Satellite Communication(EC0702)
Unit-1
B.Tech (Electronics and Communication)
Semester-VII

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Introduction to Satellite Communication and Satellite Orbits and Orbital Parameters

Semester-7

Outline

- Introduction
- Basics
- Applications of Satellite Communication
- Frequency Allocation
- Types of orbits

What is a satellite?

- The word "satellite" means a smaller, space-based object moving in a loop (an orbit) around a larger object.
- The Moon is a natural satellite of Earth, for example, because gravity locks it in orbit around our planet.
- Artificial (human-built) satellites are that which move in precisely calculated paths, circular or elliptical (oval), at various distances from Earth, usually well outside its atmosphere.

Why satellite are required?

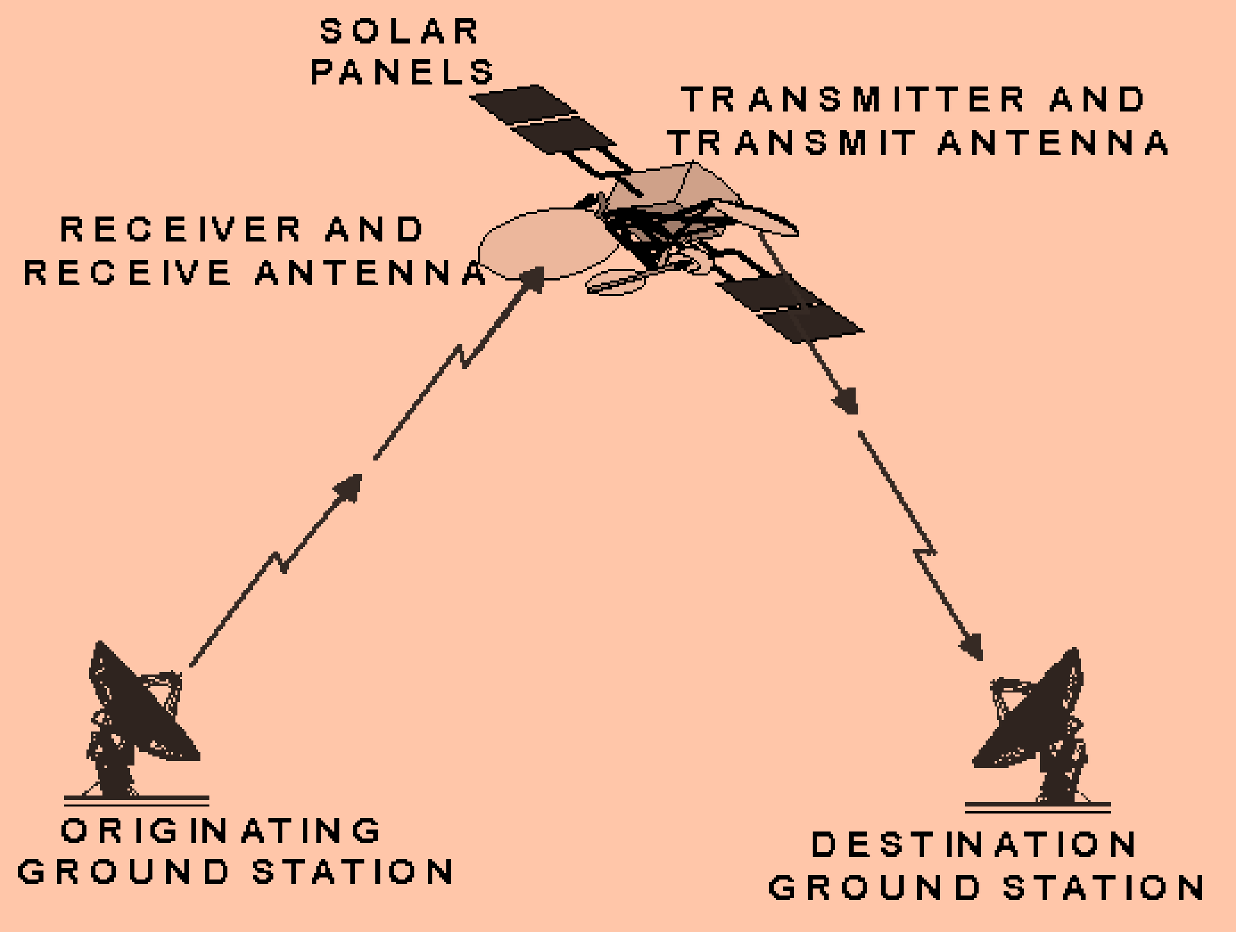
- We put satellites in space to overcome the various limitations of Earth's geography—it helps us step outside our Earth-bound lives.

- If you want to make a phone call from the North Pole, you can fire a signal into space and back down again, using a communications satellite as a mirror to bounce the signal back to Earth and its destination.

- If you want to survey crops or ocean temperatures, you could do it from a plane, but a satellite can capture more data more quickly because it's higher up and further away.

- if you want to drive somewhere you've never been before, you could study maps or ask random strangers for directions, or you could use signals from satellites to guide you instead. Satellites, in short, help us live within Earth's limits precisely because they themselves sit *outside* them.

Satellite Communication Process



Frequency Band allocation for Satellite Operation

- Allocation of frequencies to satellite services is a complicated process which requires international coordination and planning.

- To implement this frequency planning, the world is divided into three regions:

  Region 1: Europe, Africa and Mongolia
  Region 2: North and South America and Greenland
  Region 3: Asia (excluding region 1 areas), Australia and south-west Pacific

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

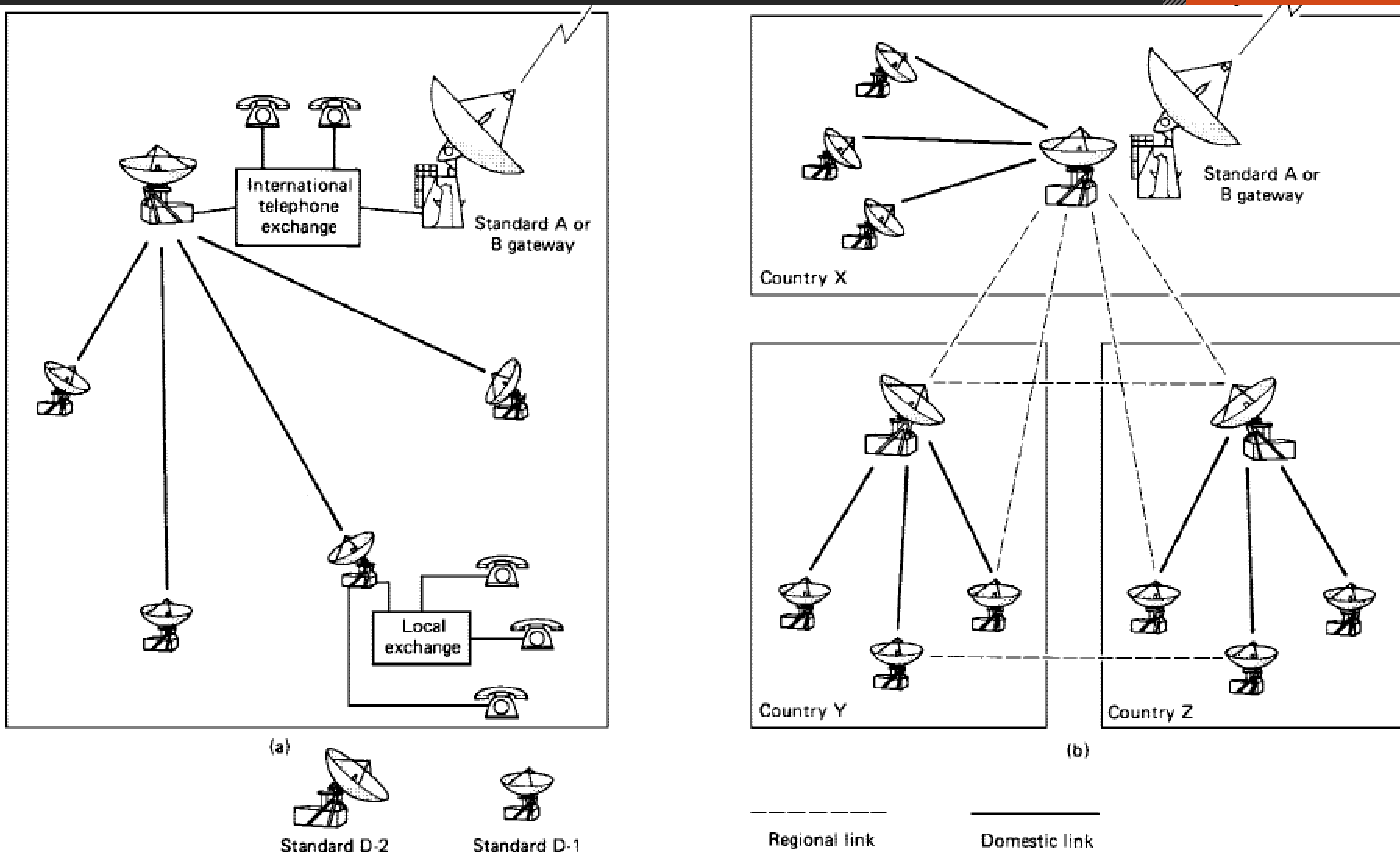
- Ku- Direct Broadcast Satellite
- C- Fixed Satellite Services
- VHF, L- Mobile and navigation services

