Highly Elliptical Orbits (HEO)

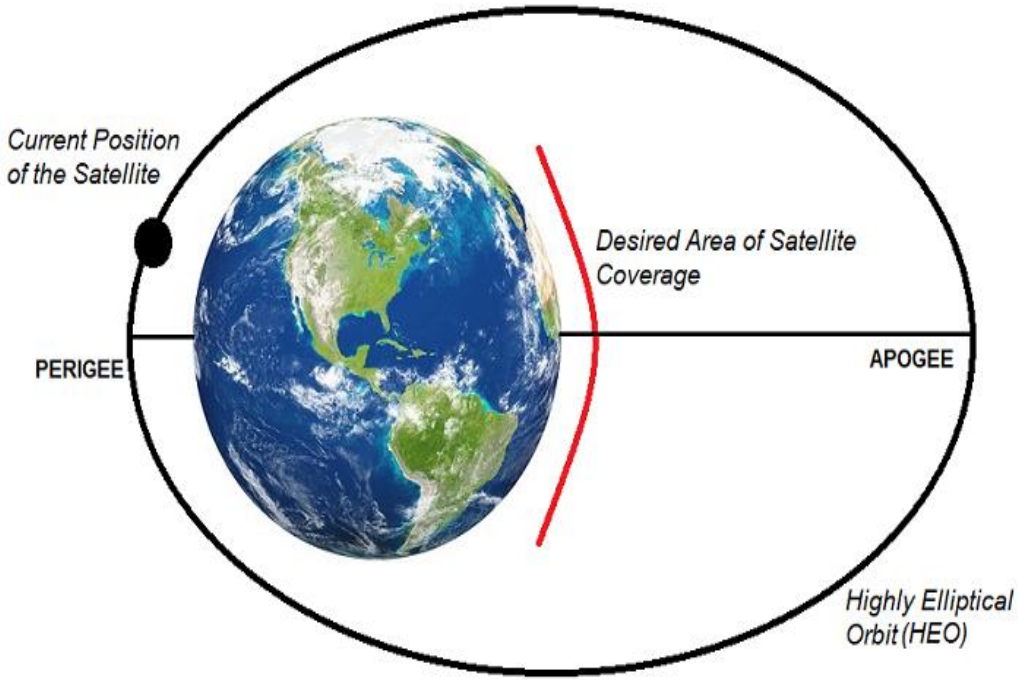
EEEN 567–SATELLITE ENGINEERING

Monday, 14 November 2025

WHAT IS A HIGHLY ELLIPTICAL ORBIT?

Key Feature:

- The orbit's shape is a highly flattened ellipse, not a circle.



Key Orbital Points:

- **Perigee:** The point in the orbit closest to Earth. Altitude is low, **typically under 1,000 km.**
- Apogee: The point in the orbit farthest from Earth. Altitude is very high, **often over 35,786 km, matching geostationary altitude**

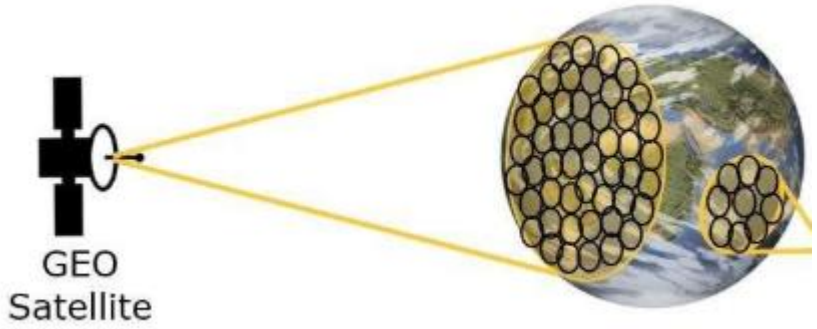
KEY HEO ORBITAL CHARACTERISTICS

Key HEO Orbital Characteristics are:

