# Unit-1

## Communication Satellite;

**Orbit & Description:** A brief history of satellite communication, satellite frequency bands, Satellite Systems, Applications.

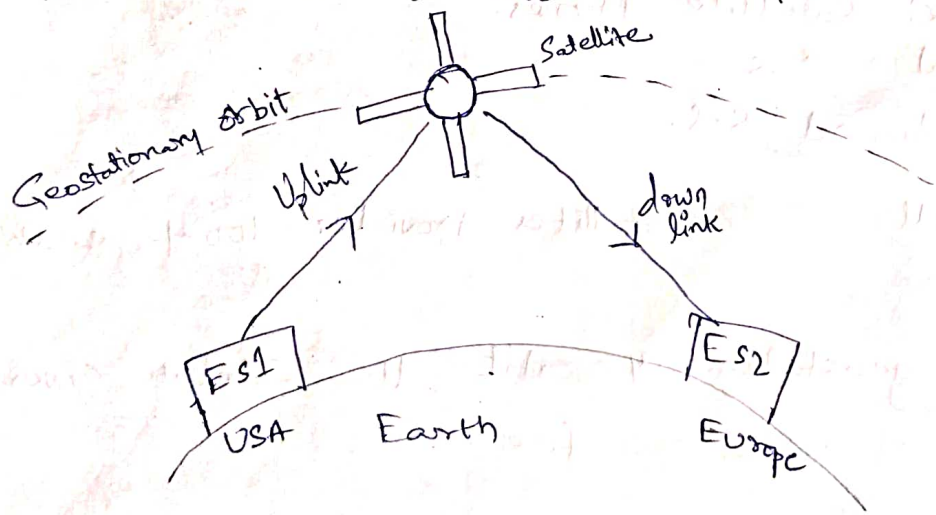
→ Two stations on Earth want to communicate through radio broadcast but are too far away to use conventional means.

→ The two stations can use a satellite as a relay station for their communication.

→ One earth station sends a transmission to the satellite. This is called a Uplink.

→ The satellite Transponder converts the signal and sends it down to the second earth station. This is called a downlink.

→ The uplink frequency and downlink frequency should not be same to avoid interference.




→ **Advantages**

1. The coverage area of a satellite greatly exceeds
2. Satellite to satellite communication is very precise.
3. Higher bandwidths are available for use.
4. Flexible
5. Lifetime 10 - 15 years.
6. Speedy & Reliable

Disadvantages :-

① Launching Satellites into orbit is costly.

② There is a larger propagation delay in satellite communication

Satellite Service Types :

① Fixed service satellite (FSS)
Ex: point to point Communication

② Broadcast Service Satellites (BSS)
Ex: Satellite TV/Radio
Also called Direct Broadcast Service (DBS) /(DTH)

③ Mobile Service Satellites (MSS)
Ex: Satellite Phones.

④ Navigational S.S

⑤ Meteorological S.S.

*** ① Theoretically 3 Geostallites provides 100% earth coverage.

② At the geostationary orbit the satellite covers 42.2% of earth's surface.

*** At exactly, 22,300 miles above the equator, the force of gravity is cancelled by the centrifugal force of rotating universe. This is the ideal spot to park a stationary satellite.

## Regions of Space :-

→ Space is defined as a place free from obstacles.

1. Air Space → region above 100 km from earth's surface.
2. Outer Space → cosmic space (100km to 42,000 km)
3. Deep Space → beyond 42,000 km.

→ Satellite Signals

Used to transmit signals and data over long distances

1. Weather forecasting
2. TV broadcasting
3. Internet Communication
4. Global Positioning Systems
5. Communications to ships & aircraft (safety communication)
6. Remote sensing areas
7. Military applications.

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→ Satellite is a solid object which revolves around some body due to the effect of gravitational force (or)

→ A Satellite is an object which has been placed into orbit by human endeavour.

→ Passive Satellites → It only reflects received signals back to earth. Ex: moon (natural satellite to earth)

→ Active Satellites → They are complicated structures having a processing equipment called Transponder. It acts as a repeater.

Transponder is a device for receiving a radio signal and automatically transmitting a different signal.

Frequency Bands : Different kinds of satellite services use different frequency bands.

1. L-Band → 1 to 2 GHz, used by MSS.
2. S-Band → ~~2 to 4~~ GHz, used by MSS, NASA, deep space research.
3. C-Band → 4 to 8 GHz, (FSS) (2-3 mts in diameter antenna)
4. X-Band → 8 to 12 GHz, FSS, Military & Meteorological satellites (search & resque)
5. Ku-Band → 12 to 18, FSS & BSS (18 inches in diameter antenna)
6. K → 18 to 26, FSS & BSS
7. Ka → 26 to 40, FSS

→ As wavelength ↑ (freq. ↓) larger antennas (satellite dishes) are necessary to gather the signals

→ ITU (International Telecommunication Union)

- ~~Sate~~ Allocating freq. to satellite services is a complicated process which requires international coordination & planning. This is carried out by ITU.

→ For Radio, Telephone communication services.

→ Also in Fax, cellular phones communication services.

→ You can talk to someone thousands of kilometers away within the comforts of your home in a matter of a few seconds

→ Used in navigational aids by vehicles on land, in the air and on sea.

→ Used to identify hidden mineral resources in countries having not-so-friendly terrains.

→ Indian Space Research Organisation (ISRO) [Sriharikota]
(Satellite launch vehicles) [Space station]

→ Meteorological Applications → Weather forecasting,
Flood forecast,
Melting of glaciers etc.,

→ Military Applications → Communication links b/w border forces & headquarters, spying, providing navigational aids to ships, aircrafts etc.,

→ In field of science & techonology → For astronomical research, monitoring of different layers of atmosphere etc.,

→ Satellites for earth Observation
↳ monitoring agriculture, forestry, detecting hidden mineral resources, forecasting weather, natural calamities, oil exploration, etc.,

→ Early warning satellites
for providing an advance warning to the owners of a missile attack.

→ Nuclear Detection (Vela Satellite)
detection of a nuclear explosion at the distance of Venus or Mars (1963-1970) by USA

# Historical Background

→ The first communication from an artificial earth satellite took place in October 1957 when the soviet satellite Sputnik I, transmitted telemetry information for 21 days.

→ Later, United States worked on Explorer I, launched in Jan. 1958, transmitted telemetry for nearly Five months.

→ For voice communication, the first satellite used for Score, launched in Dec. 1958 by United states and used to broadcast President Christmas message of that Year.

→ In 1960, US launched Echo I to avoid limitations regarding size.

→ During same Year, Courier was also launched by them which to used to store-and-forward the messages.

→ The first non-government satellite was Telstar I, an active real-time repeater, launched in July 1962 by Bell system. This satellite was placed in medium-altitude elliptical orbit (in space) by NASA.

→ Later, the government experiments continued, launched Relay I in Dec. 1962 by NASA for transmission of voice, video and data testing.

→ The use of geo-stationary orbit was first suggested by Arthur C. Clarke in mid 1940's. This orbit is in the equatorial plane, and

the orbital period is synchronized to rotation of earth.

→ The first attempt at a synchronous orbit was made by NASA, launching SYNCOM I in Feb. 1963. Which was a failed attempt. Later SYNCOM II and SYNCOM III were launched in July 1963 & August 1964 respectively which were successful for establishing communication links in synchronous orbit.

→ In 1962, Communications Satellite Corporation (Comsat) is formed according to Communications Satellite Act, signed by U.S. President Kennedy.

→ This organization includes members from over 100 nations. In July 1964, Intelsat was formed by COMSAT and agreements were signed on August 20, 1964.