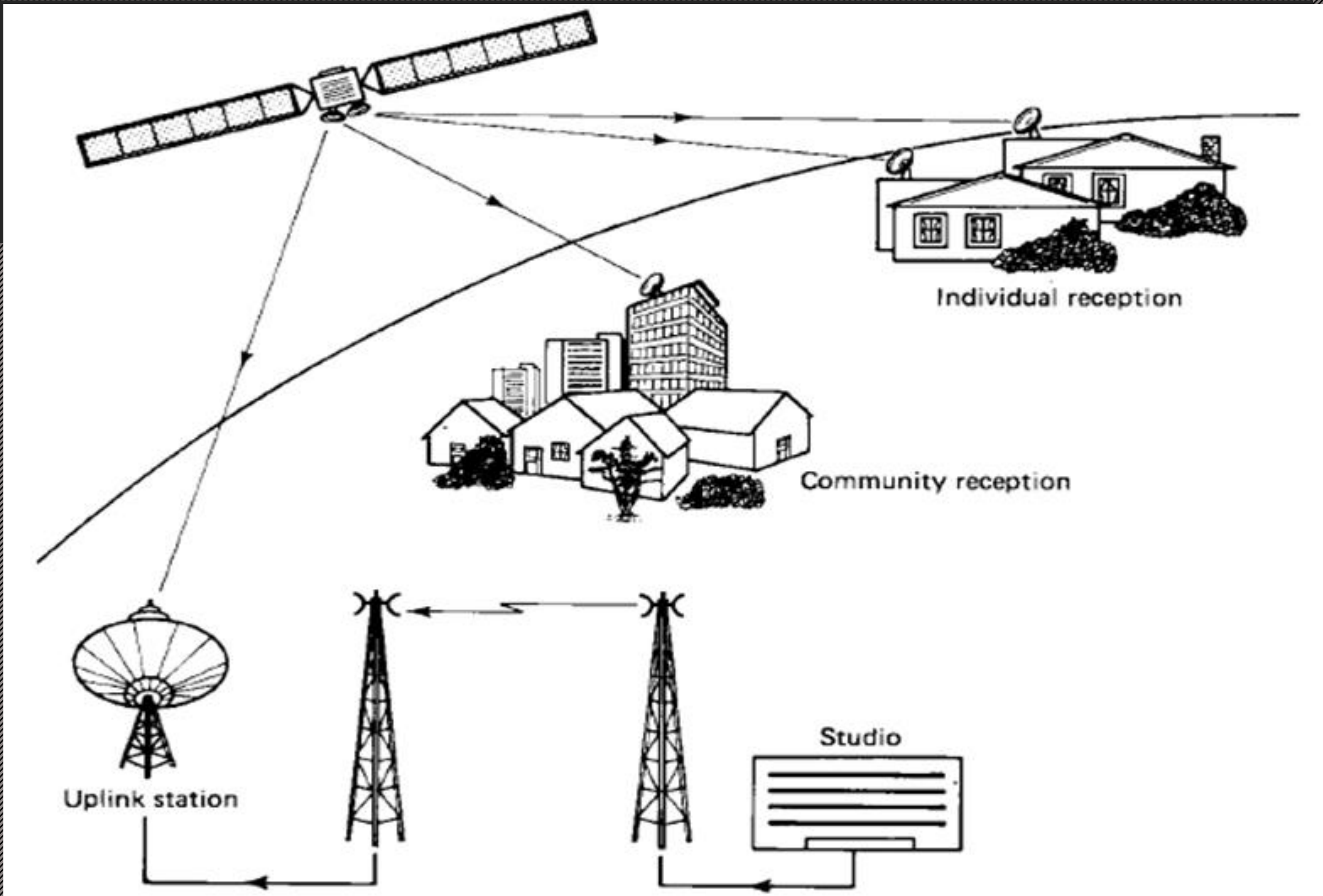
The L band is used for mobile satellite services and navigation systems. For the fixed satellite service in the C band, the most widely used subrange is approximately 4 to 6 GHz. The higher frequency is nearly always used for the uplink to the satellite, for reasons which will be explained later, and common practice is to denote the C band by 6/4 GHz, giving the uplink frequency first. For the direct broadcast service in the Ku band, the most widely used range is approximately 12 to 14 GHz, which is denoted by 14/12 GHz.

- Fixed Satellite Service(Telephone network)
- Broadcasting Satellite Service(Direct to Home)
- Mobile Satellite Service(Mobile)
- Navigational satellite services(Global positioning system)
- Meteorological satellite services(to monitor the **weather** and climate of the Earth)

Applications of Satellites

- Weather Forecasting
- Radio & TV Broadcasting
- Military Satellites
- Navigation Satellites
- Global Telephone
- Connecting Remote Areas
- Global Mobile Communication


International telephone exchange
Standard A or B gateway
Local exchange
(a)
Standard D-2
Standard D-1
Country X
Standard A or B gateway
Country Y
Country Z
(b)
Regional link
Domestic link



Components of direct broadcasting satellite system

Orbits and launching methods

- Satellites which orbits the earth follow the same laws the govern the motion of planets around the sun.
- From careful observations of planetary motion, John Kepler(1571-1630) was able to derive three laws.
- Kepler laws are quite generally applicable to any two bodies in space which interact through gravitation.
- The more the massive of the two bodies is referred to as primary, the other, the secondary or satellite.

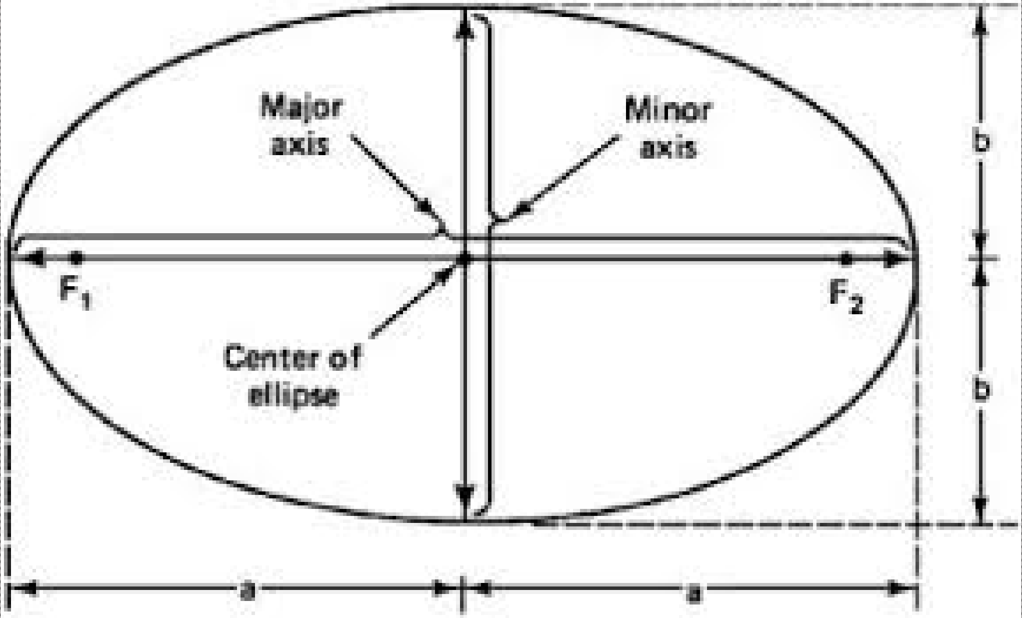
Kepler's First Law

- *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 F_1 and F_2 in Fig

- *The center of mass of the two-body system, termed the barycenter, is always centered on one of the foci.(*The *barycenter* is the center of mass of two or more bodies that are orbiting each other, which is the point around which they both orbit*)*
- 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.

Planets, moon and satellites follow elliptic orbits



The foci F_1 and F_2, the semimajor axis *a*, and the semiminor axis *b*

Orbital Elements

Orbital elements are the parameters, which are helpful for describing the orbital motion of satellites. Following are the **orbital elements**.

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

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

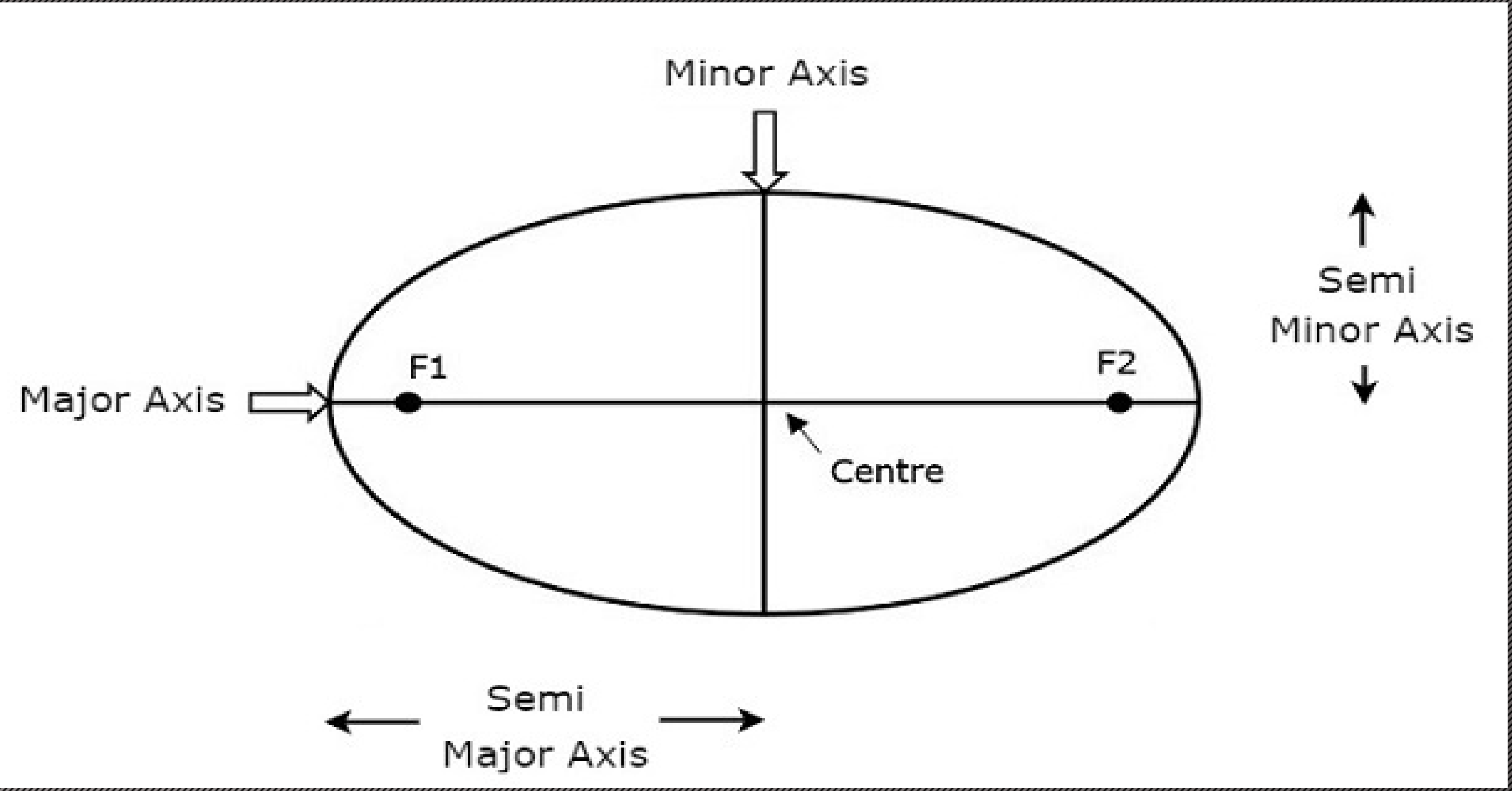
Orbital Elements

- Parameters associated with the 1st law of Kepler:

- ***Semi-Major axis (a):*** It is the longest diameter, a line that runs through the center and both foci, its ends being at the widest points of the shapes. This line joins the points of apogee(The point farthest from earth).
- The semi-major axis a is half of the greatest width of the ellipse.

- Semi-Minor axis (b): the line joining the points of perigee (The point of closest approach to earth) is called the Semi-Minor axis.

