Satellite Technology (20EC81)

V-Sem,ASE&IT, A.Y: 2024-2025

Unit-II
Orbital Mechanics

Presented by

M.Sivasankara Rao

Sr.Assistant Professor in ECE

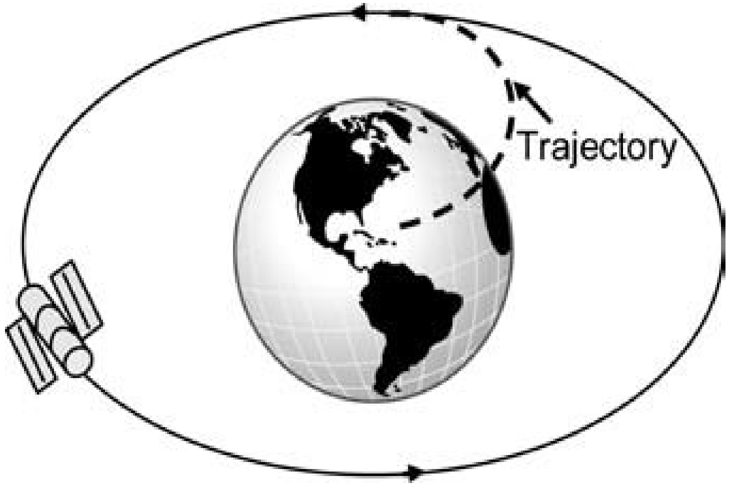
Lakireddy Bali Reddy College of Engineering, Mylavaram

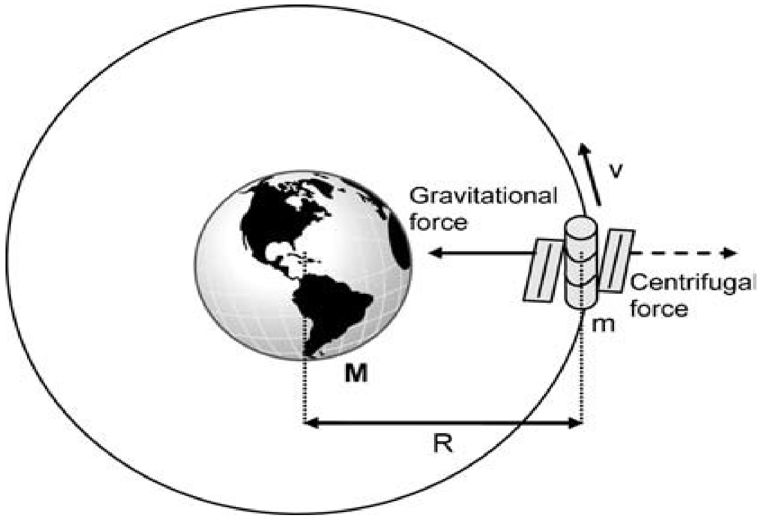
Contents

- Fundamentals of orbital dynamics
- Kepler's Laws
- Orbital parameters
- Orbital perturbations
- Need of station keeping
- Coordinate systems
- GPS system
- Ground/Earth station network requirements

Fundamentals of orbital mechanics

- When a satellite is launched, it is placed in orbit around the Earth. The Earth's gravity holds the satellite in a certain path as it goes around the Earth, and that path is called an "orbit.“
- When in a stable orbit, there are two main forces acting on a satellite: One of them is the centripetal force directed towards the centre of the Earth due to the gravitational force of attraction of Earth and the other is the centrifugal force that acts outwards from the centre of the Earth.
- If these two forces are equal the satellite remains in a stable orbit.





From the Newton's laws

- The formula for centripetal force is: $F = (mv^2)/r$
  The formula for the gravitational force between two bodies of mass M and m is $= (GMm)/r^2$
- The most common type of satellite orbit is the geostationary orbit. It is a type of orbit where the satellite is over the same point of Earth always. It moves around the Earth at the same angular speed that the Earth rotates on its axis.
- From the above formulae, to maintain the satellite stable in the orbit, the two forces must be equal,

$$(mv^2/r) = (GMm)/r^2$$

$$\Rightarrow \quad v^2/r = (GM)/r^2$$

Now, $v = (2\pi r)/T$

$$\Rightarrow (((2\pi r)/T)^2)/r = (GM)/r^2$$

$$\Rightarrow \quad (4\pi^2 r)/T^2 = (GM)/r^2$$

$$\Rightarrow \quad r^3 = (GMT^2)/4\pi^2$$

- We know that T is one day, since this is the period of the Earth.

  This is 8.64×10^4 seconds.

  We also know that M is the mass of the Earth, which is 6×10^{24} kg.

  Lastly, we know that G (Newton's Gravitational Constant) is 6.67×10^{-11} $m^3/kg.s^2$

  So we can work out r.

$$r^3 = 7.57 \times 10^{22}$$

$$\text{Therefore, } r = 4.23 \times 10^7 = 42{,}300 \text{ km.}$$

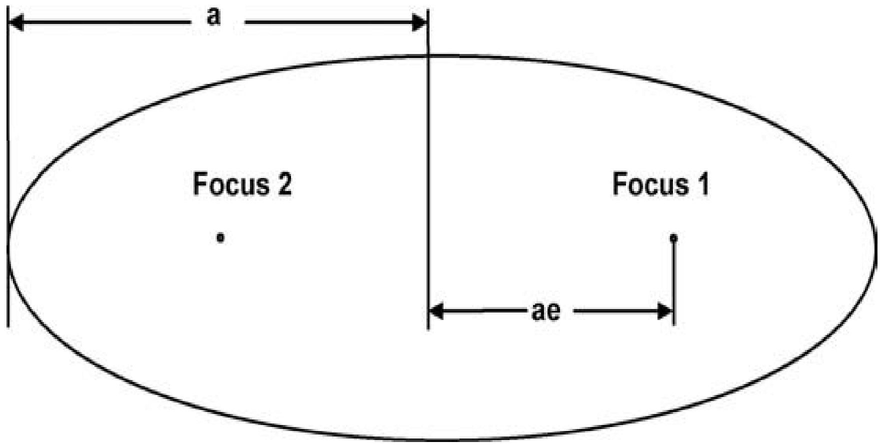
- So the orbital radius required for a geostationary, or geosynchronous orbit is 42,300km. Since the radius of the Earth is 6378 km the height of the geostationary orbit above the Earth's surface is ~36000 km.
- There are many different types of orbits used for satellite telecommunications, the geostationary orbit described above is just one of them.