→ In April 1965, (Intelsat I) Early Bird was launched into Synchronous orbit for Commercial use.

→ The series from Intelsat I through Intelsat IV A were successful.

→ Later Intelsat V with advanced capacity was launched. Intelsat VI with frequency higher than C-band was launched and continued with launch of Intelsat VII.

→ From mid-1960's through 1970's, Intelsat continued to expand and flourish.

→ In mid-1970's, a new aspect of satellite communications industry, domestic satellites, began to form.

→ These satellites have dropped the cost aspect and used for domestic and regional communication

→ Every country has its own satellite communication system to cover their entire country area.

→ United States has its own satellite communication system and Similarly, Russia has a series of geostationary satellites to provide fixed, mobile, and broadcast services in that country only.

→ In 1965, Russia launched Molniya to provide TV & voice distribution.

→ Satellite Communication began with "fixed" service later extended to "mobile and broadcast" services.

→ Submarine cables and fiber optics provide effective competition to satellites in fixed or broadcast services, but there is no alternate to satellite in mobile services.

→ The satellite communications has evolved into a multibillion dollar industry with whole world as market.

→ It has done same thing in telecommunications field like airplane did in transportation.

→ The following tables provide different data related to satellites.

## Satellite Communication Origin :

→ Radio waves travel in straight lines at microwave frequencies, so a repeater is needed to convey signals over long distances.

→ Satellites, because they can link places on earth that are thousands of miles apart, are a good place to locate a repeater, and a GEO satellite is the best place of all.

→ A repeater is simply a receiver linked to a transmitter, always using different radio frequencies, that can receive a signal from one earth station, amplify it, and retransmit it to another earth station.

→ Typical path length from an earth station to a GEO satellite is 38,500 kms.

→ There were severe restrictions on size and weight of GEO satellites, since the high cost of building and launching a satellite must be recovered over a 10 to 15 year lifetime by selling them.

→ In satellite communication systems, there is a need to receive very weak signals. In early days, very large receiving antennas, with diameters upto 30m were used for this purpose.

→ Later as satellites have become larger, heavier and more powerful, receiving antennas diameter also become smaller.

→ For example, Direct Broadcast Satellite TV receiving systems can use dish antennas as small as 0.5m in diameter.

→ Satellite systems operate in microwave & millimeter wave frequency bands, using frequencies between 1 and 50 GHz.

→ Above 10 GHz, rain causes some amount attenuation as rain enters into the path between satellite & earth station.

→ Above 20 GHz, heavy rain cause attenuation with the link to completely fail.

→ For the first 20 years of satellite communication analog signals were used, with most links employing frequency modulation (FM) for video and telephone signals.

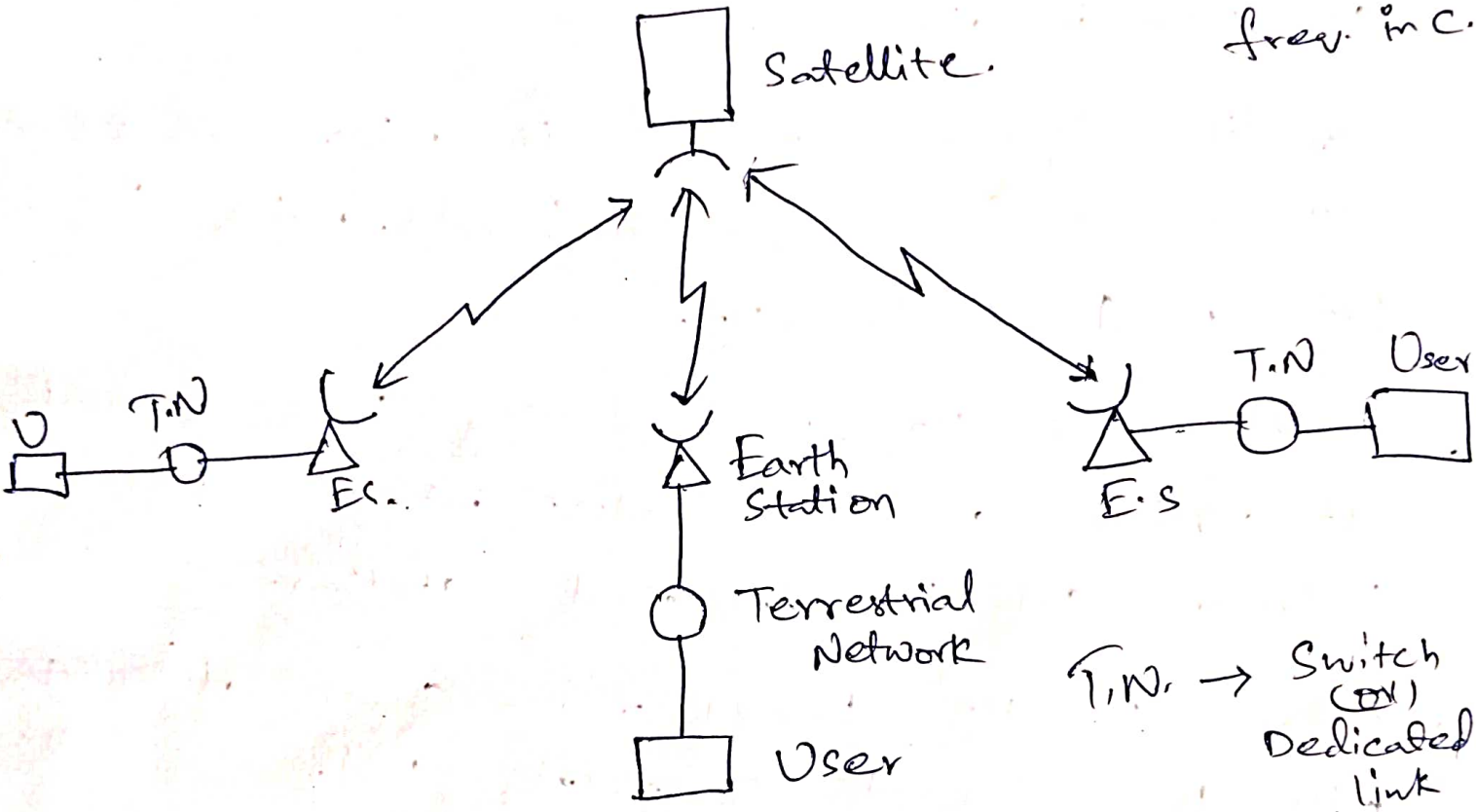
→ Later, they move towards digital transmission with more data can be transmitted than analog with large bandwidth advantage.

→ Almost all other signals are digital - telephony, data, DBS-TV, radio broadcasting and navigation

with GPS all use digital signaling techniques. Also, all of the LEO and MEO mobile Communication Systems are digital.

## A Basic Satellite System:

Rain attenuates more as freq. in C.




T.N. → Switch (or) Dedicated link to E.S.

500 MHz → B.W → U.L

500MHz → B.W. → DL.

Geostationary.

6/4 – GHz Band

Widely used. Uplink → 5.725 to 7.075 GHz

D.L → 3.4 to 4.8 GHz.

Now-a-days 14/12 GHz. Band

U.L. → 12.75 to 14.8 GHz

D.L → 10.7 to 12.3 GHz.

## Satellite Systems :-

→ A satellite system consists basically of a satellite in space which links many earth stations on the ground.

