Satellite Orbits
Orbit Classification

- Size/Period
- Location
- Shape
Orbit Classification

Size/Period

Defined by semi-major axis (a)

- Low Earth Orbit (LEO)
- Medium (High) Earth Orbit (MEO)
- Semi-synchronous Orbit
- Geo-synchronous Orbit
Orbit Classification

**Location**

- Equatorial
- Polar
Orbit Classification

Shape (Conic Sections)

- Circular Orbits
- Elliptical Orbits
Orbit Classification

Shape (Conic Sections)

- Parabolic Trajectories
- Hyperbola Trajectories
Orbit Classifications

Circular Orbits

- Characteristics
  - Constant speed
  - Nearly constant altitude

- Typical Missions
  - Reconnaissance/Weather (DMSP)
  - Manned
  - Navigational (GPS)
  - Geo-synchronous (Comm sats)
Orbit Classifications

Elliptical Orbits

- Characteristics
  - Varying speed
  - Varying altitude
  - Asymmetric Ground Track

- Typical Missions
  - Deep space surveillance (Pioneer)
  - Communications (Polar comm.)
  - Ballistic Missiles
Orbit Classifications
Parabolic/Hyperbolic Trajectories

- **Characteristics**
  - Escaped Earth’s gravitational influence
  - Heliocentric

- **Typical Missions**
  - Interplanetary exploration (Galileo, Phobos, Magellan)
Low Earth Orbits (LEOs)

- Close to Earth (100~1500 km)
- ~27,000 km/h
- 90 min period

- Space Shuttle
- Some Remote Sensing Satellites and weather satellites
- ~8,000 Space Junks – satellites, old rockets, metals, etc.
Low Earth Orbits (LEOs)

- Operate at freq. 1-2.5 GHz
- Signal to noise should be better with LEOs
- Shorter delays - between 1 - 10 ms typical
- Because LEOs move relative to the earth, they require tracking
Iridium mobile telephone Sat System having 66-sat with around 370 mile above earth (2.4 Kbps data)
Medium Earth Orbits (MEOs)

- Operate at freq. 1.2-1.66 GHz
- 5000 - 12000 km above earth surface
- Latency (Delay) ~ 70 - 80 ms
- Special antennas for small footprints needed
Comparison with LEOs

- Slower moving satellites than LEOs
- Less satellites needed than LEOs and simpler system design
- Higher sending power needed than LEOs

**GPS-Navstar** - USA Dep. of Defense
**NAVSTAR 21+6 Sats** with around 9500 mile above earth
Near-synchronous Earth Orbits

- High Elev. (19000 – 25000 miles)
- Non-Synchronous with Circular Orbits
- Slowly moving from west to east
Geosynchronous Earth Orbits (GEOS)

- Originally proposed by Arthur C. Clarke
- Satellite is always at the same position for a viewer on earth
- ‘Big-picture view’
Geosynchronous Earth Orbits (GEOS)

- Sat. must travel eastward at the same rotational speed as the earth
- The Orbit must be circular
- The Inclination of orbit must be zero.

\[
a^3 = \frac{\mu}{n^2} \quad \Rightarrow \quad P = \frac{2\pi}{n} \quad \Rightarrow \quad a_{GSO} = \left(\frac{\mu P^2}{4\pi^2}\right)^{1/3} = 42164Km
\]

- P=23hrs 56min 4.09 sec $\Rightarrow$ $\mu=3.986005\times10^{14}$

\[
a_E = 6378Km \quad \Rightarrow \quad h_{GEO} = h_{GSO} - a_E = 42164 - 6378 = 35786Km
\]
Geosynchronous Earth Orbits (GEOS)

- Angular separation about $2^\circ$ - allows 180 satellites
- Three Sats are required for full earth coverage
GEO Pros

- GEO satellites are good for com. due wide area coverage
- No tracking is required ➞ No Doppler
- No need to switch from one Sat. to another
GEO Cones

- Sophisticated and heavy propulsion devices $\rightarrow$ high precision spacemanship
- High Latency $\rightarrow$ Delay $\sim 0.5-0.6$ s
- High TX/RX power requirements
SYNCOM 2

- Picture from NASA
Antenna Lock Angles

- The look angles for the ground station antenna are the azimuth and elevation angles required at the antenna so that it points directly at the satellite.
Antenna Lock Angles