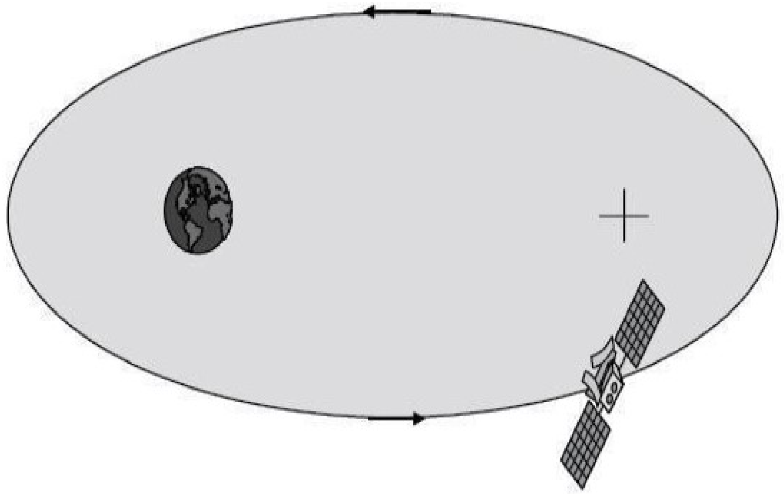
Kepler's Laws

- Johannes Kepler, based on his lifetime study, gave a set of three empirical expressions that explained planetary motion.

Kepler's First Law:

- As it applies to artificial satellite orbits, can be simply stated as follows: 'The path followed by a satellite around the earth will be an ellipse, with the center of mass of earth as one of the two foci of the ellipse.'

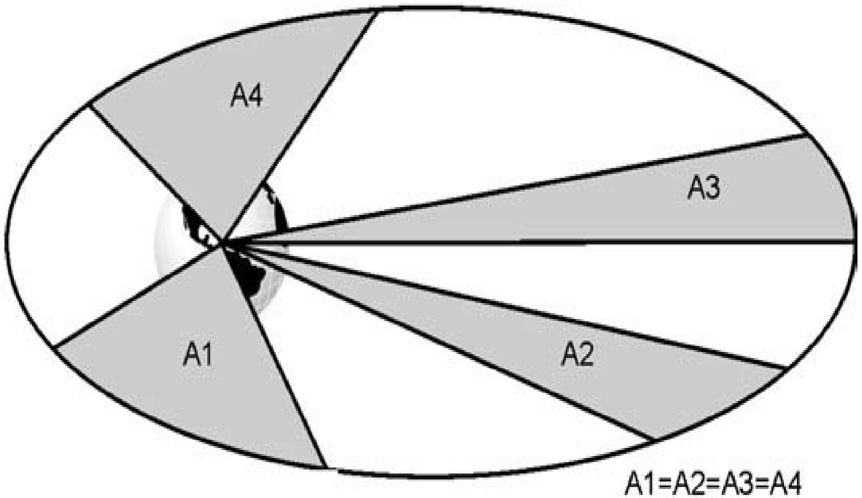


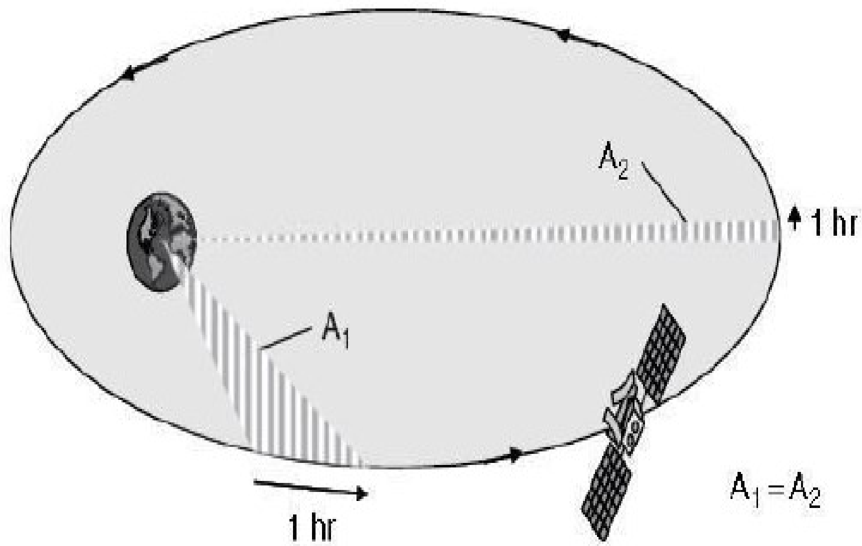


Kepler's Laws...

Kepler's second Law:

- The line joining the satellite and the centre of the Earth sweeps out equal areas in the plane of the orbit in equal time intervals
- This result also shows that the satellite orbital velocity is not constant; the satellite is moving much faster at locations near the earth, and slows down as it approaches apogee.





Kepler's Laws...