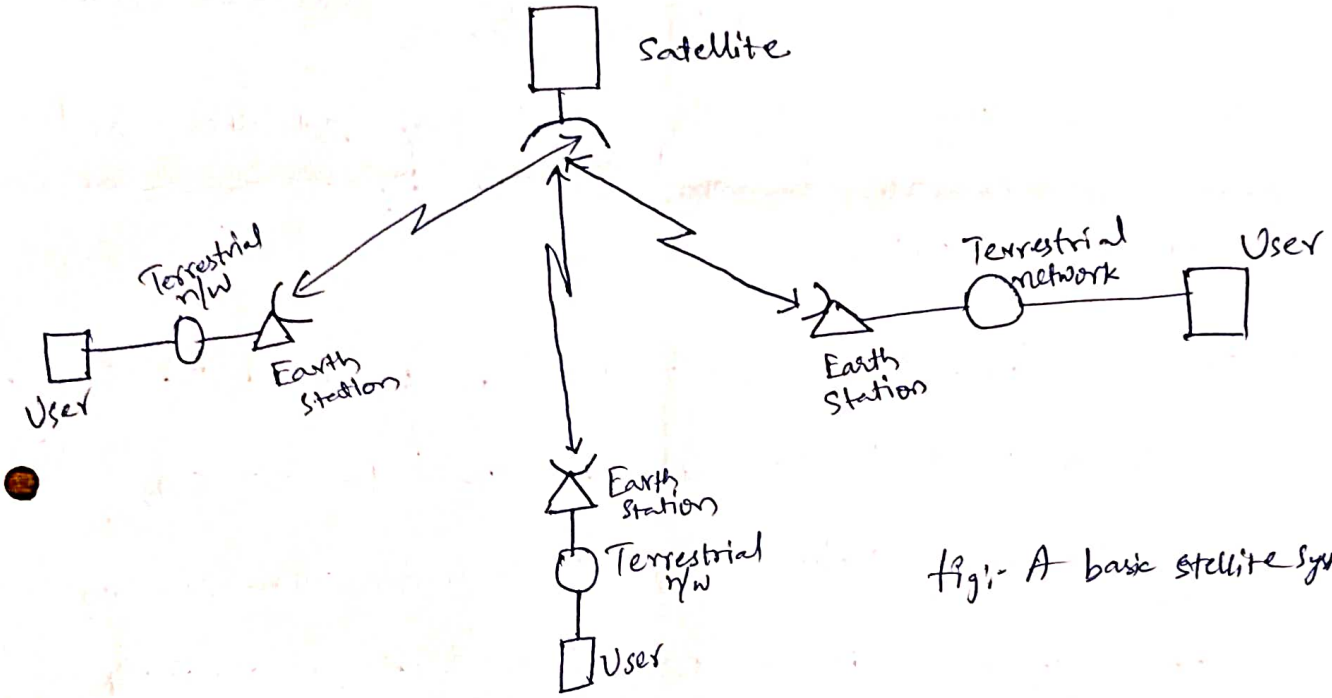



fig:- A basic stellite system

→ The user generates the baseband signal which is routed to the earth station through the terrestrial network.

→ The terrestrial network can be a telephone switch or a dedicated link to the earth station.

→ At the earth station the baseband signal is processed and transmitted by a modulated radio frequency carrier to the satellite.

→ The satellite (large repeater) receives the modulated RF carrier in its uplink frequency spectrum, amplifies these carriers and retransmits them back to earth in downlink frequency spectrum which is different from uplink freq. spectrum in order to avoid interference.

→ The receiving earth station processes the modulated RF carrier down to the baseband signal which is sent through the terrestrial network to the user.

~~VHF band~~ →

~~FM → 88 to 108 MHz~~

~~Audio~~ →

→ Most commercial communications satellites today utilize a 500 MHz bandwidth on uplink and a 500 MHz bandwidth on downlink. The most widely used frequency spectrum is 6/4 - GHz band, with an uplink 5.725 to 7.075 GHz and a downlink of 3.4 to 4.8 GHz.

→ The 6/4 - GHz band for geostationary satellites is becoming overcrowded because it is also used by common carriers for terrestrial microwave links.

→ Now, 14/12 - GHz band is used, uplink → 12.75 to 14.8 GHz

downlink → 10.7 to 12.3 GHz (or) 12.5 to 12.7 GHz.

→ Rain attenuates 14/12 - GHz signals more than 6/4 GHz.

→ 30/20 - GHz band is in experimental stage and is expensive.

uplink → 27.5 to 31 GHz & downlink → 18.1 to 21.2 GHz.

## Applications



→ for Several Thousands of Km's. (International routes).

→ In Deployment of telecommunication services between isolated communities.
↓
some populated areas seperated by vast distances. or difficult terrain (or) sea areas.

→ With advanced technology, size of ground terminal antenna & other hardware sizes have reduced where terminals can be now installed in customer premises.
These terminals are called as.
Very small Aperture Terminals (VSAT)
↓ costeffective
↓ avoids delays in transmission
↓ user accessing will be fast

→ Mobile satellite communications, roaming of mobile network internationally is possible.

→ Satellites are used to provide voice & data communications to aircraft, ships, land vehicles & handsets.

→ Also, for ships provision of live television is done.

→ Messaging & Voice communications to desktop & pocket size devices.

→ Tracking movements of truck fleets & large ships.

→ Supports relief operations in remote areas.

→ Instant contact with news reporters from inaccessible areas.

→ Satellite communication provides rapid television coverage over wide areas.

→ Disadvantages

→ Cost, malfunctioning at any stage from launch vehicle to deploying satellite in orbit; transmission delay caused by the long propagation path (mainly GEO)

## Future Trends :-

→ The use of very small aperture terminals for business & rural applications is expected to grow in all parts of world. Personal VSAT's are expected to provide broadband services accompanied by a significant reduction in call charges.

→ Satellites in mobile communications is expected to be a major growth area in coming decades. The number of satellites will be increasing in this area.

→ The use of direct-to-home broadcasting is also expected to rise in many parts of the world, which offers services like watching movies on online or downloading also.

→ Other areas being investigated include the use of non-geostationary orbits for specific applications, inter-satellite links in space, ~~to increase~~ advanced antenna concepts and others.

→ natural disaster warning and rescue operations.

→ Hilly regions & terrains. (reliable & economic).

→ Other trends are maritime mobile satellite services, aeronautical mobile
" " & land mobile
" " .

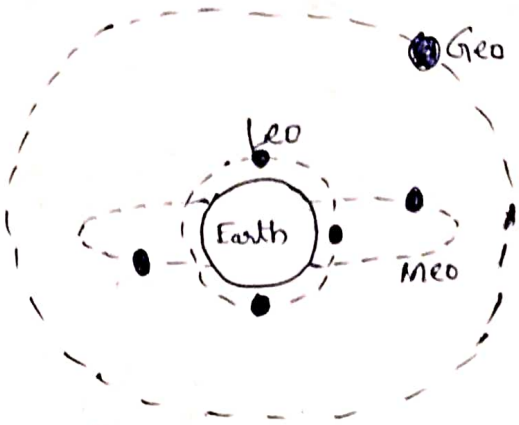
→ Station keeping (SK)

Coordinated strategies with proven computer simulations & then adopted for operations. (maintaining minimum seperation between satellites).

Cluster than individual.

## Types of Orbits

1. Low-earth-orbit (LEO)
2. Medium-earth-orbit (MEO)
3. Geostationary (GEO)




### Low-earth-orbit (LEO) :-

→ Altitude (600 – 1000km)

→ Satellite gives it a better signal strength.

→ Reduces transmission delay

→ Smaller coverage area & shorter life span (5-8 years)

→ 0.8 GHz range with low-cost & used for short communications.

