

Low Earth Orbit, Features, Types, Application, Emerging Trends

July 6, 2026 • vajiramandravi.com



Low Earth Orbit (LEO) refers to the region of space closest to the Earth, generally lying between about 160 km and 2,000 km above the surface. It is the most commonly used orbital zone for satellites due to its proximity to Earth, which makes operations easier and more efficient.

Low Earth Orbit Key Features

- Satellites in Low Earth Orbit (LEO) move at very high speeds, around **7.8 km per second**, allowing them to complete one orbit in about **90 minutes to 2 hours**.
- Due to this high speed, a satellite can circle the Earth multiple times in a single day (about 14-16 times).
- Unlike Geostationary Orbit satellites, **LEO satellites do not have to stay above the equator**.
- They can follow different paths such as **inclined orbits and polar orbits**, which helps in achieving better global and polar coverage.
- LEO satellites are commonly used for Earth observation, weather monitoring, and reconnaissance due to their flexible paths.

- Satellites cannot usually orbit below 160 km altitude because of atmospheric drag, which slows them down and eventually causes them to fall back to Earth.
- Due to this drag, LEO satellites require periodic orbit correction (station-keeping) using onboard fuel.
- The presence of a thin atmosphere in LEO also leads to gradual wear and shorter lifespan of satellites compared to higher orbits.

Types of Orbits in Low Earth Orbit

- Low Earth Orbit (LEO) includes both **Circular and Elliptical types of satellite orbits**.
- A very important type of orbit in LEO is the **Sun-synchronous orbit (SSO)**.
- In an SSO, a satellite passes over the same location at the same local time every day, ensuring consistent lighting conditions.
- This makes SSO especially useful for remote sensing, weather observation, climate studies, and environmental monitoring.
- Many Earth observation satellites use SSO to track changes over time, such as deforestation, glacier melting, and urban growth.
- Some satellites use elliptical orbits like **Molniya orbit and Tundra orbit**.
- These orbits are designed to provide longer coverage over high-latitude regions (such as polar and northern areas), where regular orbits may have limited visibility.
- Such specialized orbits are useful for communication and observation in regions not well served by geostationary satellites.

Low Earth Orbit Applications

- **Earth Observation:** LEO satellites are widely used for high-resolution imaging of the Earth. They support agriculture (crop monitoring), urban planning, disaster management (floods, earthquakes), and border surveillance.
- **Scientific Research:** The International Space Station operates in LEO, allowing scientists to conduct experiments in microgravity, including research in medicine, materials science, and space technology.
- **Communication:** Large satellite constellations, such as those developed by SpaceX (Starlink-type systems), provide low-latency internet services and improve connectivity in remote and rural areas.
- **Navigation & Defence:** LEO satellites play an important role in reconnaissance, intelligence gathering, and surveillance. In India, the **Indian Space Research Organisation** uses LEO satellites like the Cartosat and RISAT series for mapping and security purposes.
- **Weather & Climate Monitoring:** LEO satellites help track cyclones, weather patterns, forest cover, glaciers, and ocean currents, improving forecasting and climate studies.
- **Disaster Response & Management:** They enable quick damage assessment and real-time monitoring during natural disasters, helping authorities respond more effectively.
- **Environmental Protection:** LEO satellites are also used to monitor pollution levels, deforestation, and wildlife habitats, supporting sustainable development and conservation efforts.

Low Earth Orbit Advantages

- **Low Launch Cost:** Satellites in Low Earth Orbit (LEO) require less energy and fuel to reach orbit due to their closeness to Earth, making launches more cost-effective compared to higher orbits.
- **High-Resolution Imaging:** Being closer to Earth allows LEO satellites to capture clearer and more detailed images, which is useful for mapping, surveillance, and environmental monitoring.
- **Low Latency:** LEO satellites provide faster communication with minimal delay, making them ideal for modern internet services, video calls, and real-time data transfer.
- **Ease of Access:** LEO is more accessible for astronauts and spacecraft, which makes missions, repairs, and resupply operations easier, as seen with the **International Space Station**.
- **Better Coverage of Remote Areas:** LEO satellites, especially in polar and inclined orbits, can cover remote and high-latitude regions that are not easily served by geostationary satellites.
- **Frequent Revisit Time:** Due to their fast movement, LEO satellites can pass over the same area multiple times a day, allowing regular updates and monitoring.
- **Support for Satellite Constellations:** LEO is suitable for creating large constellations of satellites, which work together to provide continuous global coverage for communication and navigation.

Low Earth Orbit Limitations and Challenges

- **Short Lifespan:** LEO satellites usually last around 7-10 years because of atmospheric drag, which gradually slows them down and leads to orbital decay.
- **Need for Large Constellations:** A single LEO satellite covers only a small area, so many satellites are required to provide continuous global coverage, increasing complexity and cost.
- **Space Debris Risk:** The growing number of satellites and debris in LEO increases the chances of collisions, which can lead to the Kessler Syndrome, a dangerous chain reaction of collisions.
- **Frequent Orbital Adjustments:** Due to drag and other disturbances, satellites need regular corrections (station-keeping) using onboard fuel, which reduces their operational life.
- **Limited Field of View:** Compared to higher orbits like Geostationary Orbit, LEO satellites have a smaller coverage area at any given time.
- **Tracking Complexity:** Because LEO satellites move very fast, ground stations must constantly track and switch signals, making communication systems more complex.
- **Higher Atmospheric Effects:** Exposure to residual atmosphere and radiation can cause wear and tear, affecting satellite performance over time.

Emerging Trends

- **Growth of Private Space Companies:** There is rapid expansion of private players like SpaceX and OneWeb launching large satellite constellations (mega-constellations) in LEO.
- **Role in 5G & Broadband Connectivity:** LEO satellites are increasingly being used to support 5G networks and global high-speed internet, especially in remote and underserved areas.
- **Rise of Small Satellites:** There is growing use of miniaturized satellites like CubeSats, which are cheaper, faster to build, and easier to launch for research and commercial purposes.
- **Reusable Launch Vehicles:** Advances in reusable rocket technology have reduced launch costs and increased the frequency of missions, making LEO more accessible.

- **Military & Strategic Importance:** LEO is becoming crucial for military surveillance, intelligence gathering, and space-based security systems.
- **Space Traffic Management:** With increasing satellite numbers, there is a rising need for better regulation and coordination to manage space traffic and avoid collisions.
- **Focus on Space Sustainability:** Efforts are being made to reduce space debris, including satellite de-orbiting technologies and international guidelines for responsible space operations.

GNSS Challenges in Low Earth Orbit (LEO) Satellites and Launch Vehicles

- Satellites in Low Earth Orbit (LEO) depend on Global Navigation Satellite System (GNSS), such as **Global Positioning System (GPS)**, for position, navigation, and timing (PNT).
- These systems were mainly designed for use on Earth, so using them in space creates some challenges.
- LEO satellites move very fast (around 7.8 km/sec), which causes Doppler shift (change in signal frequency), making it difficult for receivers to track signals properly.
- The number of GNSS satellites visible keeps changing as LEO satellites move, affecting the accuracy and stability of navigation.
- GNSS signals pass through the ionosphere, and existing correction models are designed for Earth-based users, so they may not work correctly in LEO, leading to errors in position and timing.
- Launch vehicles going to LEO face similar issues along with high vibration, rapid movement, and harsh conditions, which can cause loss of GNSS signal lock.

Source: <https://vajiramandravi.com/current-affairs/low-earth-orbit/>

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