Orbital Elements

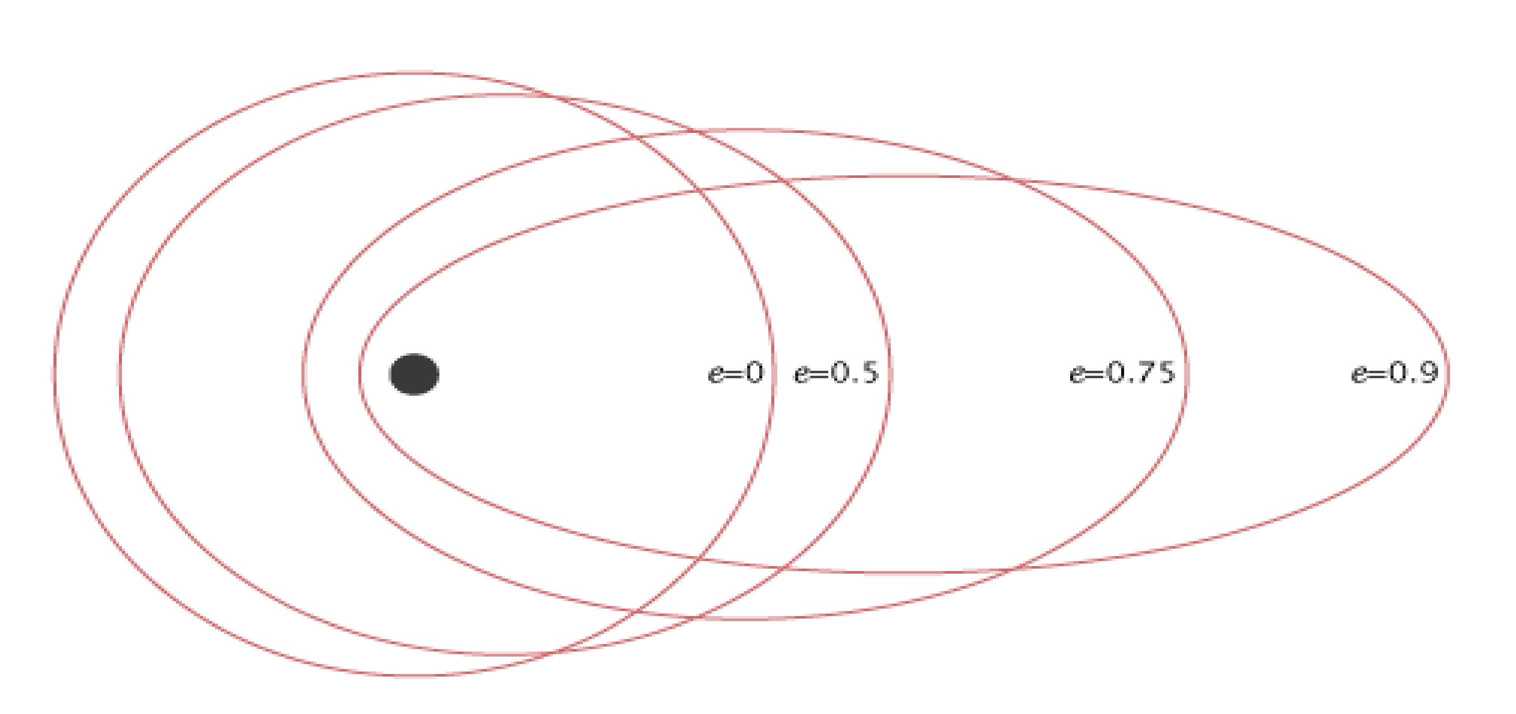


Orbital Elements

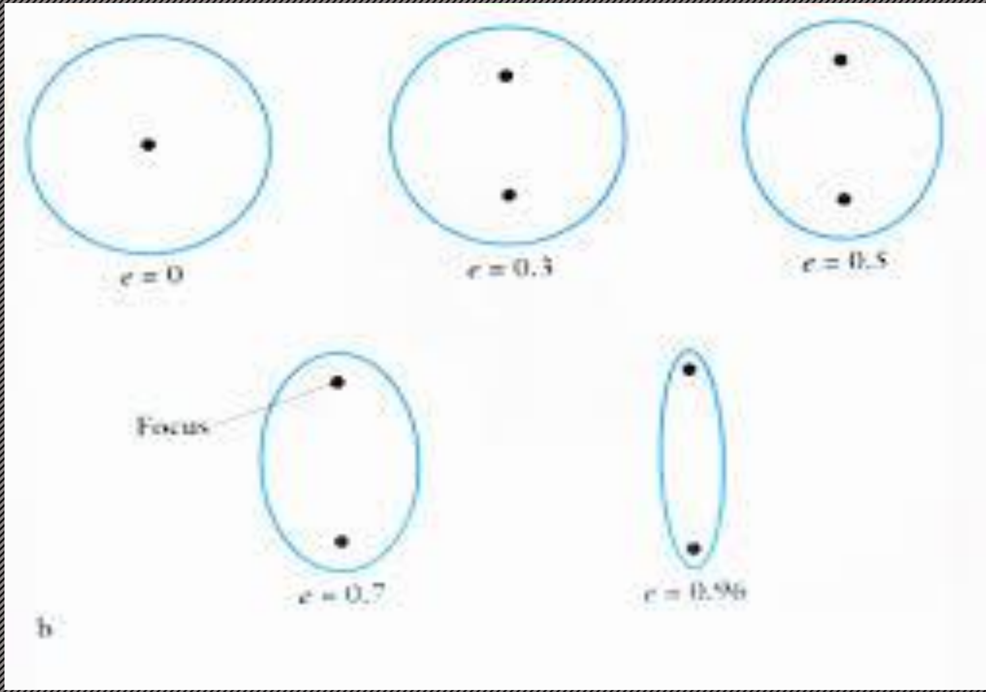
Eccentricity (e): it defines how stretched out an ellipse is from a perfect circle.

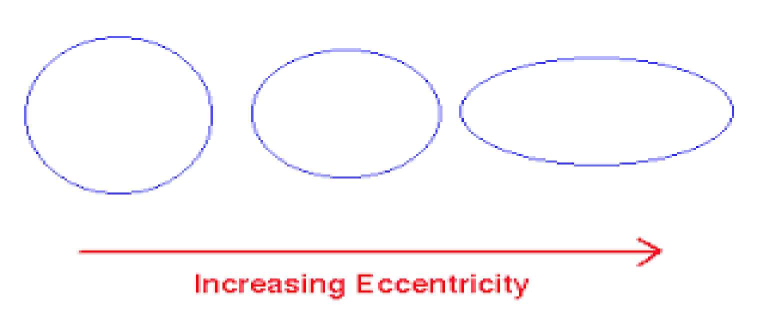
The value of e could be determined by: e = (√a2 - b2) / a

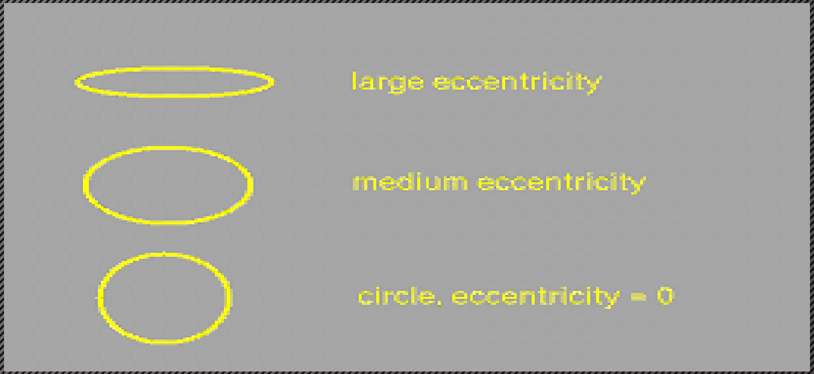
For an elliptical orbit, $0 < e < 1$. For $e=0$ the orbit becomes circular.



Eccentricity



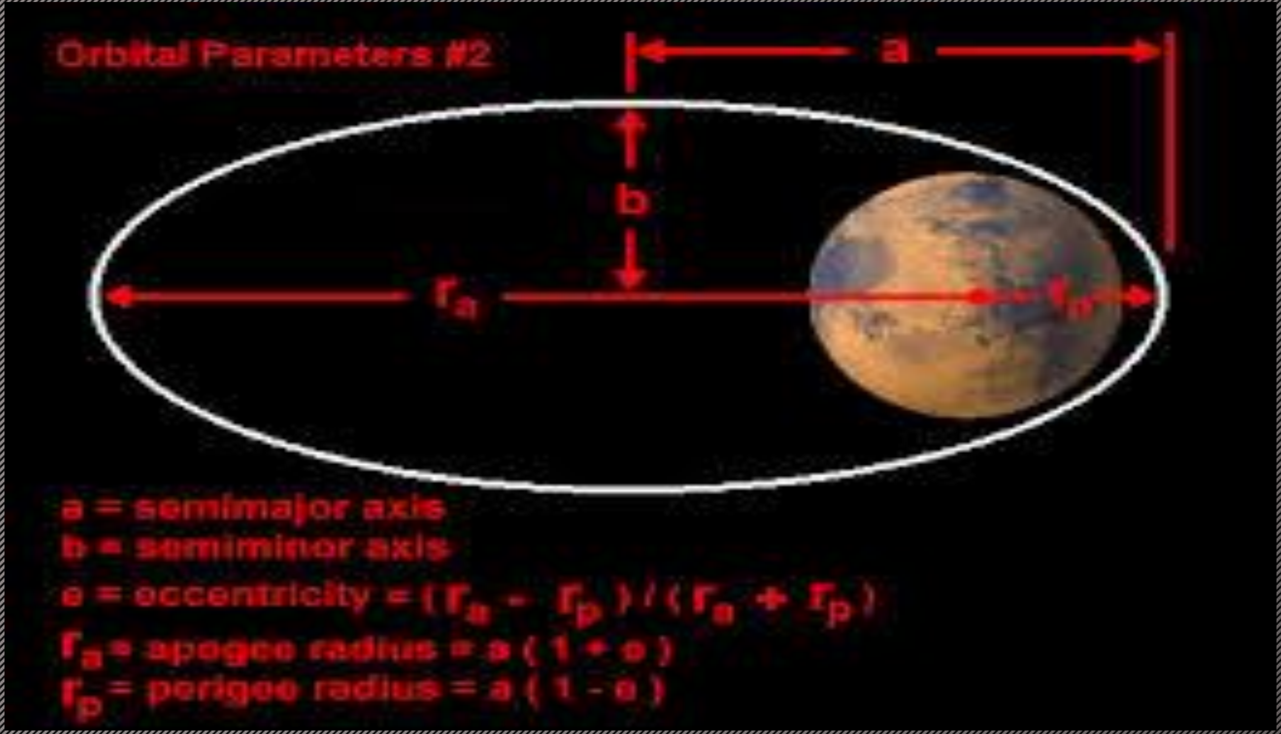




The main two elements that define the shape and size of the ellipse:

- Eccentricity (*e*)—shape of the ellipse, describing how much it is elongated compared to a circle.
- Semi major axis (*a*)—the sum of the periapsis and apoapsis distances divided by two. For circular orbits, the semi major axis is the distance between the centers of the bodies, not the distance of the bodies from the center of mass.