### Medium-earth-orbit (MEO) :-

→ MEO's orbits between the altitudes of 8000 – 20,000 km above the earth.

→ larger coverage area

→ Reserved for communication satellites that cover the north & south pole.

→ MEO's are placed in an elliptical orbit (oval-shaped).

### Geostationary-Earth-orbit (Geo) :- (38,500 kms)

→ From the ground level the satellite appears fixed.

→ Geo satellites have a 24 hour view of a particular area.

→ Coverage to 40% of area of planet by this satellite.

→ Space Segment → (Satellite)

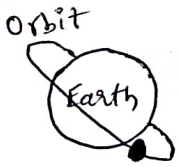
→ Ground segment → (Earth Stations)

→ orbits based on inclination (i), over the equatorial plane: (Paths)

(i) $i = 0°$ ( Equatorial orbit)

(ii) $i = 90°$ (Polar orbit) → Orbit pass both poles

(iii) $0° < i < 90°$ (inclined orbit)




Other types (Paths)

→ Circular orbit → (centre at earth's centre)

→ Elliptical orbit → (One foci at earth's centre)

Intelsat → [Intelsat I is called as Early Bird → 6th April 1965.]

→ International Telecommunication Satellite Organization was Created in 1964 as private-public association by the telecommunication agencies of 18 Countries.

→ USA was the original member of this organization.

→ The membership has risen since then and exceeded 150 nations.

→ By launching satellites in Indian Ocean Region (IOR) Pacific Ocean Region (POR), and Atlantic Ocean Region (AOR) it has been able to provide global coverage for television transmission and communication for the member Countries.

→ Intelsat currently has 61 active satellites.

→ Indian Space Research Organization (ISRO) is responsible for India's Space Program

→ In Feb 2017, ISRO created record by launching 104 Satellites in one go. by (PSLV) – C37 (On 15th Feb 2017)
(in which only 3 of them are Indian Satellite) (rocket) carries satellites

→ In 19th April 1975,
First Indian Satellite (Aryabhatta)

→ 7th June 1979, Bhaskara → experimental Satellite

→ Rohini in 1979, Rohini RS–1 in 1980,
Rohini RS–D1 in 1981

→ Bhaskara – II → 1981 November → for earth observation.

→ So far, India has launched 106 satellites since 1975.

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→ Kepler Laws

→ Satellites orbiting the earth follow the same laws that govern the motion of the planets around the sun. Kepler was able to derive three laws describing planetary motion.

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→ Calculate the semi major ~~radius~~ axis of a circular orbit for which the period is 1 day.

→ $n = \frac{2\pi}{P}$ $P = 86,400$ seconds.

$n = 7.272 \times 10^{-5}$ rad/s

from Kepler's third Law,

$a = \left[\frac{\mu}{n^2}\right]^{1/3}$

$a = 42,241.09$ kms

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

$\rightarrow a^3 = \frac{\mu}{n^2}$

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

---

~~Calculate orbital period in seconds, with 8.25×10^-5 rad/s~~

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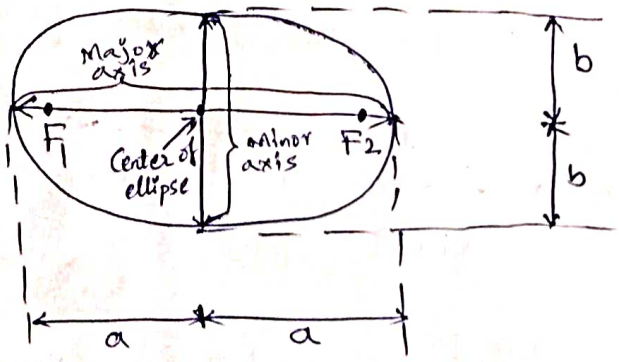
→ Kepler's Laws apply quite generally to any two bodies in space which interact through gravitation.

→ The more massive of the two bodies is referred to as the primary, the other, the secondary or satellite.

## Kepler's First Law:

→ It 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 figure. With the center of earth always at one of the foci.




→ The semimajor axis of the ellipse is denoted by a, and the semiminor axis by b. The eccentricity 'e' is given by

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

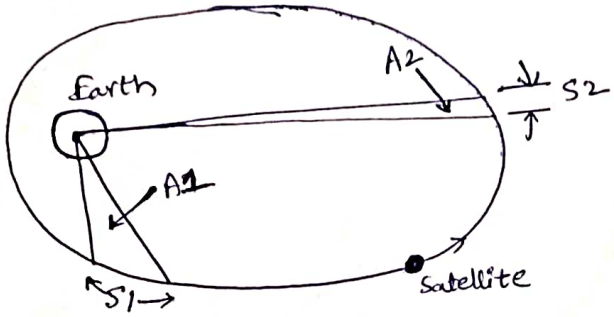
→ The eccentricity and semimajor axis are two of the orbital parameters specified for satellites orbiting the earth. For an elliptical orbit, $0 < e < 1$. When $e = 0$, orbit becomes circular.

## Kepler's second Law :-

→ It states that, for equal time intervals, a satellite will sweep out equal areas in its orbital plane.

→ from the figure assuming the satellite travels distances S1 & S2 meters in 1s, then the areas A1 & A2 will be equal.

→ The average velocity in each case is S1 & S2 m/s & because of equal area law, it follows that velocity at S2 is less than that at S1.




→ This result shows that the satellite orbital velocity is not constant; the satellite is moving much faster at locations near to earth & slows down at locations far away from earth.

## Kepler's Third Law :-

→ It 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 semimajor axis a.

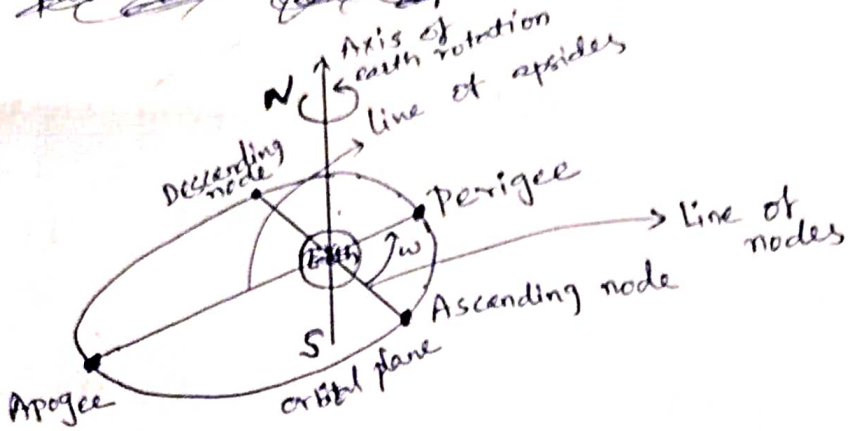
i.e., $$\boxed{a^3 = \frac{\mu}{n^2}}$$

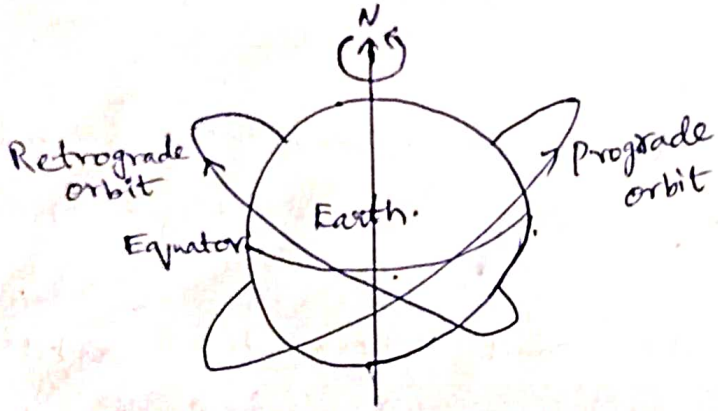
where, n is mean motion of satellite in radians per second & $\mu$ is the earth's geocentric gravitational constant. Its value is $\boxed{\mu = 3.986005 \times 10^{14} \ m^3/s^2}$

