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Internal Assessment Test 1 – November 2024

Sub:	**Satellite and Optical Communication**					Sub Code:	**BEC515D**	Branch:	**ECE**
Date:	**07/11/2024**	Duration:	90 Minutes	Max Marks:	50	Sem/Sec:			**OBE**

	Answer Any 5 Questions	MARKS	CO	RBT
1	Explain the three Kepler’s law with relevant diagrams	[10]	CO1	L2
2	Define orbital Parameters. Write the advantages of Geo Stationary orbit.	[10]	CO1	L2
3	What are the orbital parameters? Derive the expression for orbital equation of the satellite starting from Newton’s law.	[10]	CO1	L2
4	Derive the expression for azimuth angle for geostationary satellites.	[10]	CO1	L2
5	Discuss the tracking, telemetry, and command (TT&C) subsystem. How does this subsystem ensure effective communication between the satellite and the ground station?	[10]	CO2	L2
6	Identify the various types of satellite subsystems and explain how they interact with one another to achieve the satellite's mission objectives.	[10]	CO2	L2
7	Discuss the architectural design considerations for an Earth station. What factors must be taken into account when designing an Earth station for optimal performance?	[10]	CO2	L2

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Questions & Solutions

1. Explain the three Kepler's law with relevant diagrams

Solution:

Kepler's First Law

1. The orbit of a satellite around Earth is elliptical with the centre of the Earth lying at one of the foci of the ellipse.

2. Eccentricity *(e)* is the ratio of the distance between the centre of the ellipse and either of its foci (= ae) to the semi-major axis of the ellipse a.

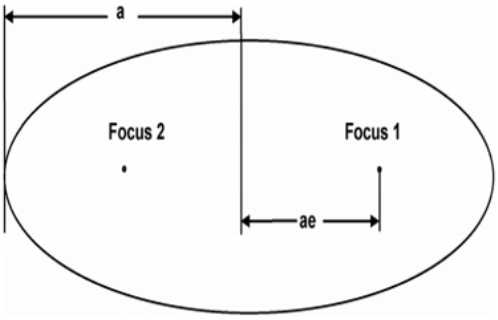


Fig: Kepler's first law

The law of conservation of energy is valid at all points on the orbit.

In the context of satellites, it means that the sum of the kinetic and the potential energy of a satellite always remain constant. The value of this constant is equal to -$Gm1m2/(2a)$, where

$m1$ = mass of Earth
$m2$ = mass of the satellite
a = semi-major axis of the orbit

$$\text{Kinetic energy} = \frac{1}{2}(m_2 v^2)$$

$$\text{Potential energy} = -\frac{G m_1 m_2}{r}$$

$$\frac{1}{2}(m_2 v^2) - \frac{G m_1 m_2}{r} = -\frac{G m_1 m_2}{2a}$$

$$v^2 = G m_1 \left(\frac{2}{r} - \frac{1}{a}\right)$$

$$v = \sqrt{\left[\mu\left(\frac{2}{r} - \frac{1}{a}\right)\right]}$$

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
i.e. the rate ($\mathrm{d}A/\mathrm{d}t$) at which it sweeps area A is constant.

The rate of change of the swept-out area is given by

$$\frac{\mathrm{d}A}{\mathrm{d}t} = \frac{\text{angular momentum of the satellite}}{2m}$$

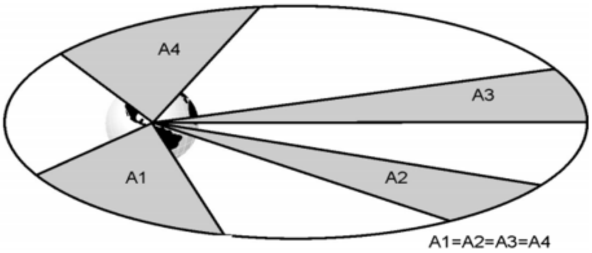
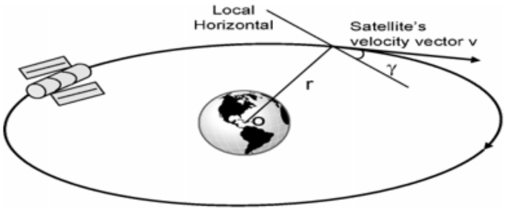


Fig: Satellite's position at any given time



Kepler's second law is also equivalent to the law of conservation of momentum, which implies that the angular momentum of the orbiting satellite given by the product of the radius vector and the component of linear momentum perpendicular to the radius vector is constant at all points on the orbit.

$$v_p r_p = v_a r_a = v r \cos\gamma$$

where
vp = velocity at the perigee point
rp = perigee distance
va = velocity at the apogee point
ra = apogee distance
v = satellite velocity at any point in the orbit
r = distance of the point
γ = angle between the direction of motion of the satellite and the local horizontal

Kepler's Third Law

- 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.
- A circular orbit is only a special case of an elliptical orbit with both the semi-major axis and semi-minor axis equal to the radius.