Kepler's third Law:

- According to the Kepler's third law, also known as the law of periods, the square of the time period of any satellite is proportional to the cube of the semi-major axis of its elliptical orbit.
- A circular orbit with radius *r is* assumed,

$$T^2 = \left(\frac{4\pi^2}{Gm_1}\right) r^3 \quad \Rightarrow \quad T^2 = \left(\frac{4\pi^2}{\mu}\right) r^3$$

- The above equation holds good for elliptical orbits provided *r is replaced by the semi-major* axis *a. This gives the expression for the time period of an elliptical orbit as*

$$T^2 = \left(\frac{4\pi^2}{\mu}\right) a^3 \quad \Rightarrow \quad T = \left(\frac{2\pi}{\sqrt{\mu}}\right) a^{3/2}$$

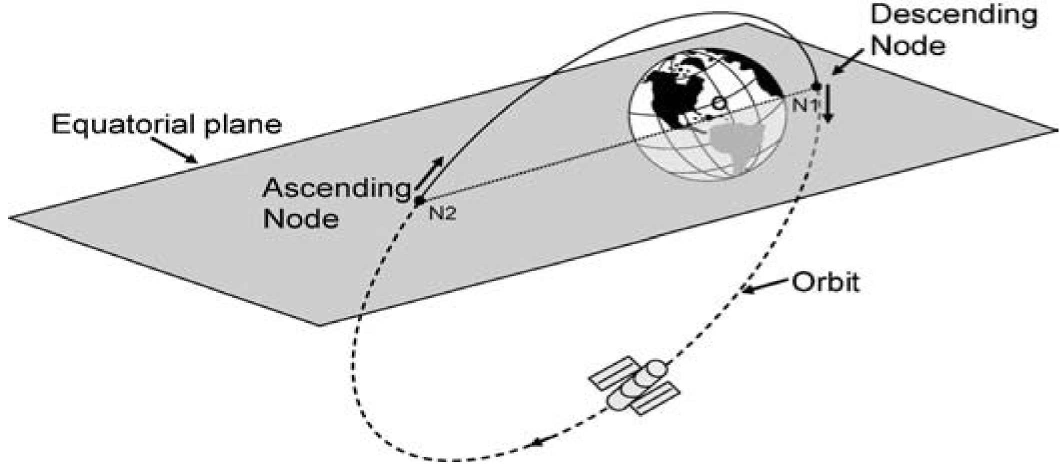
- μ= Kepler's constant = 3.986004×105 km^3/s^2 = Gm_1

Orbital parameters

1. Ascending and descending nodes
2. Apogee (Apoapsis)
3. Perigee (Periapsis)
4. Eccentricity
5. Semi-major axis
6. Right ascension of the ascending node
7. Inclination
8. Argument of the perigee
9. True anomaly of the satellite

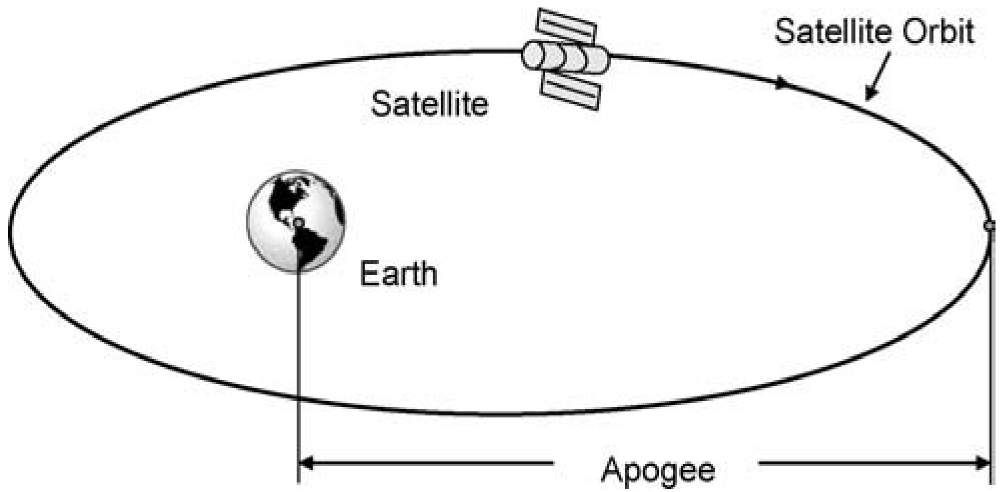
1. Ascending and descending nodes

- The satellite orbit cuts the equatorial plane at two points:
- the first, called the descending node (N1), where the satellite passes from the northern hemisphere to the southern hemisphere, and
- the second, called the ascending node (N2), where the satellite passes from the southern hemisphere to the northern hemisphere



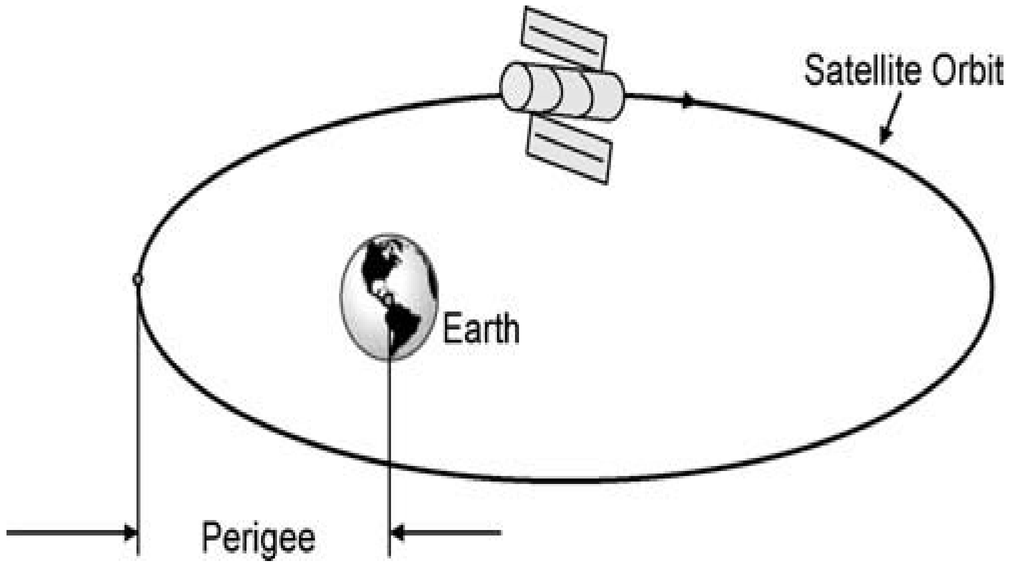
2. Apogee

- Apogee is the point on the satellite orbit that is at the farthest distance from the centre of the Earth. The apogee distance can be computed from the known values of the orbit eccentricity *e and the semi-major axis a*
- Apogee distance = $a\ (1 + e)$