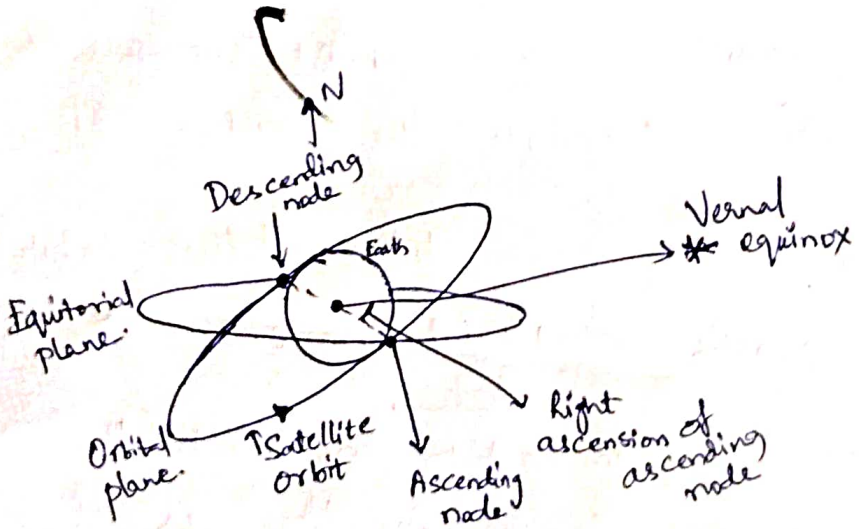
→ With n in radians per second, the orbital period in seconds is given by

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

# Terms of Earth-Orbiting Satellites:




$n = 1.085 \times 10^{-3}$

5789.84 sec

→ Argument of perigee (ω) :- The angle from ascending node to perigee, measured in the orbital plane at the earth's center, in the direction of satellite motion.

→ India's first experimental scientific satellite Aryabhata had low earth elliptical orbit with semi-major axis of 6969 Km and eccentricity of 0.00402. Find the apogee and perigee heights of this satellite? 5789.84 secs

$r_a - r_e$ & $r_p - r_e$

$r_a = a(1+e)$

$r_p = a(1-e)$

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

→ Apogee → The point farthest from earth.

→ Perigee → The point of closet approach to earth.

→ Line of apsides :- The line joining the perigee and apogee through the center of 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.

→ Line of nodes :- The line joining the ascending and descending nodes through the center of the earth.

→ Inclination :- The angle between the orbital plane and the earth's equatorial plane.

→ Prograde orbit :- An orbit in which the satellite moves in the same direction as the earth's rotation. The prograde orbit is also known as a direct orbit. The inclination of a prograde orbit always lies between 0° and 90°.

→ Retrograde orbit :- An orbit in which the satellite moves in a direction counter to the earth's rotation. The inclination of a retrograde orbit always lies between 90° and 180°.

## Orbital Elements :-

→ Earth-orbiting artificial satellites are defined by six orbital elements referred to as the "Keplerian element set".

→ Semi-major axis, eccentricity, time of perigee, right ascension of ascending node, inclination and the argument of perigee.

### 1.) Semi-major axis (a) :-

→ This is a constant equal to one half of the sum of maximum and minimum radii of the orbit.

→ $$a = \frac{1}{2}(r_a + r_p)$$

$r_a$ → max. radius of ellipse, (distance from apogee to centre of earth).

$r_p$ → min. radius of ellipse, (distance from perigee to centre of earth).

### 2.) Eccentricity (e) :-

→ It is the ratio of the distance b/w the foci to the length of major axis and defines shape of orbit.

From geometry of ellipse,

$$r_a = a(1+e) \quad -(1)$$

$$r_p = a(1-e) \quad -(2)$$

→ (1) + (2) ⇒ $r_a + r_p = a + ae + a - ae = 2a \quad -(3)$

→ (1) − (2) ⇒ $r_a - r_p = a + ae - a + ae = 2ae \quad -(4)$

$$\frac{(4)}{(3)} \Rightarrow \frac{2ae}{2a} = \frac{r_a - r_p}{r_a + r_p} \Rightarrow e = \frac{r_a - r_p}{r_a + r_p}.$$

→ The heights of apogee and perigee are obtained by subtracting the radius of earth, $r_e$ from the apogee and perigee distances from the center of earth.

$r_e = 6378$ kms
radius of earth

Apogee height $(h_a) = r_a - r_e$

Perigee height $(h_p) = r_p - r_e$

3) Time of Perigee :

It is the time when satellite last passed the perigee, or the last time when the satellite was nearest to earth.

4) Right Ascension of Ascending node :-

→ When a satellite is in an inclined orbit, there are infinite possible orbits with a given inclination.

→ Thus, just by specifying the inclination angle, it is not possible to completely specify the satellite orbit.

→ To completely specify the orbit, we must fix the points (nodes) on the equator where the satellite orbit intersects.

→ The ascending node is one of these points where the satellite crosses the equator going from south to North and at descending node crosses from north to south.

→ Right ascension is an angle measured in the equatorial plane from the line joining the centre of the earth to a reference point in the sky, called vernal equinox, to the line joining the centre of earth to the ascending node.

## Orbital Perturbations:

→ A satellite is expected to move in an orbit until its life is over. However, a satellite is deviated from its normal path due to several forces. This deviation is termed as orbital perturbation.

→ The causes for perturbation are ~~mentioned~~

(i) Non-sphericity of the Earth :-

The earth is not a true sphere, but is bulged in the equatorial plane & flat at the poles. It looks more like an apple rather than a ball. The difference in the radii along the equator and poles is about 21.4 km. The cross section of the earth at the equator is also not a circle, but is elliptical.

(ii) Atmospheric Drag :-

Atmosphere near earth has higher density which becomes less and less at higher altitudes. The satellites with their orbits passing through the

atmosphere, such as the LEO or orbits with low perigee, experience drag causing them to lose their altitude. Satellites in orbits above 1000km are not affected by atmospheric drag.

(iii) Sun and Moon's Gravity :-

The gravity of sun and moon mostly affect the geosynchronous orbit, particularly its inclination. The annual change in the inclination can be between 0.75° & 0.95°.

(iv) Solar Radiation Pressure :-

Geostationary satellites, used for communication application, carry many transponders and antennas and are usually large in size and heavy in weight compared to satellites in non-geo orbits. The power requirement of these satellites is large and is obtained from large solar sails facing the sun. The solar radiation applies pressure on these sails disturbing the position of the satellites. The result is the change in the shape of the orbit converting the original circular orbit to an elliptical orbit.

(4) Determine the orbit eccentricity of a satellite moving in an elliptical orbit having the semi-major axis equal to 7000 kms. If the difference between apogee & perigee is 100 kms & earth's diameter is approximately 12,756 kms. Find apogee height and perigee height of this satellite?