Orbital Elements



- Apogee means the furthest distance of a satellite gets from Earth in its orbit.
- Apogee is related to the semi-major axis and eccentricity.
- ra(length of radius vector at apogee)=a(1+e)
- ha(apogee height)= ra- R(earth radius)
- Perigee means the closest distance of a satellite gets to Earth in its orbit.
- rp(length of radius vector at Perigee)=a(1-e)
- hp (perigee height)= rp- R(earth radius)

- ***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*** center of the Earth. It is the major axis of the orbit. One-half of this line's length is the semi-major axis equivalents to Satellite's mean distance from the Earth.

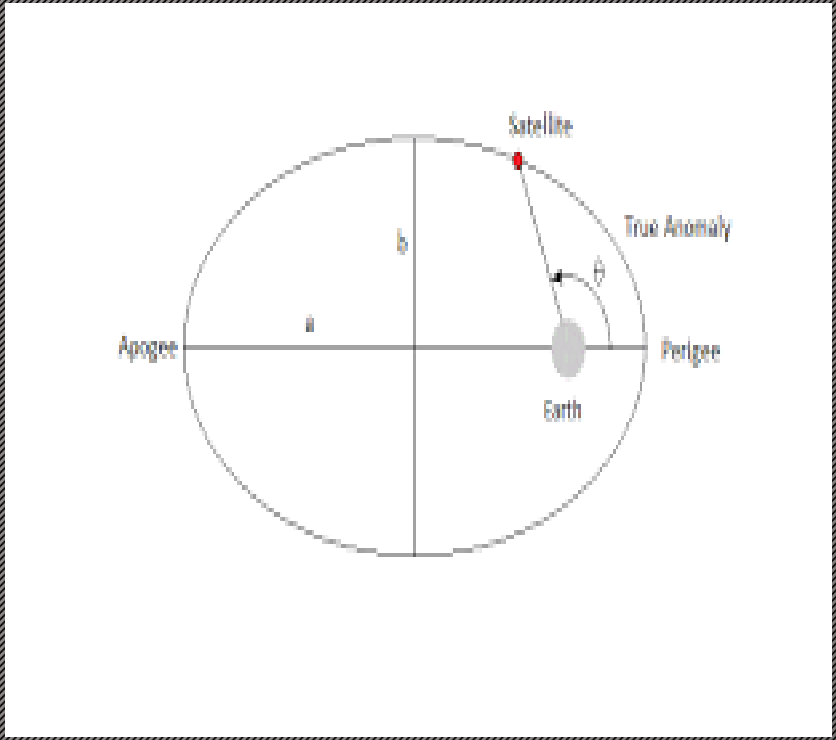
Orbital Elements

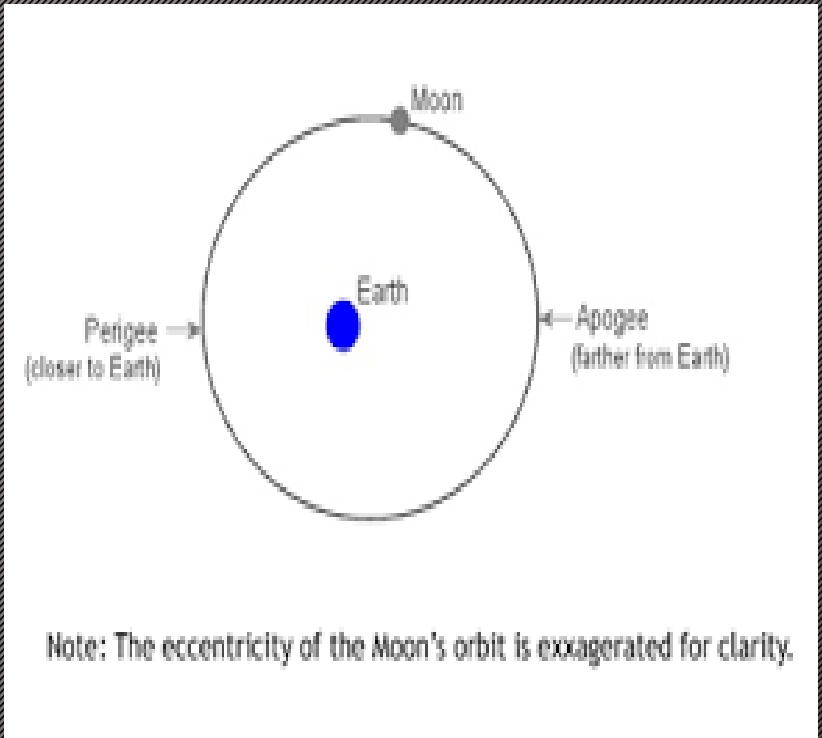
Mean Anomaly

For a satellite, the point which is closest from the Earth is known as Perigee. **Mean anomaly** (M) gives the average value of the angular position of the satellite with reference to perigee.

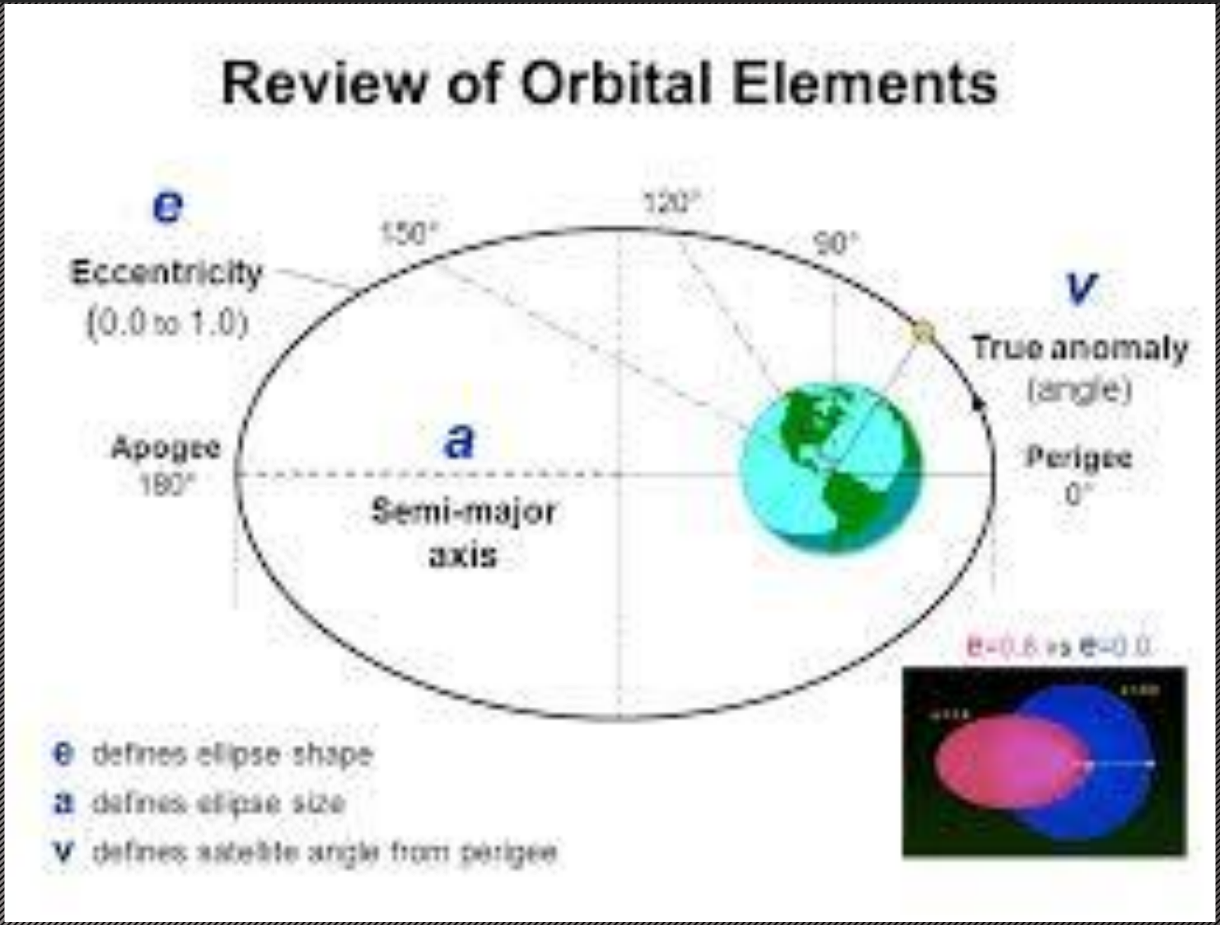
If the orbit is circular, then Mean anomaly gives the angular position of the satellite in the orbit. But, if the orbit is elliptical, then calculation of exact position is very difficult. At that time, Mean anomaly is used as an intermediate step.

Orbital Elements





Orbital Elements



Orbital Elements

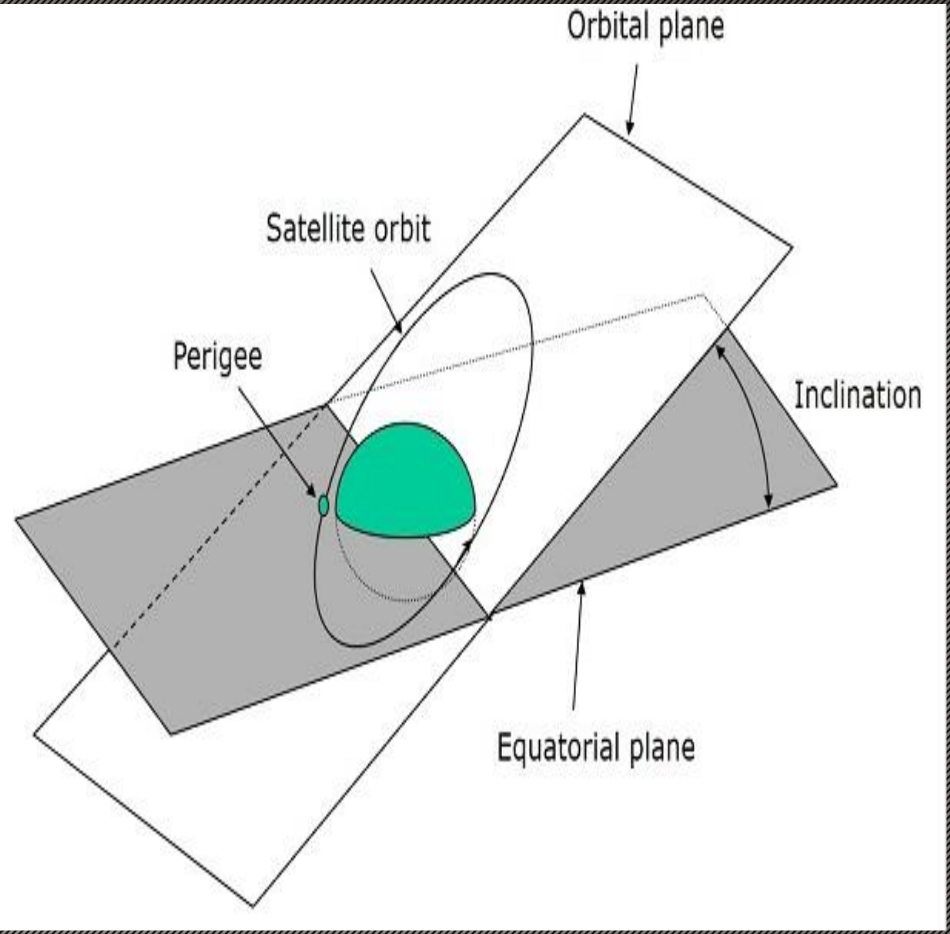
Argument of Perigee

Satellite orbit cuts the equatorial plane at two points. First point is called as **descending node**, where the satellite passes from the northern hemisphere to the southern hemisphere. Second point is called as **ascending node**, where the satellite passes from the southern hemisphere to the northern hemisphere.