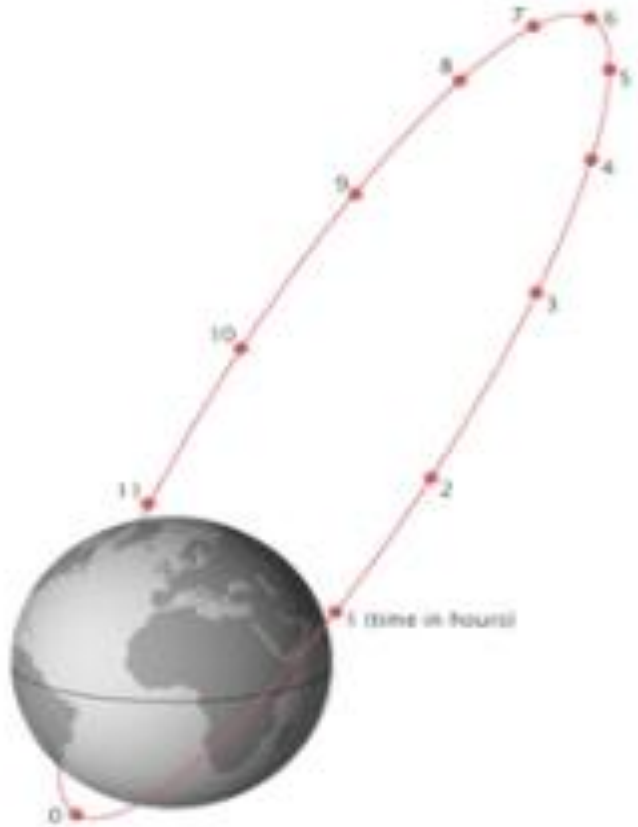
1. **Variable Speed:** A satellite in a HEO moves **much faster** at perigee and **much slower** at apogee due to gravitational forces.
2. **The "Apogee Dwell":** The satellite spends the **majority of its orbital period** near apogee, where its slow speed allows it to appear to "dwell" over a specific region for long periods.
3. **Ground Coverage:** Near apogee, the satellite has a **wide field of view** and maximum coverage of the Earth's surface it is facing.

WHY USE A HEO? THE COVERAGE ADVANTAGE

- **Solving the Polar Problem:** Geostationary (GEO) satellites cannot effectively cover high-latitude and polar regions because they appear very low on the horizon from these areas.



- **HEO Solution:** By using an orbit with a high inclination, HEO satellites can loop high over the polar regions, providing excellent coverage for far northern and southern areas.



- **Primary Users:** This makes HEOs particularly valuable for countries like Russia and for services targeting North America

TYPES OF HEO ORBITS - MOLNIYA

1. **Origin:** Named after the series of Soviet Molniya communication satellites.
2. **Orbital Parameters:**
   - **Inclination:** 63.4 degrees (avoids orbital precession).
   - **Period:** Approximately 12 hours.
   - **Eccentricity:** High (e.g., 0.722).
3. **Use Case:** Designed to provide continuous communications coverage over the **Northern Hemisphere**, particularly Russia

CLASS EXERCISE – TRACKING OF MOLNIYA SATELLITES

1. Go to the satellite tracking website: n2yo.com
2. Track the following satellites:
   a) MOLNIYA 3-13
   b) MOLNIYA 1-40
3. For each satellite, write down the following:
   a) NORAD ID: _____
   b) Int'l Code: _____
   c) Perigee: _____
   d) Apogee: _____
   e) Inclination: _____
   f) Period: _____
   g) Semi major axis: _____
   h) RCS: _____
4. Discuss coverage and use of each of the satellites

TYPES OF HEO ORBITS - TUNDRA

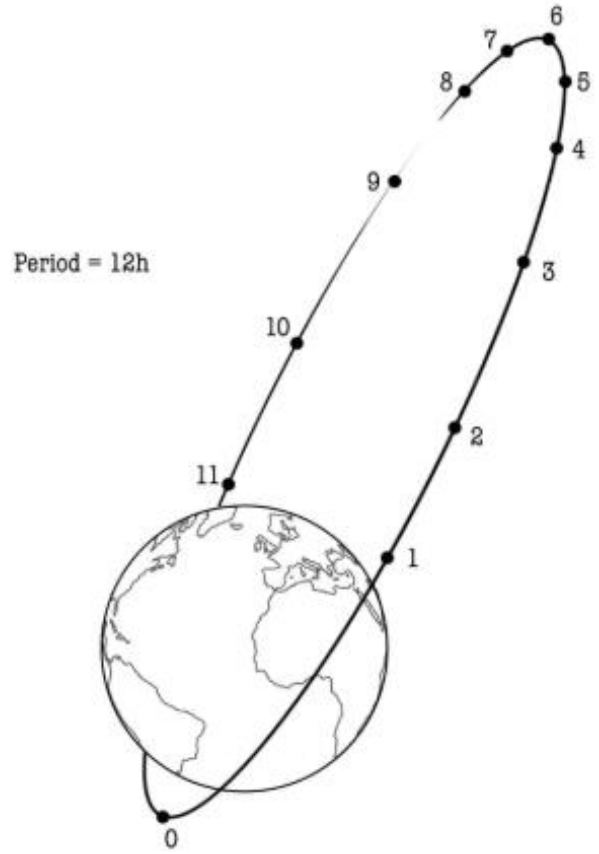
1. **Origin:** A derivative of the Molniya orbit.
2. **Orbital Parameters:**
   - Inclination: Also 63.4 degrees.
   - Period: Approximately 24 hours (one sidereal day).
3. **Eccentricity:** High.
4. **Use Case:** Provides an even longer dwell time over the service area. Used by systems like the former Sirius Satellite Radio to keep satellites positioned above North America

ACHIEVING CONTINUOUS COVERAGE USING HEO

1. **Single-Satellite Problem:** A single satellite in HEO is only useful during its apogee dwell; it moves quickly and disappears when near perigee.

