ECE 521E – RADAR & SATELLITE ENGINEERING

ORBITAL MECHANICS – STUDY GUIDE/REVISION

I. FOUNDATIONS: WHY EE STUDENTS NEED ORBITAL MECHANICS

1. **Relevance to Electrical & Communication Engineering**:
    - Satellite communications (signal path loss, Doppler shift).
    - Remote sensing (coverage, revisit time).
    - Power system design (eclipse management).
    - Antenna pointing & ground station tracking.
2. **Key Applications**: Broadband Internet, Broadcasting, GPS, IoT, 5G/6G backhaul, Earth observation.

II. CORE CONCEPTS & LAWS

1. **Newton's Laws & Gravitation**
    - Newton's Law of Universal Gravitation:

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

    - Kepler's Laws:
        - Orbits are elliptical with Earth at one focus.
        - Equal area swept in equal time (angular momentum).
        - $T2 \propto a^3$ (orbital period vs. semi-major axis).
    - EE Connection: Orbital period determines satellite visibility for communication.
2. **Orbital Elements**
    - **6 Orbital Parameters**:
        i. **Semi-major axis (*a*):** The semi-major axis of an ellipse is half the length of the longest diameter, which passes through the centre and both foci of the ellipse.

        Semi-major axis represents the longest radius of the ellipse and is often denoted as 'a'.

        You can also define it as the distance from the centre of the ellipse to its furthest point.

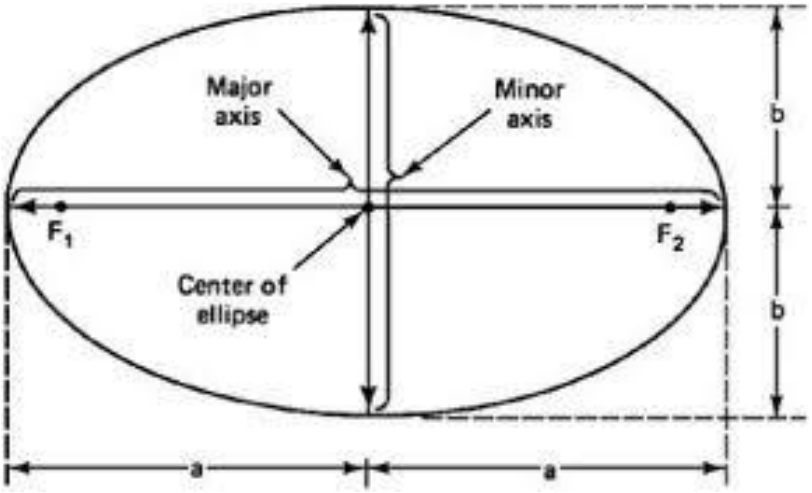


Figure 1. Major and minor axis

ii. **eccentricity (e)** of an ellipse is a value that describes how "round" or "flat" the ellipse is.

$$e = \frac{r_a - r_p}{r_a + r_p}$$

$$0 \leq e < 1$$

e =0 represents a perfect circle and values closer to 1 indicate a more elongated, flattened ellipse.

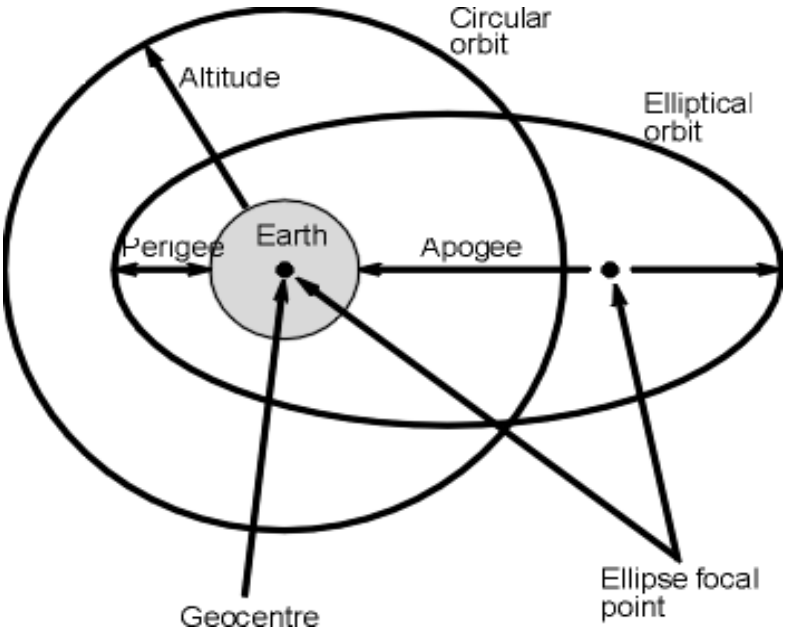


Figure 2. Circular and elliptical orbits

iii. **inclination angle(i):** The angle between orbital plane and earth's equatorial plane is called angle of inclination.