Equating the gravitational force with the centrifugal force gives

$$\frac{Gm_1m_2}{r^2} = \frac{m_2v^2}{r}$$

Replacing v by ωr in the above equation gives

$$\frac{Gm_1m_2}{r^2} = \frac{m_2\omega^2r^2}{r} = m_2\omega^2 r$$

which gives $\omega^2 = Gm_1/r^3$. Substituting $\omega = 2\pi/T$ gives

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

This can also be written as

$$T = \left(\frac{2\pi}{\sqrt{\mu}}\right)r^{3/2}$$

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

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

2. Define orbital Parameters. Write the advantages of Geo Stationary orbit.

Solution:

Orbital parameters are the fundamental elements that define the specific trajectory and shape of an orbit around a celestial body. For satellites and other space objects, these parameters describe the position, shape, and orientation of an orbit, allowing scientists and engineers to predict and control satellite motion. The primary orbital parameters include:

1. Semi-Major Axis (a): This is the longest radius of an elliptical orbit and determines the size of the orbit.
2. Eccentricity (e): This describes the shape of the orbit, indicating how much it deviates from a perfect circle (0 for circular orbits and values close to 1 for highly elliptical orbits).
3. Inclination (i): The tilt of the orbit relative to the equatorial plane of the primary body, measured in degrees.
4. Right Ascension of the Ascending Node (RAAN or Ω): The angle from a reference direction (usually the vernal equinox) to the direction of the ascending node, where the orbit crosses the equatorial plane going northward.
5. Argument of Periapsis (ω): The angle within the orbital plane between the ascending node and the orbit's point of closest approach to the primary body.
6. True Anomaly (ν): The angle between the periapsis and the satellite's current position in its orbit, measured at the primary body.

These parameters help in determining the orbit's orientation, size, and shape, allowing precise calculations for satellite positioning and tracking.

Advantages of Geostationary Orbit:

A geostationary orbit (GEO) is a high Earth orbit where a satellite moves at the Earth's rotational speed, maintaining a fixed position relative to the Earth's surface at an altitude of approximately 35,786 km. Key advantages of geostationary orbits include:

1. Constant Position: A geostationary satellite remains above the same point on Earth, making it ideal for continuous observation and communications with a fixed area.
2. Ideal for Telecommunications: The stationary position simplifies the design of ground-based antennas, which do not need to track the satellite's movement. This makes GEO satellites suitable for TV broadcasting, internet, and telephone services.

3. Wide Coverage: Due to its high altitude, a single GEO satellite can cover a large portion of the Earth's surface, particularly valuable for regions near the equator.
4. Weather Monitoring: GEO satellites provide consistent imaging of the same region, essential for weather forecasting and environmental monitoring.
5. Lower Maintenance Costs: Geostationary satellites do not require complex ground-based tracking, reducing operational and maintenance costs for ground stations.

3. What are the orbital parameters? Derive the expression for orbital equation of the satellite starting from Newton's law.

Solution:

Orbital parameters are the fundamental elements that define the specific trajectory and shape of an orbit around a celestial body. For satellites and other space objects, these parameters describe the position, shape, and orientation of an orbit, allowing scientists and engineers to predict and control satellite motion. The primary orbital parameters include:

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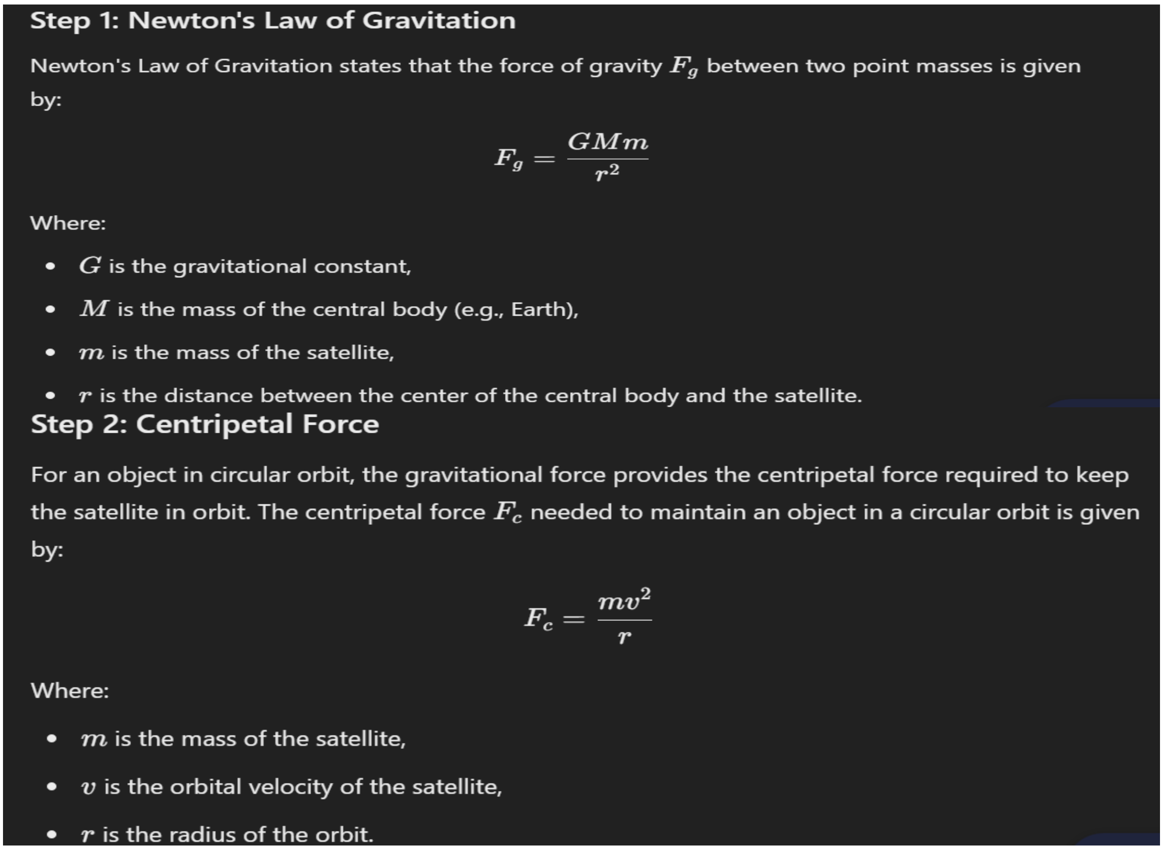
To derive the orbital equation for a satellite, we can start from Newton's law of gravitation and Newton's second law of motion. These laws provide a foundation for understanding how gravitational forces govern satellite motion. Here's a step-by-step derivation:



Step 1: Newton's Law of Gravitation

Newton's Law of Gravitation states that the force of gravity F_g between two point masses is given by:

$$F_g = \frac{GMm}{r^2}$$

Where:

- G is the gravitational constant,
- M is the mass of the central body (e.g., Earth),
- m is the mass of the satellite,
- r is the distance between the center of the central body and the satellite.

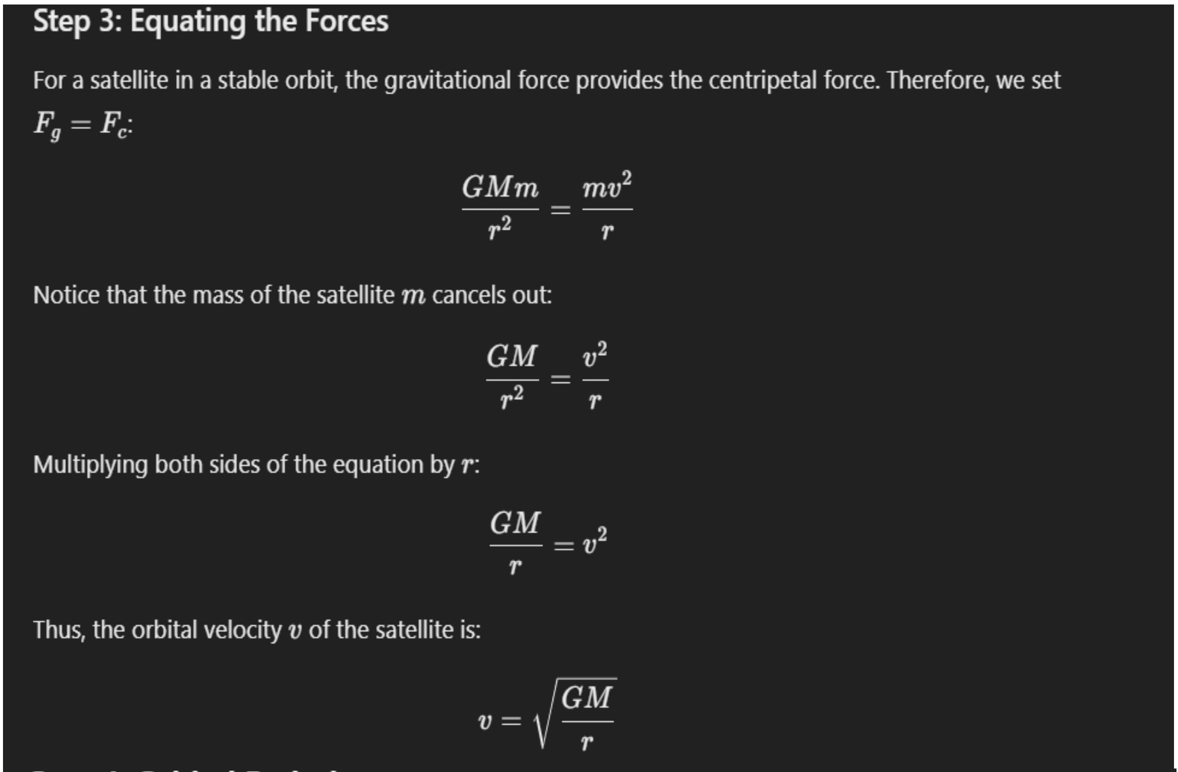
Step 2: Centripetal Force

For an object in circular orbit, the gravitational force provides the centripetal force required to keep the satellite in orbit. The centripetal force F_c needed to maintain an object in a circular orbit is given by:

$$F_c = \frac{mv^2}{r}$$

Where:

- m is the mass of the satellite,
- v is the orbital velocity of the satellite,
- r is the radius of the orbit.



