EEEN 567 –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 θbeamθ_{beam} = beamwidth, vv = 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 (η > 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**: ±200°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 dd = slant range (500–2,000 km), λλ = 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 aa = semi-major axis, μμ = Earth's gravitational parameter

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

math

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

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 ββ = 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)