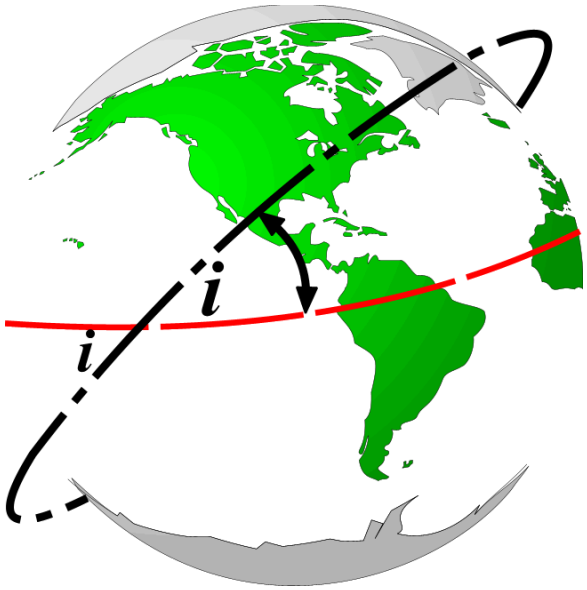


Figure 3. Inclination angle

iv. **Ascending Node** is the point of intersection of orbit path with the equatorial plane while travelling from south to north.

v. **Descending Node** is the point of intersection of orbit path with the equatorial plane while travelling from north to south.

- **Importance of Inclination**: Inclination affects ground coverage latitude; eccentricity impacts signal delay variation.

III. ORBIT TYPES & ECE IMPLICATIONS

Orbit Type	Altitude	Period	EE Applications	Pros/Cons for ECE
LEO (Low Earth)	300–1,500 km	90–120 min	IoT, Earth imaging, science, Internet (Starlink, Oneweb, Kuiper)	• Low latency, low power • Frequent handoffs, short visibility
MEO (Medium)	8,000–20,000 km	2–12 hr	GNSS (GPS, BEIDOU, GALILEO)	• Balanced coverage/latency • Moderate power requirements
GEO (Geostationary)	35,786 km	24 hr	Broadcast TV, weather	• Fixed antennas, continuous coverage • High latency, high launch cost
HEO (Highly Elliptical)	e.g., Molniya	Varies	Arctic comms, surveillance	• High-latitude coverage • Complex tracking

IV. KEY PARAMETERS FOR EE DESIGN

1. **Orbital Velocity & Vis-Viva Equation**:

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

   - μ = Earth's gravitational parameter (3.986×10^5 km^3/s^2).
   - ECE Impact: Doppler shift $\Delta f = \frac{v f_o}{c}$(adjust receiver frequencies).

2. **Elevation Angle & Slant Range**:
   - Minimum elevation (θ_{min}) for ground stations (typical: 5°–30°).
   - Slant range (d): Distance to satellite → impacts **path loss** ($L_p \propto d^2$).
3. **Coverage & Revisit Time**:
   - **Footprint**: The geographical area on Earth where a satellite's signals can be received with sufficient strength and quality.
   - **Revisit**: The frequency at which a satellite returns to and captures images of the same location on Earth. It's a crucial factor in remote sensing, dictating how often observations can be made of a particular area.