Step 3: Equating the Forces

For a satellite in a stable orbit, the gravitational force provides the centripetal force. Therefore, we set $F_g = F_c$:

$$\frac{GMm}{r^2} = \frac{mv^2}{r}$$

Notice that the mass of the satellite m cancels out:

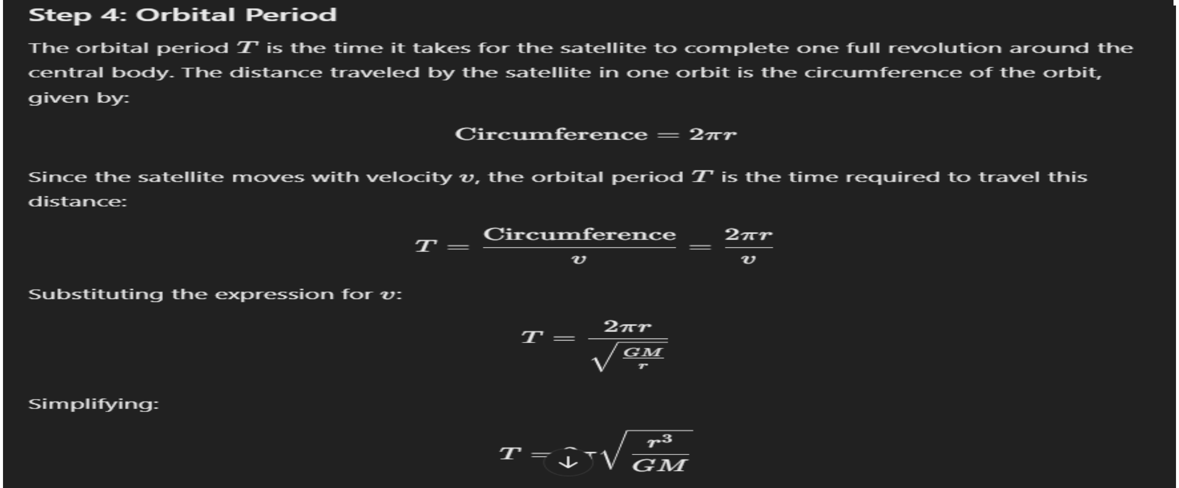
$$\frac{GM}{r^2} = \frac{v^2}{r}$$

Multiplying both sides of the equation by r:

$$\frac{GM}{r} = v^2$$

Thus, the orbital velocity v of the satellite is:

$$v = \sqrt{\frac{GM}{r}}$$



Step 4: Orbital Period

The orbital period T is the time it takes for the satellite to complete one full revolution around the central body. The distance traveled by the satellite in one orbit is the circumference of the orbit, given by:

$$\text{Circumference} = 2\pi r$$

Since the satellite moves with velocity v, the orbital period T is the time required to travel this distance:

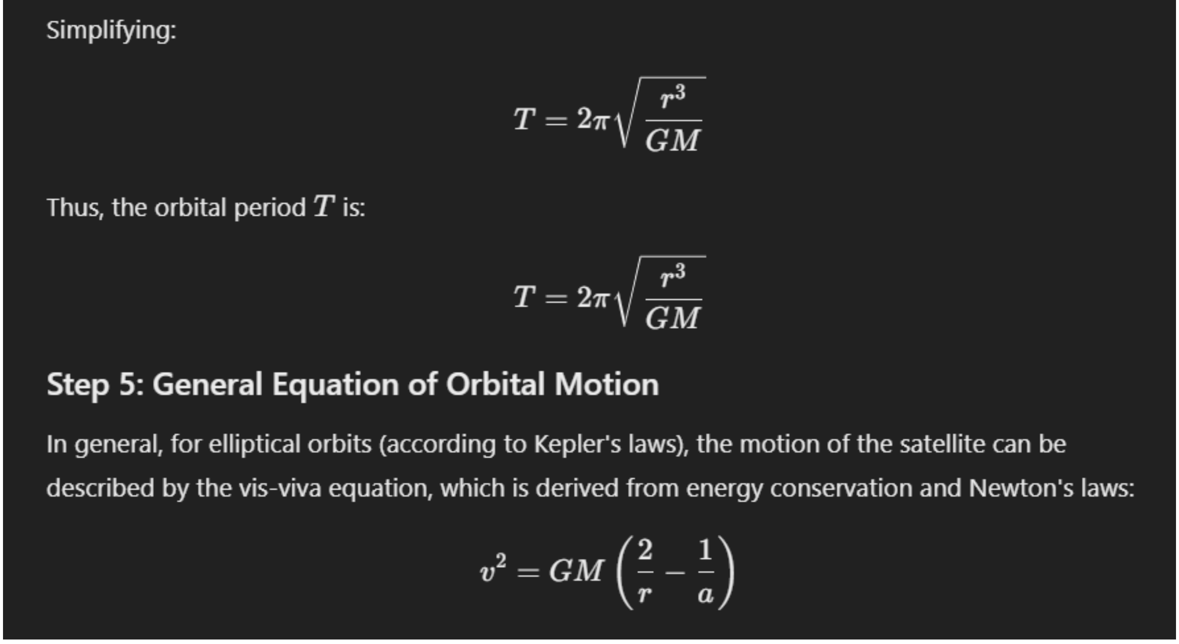
$$T = \frac{\text{Circumference}}{v} = \frac{2\pi r}{v}$$