3. Perigee

- Perigee is the point on the orbit that is nearest to the centre of the Earth. The perigee distance can be computed from the known values of orbit eccentricity *e and the semi-major axis a*
- Perigee distance = *a (1 − e)*



4. Eccentricity, 5. Semi-major axis

- The orbit eccentricity *e is the ratio of the distance between the centre of the* ellipse and the centre of the Earth to the semi-major axis of the ellipse. It can be computed from any of the following expressions:

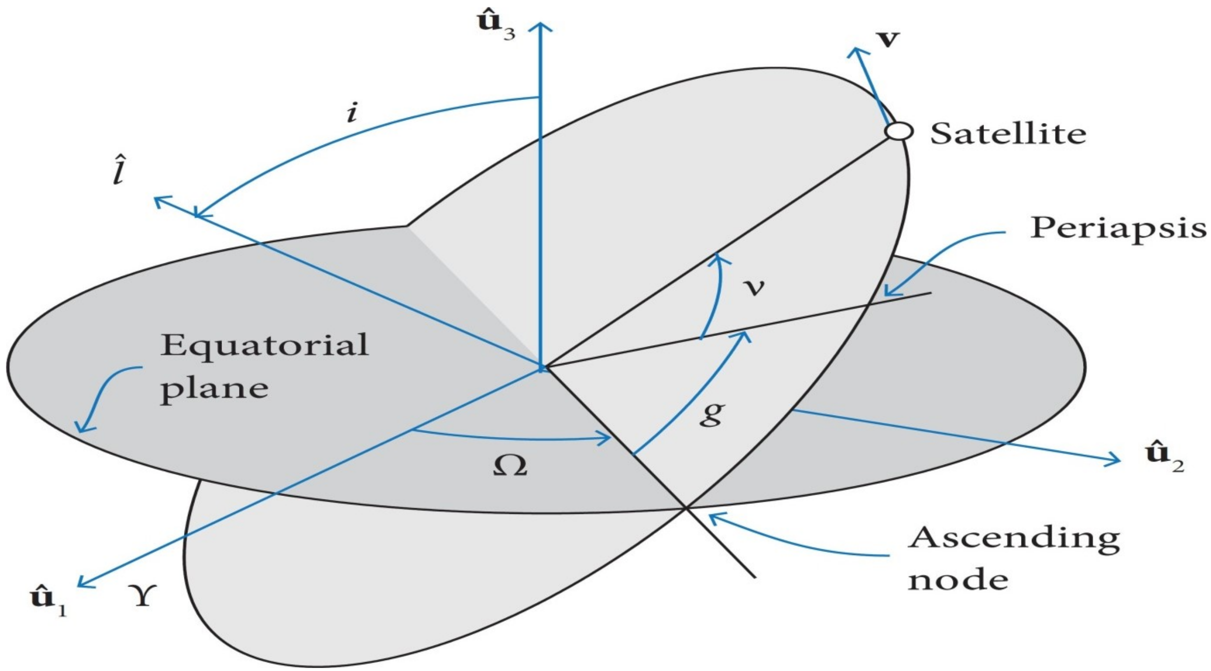
$$e = \frac{apogee - perigee}{apogee + perigee} \quad (or) \quad e = \frac{apogee - perigee}{2a}$$

- Semi-major axis a is a geometrical parameter of an elliptical orbit. It can, however, be computed from known values of apogee and perigee distances as

$$a = \frac{apogee + perigee}{2}$$

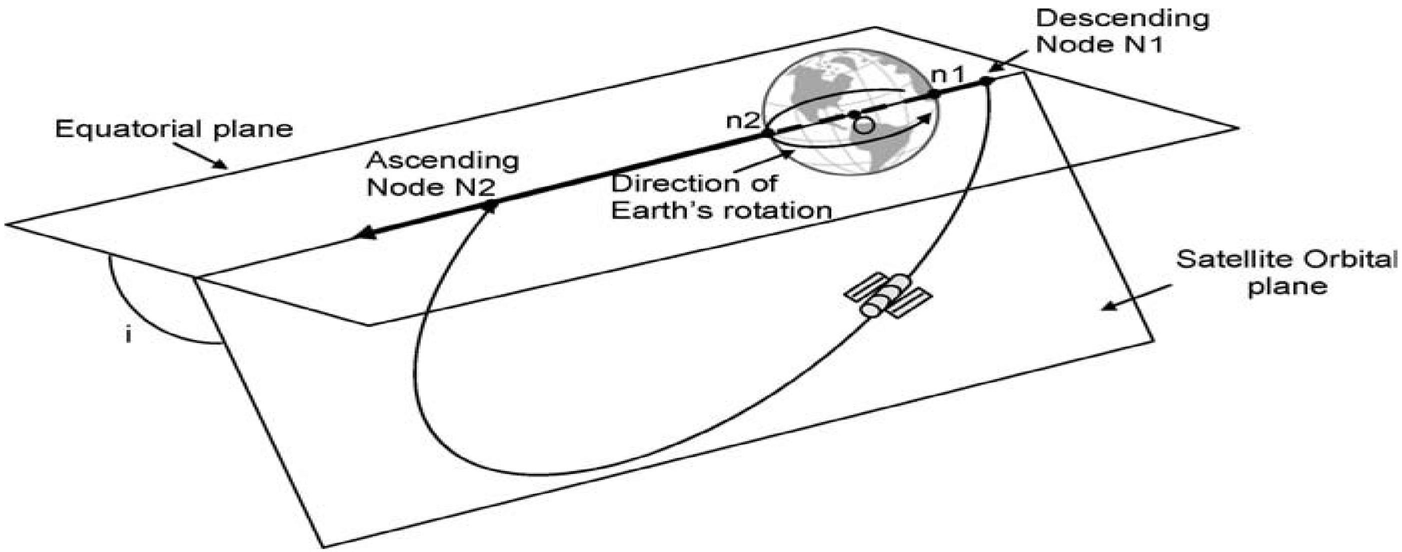
6. Right ascension of the ascending node