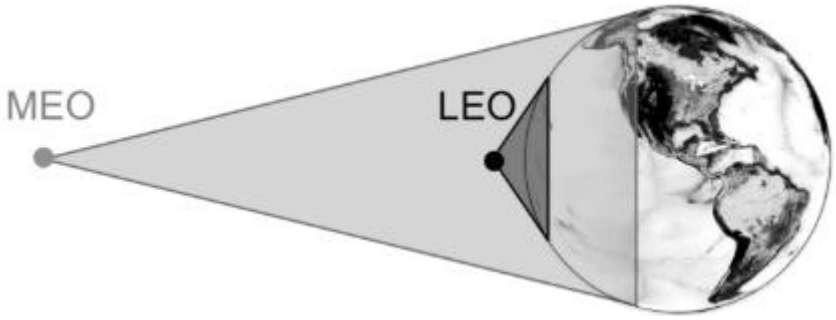


Figure 4. Illustration of LEO & MEO Satellite Footprints

4. **Eclipse & Solar Access**:
   - Duration affects **battery sizing** and thermal control.
   - GEO satellites: 70 days/year eclipsed near equinoxes.

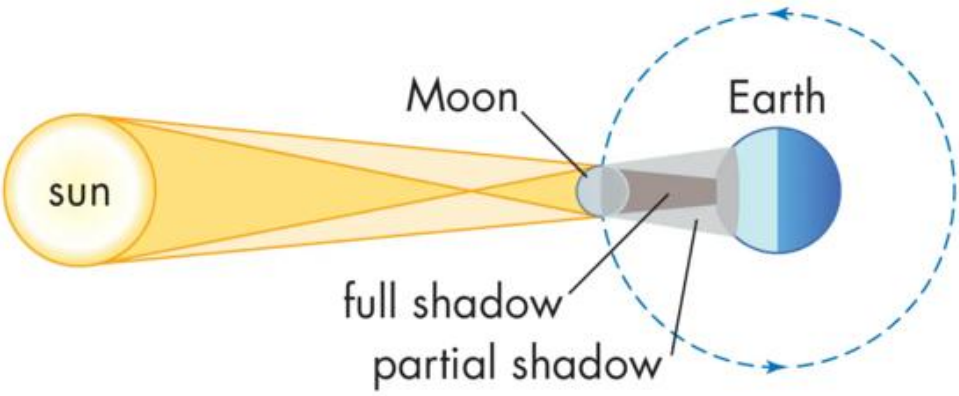


Figure 5. Solar eclipse

V. PERTURBATIONS & STATION KEEPING

- **Sources**: Earth's oblateness (J2), atmospheric drag (LEO), solar radiation pressure, lunar/solar gravity.

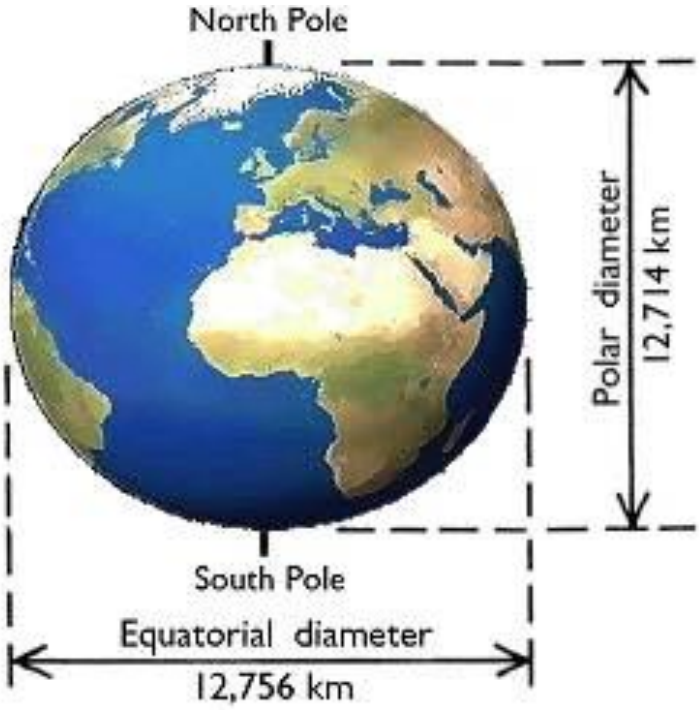


Figure 6. Earth oblateness

- **ECE Impact**:
    - J2 causes RAAN drift which require constellation phasing adjustments.
    - Drag reduces LEO satellite lifetime which in turn impacts mission duration/power.
- **Station Keeping**: Maneuvers to maintain orbit leads to increased fuel consumption and reduced operational life.