Argument of perigee (ω) is the angle between ascending node and perigee. If both perigee and ascending node are existing at same point, then the argument of perigee will be zero degrees.

Argument of perigee is measured in the orbital plane at earth's center in the direction of satellite motion.

Orbital Elements



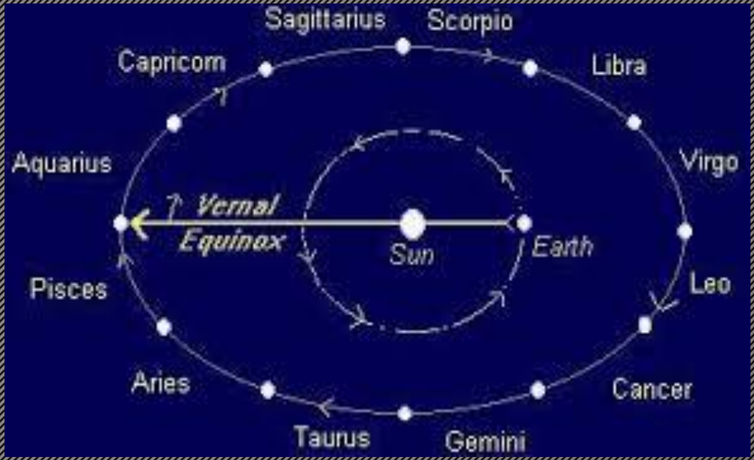
Inclination

The angle between orbital plane and earth's equatorial plane is known as **inclination (i)**. It is measured at the ascending node with direction being east to north. So, inclination defines the orientation of the orbit by considering the equator of earth as reference

Longitude of the ascending node(Right ascension of the ascending node) (Ω)—

The angle measured east ward in the equatorial plane from the reference line (line of Aries) to the ascending node.

The First Point of *Aries*, is the location of the *vernal equinox*, used as *a* reference point in celestial coordinate systems.(*Vernal equinox*, two moments in the year when the Sun is exactly above the Equator and day and night are of equal length)

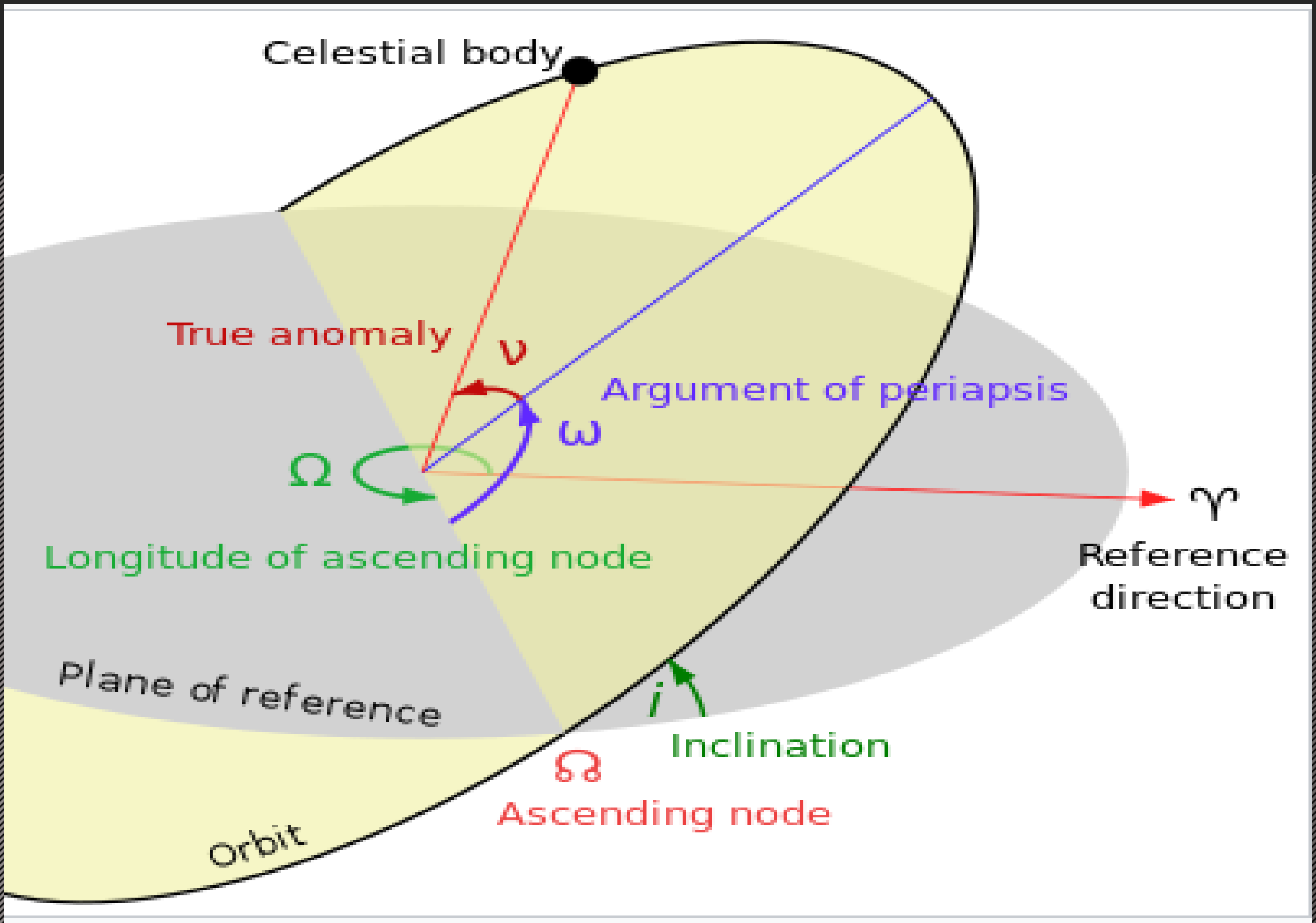


Right Ascension of Ascending node

We know that **ascending node** is the point, where the satellite crosses the equatorial plane while going from the southern hemisphere to the northern hemisphere.

Right Ascension of ascending node **(Ω)** is the angle between line of Aries and ascending node towards east direction in equatorial plane. Aries is also called as vernal and equinox.

- Satellite's **ground track** is the path on the surface of the Earth, which lies exactly below its orbit. The ground track of a satellite can take a number of different forms depending on the values of the orbital elements



Celestial body is any natural **body** outside of the Earth's atmosphere. Easy examples are the Moon, Sun, and the other planets of our solar system

Orbits

There are four types of orbits based on the angle of inclination.

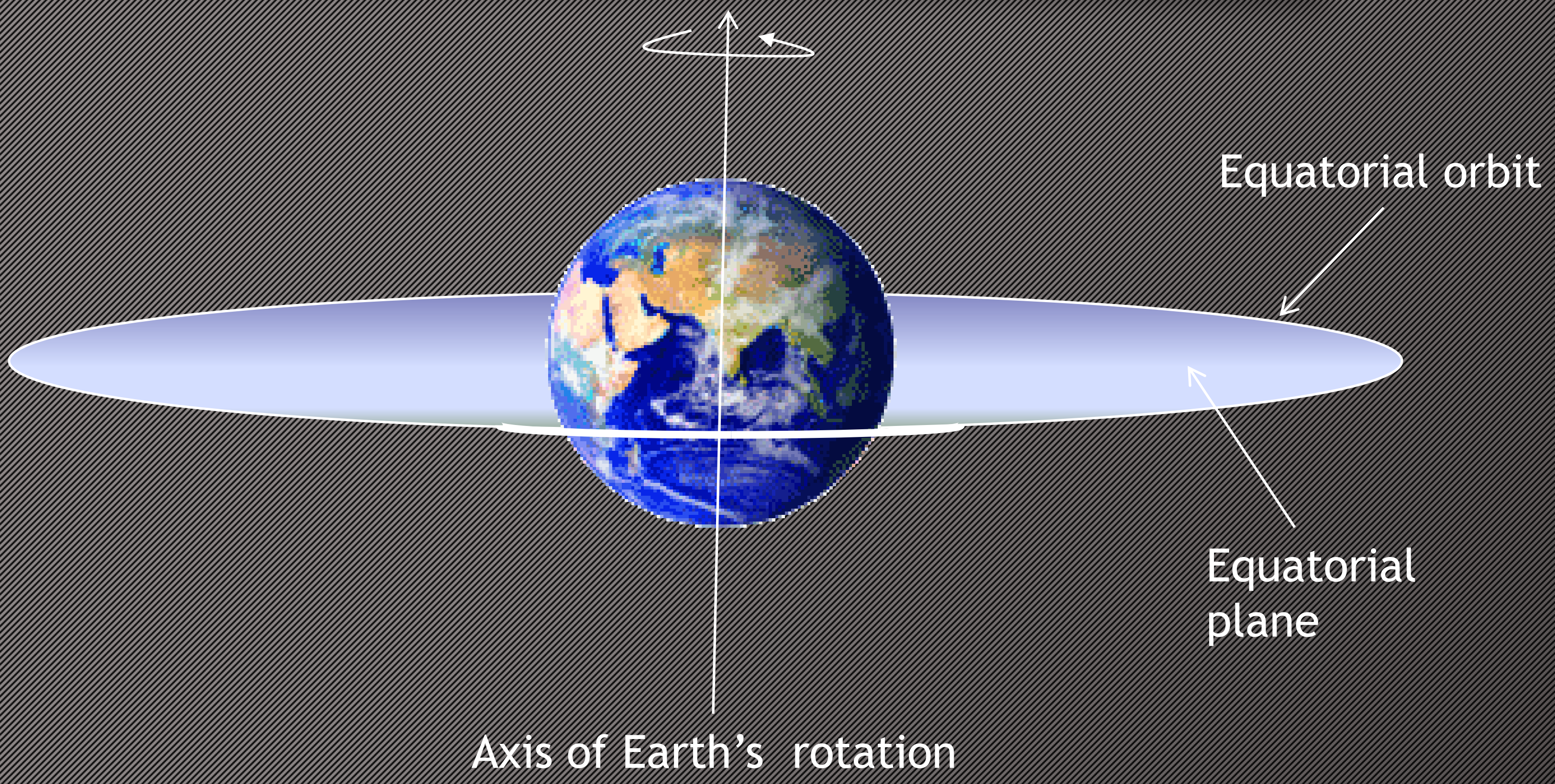
.**Equatorial orbit** – Angle of inclination is either zero degrees or 180 degrees.

.**Polar orbit** – Angle of inclination is 90 degrees.

.**Prograde orbit** – Angle of inclination lies between zero and 90 degrees.