- The right ascension of the ascending node tells about the orientation of the line of nodes, which is the line joining the ascending and descending nodes, with respect to the direction of the vernal equinox. It is expressed as an angle *measured from the vernal equinox towards the line of nodes in the direction* of rotation of Earth. The angle could be anywhere from 0◦ to 360◦.



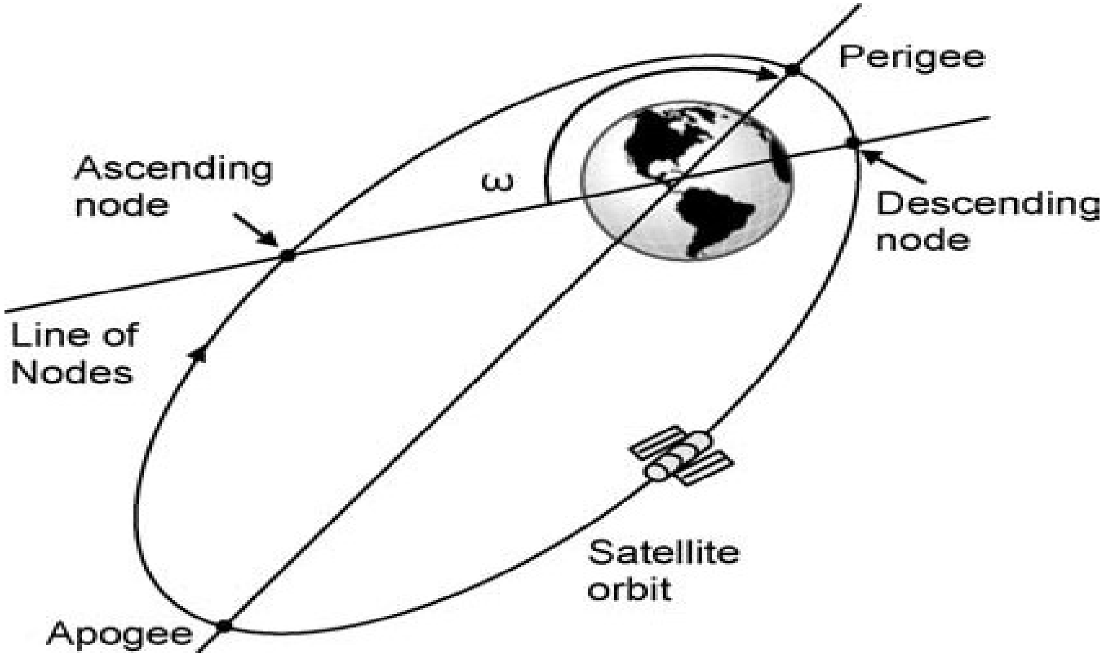
7. Inclination

- Inclination is the angle that the orbital plane of the satellite makes with the Earths'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.**



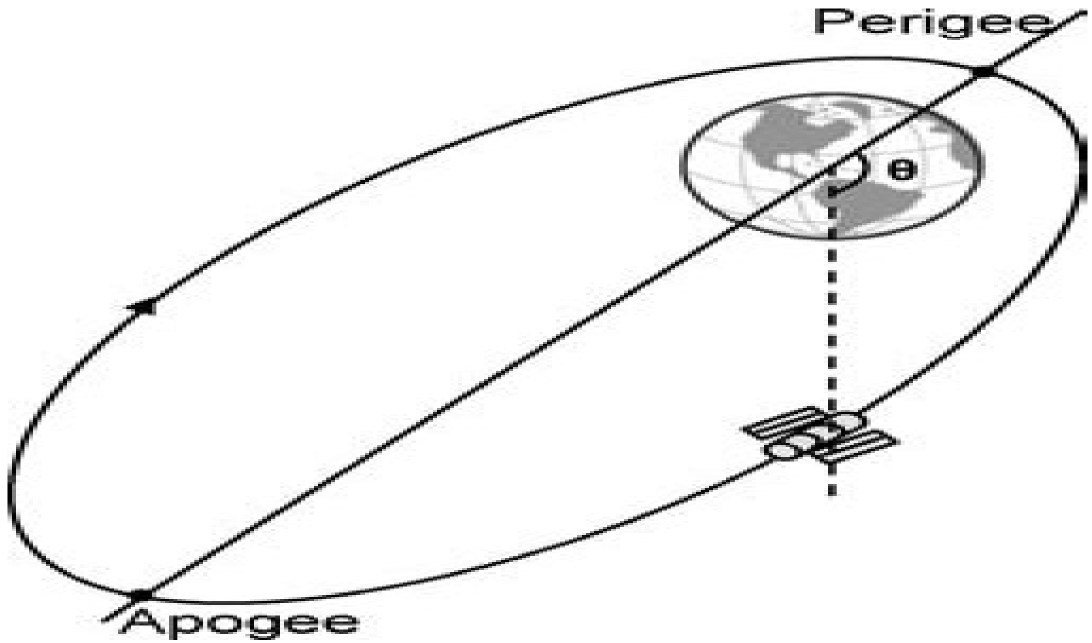
8. Argument of the perigee

- This parameter defines the location of the major axis of the satellite orbit. It is measured as the angle *ω between the line joining the perigee and the* centre of the Earth and the line of nodes from the ascending node to the descending node in the same direction as that of the satellite orbit



