



ECE 514E – RADAR & SATELLITE ENGINEERING

MEDIUM EARTH SATELLITES (MEO) – STUDY GUIDE/REVISION

I. MEDIUM EARTH ORBIT (MEO) FUNDAMENTALS

1. Orbital Characteristics:

- **Altitude:** 2,000–35,786 km (typically 8,000–20,000 km)
- **Orbital Period:** 2–12 hours (e.g., 12 hours at 20,200 km)
- **Inclination:** 55°–65° (optimized for global coverage)
- **Velocity:** 3–7 km/s (slower than LEO, faster than GEO)

2. Key Advantages vs. Other Orbits:

Parameter	MEO	LEO (300–1,500 km)	GEO (35,786 km)
Coverage	Regional/Global	Local	Hemispheric
Latency	40–150 ms	5–20 ms	250–280 ms
Satellites Needed	10–24 (constellation)	100s–1000s	3–4 (global)

3. Orbital Mechanics:

- **Centrifugal Force:** $F_c = mv^2/r$
- **Gravitational Force:** $F_g = GM_e m/r^2$
- **Equilibrium:** $v = \sqrt{GM_e/r}$ (e.g., 3.87 km/s at 10,000 km)

II. CONSTELLATION DESIGN

1. Walker Delta Pattern:

- **Parameters:**
 - *t*: Number of orbital planes
 - *p*: Satellites per plane
 - *f*: Phasing between planes

- **Example:** GPS uses 24 satellites (6 planes × 4 satellites, 55° inclination)

2. Coverage Analysis:

- **Minimum Elevation Angle:** 5°–10° (reduces ground station obstructions)
- **Revisit Time:** 2–4 hours (depends on altitude and constellation density)

3. Doppler Shift Calculations:

- $f_d = v_r f_c$
 - Max $v_r \approx 1.5$ km/s (MEO) → Doppler shift ~ 8 kHz at L-band (1.5 GHz)

III. COMMUNICATION SYSTEMS

1. Frequency Bands:

- **L-band (1–2 GHz):** GPS/GLONASS navigation
- **C-band (4–8 GHz):** TT&C (Telemetry, Tracking & Command)
- **Ka-band (26–40 GHz):** High-throughput payloads (e.g., O3b mPOWER)

2. Link Budget Essentials:

plaintext

$$EIRP = P_t + G_t - L_{tx}$$

$$P_r = EIRP - FSPL + G_r - L_{rx}$$

$$FSPL = 20\log_{10}(d) + 20\log_{10}(f) + 92.45 \text{ (d in km, f in GHz)}$$

- **Typical Values:**
 - Transmit power (P_t): 10–50 W
 - Antenna gain (G_t): 15–30 dBi
 - FSPL at 20,000 km: ~ 188 dB (L-band)

3. Modulation Schemes:

- **Navigation:** BPSK, BOC (Binary Offset Carrier)
- **Data Links:** QPSK, 8PSK, APSK

IV. SUBSYSTEM ENGINEERING

1. Power System:

- Solar arrays: 500–2000 W (GaAs cells, 28% efficiency)
- Batteries: Li-ion (60–100 Ah), depth-of-discharge <30%

2. Attitude Control:

- Sensors: Star trackers, sun sensors
- Actuators: Reaction wheels, magnetorquers

- Pointing accuracy: $<0.1^\circ$ (critical for narrow-beam antennas)

3. Thermal Management:

- **Heat Sources:** Power amplifiers, electronics
- **Solutions:** Radiators, heat pipes, MLI (Multi-Layer Insulation)

4. Propulsion:

- Electric propulsion (Hall-effect thrusters): $I_{sp} = 1,500\text{--}3,000$ s
- Chemical propulsion (monopropellant): $\Delta v \sim 300$ m/s for station-keeping

V. KEY APPLICATIONS & SYSTEMS

1. Global Navigation (GNSS):

- **GPS:** 24 MEO sats at 20,200 km
- **Galileo:** 30 MEO sats at 23,222 km

2. Communications:

- **O3b mPOWER (SES):** 432 MEO sats at 8,062 km (Ka-band broadband)
- **ICO Communications:** 10 MEO sats at 10,390 km

3. Scientific Missions:

- **Van Allen Probes:** 2 MEO sats studying radiation belts (600×30,000 km)

VI. DESIGN CHALLENGES

1. Radiation Hardening:

- **MEO Radiation Belts:** Trapped protons/electrons (South Atlantic Anomaly)
- **Mitigation:** Shielding, rad-hard ICs (e.g., RHBD FPGAs)

2. Orbital Debris Avoidance:

- Collision probability $>$ LEO but $<$ GEO
- Maneuver frequency: 1–2 times/year

3. Signal Propagation:

- Ionospheric delay: 1–30 m (corrected via dual-frequency)
- Tropospheric attenuation: 0.5–2 dB at low elevation

VII. FUTURE TECHNOLOGIES

1. Optical Inter-Satellite Links:

- Wavelength: 1550 nm
- Data rates: 10–100 Gbps (e.g., Starlink laser links)

2. AI-Based Station-Keeping:

- Autonomous orbit prediction using ML algorithms

3. Quantum Key Distribution:

- Secure communications via entangled photons

VIII. EQUATIONS & CALCULATIONS

1. Orbital Period: $T = 2\pi a^3/\mu$

- $\mu = 3.986 \times 10^5 \text{ km}^3/\text{s}^2$ (Earth's gravitational parameter)
- *Example:* $a = 26,600 \text{ km}$ (GPS) $\rightarrow T \approx 11 \text{ h } 58 \text{ m}$

2. Free-Space Path Loss:

$$\text{FSPL (dB)} = 32.44 + 20 \log_{10}(d_{\text{km}}) + 20 \log_{10}(f_{\text{MHz}})$$

3. Link Margin:

- Target margin: 3–6 dB

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IX. STUDY RESOURCES

1. Textbooks:

- *Satellite Communications* (Timothy Pratt)
- *Fundamentals of Astrodynamics* (Bate, Mueller, White)

2. Software:

- STK (Systems Tool Kit) for orbit simulation
- GNU Radio for signal processing

3. Online:

- ESA's MEO Mission Database
- NASA Space Science Data Centre

X. KEY STUDY TIPS

- Master orbital mechanics calculations
- Practice link budget analysis for different frequencies
- Compare MEO vs. LEO/GEO trade-offs using real mission data
- Explore radiation effects on satellite electronics