$a = 7000\,kms, \quad r_a - r_p = 100\,kms. \quad -(1)$

$\rightarrow d_e = 12{,}756\,kms \Rightarrow r_e = \frac{d_e}{2} = \frac{12{,}756}{2} = 6378\,kms$

$\rightarrow a = \frac{1}{2}(r_a + r_p) \Rightarrow r_a + r_p = 2a = 2(7000) = 14000\,kms \quad -(2)$

w.k.T., $e = \frac{r_a - r_p}{r_a + r_p} = \frac{100 \times 10^3}{14000 \times 10^3} = \frac{1}{140} = 0.00714$

from (1), $r_a = 100\,kms + r_p \rightarrow$ Sub. in (2)

$r_a + r_p = 14000\,kms$

$\Rightarrow 100 + r_p + r_p = 14000$

$\Rightarrow r_p = \frac{13900}{2} = 6950\,kms$

$\therefore r_a = 100\,kms + 6950\,kms = 7050\,kms$

Now,

$h_a = r_a - r_e = 7050 - 6378 = 672\,kms$

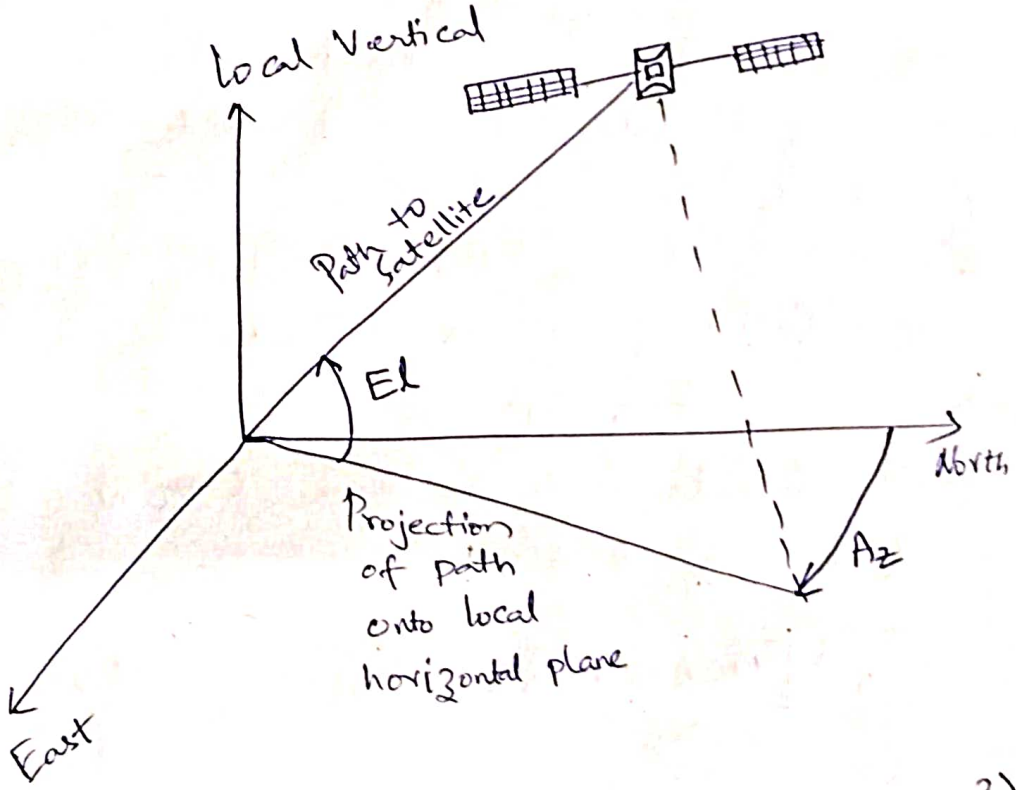
$h_p = r_p - r_e = 6950 - 6378 = 572\,kms$

# Look Angle Determination

→ The coordinates to which an earth station antenna must be pointed to communicate with a satellite are called as 'look Angles'. They are Azimuth (Az) & Elevation (El)

→ Azimuth is measured eastward (Clockwise) from geographic north to the projection of the satellite path on a (locally) horizontal plane at the earth station.

→ Elevation is the angle measured upward from the local horizontal plane at the earth station to the satellite path.




$$El. = \tan^{-1}\left[(6.6107345 - \cos\delta) / \sin\delta\right] - \delta$$

$\delta$ → central angle.

$\rightarrow \alpha = \tan^{-1}\left[\dfrac{\tan|l_s - l_e|}{\sin(L_e)}\right]$

$l_s \rightarrow$ Satellite longitude
$l_e \rightarrow$ earth station longitude
$L_e \rightarrow$ earth station latitude

$\alpha \rightarrow$ Intermediate angle.

For Azimuth angle,

Case 1 : Earth station in the Northern Hemisphere with

(a) Satellite to SE of earth station ; $A_Z = 180° - \alpha$
(b) Satellite to SW of earth station, $A_Z = 180° + \alpha$

Case 2 : Earth station in the Southern Hemisphere with

(c) Satellite to NE of earth station, $A_Z = \alpha$
(d) Satellite to NW of earth station, $A_Z = 360° - \alpha$

→ An earth station situated in Docklands of London, England, needs to calculate the look angle to a geostationary satellite in the Indian Ocean ~~by~~ operated by NASA. The details of the earth station site & satellite are as follows.

Central angle $\gamma \rightarrow 75.4981°$
Earth station latitude & longitude are 52.0°N & 0°
Satellite longitude is 66.0° E,

Sol :

$\rightarrow El = \tan^{-1}\left[(6.6107345 - \cos(75.4981°)) / \sin(75.4981°)\right] - 75.4981$

$= 5.847°$

$\rightarrow \alpha = \tan^{-1}\left[\dfrac{\tan|66.0 - 0|}{\sin(52.0)}\right] = 70.667°$

E.S. is in Northern Hemisphere & satellite is to SE of Earth station.

$\rightarrow A_Z = 180° - \alpha = 180 - 70.667 = 109.333°$ (clockwise north from true

## Orbit Determination:

→ Orbit Determination requires that sufficient measurements be made to determine six orbital elements uniquely which are needed to calculate orbit of a satellite & to keep it within the orbital location.

→ The control earth stations used to determine these measurements of the satellite along with range measurements using unique time stamps in the telemetry stream.

→ These earth stations are generally referred to as TTC&M (telemetry, tracking, command & monitoring) stations of the satellite network.

→ Major satellite networks maintain their own TTC&M stations around the world. Smaller satellite systems generally contract TTC&M stations from spacecraft manufacturer or from larger satellite system operators, as it is generally uneconomic to build advanced TTC&M stations with fewer than three ~~Stat~~ satellites to control.

## Launches and Launch Vehicles:

→ Launch vehicles have multiple stages and as each stage is completed that portion of the launcher is expended until the final stage places the satellite into the desired trajectory. This type are named as "Expendable launch vehicle (ELV)"

→ The space shuttle, called the Space Transportation System (STS) by NASA is partially reusable. The solid rocket boosters are recovered and refurbished for future purpose and reused. This type are "Reusable launch vehicle (RLV)".

→ More advanced launch vehicles are being developed.

→ There are also a number of private ventures that aim to achieve RLV capabilities.

→ There is a healthy market for ELVs for commercial public uses, they are more used by private companies than government.

→ Initially US was in the market, later Russian entered followed by China and India.

→ Some of Launch Vehicle Selection Factors:

1. Price / Cost
2. Reliability
3. Launch schedule (urgency of your launch requirement)
4. Performance
5. Spacecraft fit to launcher (size, acoustic and vibration environment).
6. Safety issues
7. Launch site location & its Availability (Checking its previous launch history/Success/failure)
8. Market issues.
   (In the market its purpose of usage).

→ A satellite is in an elliptical orbit with a perigee of 1000km and an apogee of 4000km. Using a mean earth radius of 6378.km, find the period of orbit in hours, minutes and seconds. (Assume $\mu = 3.986 \times 10^5$ $km^3/s^2$) Kepler's constant.