9. True anomaly of the satellite

- This parameter is used to indicate the position of the satellite in its orbit. This is done by defining an angle θ (*ϑ) , called the true anomaly of the satellite,* formed by the line joining the perigee and the centre of the Earth with the line joining the satellite and the centre of the Earth



6 main orbital parameters

Element	*Name*	*Description*	*Definition*	*Remarks*
a	semimajor axis	orbit *size*	half the long axis of the ellipse	orbital period and energy depend on orbit size
e	eccentricity	orbit *shape*	ratio of half the foci separation (c) to the semimajor axis (a)	closed orbits: $0 \le e < 1$ open orbits: $e \ge 1$
i	inclination	orbital plane's *tilt*	angle between the orbital plane and equatorial plane, measured counterclockwise at the ascending node	equatorial: $i = 0°$ or $180°$ prograde: $0° \le i < 90°$ polar: $i = 90°$ retrograde: $90° < i \le 180°$
Ω	right ascension of the ascending node	orbital plane's *rotation* about the earth	angle, measured eastward, from the vernal equinox to the ascending node	$0° \le \Omega < 360°$ undefined when $i = 0°$ or $180°$ (equatorial orbit)
ω	argument of perigee	orbit's *orientation* in the orbital plane	angle, measured in the direction of satellite motion, from the ascending node to perigee	$0° \le \omega < 360°$ undefined when $i = 0°$ or $180°$, or $e = 0$ (circular orbit)
ν	true anomaly	satellite's *location* in its orbit	angle, measured in the direction of satellite motion, from perigee to the satellite's location	$0° \le \nu < 360°$ undefined when $e = 0$ (circular orbit)

Orbital perturbations

- The satellite, once placed in its orbit, experiences various perturbing torques that cause variations in its orbital parameters with time.
- These include gravitational forces from other bodies like solar and lunar attraction, magnetic field interaction, solar radiation pressure, asymmetry of Earth's gravitational field etc.
- Due to these factors, the satellite orbit tends to drift and its orientation also changes and hence the true orbit of the satellite is different from that defined using Kepler's laws.

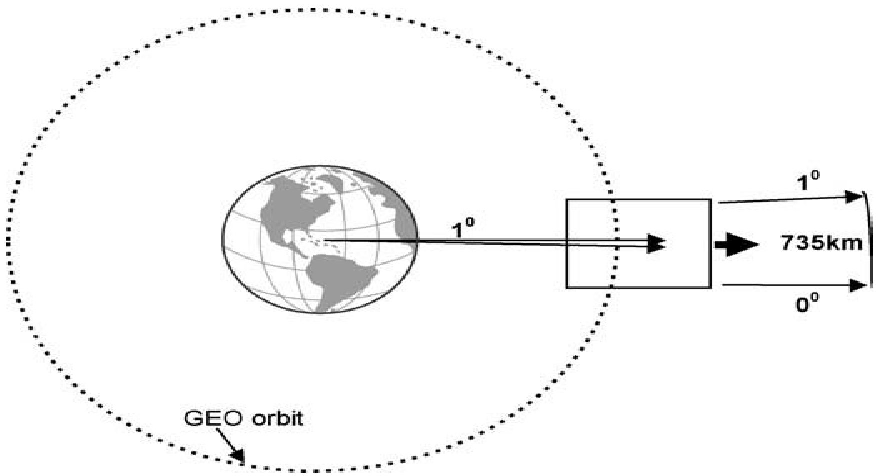
Orbital perturbations

PERTURBATIONS

- Definition
  - A disturbance in the regular motion of a satellite
- Types
  - Gravitational
  - Atmospheric Drag
  - Third Body Effects
  - Solar Wind/Radiation Effects
  - Electro-magnetic

Orbital perturbations

- The satellite's position thus needs to be controlled both in the east–west as well as the north–south directions.
- The east–west location needs to be maintained to prevent radio frequency (RF) interference from neighbouring satellites.
- It may be mentioned here that in the case of a geostationary satellite, a 1◦ drift in the east or west direction is equivalent to a drift of about 735 km along the orbit.
- The north–south orientation has to be maintained to have proper satellite inclination.



Orbital perturbations

- The Earth is not a perfect sphere and is flattened at the poles. Also, the equatorial radius of the Earth is not constant. In addition, the average density of Earth is not uniform.
- All of this results in a non-uniform gravitational field around the Earth which in turn results in variation in gravitational force acting on the satellite due to the Earth. The effect of variation in the gravitational field of the Earth on the satellite is more predominant for geostationary satellites
- In the case of a geostationary satellite, these forces result in an acceleration or deceleration component that varies with the longitudinal location of the satellite.
- In addition to the variation in the gravitational field of the Earth, the satellite is also subjected to the gravitational pulls of the sun and the moon.