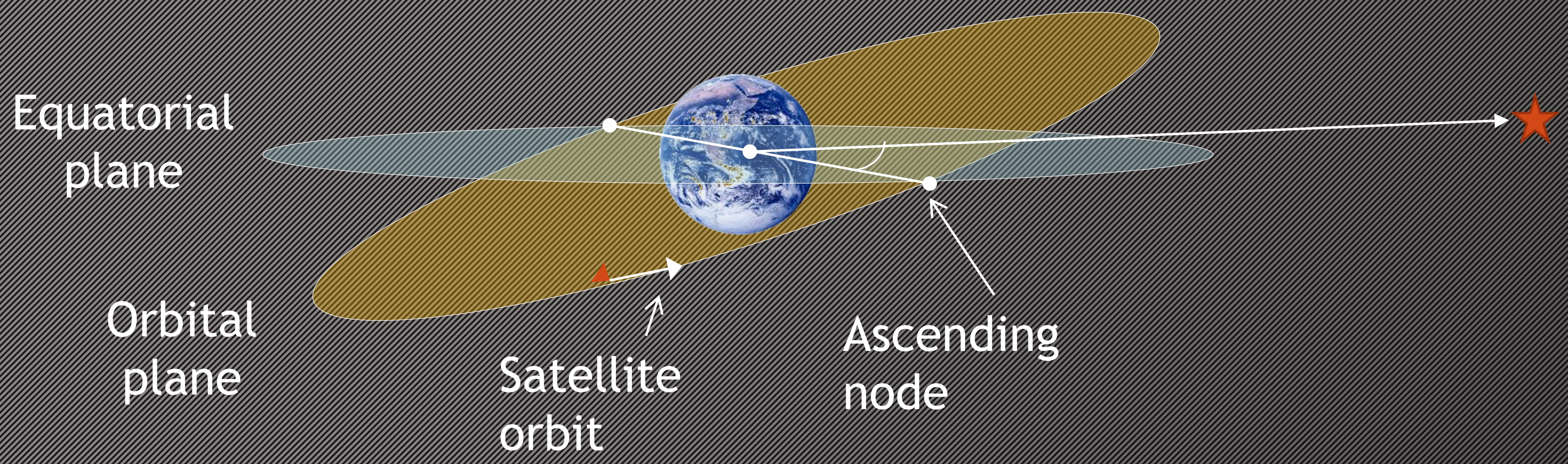
.**Retrograde orbit** – Angle of inclination lies between 90 and 180 degrees.

Orbits

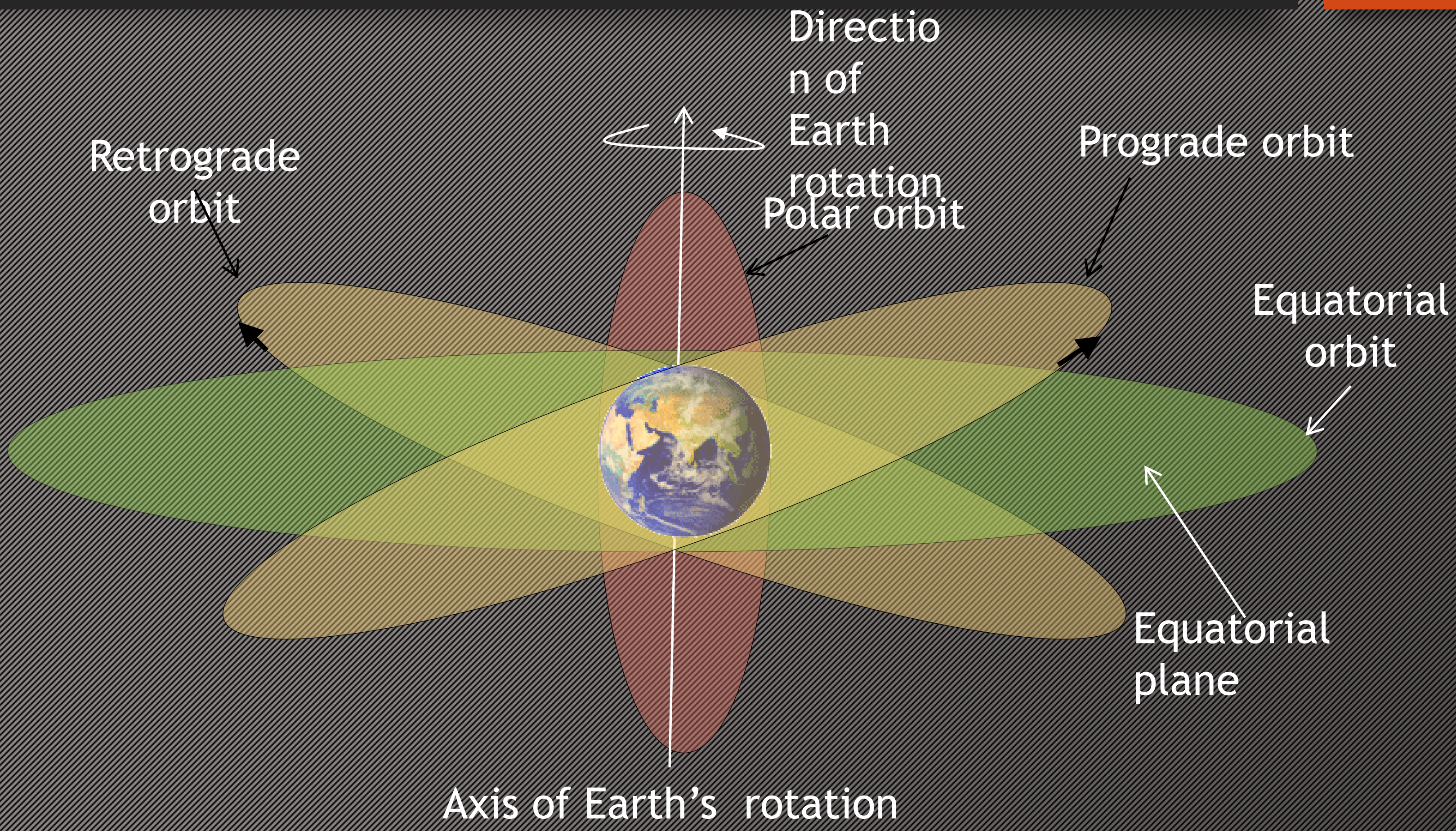


Equatorial orbit
Equatorial
plane
Axis of Earth's rotation

Orbits


Equatorial plane
Orbital plane
Satellite orbit
Ascending node

Orbits

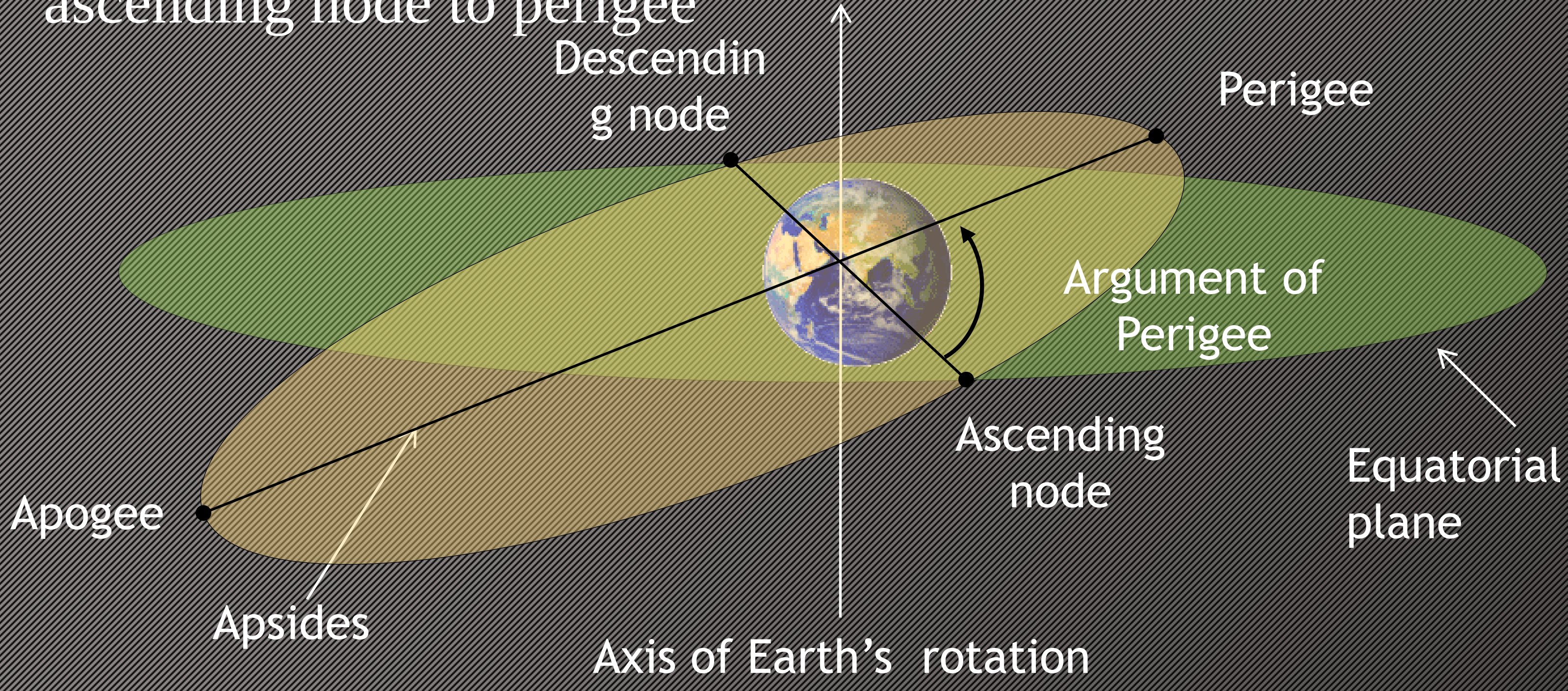

Direction of Earth rotation
Retrograde orbit
Prograde orbit
Polar orbit
Equatorial orbit
Equatorial plane
Axis of Earth's rotation

Orbits

- ***Prograde Orbit: an orbit in which satellite moves in the same*** direction as the Earth's rotation. Its inclination is always between 00 to 90. 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*** same direction counter to the Earth's rotation.

Argument of perigee

- It is an **angle** between the line of apsides (line joining the perigee and apogee passing through the center of the earth) and the line joining the ascending and descending nodes (also passing through the center of earth). Angle measured along the orbit from ascending node to perigee



- ***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 center of Earth.

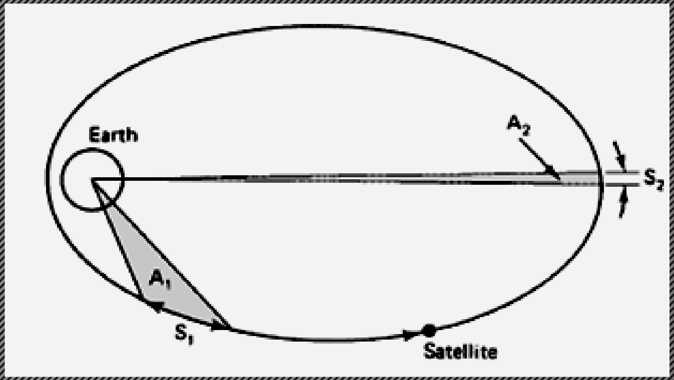
- ***Ascending Node: The point where the orbit crosses the*** equatorial plane going from north to south.
- ***Descending Node: The point where the orbit crosses the*** equatorial plane going from south to north.