Sol:- $h_a = r_a - r_e$

$h_p = r_p - r_e$

$\Rightarrow r_a = h_a + r_e$ & $r_p = h_p + r_e$

W.K.T, $r_a + r_p = 2a$ (or) $\Rightarrow (h_a + r_e) + (h_p + r_e) = 2a$

i.e., $(2r_e) + (h_a) + (h_p) = 2a$

$\Rightarrow r_a = 10,378$ kms & $r_p = 7378$ km

W.K.T. $r_a + r_p = 2a$

$10,378 + 7378 = 2a$

$\Rightarrow a = \frac{17756}{2} = 8878$ kms.

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

& $a^3 = \frac{\mu}{n^2} \Rightarrow \frac{1}{n} = \sqrt{\frac{a^3}{\mu}}$

$\therefore P = 2\pi . \sqrt{\frac{a^3}{\mu}}$

& $\mu = 3.98 \times 10^5$ $km^3/s^2$

$P = 8331$ sec

$P = (7200) + 1131 = 7200 + 1080 + 51$

$= 2h\ 18min\ 51sec$

→ Determine the orbit eccentricity of a satellite.

$a = 16000\,km$, $r_a - r_p = 25000\,km$

$$r_a - r_p = 2ae$$

moon b/w sun & earth (solar eclipse)

$$\Rightarrow e = \frac{r_a - r_p}{2a} = 0.78$$

---

## Eclipse

→ Solar eclipses caused by the earth and moon to the satellite are important as these affect the working of satellites, in particular the energy generated by solar cells is greatly affected.

**Solar Eclipse caused by Earth:-** (earth b/w sun & satellite)

→ The inclination angle of the earth's equatorial plane $i_e(t)$ with respect to the sun's direction is as that shown in figure 1.

→ The annual variation $i_e(t)$ is sinusoidal in nature. The apparent movement of the sun relative to the earth is shown in figure 1(b).

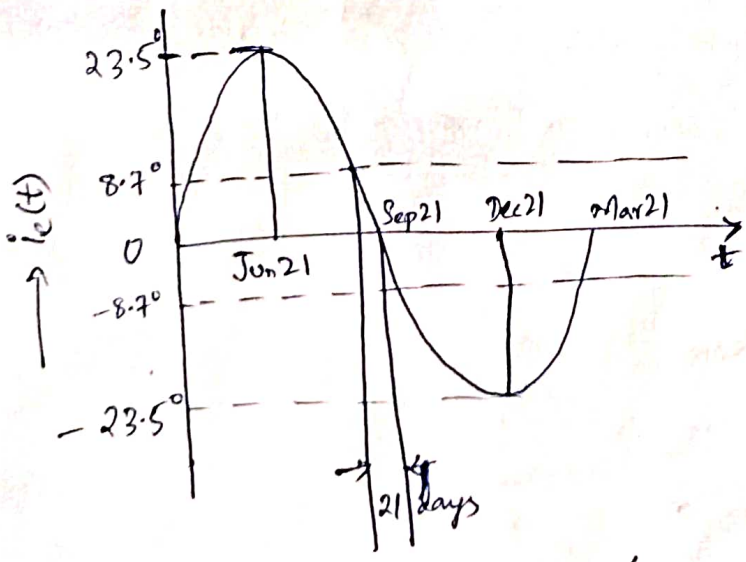



fig 1(a). Variation of Earth's Equatorial Plane inclination angle $i_e(t)$.

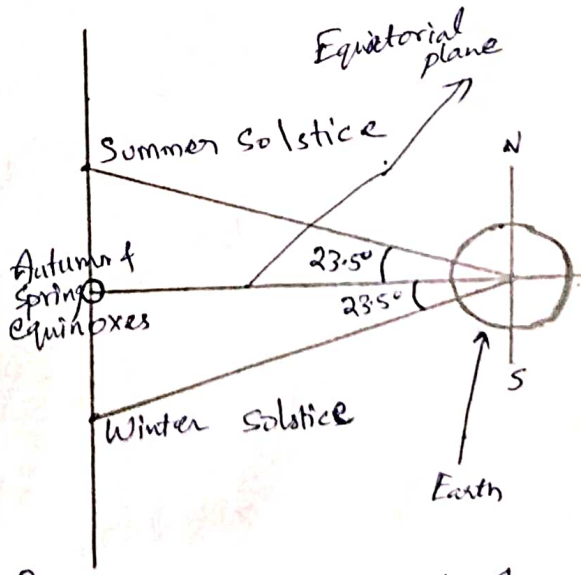



fig 1(b). Apparent movement of Sun relative to earth.

→ It is apparent that summer solstice occurs on 21st June and winter solstice is on 21st dec. Similarly Spring & Autumn equinoxes occur on 21st March & 21st Sep.

→ The variation of $i_e(t)$ as that shown in fig can be written mathematically as

$$i_e(t) = 23.5 \sin \omega t = 23.5 \sin \frac{2\pi t}{T}.$$

where, T is annual period equal to 365 days. & max. inclination angle $i_e(t)$ is 23.5°.

→ At the spring and autumn equinoxes the inclination angle is zero whereas it is at its maximum on summer & winter solstices.

→ The satellite is always illuminated at the solstice. It goes the maximum duration of eclipse during equinoxes. The solar eclipse during equinox is as that shown in fig.2.

→ From the first day of eclipse 21 days are needed to reach the equinox, in total for 42 days the solar eclipse near equinox affects the satellite working.

→ Thus the satellite services are interrupted and it needs a battery backup.

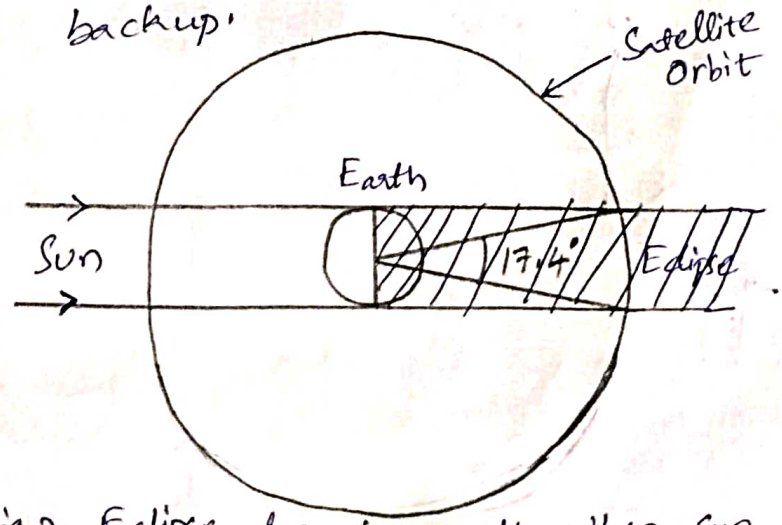



fig.2 Eclipse due to earth when sun is at equinox.

## Eclipse caused by moon :- (moon b/w sun & satellite)

→ The solar eclipse caused by moon to the geostationary satellite occurs when the moon passes in front of the sun.

→ The eclipse occurs irregularly in time of duration

→ oftenly eclipses may occur twice within a 24 hr period.

→ Eclipse duration may range from a few minutes to over two hours with an average duration of about 40 mins.

→ Compared to earth-solar eclipse, the number of moon solar eclipse range from zero to four with an average of two per year.

→ It is to note that if moon solar eclipse of long duration occurs just before or just after the earth solar eclipse, the satellite has to face special problems in connection with battery recharging and its reliability.

