d}\sin b\right)$$

Example 3.1 A geostationary satellite is located at 90°W. Calculate the azimuth angle for an earth station antenna at latitude 35°N and longitude 100°W. Also find and the elevation angle by finding the distance d.

solution The given quantities are

$$\phi_{SS} := -90 \cdot \deg \qquad \phi_E := -100 \cdot \deg \qquad \lambda_E := 35 \cdot \deg$$

$$B := \phi_E - \phi_{SS} \qquad B = -10 \cdot \deg$$

$$b := \operatorname{acos}\left(\cos(B) \cdot \cos(\lambda_E)\right) \qquad b = 36.2 \cdot \deg$$

$$A := \operatorname{asin}\left(\frac{\sin(|B|)}{\sin(b)}\right) \qquad A = 17.1 \cdot \deg$$

$$A_z := 180 \cdot \deg - A \qquad A_z = 162.9 \cdot \deg$$

$$d := \sqrt{R^2 + a_{GSO}{}^2 - 2 \cdot R \cdot a_{GSO} \cdot \cos(b)} \qquad d = 37{,}215\ \mathrm{km}$$

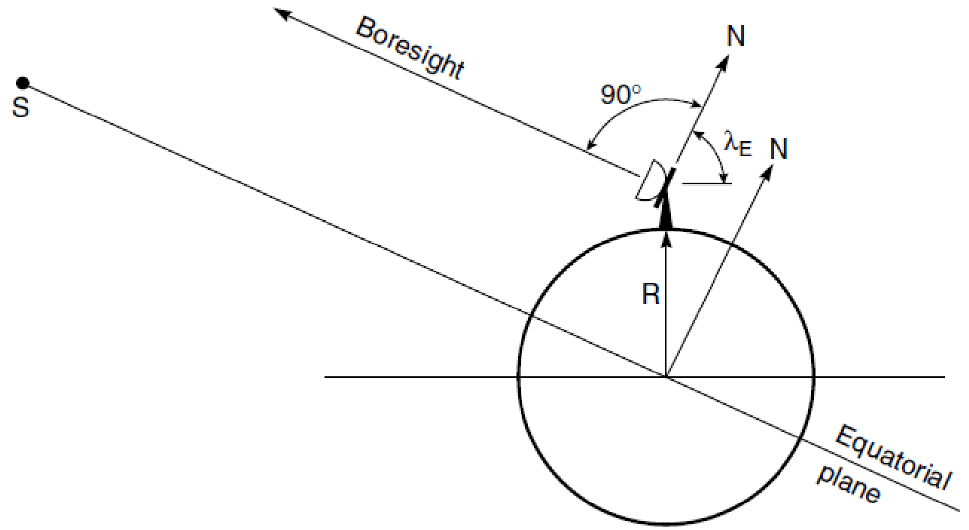
$$El := \operatorname{acos}\left(\frac{a_{GSO}}{d} \cdot \sin(b)\right) \qquad El = 48 \cdot \deg$$