Substituting the expression for v:

$$T = \frac{2\pi r}{\sqrt{\frac{GM}{r}}}$$

Simplifying:

$T =$ [illegible] $\sqrt{\frac{r^3}{GM}}$



Simplifying:

$$T = 2\pi\sqrt{\frac{r^3}{GM}}$$

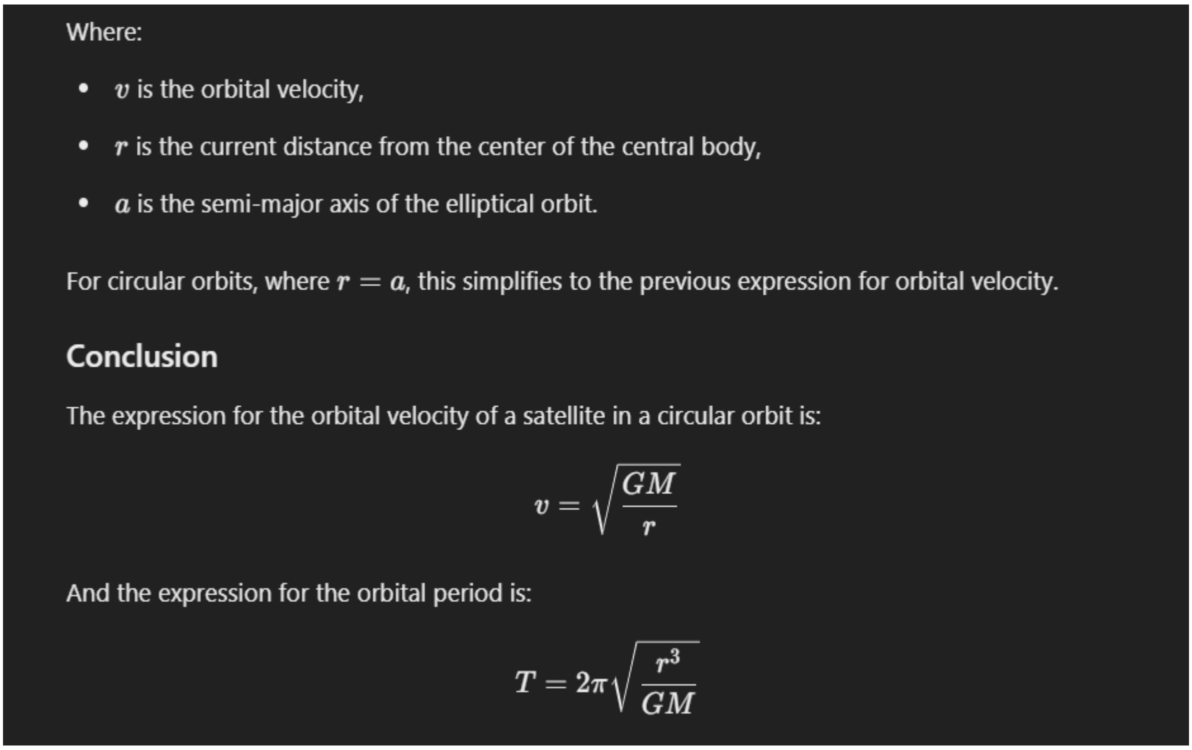
Thus, the orbital period T is:

$$T = 2\pi\sqrt{\frac{r^3}{GM}}$$

Step 5: General Equation of Orbital Motion

In general, for elliptical orbits (according to Kepler's laws), the motion of the satellite can be described by the vis-viva equation, which is derived from energy conservation and Newton's laws:

$$v^2 = GM\left(\frac{2}{r} - \frac{1}{a}\right)$$



Where:

- v is the orbital velocity,
- r is the current distance from the center of the central body,
- a is the semi-major axis of the elliptical orbit.

For circular orbits, where $r = a$, this simplifies to the previous expression for orbital velocity.

Conclusion

The expression for the orbital velocity of a satellite in a circular orbit is:

$$v = \sqrt{\frac{GM}{r}}$$

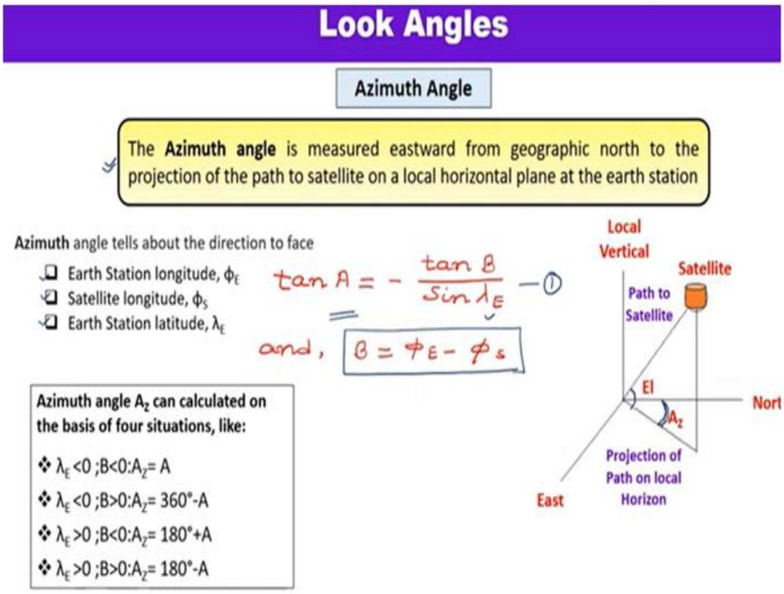
And the expression for the orbital period is:

$$T = 2\pi\sqrt{\frac{r^3}{GM}}$$

4. Derive the expression for azimuth angle for geostationary satellites

Solution:

Azimuth Angle



Look Angles

Azimuth Angle

The **Azimuth angle** is measured eastward from geographic north to the projection of the path to satellite on a local horizontal plane at the earth station

Azimuth angle tells about the direction to face

- ☑ Earth Station longitude, ϕ_E
- ☑ Satellite longitude, ϕ_S
- ☑ Earth Station latitude, λ_E

$$\tan A = -\frac{\tan B}{\sin \lambda_E} \quad \text{—①}$$

and, $\boxed{B = \phi_E - \phi_S}$

Azimuth angle A_Z can calculated on the basis of four situations, like:

- $\lambda_E < 0$;$B<0$:$A_Z = A$
- $\lambda_E < 0$;$B>0$:$A_Z = 360° - A$
- $\lambda_E > 0$;$B<0$:$A_Z = 180° + A$
- $\lambda_E > 0$;$B>0$:$A_Z = 180° - A$

> The azimuth angle *A* of an Earth station is defined as the angle produced by the line of intersection of the local horizontal plane and the plane passing through the Earth station, the satellite and the centre of the Earth with the true north.

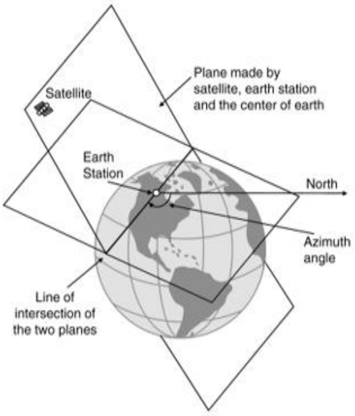


Fig: Azimuth angle

5. Discuss the tracking, telemetry, and command (TT&C) subsystem. How does this subsystem ensure effective communication between the satellite and the ground station?

Solution:

Tracking, Telemetry and Command Subsystem

- The tracking, telemetry and command (TT&C) subsystem monitors and controls the satellite right from the lift-off stage to the end of its operational life in space.
- The tracking part of the subsystem determines the position of the spacecraft and follows its travel using angle, range and velocity information.
- The telemetry part gathers information on the health of various subsystems of the satellite. It encodes this information and then transmits the same towards the Earth control centre.

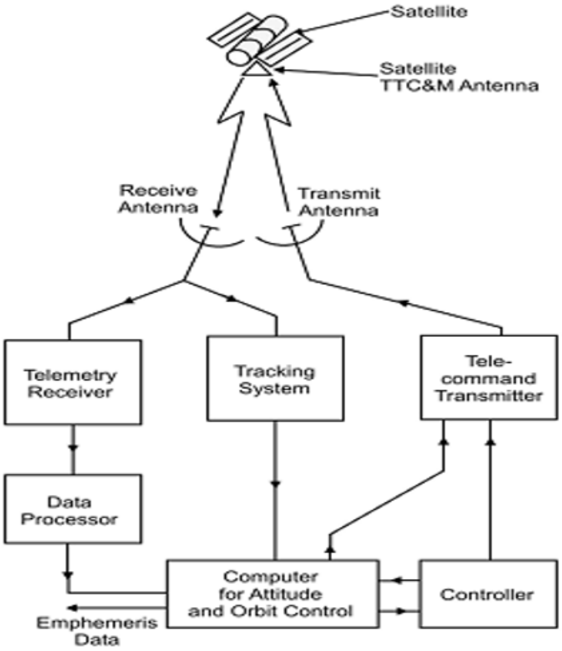


Fig: Block schematic arrangement of the basic TT&C subsystem

- The command element receives and executes remote control commands from the control centre on Earth to effect changes to the platform functions, configuration, position and velocity.
- Tracking is used to determine the orbital parameters of the satellite on a regular basis.
- This helps in maintaining the satellite in the desired orbit and in providing look-angle information to the Earth stations.
- During the orbital injection and positioning phase, the telemetry link is primarily used by the tracking system to establish a satellite-to-Earth control centre communications channel.
- Its primary function is to monitor the health of various subsystems on board the satellite.
- It gathers data from a variety of sensors and then transmits that data to the Earth control centre.
- With the modulation signal as digital, various signals are multiplexed using the time division multiplexing (TDM) technique.
- The bit rates involved in telemetry signals are low, it allows a smaller receiver bandwidth to be used at the Earth control centre with good signal-to-noise ratio.
- The command element is used to receive, verify and execute remote control commands from the satellite control centre.