Required Info

1. The earth station latitude, denoted here by $\lambda_E$
2. The earth station longitude, denoted here by $\phi_E$
3. The longitude of the subsatellite point, denoted here by $\phi_{SS}$ (often this is just referred to as the satellite longitude)
Antenna Lock Angles

\[ a = 90^\circ \]
\[ c = 90^\circ - \lambda_E \]
\[ B = \phi_E - \phi_{SS} \]
\[ b = \arccos \left( \cos B \cos \lambda_E \right) \]
\[ A = \arcsin \left( \frac{\sin |B|}{\sin b} \right) \]

<table>
<thead>
<tr>
<th>TABLE 3.1 Azimuth Angles $A_z$ from Fig. 3.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig. 3.3</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>$a$</td>
</tr>
<tr>
<td>$b$</td>
</tr>
<tr>
<td>$c$</td>
</tr>
<tr>
<td>$d$</td>
</tr>
</tbody>
</table>
Antenna Lock Angles: Example 1

![Antenna Lock Angles Diagram](image)

<table>
<thead>
<tr>
<th>Fig. 3.3</th>
<th>$A_\omega$, degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>$A$</td>
</tr>
<tr>
<td>$b$</td>
<td>$360^\circ - A$</td>
</tr>
<tr>
<td>$c$</td>
<td>$180^\circ - A$</td>
</tr>
<tr>
<td>$d$</td>
<td>$180^\circ + A$</td>
</tr>
</tbody>
</table>
Antenna Lock Angles: Example 1

Example 3.1  A geostationary satellite is located at $90^\circ W$. Calculate the azimuth angle for an earth station antenna at latitude $35^\circ N$ and longitude $100^\circ W$.

**solution**  The given quantities are

$$\phi_{SS} : = -90 \cdot \deg \quad \phi_E : = -100 \cdot \deg \quad \lambda_E : = 35 \cdot \deg$$

Equation (3.7):

$$B : = \phi_E - \phi_{SS} \quad B = -10 \cdot \deg$$

Equation (3.8):

$$b : = \cos^{-1} (\cos (B) \cdot \cos (\lambda_E)) \quad b = 36.2 \cdot \deg$$

Equation (3.9):

$$A : = \arcsin \left( \frac{\sin (|B|)}{\sin (b)} \right) \quad A = 17.1 \cdot \deg$$

By inspection, $\lambda_E > 0$ and $B < 0$. Therefore, Fig. 3.3c applies, and

$$A_z : = 180 \cdot \deg - A \quad A_z = 162.9 \cdot \deg$$
Applying the cosine rule for plane triangles to the triangle of Fig. 3.2b allows the range $d$ to be found to a close approximation:

$$d = \sqrt{R^2 + a_{GSO}^2 - 2Ra_{GSO} \cos b}$$  \hspace{1cm} (3.11)$$

Applying the sine rule for plane triangles to the triangle of Fig. 3.2b allows the angle of elevation to be found:

$$El = \arccos \left( \frac{a_{GSO}}{d} \sin b \right)$$  \hspace{1cm} (3.12)$$
Example 3.2  Find the range and antenna elevation angle for the situation specified in Example 3.1.

solution

\[ \text{R : = 6371 \cdot km} \quad \text{a}_{\text{GSO}} : = 42164 \cdot \text{km} \]

From Example 3.1:

\[ \text{b : = 36.2 \cdot deg} \]

Equation (3.11):

\[ \text{d : = } \sqrt{\text{R}^2 + \text{a}_{\text{GSO}}^2 - 2 \cdot \text{R} \cdot \text{a}_{\text{GSO}} \cdot \cos (\text{b})} \quad \text{d = 37,215 km} \]

Equation (3.12):

\[ \text{El : = } \cos \left( \frac{\text{a}_{\text{GSO}}}{\text{d}} \cdot \sin (\text{b}) \right) \quad \text{El = 48 \cdot deg} \]
Antenna Lock Angles: Example 3

Figure 3.4 Azimuth-elevation angles for an earth station location of 48.42°N, 89.26°W (Thunder Bay, Ontario). Ku-band satellites are shown.
Limits of Visibility

- Line of sight for an earth station that defines the farthest satellite away that can be seen looking east or west of the earth station.

\[ \theta = \arccos \frac{a_E}{a_{GSO}} \]

\[ = \arccos \frac{6378}{42,164} \]

\[ = 81.3^\circ \] (3.16)

Thus, for this situation, an earth station could see satellites over a geostationary arc bounded by ±81.3° about the earth station longitude.
Limits of Visibility

- In practice, the lower limit of visibility is set to 5° in order to reduce the effect of noise picked up from the earth (atmospheric conditions + ground reflections.