Orbital perturbations

PERTURBATIONS

Gravitational: Libration

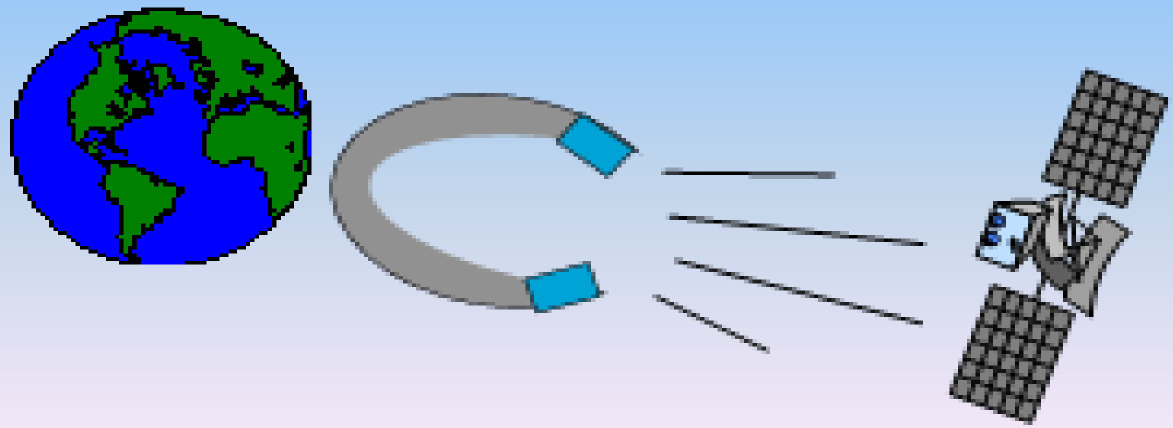
- **Ellipticity of the Earth causes gravity wells and hills**
- **Stable points: 75E and 105W**
  -- Himalayas and Rocky Mountains
- **Unstable points: 165E and 5W**
  -- Marshall Islands and Portugal
- **Drives the requirement for station keeping**

Orbital perturbations

PERTURBATIONS

Electro-Magnetic

- Interaction between the Earth's magnetic field and the satellite's electro-magnetic field results in magnetic drag



Station Keeping

- Station keeping is the process of maintenance of the satellite’s orbit against different factors that cause temporal drift.
- Satellites need to have their orbits adjusted from time to time because the satellite, even though initially placed in the correct orbit, can undergo a Progressive drift due to some natural forces such as minor gravitational perturbations due to the sun and moon, solar radiation pressure, Earth being an imperfect sphere, etc.
- The orbital adjustments are usually made by releasing jets of gas or by firing small rockets tied to the body of the satellite.
- In the case of spin-stabilized satellites, station keeping in the north–south direction is maintained by firing thrusters parallel to the spin axis in a continuous mode. The east–west station keeping is obtained by firing thrusters perpendicular to the spin axis.
- In the case of three-axis stabilization, station keeping is achieved by firing thrusters in the east–west or the north–south directions in a continuous mode.

Coordinate systems

- coordinates are used to identify locations on the earth's surface are based on measurements of displacement from a given location are of two types:
- **Plane**
- **Global**
- **PLANE COORDINATE SYSTEMS - CARTESIAN COORDINATES Determining Coordinates**
- Cartesian coordinates are determined as follows: 1. locate an origin 2. set two axes through origin in fixed directions, at right angles to each other
    - by convention these are usually:
    - identified as x and y
    - x is horizontal and y vertical
    - i.e. y is anticlockwise from x

Measuring Distance

- Cartesian coordinates can be used directly to calculate distance between two points
- 1. Euclidean (Pythagorean) Distance
    - distance defined in a straight line from point (x1,y1) to point (x2,y2):
    - $D^2 = (x1 - x2)^2 + (y1 - y2)^2$
- 2. Manhattan Metric
    - assumes a rectilinear route paralleling the x and y axes: $D = |x1 - x2| + |y1 - y2|$

Coordinate systems

- **PLANE COORDINATE SYSTEMS - POLAR COORDINATES**
- use distance from the origin (r) and angle from fixed direction (q)
  - usually fixed direction is north and the angle is measured clockwise from it
- polar coordinates are useful for measuring from some fixed point such as the center of the city or when using data from sources such as ground surveys and radar to translate from (r, q) to (x, y) x = r sin(q)   y = r cos(q)