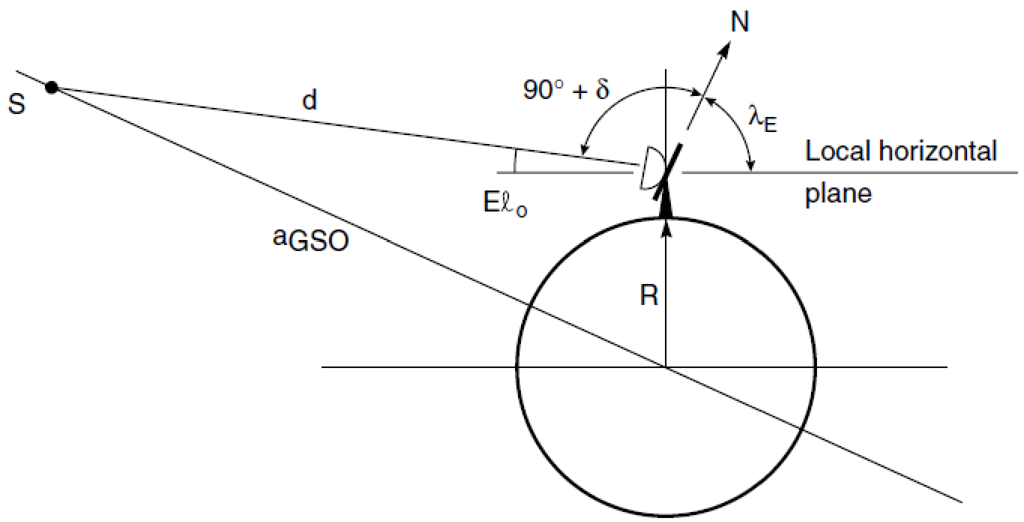
Polar Mount antennas

steerable home antenna use of separate azimuth and elevation actuators and hence expensive. Instead, a single actuator is used which moves the antenna in a circular arc. This is known as a *polar mount antenna*. The antenna pointing can only be accurate for one satellite and some pointing error must be accepted for satellites on either side of this.

With the polar mount antenna, the dish is mounted on an axis termed the *polar axis* such that the antenna boresight is normal to this axis, as shown in Fig.

The polar mount is aligned along a true north line as shown in Fig. with the boresight pointing due south.





The angle between the polar mount and the local horizontal plane is set equal to the earth station latitude λ_E

This makes the bore sight lie parallel to the equatorial plane.

Next, the dish is tilted at an angle δ(referred to as the *declination*) relative to the polar mount until the boresight is pointing at a satellite position due south of the earth station.

The required angle of tilt is found as follows:

From the geometry of Fig. *b*,

$$\delta = 90^\circ - El_0 - \lambda_E \quad \text{--- A}$$

where El_0 is the angle of elevation required for the satellite position due south of the earth station.

But for the due south situation, angle B in Eq. $B = \phi_E - \phi_{SS}$ is equal to zero

hence $b = \arccos(\cos B \cos \lambda_E)$ gives $b = \lambda_E$.

Hence elevaton angle is given by

$$El = \arccos\left(\frac{a_{GSO}}{d}\sin b\right) \quad \text{i.e} \quad \cos El_0 = \frac{a_{GSO}}{d}\sin \lambda_E \quad \text{-------B}$$

Combining Eqn.s A abd B angle of tilt can be expressed as

$$\delta = 90^\circ - \arccos\left(\frac{a_{GSO}}{d} \sin \lambda_E\right) - \lambda_E$$

Polar mount antenna, Limits of visibility, Earth eclipse of satellite, Sun transit outage.-Refer Text1 Chapter3