- The functions performed by the command element include controlling certain functions during the orbital injection and positioning phase, including firing the apogee boost motor and extending solar panels, during the launch phase.

- The control commands received by the command element on the satellite are first stored on the satellite and then retransmitted back to the Earth control station via a telemetry link for verification.

6. Identify the various types of satellite subsystems and explain how they interact with one another to achieve the satellite's mission objectives.

Solution:

A satellite consists of several subsystems that work together to ensure the successful operation and achievement of its mission objectives. These subsystems are responsible for various functions, from communication and power generation to thermal control and propulsion. Below is an overview of the major satellite subsystems and how they interact to achieve the satellite's mission goals:

1. Power Subsystem

Function:

The power subsystem is responsible for generating, storing, and distributing electrical power to all other subsystems. This is typically achieved using solar panels that convert sunlight into electricity, and batteries that store the energy for use when the satellite is in the shadow of the Earth.

Interaction:

- The solar panels generate power, which is then regulated and stored in the batteries
- The batteries supply power to all other subsystems when the satellite is not in sunlight (e.g., during the night portion of its orbit).
- Power is distributed to subsystems such as communications, propulsion, and payloads to ensure smooth operation.

2. Communication Subsystem

Function:

This subsystem facilitates the transmission of data between the satellite and the ground station or other spacecraft. It consists of antennas, transmitters, receivers, and sometimes repeaters.

Interaction:

- The communication subsystem depends on the power subsystem to provide the necessary energy for operation.
- It transmits and receives data from the satellite's payload (such as scientific instruments or imaging devices) to the ground control or relays data between satellites in a constellation.
- It also interacts with the attitude control subsystem to maintain the correct orientation for optimal signal reception and transmission.

3. Thermal Subsystem

Function:

The thermal subsystem ensures the satellite maintains a temperature range in which all its components can function properly. This includes heat radiators, thermal blankets, heat pipes, and sometimes active cooling systems.

Interaction:

- The thermal subsystem interacts with almost all other subsystems because heat generation is inherent in most electronic components, such as the power subsystem (solar panels and batteries), communications (transmitters), and the payload.
- It helps to manage the heat produced by the **propulsion subsystem** during burns or maneuvers, ensuring the satellite does not overheat.
- It also interacts with the payload to ensure that the instruments operate within their specified temperature ranges.

4. Attitude and Control Subsystem (ACS)

Function:

The ACS maintains the satellite's orientation (attitude) relative to Earth, the Sun, or other objects in space. It uses sensors like gyroscopes, star trackers, and magnetometers, along with actuators such as reaction wheels, control moment gyroscopes, or magnetorquers.

Interaction:

- The attitude control subsystem ensures the satellite's orientation is correct for communications (aligning antennas), payload operations (such as pointing scientific instruments), and solar power generation (orienting the solar panels toward the Sun).
- It works closely with the communication subsystem to maintain the correct attitude for signal transmission.
- The thermal subsystem also works with ACS to maintain proper alignment for effective heat dissipation, especially when the satellite is in direct sunlight or the shadow of the Earth.

5. Propulsion Subsystem

Function:

The propulsion subsystem provides the means for the satellite to change its orbit or attitude. This includes thrusters, fuel tanks, and control valves.

Interaction:

- The propulsion subsystem interacts with the attitude control subsystem during orbit changes or station-keeping maneuvers, requiring precise orientation.
- The power subsystem provides the necessary energy to power the propulsion system's thrusters and fuel systems.
- It can also interact with the thermal subsystem as fuel and propulsion components may generate heat during burns.

6. Payload Subsystem

Function: The payload is the main component of the satellite that fulfills its mission objectives. This could be a camera for Earth observation, scientific instruments for research, or communication equipment for data relay.

Interaction:

- The payload interacts with the communication subsystem to transmit the collected data to Earth.
- It may also need to interact with the thermal subsystem to keep the instruments within operational temperature ranges.
- The attitude control subsystem ensures the satellite is oriented correctly for accurate data collection by the payload (for example, pointing the camera or antenna).

