



ECE 514E – RADAR & SATELLITE ENGINEERING
LOW EARTH SATELLITES (LEO) – STUDY GUIDE/REVISION

I. LEO FUNDAMENTALS

1. Orbital Characteristics:

- **Altitude:** 180–2,000 km (most <1,200 km)
- **Orbital Period:** 90–130 minutes
- **Velocity:** ~7.8 km/s (28,000 km/h)
- **Coverage:** Footprint diameter 1,000–3,000 km

2. Key Advantages:

- Low latency (5–50 ms vs. GEO's 600 ms)
- Reduced launch costs
- High-resolution Earth observation
- Lower signal path loss

3. Key Challenges:

- Atmospheric drag (requires station-keeping)
- Short orbital lifetime (5–7 years)
- Complex handover management
- Space debris collision risk

II. CONSTELLATION DESIGN & ORBITAL MECHANICS

1. Constellation Types:

- **Walker Star:** Polar orbits (e.g., Iridium)
- **Walker Delta:** Inclined orbits (e.g., OneWeb)
- **Rosette:** Hybrid patterns (e.g., Starlink)

2. Orbital Parameters:

- **Inclination:** 53° (Starlink), 86.4° (Iridium), 90° (polar)
- **Planes:** 72 planes × 22 sats/plane (Starlink Gen1)
- **Satellite Density:** 300–40,000+ satellites in modern constellations

3. Handover Mathematics:

math

$$T_{\text{handover}} = \frac{R_{\text{earth}} \cdot \theta_{\text{beam}}}{v_{\text{sat}} - v_{\text{user}}}$$

Where θ_{beam} = beamwidth, v = velocities

III. COMMUNICATIONS SUBSYSTEMS

1. Frequency Bands:

Band	Range	Use Case
V	40–75 GHz	High-throughput backhaul
Ka	26.5–40 GHz	User downlinks (Starlink)
Ku	12–18 GHz	Legacy LEO broadband

2. Antenna Technologies:

- **User Terminals:** Electronically steered phased arrays (e.g., Starlink dish)
- **Satellite Antennas:**
 - Parabolic reflectors (Iridium)
 - Planar phased arrays (OneWeb)
 - Lens antennas (Kymeta)

3. Modulation & Multiple Access:

- **Waveforms:** OFDM, FBMC
- **Access Schemes:**
 - TDMA (Iridium)
 - CDMA (Globalstar)
 - FDMA + OFDMA (Starlink)

IV. POWER & THERMAL SYSTEMS

1. Power Budget:

- **Generation:** Triple-junction GaAs solar cells ($\eta > 30\%$)
- **Storage:** Li-ion batteries (100–200 Wh/kg)
- **Load Profile:**

text

Peak Power = 5–10 kW (broadband sats)

Eclipse Duration: 30 min/orbit

2. Thermal Management:

- **Passive:** MLI blankets, heat pipes, radiators

- **Active:** Louvers, heaters
- **Design Challenge:** $\pm 200^{\circ}\text{C}$ temperature swings

V. SIGNAL PROPAGATION & LINK BUDGET

1. Path Loss:

math

$$L_{\text{FS}} = 20 \log_{10} \left(\frac{4\pi d}{\lambda} \right)$$

Where d = slant range (500–2,000 km), λ = wavelength

2. Link Budget Example (Starlink user downlink):

Parameter	Value
Tx Power	30 dBW
Antenna Gain (Tx)	30 dBi
Path Loss (Ka-band)	180 dB
Rx Antenna Gain	35 dBi (user)
SNR Required	10 dB

3. Rain Fade Mitigation:

- Adaptive coding/modulation (ACM)
- Site diversity switching

VI. KEY APPLICATIONS

1. Broadband Internet:

- Starlink (SpaceX), Kuiper (Amazon)
- Throughput: 50–500 Mbps/user

2. Earth Observation:

- **Synthetic Aperture Radar (SAR):** Capella Space
- **Hyperspectral Imaging:** Planet Labs

3. IoT/M2M Connectivity:

- Swarm Technologies (small-sat network)

4. Scientific Missions:

- ICON (ionosphere studies), GEDI (forest mapping)

VII. EMERGING TECHNOLOGIES

1. Inter-Satellite Links (ISL):

- Optical lasers (Starlink: 5–10 Gbps/link)
- RF crosslinks (60 GHz)

2. **Advanced Processing:**

- Onboard AI for data reduction
- Software-defined radios (SDRs)

3. **Debris Mitigation:**

- Autonomous collision avoidance
- De-orbit sails (e.g., DragRacer mission)

VIII. DESIGN CHALLENGES FOR EE STUDENTS

1. **Doppler Compensation:**

- Frequency offset up to ± 100 kHz at Ka-band
- Solved with automatic frequency control (AFC) loops

2. **Handover Management:**

- Seamless beam-to-beam/satellite-to-satellite handoffs
- Requires predictive algorithms

3. **Regulatory Compliance:**

- ITU frequency coordination
- Orbital debris mitigation standards

IX. EQUATIONS TO MEMORIZE

1. **Orbital Period:**

math

$$T = 2\pi \sqrt{\frac{a^3}{\mu}}$$

Where a = semi-major axis, μ = Earth's gravitational parameter

2. **Free-Space Path Loss:**

math

$$L_{\text{FS}} \text{ (dB)} = 92.45 + 20 \log_{10}(f_{\text{GHz}}) + 20 \log_{10}(d_{\text{km}})$$

3. **Slant Range:**

math

$$d = \sqrt{(R_{\text{earth}} + h_{\text{sat}})^2 - R_{\text{earth}}^2 \cos^2 \beta} - R_{\text{earth}} \sin \beta$$

Where β = elevation angle

X. STUDY RESOURCES

1. Textbooks:

- *Satellite Communications* (Timothy Pratt)
- *Space Mission Analysis and Design* (Wertz & Larson)

2. Software Tools:

- STK (Systems Tool Kit) for orbit simulation
- GNU Radio for SDR prototyping

3. Online Courses:

- MIT OpenCourseWare: *Space Systems Engineering*
- Coursera: *Satellite Communications* (EPFL)