2. **Constellation Solution:** Continuous, 24/7 coverage is achieved by deploying multiple satellites in the same or similar orbital planes.

3. **Orchestrated Timing:** The satellites are timed so that as one finishes its dwell and moves away, another arrives at its apogee to take over coverage, creating a seamless service



APPLICATIONS OF HEO SATELLITES

1. **Communications:** The classic application, especially for polar and high-latitude regions (e.g., Molniya system).
2. **Radio Broadcasting:** Used by SiriusXM (formerly Sirius Satellite Radio) to broadcast across North America.
3. **Scientific Research & Earth Observation:** Useful for monitoring weather, climate, and environmental phenomena over large areas.
4. **Military and Defense:** Employed for communications, surveillance, reconnaissance, and missile tracking

COMPARISON OF HEO & OTHER ORBITS

FEATURE	HEO	LEO	MEO	GEO
Altitude	Varies (Low Perigee, High Apogee)	160 - 2,000 km	2,000 - 35,786 km	35,786 km
Orbital Period	Varies (e.g., 12 or 24 hrs)	~90 minutes	2 - 24 hours	24 hours
Primary Advantage	Long dwell over poles/high-latitudes	Low latency, high resolution	Balanced coverage & latency	Continuous fixed coverage
Typical Use	Comms (polar), Broadcasting	ISS, Imaging, Starlink	GPS, Galileo	

ADVANTAGES AND CHALLENGES

Advantages:

1. **Excellent for Polar Coverage:** Fills a critical gap left by GEO satellites.
2. **Long Dwell Time:** Provides extended coverage over a targeted region.
3. **Global Coverage Potential:** Can be designed to cover any point on the globe.

Challenges:

1. **Requires Multiple Satellites:** Needs a constellation (usually 2-3) for continuous service, increasing cost and complexity.
2. **Orbital Tracking:** Ground antennas must track the satellite's movement, as it is not stationary like a GEO satellite.
3. **Radiation Belts:** The orbit may pass through the **Van Allen radiation belts**, requiring robust shielding for satellite electronics

VAN ALLEN RADIATION BELTS

1. **Van Allen radiation belts** consist of energetic charged particles, mostly from the solar wind, that are trapped by Earth's magnetic field.
2. **They are described as two main belts**, though other temporary ones can form.
    - **Inner belt:** located from approximately **1,000 to 5,000 km** above Earth, is more stable and consists mainly of high-energy protons.
    - **Outer belt:** spanning **15,000 to 25,000 km**, is more dynamic and contains softer electrons that are heavily influenced by solar activity.

REAL-WORLD EXAMPLE: JAPAN'S QZSS ("MICHIBIKI"):

1. Japan's **QZSS ("Michibiki") is a Quasi-Zenith Satellite System is a regional GNSS augmentation system.**
2. While some satellites are in GEO, others operate in HEO.
3. This unique orbit is **designed so that one satellite appears near the zenith (directly overhead) over Japan for about 8 hours per day, providing strong-positioning signals in urban canyons and mountainous areas**

CLASS EXERCISE – JAPANEESE MICHIBIKI

1. Go to the satellite tracking website: n2yo.com
2. Track the following satellites:
   - QZS-1 (MICHIBIKI)
   - QZS-2 (ICHIBIKI-2
   - QZS-3 (MICHIBIKI-3)
   - QZS-4 (MICHIBIKI-4)
3. For each satellite, write down the following:
   a) NORAD ID: _____
   b) Int'l Code: _____
   c) Perigee: _____
   d) Apogee: _____
   e) Inclination: _____
   f) Period: _____
   g) Semi major axis: _____
   h) RCS: _____
4. Discuss coverage and use of each of the satellites

SUMMARY & KEY TAKEAWAYS

1. **HEOs are eccentric, elliptical orbits with a low perigee and a high apogee.**
2. Their key feature is the "**apogee dwell,**" providing long coverage times over specific regions, especially polar and high-latitude areas.
3. Major types include the **Molniya and Tundra orbits.**
4. **Constellations of 2-3 satellites are used to provide continuous service.**
5. **They are indispensable for communications, broadcasting, and navigation in regions where GEO satellites are ineffective.**