- ***Argument of Perigee: An angle from the point of perigee*** measure in the orbital plane at the Earth's center, in the direction of the satellite motion.
- ***Mean anomaly: It gives the average value to the angular*** position of the satellite with reference to the perigee.
- ***True anomaly: It is the angle from point of perigee to the*** satellite's position, measure at the Earth’s center.

- ***Right ascension of ascending node: 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.

Kepler's Second law

- For equal time intervals, a satellite will sweep out equal areas in its orbital plane focused at the
- Assuming the satellite travels distances S1 and S2 meters in 1s,then the areas A1 and A2 will be equal.
- The average velocity in each case is S1 and S2 m/s and it follows that the velocity at S2 is less than at S1.
- Satellite takes longer time to travel a given distance when it is far away from earth.



With respect to the laws governing the planetary motion around the sun, This law could be stated as "A line joining a planet and the sun sweeps our equal area during equal intervals of time".

The areas A1 and A2 swept out in unit intervals of time.

- From figure and considering the law stated above, if satellite travels distances S1 and S2 meters in 1 second, then areas A1 and A2 will be equal.

Kepler's 3rd law

- The square of the periodic time of orbit is proportional to the cube of the mean distance between the two bodies.
- The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit.
- This law shows the relationship between the distances of satellite from earth and their orbital period.

Kepler's 3rd law

- $a^3 = \mu/n^2$ (μ is known and a is given)

- Where **n** is the mean motion of satellite in radians per second and **μ** is the Earth's geocentric gravitational constant.

  $\mu = 3.986005 \times 1014\ m^3/sec^2$ (Ideal condition, spherical earth of uniform mass)

- Due to Earth's oblateness(Shape) and atmospheric drag will be taken in account,

  (Orbital period in seconds)$P = 2\Pi / n$, $(n=2\Pi/P)$

- Here, P is in seconds and n is in radians/ second This law also confirms the fact that there is a fixed relation between period and semi major axis(size).

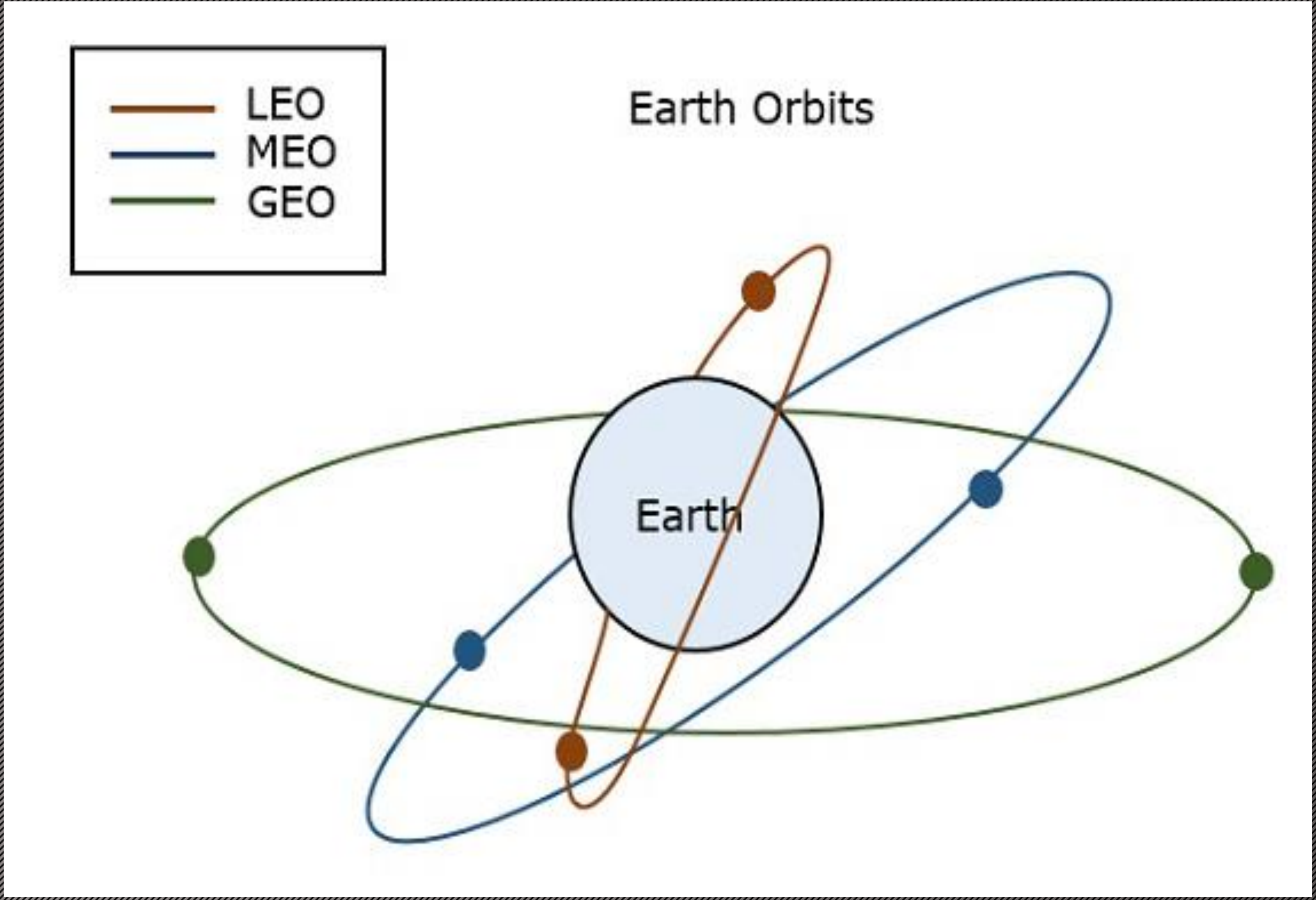
- **Earth Orbit Satellites**

- Satellite should be properly placed in the corresponding orbit after leaving it in the space. It revolves in a particular way and serves its purpose for scientific, military or commercial. The orbits, which are assigned to satellites with respect to earth, are called as **Earth Orbits**. The satellites present in those orbits are called as **Earth Orbit Satellites.**

- Following are the three important **types of Earth Orbit satellites** –

- Geosynchronous Earth Orbit Satellites
- Medium Earth Orbit Satellites
- Low Earth Orbit Satellites

The following **figure** depicts the paths of LEO, MEO and GEO



We should choose an orbit properly for a satellite based on the requirement. For example, if the satellite is placed in lower orbit, then it takes less time to travel around the earth and there will be better resolution in an onboard camera. Similarly, if the satellite is placed in higher orbit, then it takes more time to travel around the earth and it covers more earth's surface at one time.

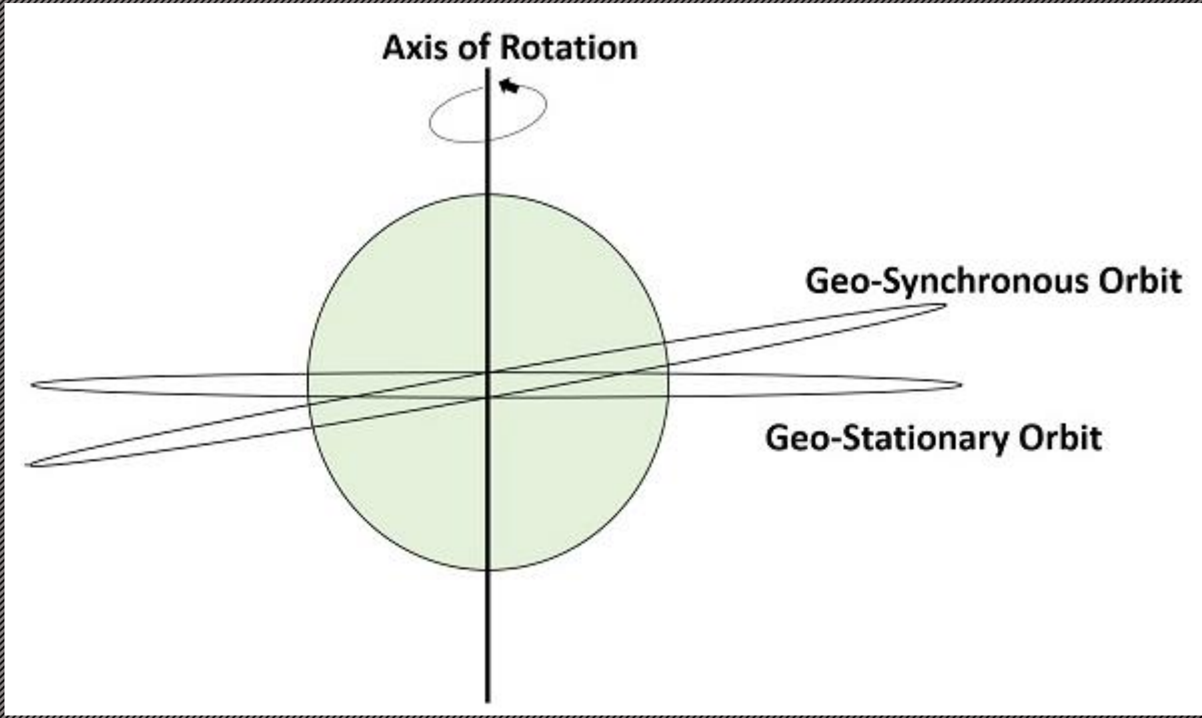
Geosynchronous Earth Orbit Satellites

A Geo-synchronous Earth Orbit **(GEO) Satellite** is one, which is placed at an altitude of **22,300** miles (35,900 km) above the Earth. This orbit is synchronized with a sidereal day (i.e., 23 hours 56 minutes). This orbit can have inclination and eccentricity.

It may not be circular. This orbit can be tilted at the poles of the earth. But, it appears stationary when observed from the Earth. These satellites are used for satellite Television.

The same geo-synchronous orbit, if it is circular and in the plane of equator, then it is called as **Geostationary orbit**. These Satellites are placed at 35,900kms (same as Geosynchronous) above the Earth's Equator and they keep on rotating with respect to earth's direction (west to east).

The following figure shows the difference between Geo-synchronous and Geo-stationary orbits. The axis of rotation indicates the movement of Earth.



- The satellites present in these orbits have the angular velocity same as that of earth. Hence, these satellites are considered as **stationary** with respect to earth since, these are in synchronous with the Earth's rotation.

- The **advantage** of Geostationary orbit is that no need to track the antennas in order to find the position of satellites.
- Geostationary Earth Orbit Satellites are used for weather forecasting, satellite TV, satellite radio and other types of global communications.