Coordinate systems

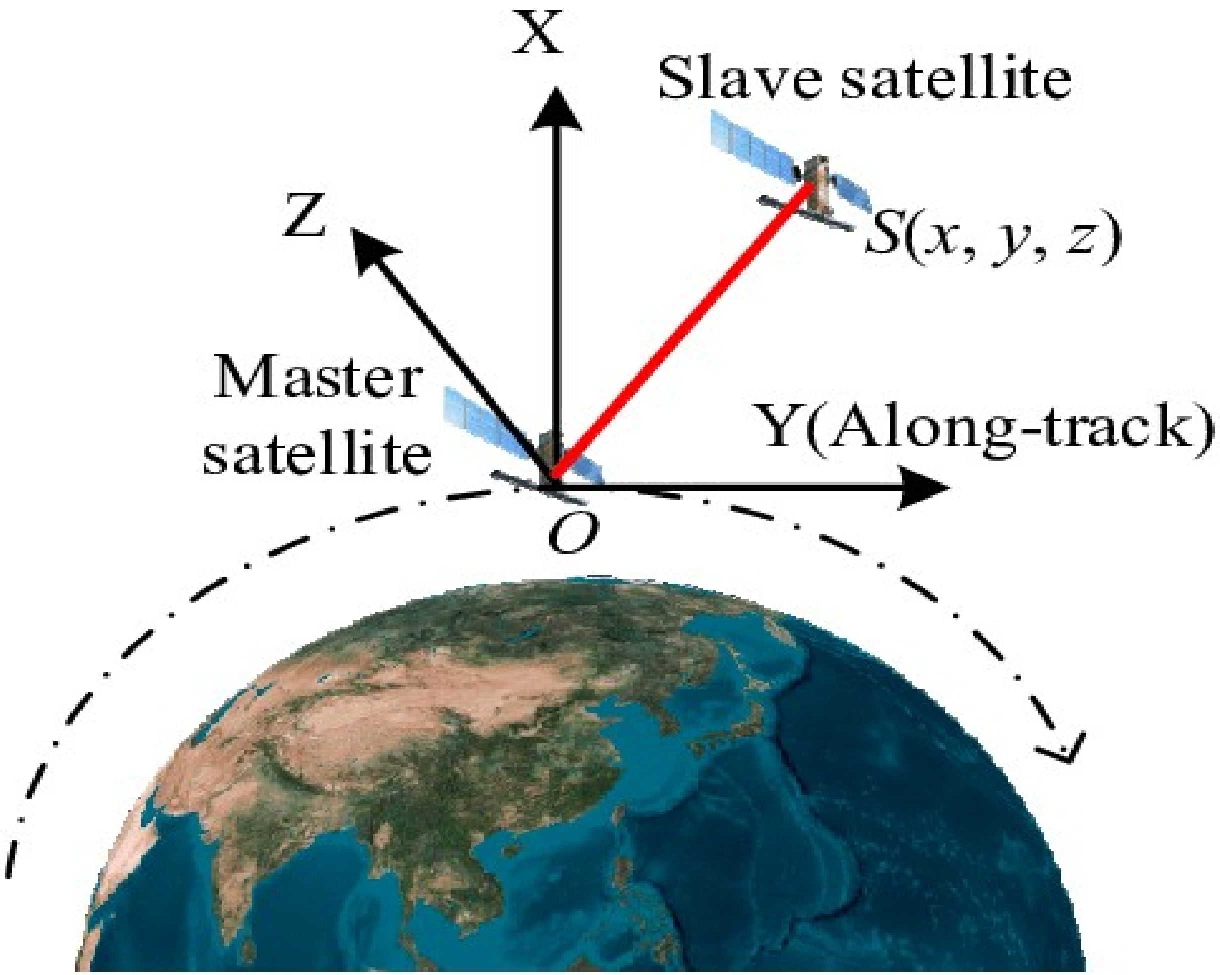
GLOBAL COORDINATES - LATITUDE AND LONGITUDE Determining Coordinates

- start with a line connecting N and S pole through the point
  - called a meridian
- latitude (j) - measures angle between the point and the equator along the meridian1
  - has range: -900 (S pole) to +900 (N pole)
- longitude (l) - measures the angle on the equatorial plane between the meridian of the point and the central meridian (through Greenwich, England)
  - has range: -1800 (westerly) to +1800 (easterly)

Important Terms

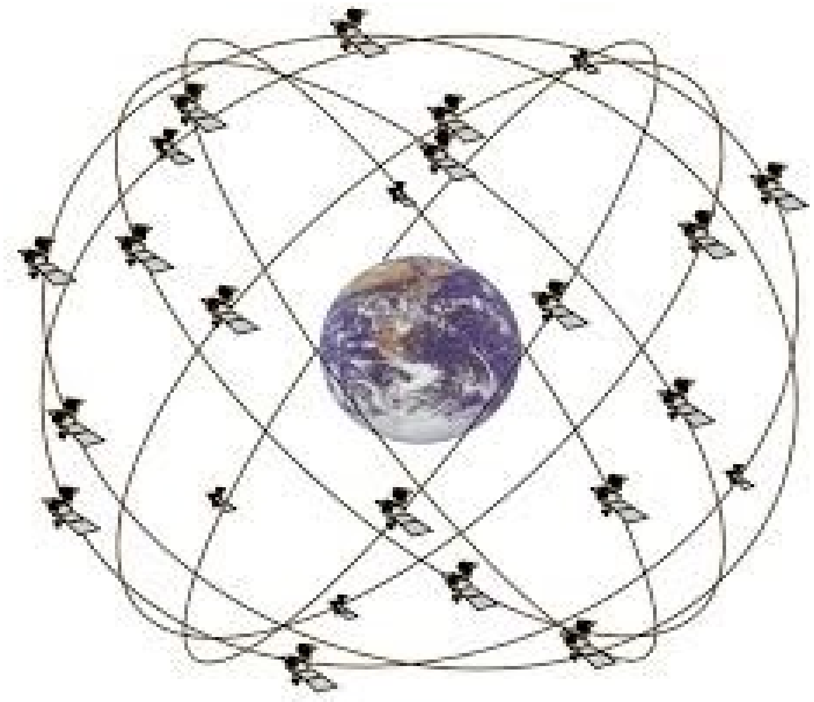
- meridian - line of constant longitude. parallel - line of constant latitude
- great circle - imaginary circle made on the earth's surface by a plane passing through the center of the earth
- small circle - imaginary circle made on the earth's surface by a plane that does not pass through the center of the earth

Coordinate systems



GPS system

- In the GPS system, a constellation of 24 satellites circles the earth in near-circular inclined orbits. By receiving signals from at least four of these satellites, the receiver position (latitude, longitude, and altitude) can be determined accurately.



Advantages of GPS Tracking Software Outweigh the Disadvantages

Advantages

- Live Locational Tracking
- IoT Sensor Integration
- Advanced Reporting
- Better Security Measures
- Geofencing
- Automated Operations
- Low Operational Costs
- Increased Profitability

Disadvantages

- Long Learning Curve
- Need to Form a Habit
- Infrastructural Needs
- Over-reliance on Tools

W W W . T R A C K O B I T . C O M

Ground/Earth station network requirements

- Earth stations provide access to the space segment, interconnecting users with one another and with terrestrial networks such as the Internet and the public telephone network.
- **Performance Requirements**
- That is to ensure that there is a satisfactory RF link between the ground and the space segments under all expected conditions and for the range of required services.
- In addition, the Earth station determines the baseband quality and much of the end-to-end communication performance of the services being provided.
- **Frequency criteria**
- **Transmit EIRP**
- **Receive G/T**
- **Location and Platform Requirements**

Thank You