**Explain why:**

geosynchronous satellites are not used for communications at the earth pole locations.
Atmospheric attenuation

Example: satellite systems at 4-6 GHz

Attenuation of the signal in %

- rain absorption
- fog absorption
- atmospheric absorption

elevation of the satellite
Polar Orbit

- One type of LEO
- High inclination (80°-100°)
- Can scan the entire surface due to earth rotation (east-west) and satellite orbit (north-south)
Polar Orbit

- Satellite passes through the earth's shadow and permits viewing of the entire earth’s surface each day with a single satellite
Polar Orbit

- National Oceanic and Atmospheric Administration (NOAA) → http://www.noaa.gov/

**TABLE 1.7  NOAA KLM Satellites**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NOAA-L: September 14, 2000</td>
</tr>
<tr>
<td></td>
<td>NOAA-M: May 2001</td>
</tr>
<tr>
<td></td>
<td>NOAA-N: December 2003</td>
</tr>
<tr>
<td></td>
<td>NOAA-N: July 2007</td>
</tr>
<tr>
<td>Mission life</td>
<td>2 years minimum</td>
</tr>
<tr>
<td>Orbit</td>
<td>Sun-synchronous, 833 ± 19 km or 870 ± 19 km</td>
</tr>
<tr>
<td>Sensors</td>
<td>Advanced Very High Resolution Radiometer (AVHRR/3)</td>
</tr>
<tr>
<td></td>
<td>Advanced Microwave Sounding Unit-A (AMSU-A)</td>
</tr>
<tr>
<td></td>
<td>Advanced Microwave Sounding Unit-B (AMSU-B)</td>
</tr>
<tr>
<td></td>
<td>High Resolution Infrared Radiation Sounder (HIRS/3)</td>
</tr>
<tr>
<td></td>
<td>Space Environment Monitor (SEM/2)</td>
</tr>
<tr>
<td></td>
<td>Search and Rescue (SAR) Repeater and Processor</td>
</tr>
<tr>
<td></td>
<td>Data Collection System (DCS/2)</td>
</tr>
</tbody>
</table>
Sun-synchronous Orbit

- These orbits allow a satellite to pass over a section of the Earth at the same time of day.
- Since there are 365 days in a year and 360 degrees in a circle, it means that the satellite has to shift its orbit by approximately one degree per day.
- These satellites orbit at an altitude between 700 to 800 km.
Sun-synchronous Orbit

- These orbits are used for satellites that need a constant amount of sunlight.
- Sun synchronous have 95 – 105° inclination
- Procession of orbital plane synchronized with the earth’s rotation so satellite is always in view of the sun

### TABLE 2.3 Tiros-N Series Orbital Parameters

<table>
<thead>
<tr>
<th></th>
<th>833-km orbit</th>
<th>870-km orbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inclination</td>
<td>98.739°</td>
<td>98.899°</td>
</tr>
<tr>
<td>Nodal period</td>
<td>101.58 min</td>
<td>102.37 min</td>
</tr>
<tr>
<td>Nodal regression</td>
<td>25.40°/orbit W</td>
<td>25.59°/orbit W</td>
</tr>
<tr>
<td>Nodal precession</td>
<td>0.986°/day E</td>
<td>0.986°/day E</td>
</tr>
<tr>
<td>Orbits per day</td>
<td>14.18</td>
<td>14.07</td>
</tr>
</tbody>
</table>
Elliptical (Molnyia) Orbit

- Perigee (closest), Apogee (farthest)
- Period: ~12hrs
- Polar coverage
- Communication satellites for north and south region
GROUND TRACES

THE POINTS ON THE EARTH’S SURFACE OVER WHICH A SATELLITE PASSES AS IT TRAVELS ALONG ITS ORBIT

PRINCIPLE: GROUND TRACE IS THE RESULT OF THE ORBITAL PLANE BEING FIXED AND THE EARTH ROTATING UNDERNEATH IT

AMPLITUDE OF GROUND TRACE (LATITUDE RANGE) IS EQUAL TO THE ORBITAL INCLINATION

MOVEMENT OF GROUND TRACE IS DICTATED BY THE SATELLITE ALTITUDE AND THE CORRESPONDING TIME FOR IT TO COMPLETE ONE ORBIT
Ground Tracks
Westward Regression

A - time zero
B - after one orbit
C - after two orbits
Ground Track for Molnyia orbit
eccentricity = .7252
Ground tracks

Inclination

Inclination = 45 degrees
Eccentricity ~ 0