VI. CONSTELLATIONS & RELATIVITY (FOR GPS)

- **What is a Satellite Constellation?**

A satellite constellation is a group of artificial satellites working together as a system to provide a specific service or achieve a particular goal, such as global communication, navigation, or Earth observation.

Satellites in a constellation are typically in coordinated orbits and communicate with each other and with ground stations to deliver comprehensive coverage of the Earth's surface.

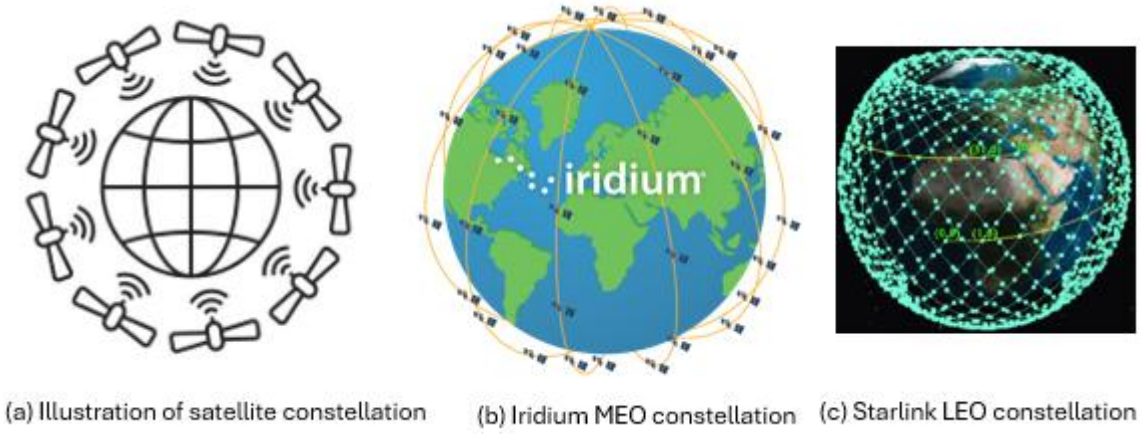


Figure 7. Satellite constellations

- **Walker Delta Patterns**: is a specific arrangement of satellites in a constellation, designed to provide global coverage and other benefits. It's characterized by its symmetrical geometry and is often used in satellite constellations for communication and navigation. Used in Starlink, Iridium.

  The pattern is defined using a notation (I:T/P/F), where I is the orbital inclination, T is the total number of satellites, P is the number of planes, and F is the phasing between satellites in adjacent planes.

- **GPS Relativity Correction**:
  - PS relativity correction refers to the adjustments made to GPS satellite clocks to account for the effects of Einstein's theories of relativity, which impact how time passes on the satellites compared to clocks on Earth.
  - Clocks on MEO satellites run faster by ~38 μs/day due to gravity/time dilation.
  - Must be corrected for precise positioning.

VII. SOFTWARE & TOOLS

1. **STK (Systems Tool Kit)**: Visualize orbits, coverage, link budgets.
2. **Python Libraries**: skyfield, poliastro for orbit propagation.
3. **Link Budget Analysis**: Include slant range, Doppler, atmospheric losses.

VIII. PRACTICE PROBLEMS

1. Calculate orbital period for a 600 km circular LEO orbit.
2. Find max Doppler shift for a 2 GHz signal received from a LEO satellite (v = 7.5 km/s).
3. Determine min elevation angle for a GEO satellite at 75°W longitude from Austin, TX (97°W).

4. Estimate path loss for a Ka-band (30 GHz) downlink from GEO to ground.

IX. RECOMMENDED RESOURCES

- **Texts**:
    - *Fundamentals of Astrodynamics* (Bate, Mueller, White) — **Concisely covers math**.
    - *Space Mission Analysis and Design* (Wertz, Larson) — **Systems perspective**.
- **Online**:
    - NASA's "Basics of Space Flight" web guide.
    - AGI's STK tutorials.
- **For EE Focus**:
    - *Satellite Communications* (Timothy Pratt) — **Orbit mechanics in comms context**.

X. STUDY TIPS FOR ECE STUDENTS

- **Prioritize**: Coverage, link budget, Doppler, and eclipse effects over complex perturbation math.
- **Visualize**: Use software (STK, Celestia) to simulate orbits.
- **Connect**: Always tie orbital parameters to communication/power system constraints.