Low Earth Orbit Satellites

Low Earth Orbit **LEO)** satellites are mainly classified into three categories. Those are little LEOs, big LEOs, and Mega-LEOs. LEOs will orbit at a distance of **500 to 1000 miles** above the earth's surface. These satellites are used for satellite phones and GPS.

This relatively short distance reduces transmission delay to only 0.05 seconds. This further reduces the need for sensitive and bulky receiving equipment. Twenty or more LEO satellites are required to cover entire earth.

Little LEOs will operate in the 800 MHz (0.8 GHz) range. Big LEOs will operate in the 2 GHz or above range, and Mega-LEOs operates in the 20-30 GHz range.

The higher frequencies associated with **Mega-LEOs** translates into more information carrying capacity and yields to the capability of real-time, low delay video transmission scheme.

Medium Earth Orbit Satellites

Medium Earth Orbit **(MEO)** satellites will orbit at distances of about **8000 miles** from earth's surface. Signals transmitted from a MEO satellite travel a shorter distance. Due to this, the signal strength at the receiving end gets improved. This shows that smaller and light weight receiving terminals can be used at the receiving end.

Transmission delay can be defined as the time it takes for a signal to travel up to a satellite and back down to a receiving station. In this case, there is less transmission delay. Because, the signal travels for a shorter distance to and from the MEO satellite.

For **real-time communications**, the shorter the transmission delay, the better will be the communication system. As an example, if a GEO satellite requires 0.25 seconds for a round trip, then MEO satellite requires less than 0.1 seconds to complete the same trip. MEOs operate in the frequency range of 2 GHz and above.

These satellites are used for High speed telephone signals. Ten or more MEO satellites are required in order to cover entire earth.

Orbital Slots

Here, a question may arise that with more than **200 satellites** that are in geosynchronous orbit, how do we keep them from running into each other or from attempting to use the same location in space?

- International regulatory bodies like the International Telecommunications Union **(ITU)** and national government organizations like the Federal Communications Commission **(FCC)** designate the locations on the geosynchronous orbit, where the communications satellites can be located.
- These locations are specified in degrees of longitude and are called as **orbital slots**. The FCC and ITU have progressively reduced the required spacing down to only 2 degrees for C-band and Ku-band satellites due to the huge demand for orbital slots.

Calendars

- A calendar is a time keeping device in which the year is divided into months, weeks and days.
- Calendar days are units of time based on the earth's motion relative to sun.
- Since the motion is not uniform, a fictitious sun called a mean sun is introduced.
- A *fictitious sun* used for timekeeping that moves uniformly along the celestial equator and maintains a constant rate of apparent motion .
- Time taken by sun(real or mean) to complete one orbit of earth is called as tropical year.
- A day measured relative to this mean sun is termed as mean solar day.
- A tropical year consists of 365.2422 days.

Calendars

- A tropical year (also known as a solar year) is the time that the Sun takes to return to the same position in the cycle of seasons, as seen from Earth
- After every 100 years there is discrepancy of 24 days between calendar year and tropical year.
- Julius creaser has removed this discrepancy by introducing leap year.
- Here, one extra day is added in February after every 4 years. This gave Julian calendar having days 365.25

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

solution

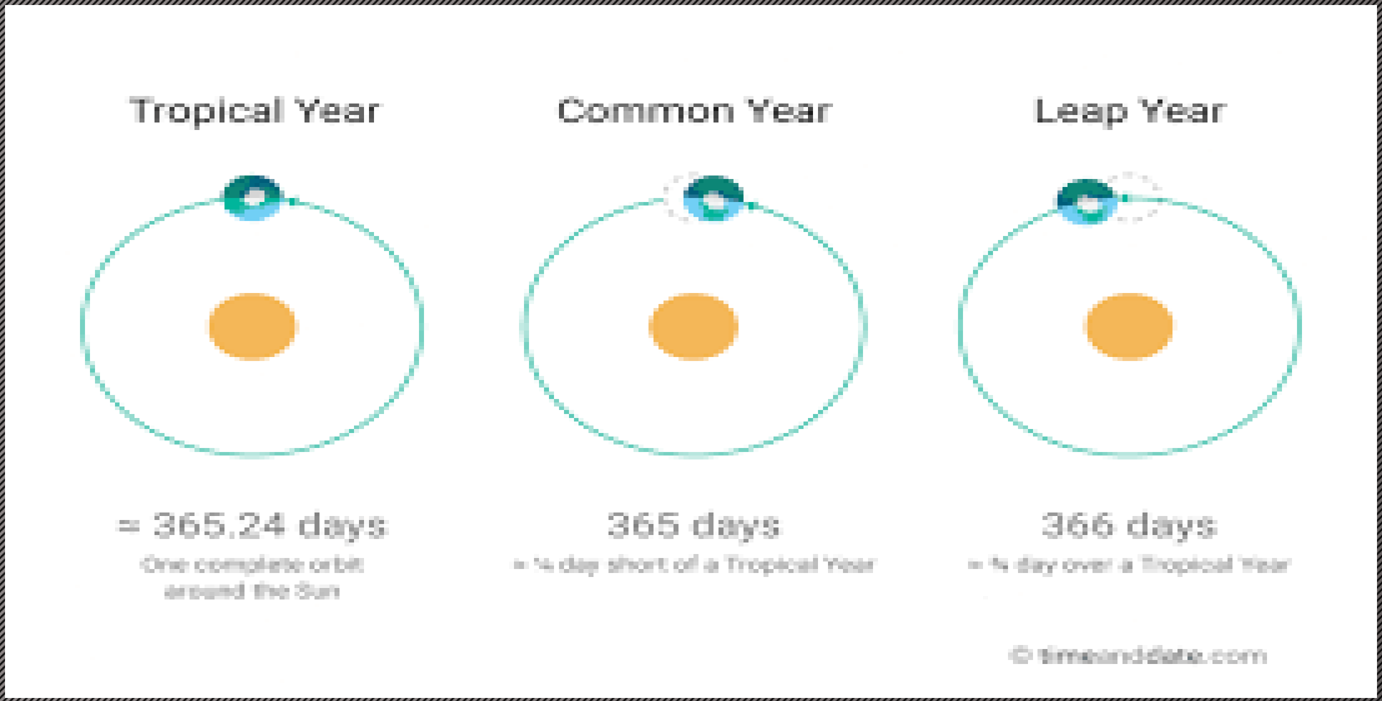
a) 1987/4 = 496.75 (therefore, 1987 is not a leap year)

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

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.

Universal time coordinated is equivalent to *Greenwich mean time* (GMT), as well as *Zulu* (Z) *time*.


Tropical Year
Common Year
Leap Year
≈ 365.24 days
One complete orbit around the Sun
365 days
≈ ¼ day short of a Tropical Year
366 days
≈ ¾ day over a Tropical Year
© timeanddate.com

Universal time

- Universal time coordinate (UTC) is the time used for all civic time keeping purpose. Fundamental unit of UTC is mean solar day. UTC is equivalent to Greenwich mean time (GMT)
- 1 Mean Solar Day s divided into 24 hours; 1 Hour into 60 minutes; 1 Minute into 60 seconds. Thus there are 86,400 seconds in a day

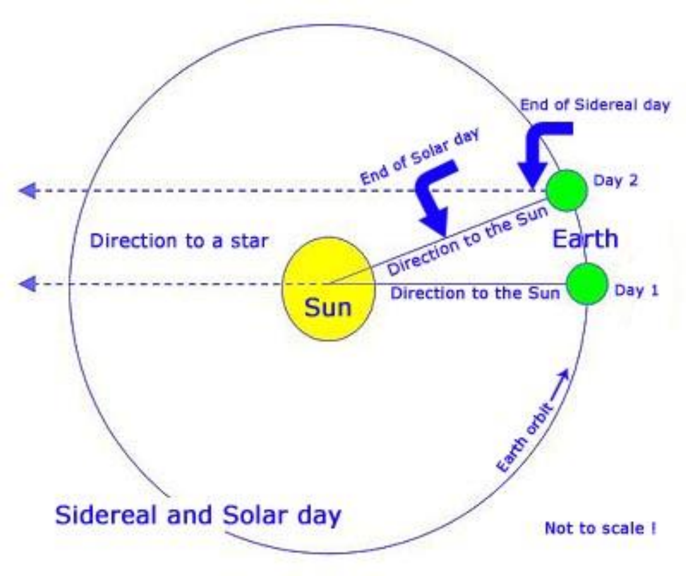
Calculate the average length of the civil year in the Gregorian calendar.

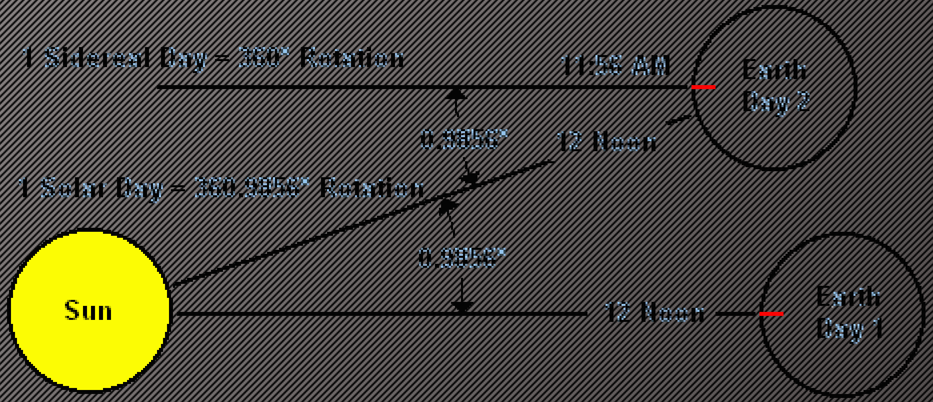
solution The nominal number of days in 400 years is $400 \times 365 = 146{,}000$. The nominal number of leap years is $400/4 = 100$, but this must be reduced by 3, and therefore, the number of days in 400 years of the Gregorian calendar is $146{,}000 + 100 - 3 = 146{,}097$. This gives a yearly average of $146{,}097/400 = 365.2425$.

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.

Sidereal time

The time measured with respect to stationary stars is called sidereal time. It is observed that one complete rotation of the Earth is relative to the fixed stars is not a complete rotation relative to the sun. This happens as Earth also moves in its orbit around the sun.





Numerical

- Find the relationship between sidereal time and solar time in days, time and seconds.

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

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

Geo stationary orbit

- A satellite that appears stationary with respect to Earth is hence named Geostationary. To appear stationary, these satellites have to fulfil three conditions:
  - It must travel eastward at the same rotational speed as the Earth.
  - The inclination of the orbit must be zero.
  - The orbit must be circular. If the satellite has to appear stationary, then it has to move at the same speed as the Earth (which is constant).
- Constant speed means equal areas must be swept out at equal intervals of time. This could only be attained using a circular orbit.
- Inclination must be zero as having any inclination would lead the satellite to move from north-south directions. Orbits with zero inclination lie in the Earth's equatorial plane.

Reference

- Dennis Roddy, “Satellite Communication”, 4^{th} Ed., McGraw Hill, 2008