→ To overcome such kind of solar battery problems during eclipses an energy reserve is provided with the satellite.

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## Orbital Effects in Communications Systems Performance

1. Solar Eclipse (by Earth & Moon)
2. Doppler shift → LEO↑
3. Range Variations → GEO↑
4. Sun Transit Outage → Fade margin of 6 exceed.

## Doppler Shift

To a stationary observer, the frequency of a moving radio transmitter varies with the transmitter's velocity relative to the observer. If the true transmitter frequency (i.e., the

frequency that the transmitter would send when at rest) is $f_T$, the received frequency $f_R$ is higher than $f_T$ when the transmitter is moving toward the receiver and lower than $f_T$ when the transmitter is moving away from the receiver. Mathematically, the relationship [Eq. (2.44a)] between the transmitted and received frequencies is

$$\frac{f_R - f_T}{f_T} = \frac{\Delta f}{f_T} = \frac{V_T}{v_p} \tag{2.44a}$$

or

$$\Delta f = V_T f_T / c = V_T / \lambda \tag{2.44b}$$

where $V_T$ is the component of the transmitter velocity directed toward the receiver, $v_p = c$ the phase velocity of light ($2.9979 \times 10^8 \approx 3 \times 10^8$ m/s in free space), and $\lambda$ is the wavelength of the transmitted signal. If the transmitter is moving away from the receiver, then $V_T$ is negative. This change in frequency is called the *Doppler shift*, the Doppler effect, or more commonly just "Doppler" after the German physicist who first studied the phenomenon in sound waves. For LEO satellites, Doppler shift can be quite pronounced, requiring the use of frequency-tracking receivers. For geostationary satellites, the effect is negligible.

## Range Variations

Even with the best station-keeping systems available for geostationary satellites, the position of a satellite with respect to the earth exhibits a cyclic daily variation. The variation in position will lead to a variation in range between the satellite and user terminals. If time division multiple access (TDMA) is being used, careful attention must be paid to the timing of the frames within the TDMA bursts (see Chapter 6) so that the individual user frames arrive at the satellite in the correct sequence and at the correct time. Range variations on LEO satellites can be significant, as can path loss variations. While guard times between bursts can be increased to help in any range and/or timing inaccuracies, this reduces the capacity of the transponder. The on-board capabilities of some satellites permit both timing control of the burst sequence and power level control of individual user streams.

## Sun Transit Outage

During the equinox periods, not only does the satellite pass through the earth's shadow on the "dark" side of the earth, but the orbit of the satellite will also pass directly in front of the sun on the sunlit side of the earth (Figure 2.23). The sun is a "hot" microwave source with an equivalent temperature of about 6000 to 10,000 K, depending on the time within the 11-year sunspot cycle, at the frequencies used by communications satellites (4 to 50 GHz). The earth station antenna will therefore receive not only the signal from the satellite but also the noise temperature transmitted by the sun. The added noise temperature will cause the fade margin of the receiver to be exceeded and an outage will occur. These outages may be precisely predicted. For satellite system operators with more

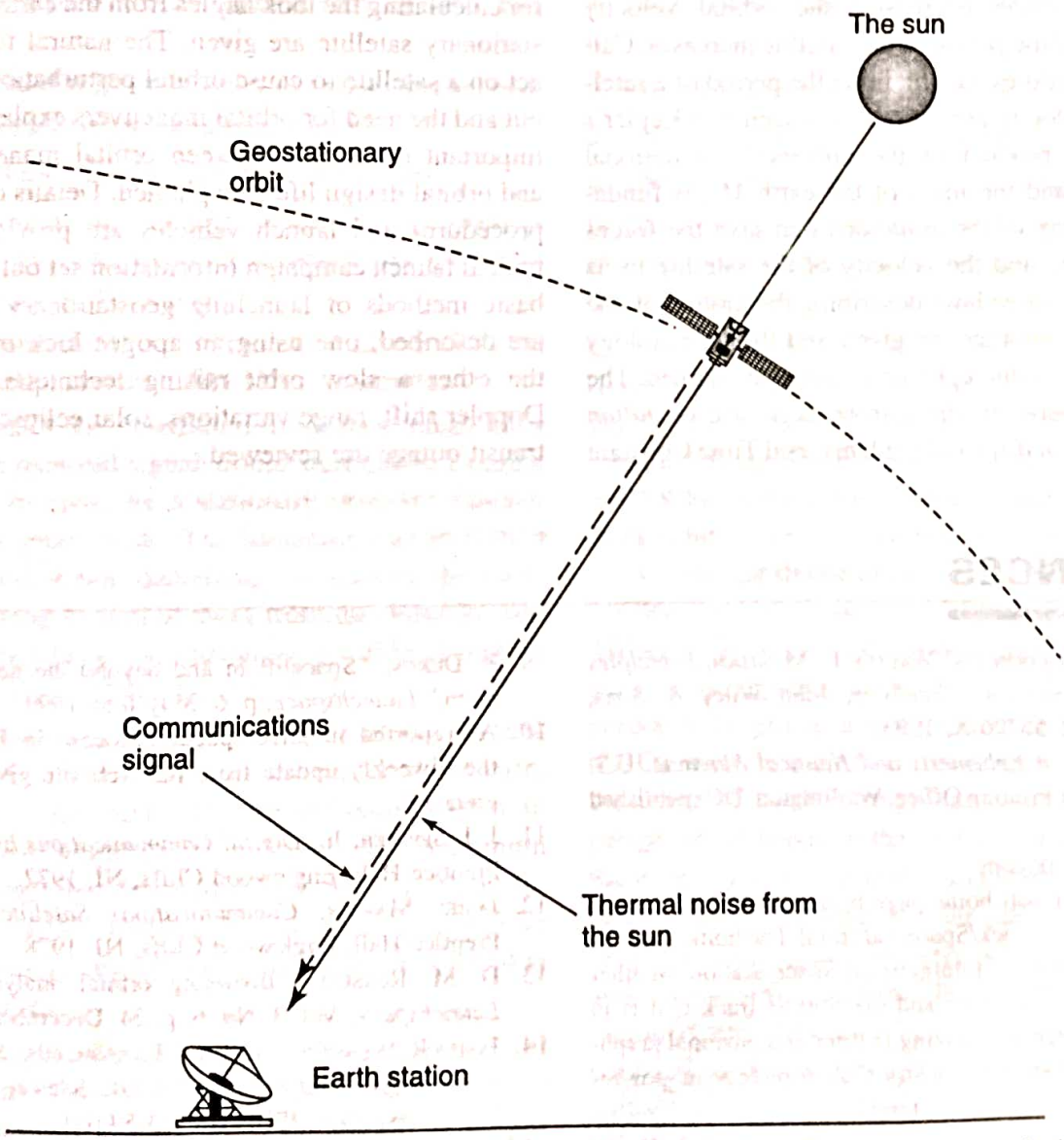


**FIGURE 2.23** Schematic of sun outage conditions. During the equinox periods, not only does the earth's shadow cause eclipse periods to occur for geostationary satellites, during the sunlit portion of the orbit, there will be periods when the sun appears to be directly behind the satellite. At the frequencies used by communications satellites (4 to 50 GHz), the sun appears as a hot noise source. The effective temperature of the sun at these frequencies is on the order of 10,000 K. The precise temperature observed by the earth station antenna will depend on whether the beamwidth partially, or completely, encloses the sun.

than one satellite at their disposal, traffic can be off-loaded to satellites that are just out of, or are yet to enter, a sun outage. The outage in this situation can therefore be limited as far as an individual user is concerned. However, the outages can be detrimental to operators committed to operations during daylight hours.