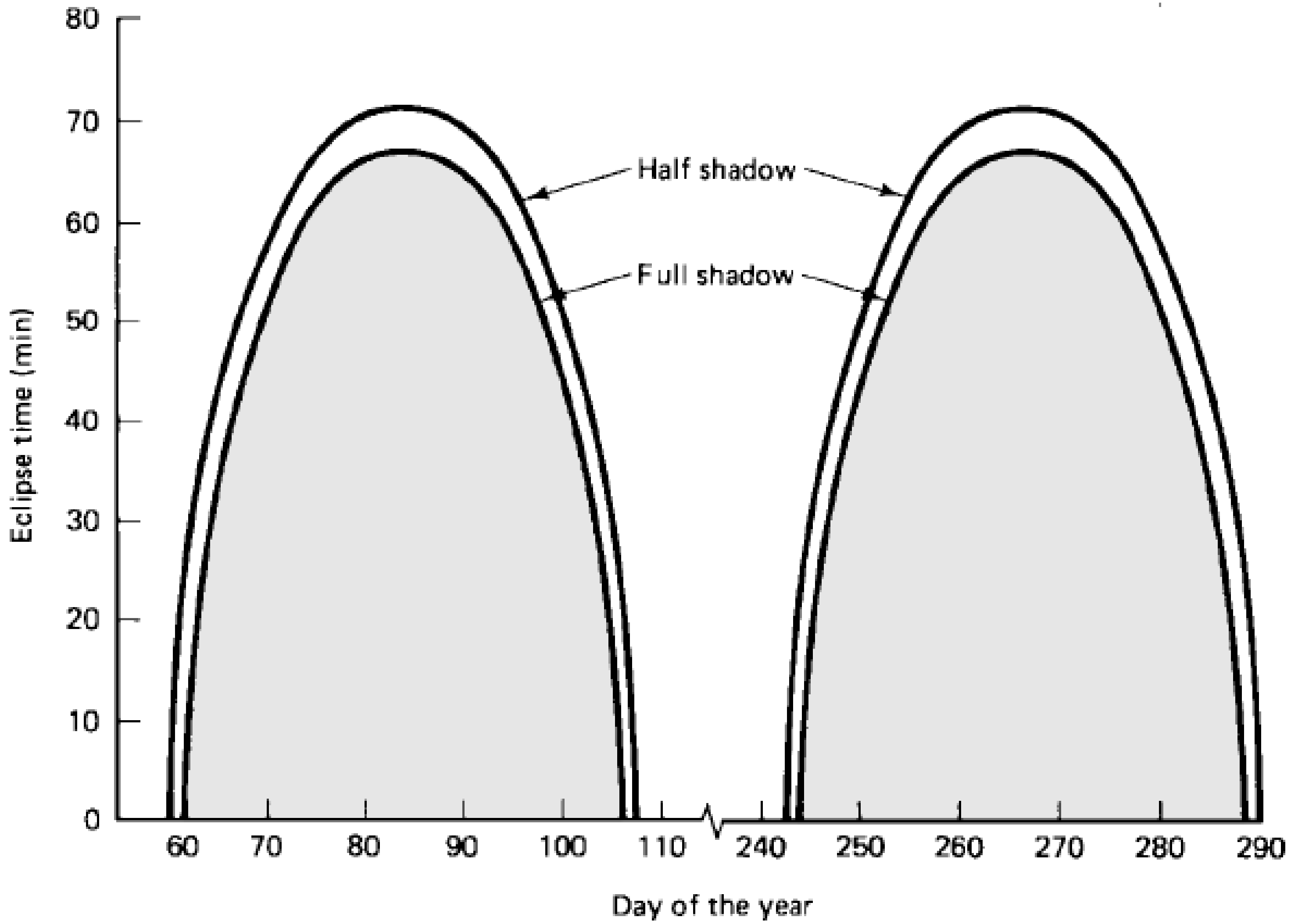


Figure 7.3 Satellite eclipse time as a function of the current day of the year. (*From Spilker, 1977. Reprinted by permission of Prentice-Hall, Englewood Cliffs, NJ.*)

Module2

Satellite Subsystems: Transponders, Satellite antennas (concept only), Satellite Control System, Power system, Telemetry, Tracking and Command system (TTC), Structures, Thermal Control System, Reliability, Steps in satellite mission realization. Test and Evaluation of the Satellite components, Satellite subsystems and Satellite as a system.

Radio wave Propagation: Atmospheric Losses, Ionospheric effects, Rain Attenuation, Other Propagation Impairments

Introduction

A satellite communications system can be broadly divided into two segments,

The ground segment –

The space segment – include the satellites, but it also includes the ground facilities needed to keep the satellites operational, referred to as the *tracking, telemetry, and command* (TT&C) facilities.

In many networks it is common practice to employ a ground station solely for the purpose of TT&C.

The equipment carried aboard the satellite also can be classified according to function

For example

The Payload refers to the equipment used to provide the service for which the satellite has been launched.

The *bus* refers not only to the vehicle which carries the payload but also to the various subsystems which provide the power, attitude control, orbital control, thermal control, and command and telemetry functions required to service the payload.

In a communications satellite,

the equipment which provides the connecting link between the satellite's transmit and receive antennas is referred to as the *transponder*.

The transponder forms one of the main sections of the payload, the other being the antenna subsystems.

Power supply, Thermal control and Transponder –Refer Text1 Chapter7