7. Structure Subsystem

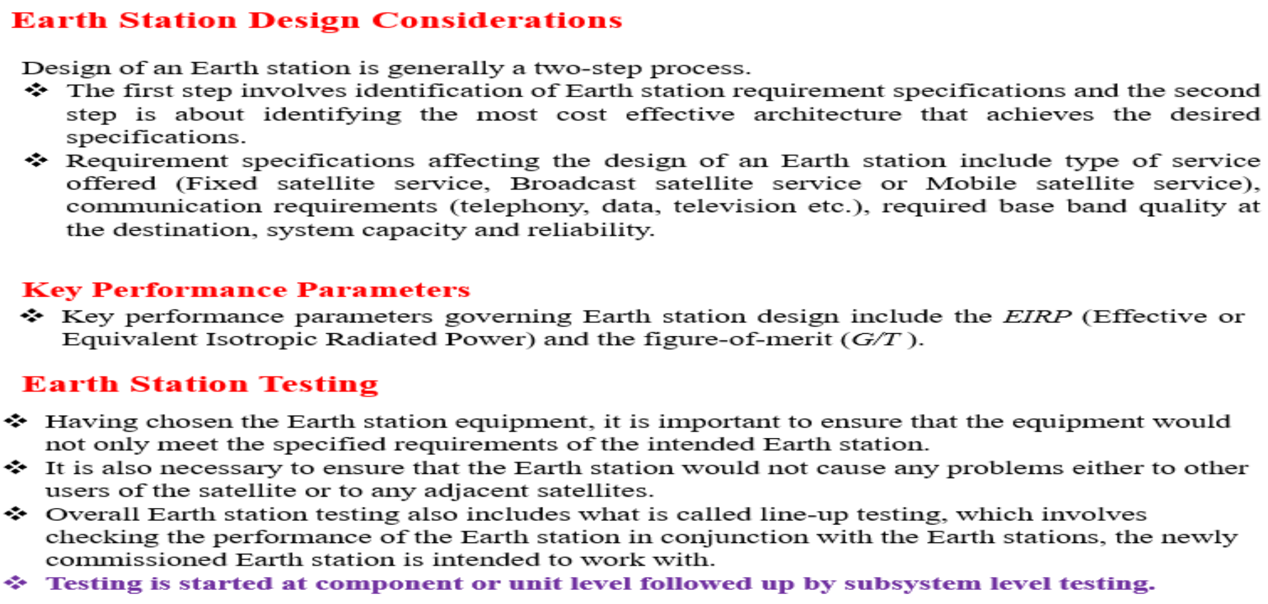
Function: The structure subsystem provides the physical framework that holds all the other subsystems together and protects them from mechanical stresses during launch and in orbit.

Interaction:

- The structure subsystem supports and integrates all other subsystems, ensuring that each subsystem is securely mounted and aligned.
- It interacts with the thermal subsystem through thermal shields or radiators to dissipate heat.
- The attitude control subsystem is mounted onto the structure and relies on it to ensure stability during maneuvers.

7. Discuss the architectural design considerations for an Earth station. What factors must be taken into account when designing an Earth station for optimal performance?

Solution:



Earth Station Design Considerations

Design of an Earth station is generally a two-step process.

- The first step involves identification of Earth station requirement specifications and the second step is about identifying the most cost effective architecture that achieves the desired specifications.
- Requirement specifications affecting the design of an Earth station include type of service offered (Fixed satellite service, Broadcast satellite service or Mobile satellite service), communication requirements (telephony, data, television etc.), required base band quality at the destination, system capacity and reliability.

Key Performance Parameters

- Key performance parameters governing Earth station design include the *EIRP* (Effective or Equivalent Isotropic Radiated Power) and the figure-of-merit (G/T).

Earth Station Testing

- Having chosen the Earth station equipment, it is important to ensure that the equipment would not only meet the specified requirements of the intended Earth station.
- It is also necessary to ensure that the Earth station would not cause any problems either to other users of the satellite or to any adjacent satellites.
- Overall Earth station testing also includes what is called line-up testing, which involves checking the performance of the Earth station in conjunction with the Earth stations, the newly commissioned Earth station is intended to work with.
- **Testing is started at component or unit level followed up by subsystem level testing.**

Factors must be taken into account when designing an Earth station for optimal performance

1. **Antenna Design and Size**: Choose the right type (e.g., parabolic dish, phased array) and size of antenna based on satellite communication needs to achieve high gain and precise alignment.
2. **Frequency Band Selection**: Select appropriate uplink and downlink frequencies that minimize interference and comply with regulatory bodies like the ITU.
3. **Transmission Power**: Ensure adequate transmission power for effective signal strength and achieve an optimal link budget, considering both uplink and downlink power requirements.

4. **Site Location and Environmental Conditions**: Choose an ideal location with stable ground, good satellite visibility, and minimal environmental interference (e.g., weather, terrain).
5. **Satellite Tracking Capability**: Implement tracking systems for accurate satellite positioning, especially for LEO satellites, and maintain precise antenna alignment.
6. **Signal Quality and Link Reliability**: Optimize signal-to-noise ratio (SNR) and use error correction techniques to maintain reliable communication, especially in adverse conditions.
7. **Redundancy and Reliability**: Design for system redundancy (e.g., backup power, antennas) to ensure continuous communication and minimize downtime.
8. **Regulatory Compliance**: Ensure compliance with frequency licensing, emission standards, and other regulatory requirements set by local and international bodies.
9. **Data Handling and Processing**: Ensure the Earth station can handle the required data throughput with appropriate modems, receivers, and signal processors for smooth communication.
10. **Security and Data Protection**: Implement encryption methods for secure data transmission and ensure physical security of the Earth station against theft or sabotage.