ECE 514E – RADAR & SATELLITE ENGINEERING

GEOSTATIONARY SATELLITES – STUDY GUIDE/REVISION

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1. INTRODUCTION TO GEOSTATIONARY SATELLITES

- **Definition**: Satellites in geostationary orbit (GEO) at ~35,786 km altitude, orbiting Earth's equator with a period of 24 hours.
- **Key Properties**:
    - Stationary relative to Earth (fixed longitudinal position).
    - Coverage: 1/3 of Earth's surface (global beams or spot beams).
- **Applications**: TV broadcasting, weather monitoring (e.g., GOES), telecommunications (VSAT, DTH), navigation augmentation (SBAS).

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2. ORBITAL MECHANICS

- **Kepler's Laws & Newtonian Physics**:
    - Centripetal force = Gravitational force: $\frac{mv^2}{r} = \frac{GMm}{r^2}$
    - Orbital period, $T = 2\pi\sqrt{\frac{r^3}{GM}}$
- **GEO Satellite Orbital Parameters:**
    - Altitude: 35,786 km (from Earth's surface).
    - Inclination = 0°, Eccentricity ≈ 0.
- **Perturbations**:
    - Gravitational (lunar/solar), Earth's oblateness, solar radiation pressure.
    - **Station Keeping**: Thrusters correct inclination (N-S) and longitude (E-W) drift.

3. COMMUNICATION SYSTEMS

- **Frequency Bands:**
    - C-band (4–8 GHz), Ku-band (12–18 GHz), Ka-band (26–40 GHz).
    - Trade-offs: Rain fade (Ka > Ku > C), antenna size, bandwidth.
- **Transponder Architecture:**
    - **Bent-pipe**: Receive → Low-noise amp (LNA) → Frequency conversion → High-power amp (HPA) → Transmit.

- **Onboard Processing**: Digital signal regeneration (modern satellites).

- **Link Budget Analysis:**
  - **Key Equation**:

$$\frac{C}{N} = \frac{EIRP\,.\left(\frac{G_r}{T}\right)\lambda^2}{(4\pi d)^2 kBL}\ \text{dB}$$

    - EIRP: Effective isotropic radiated power.
    - Gr/T: Receiver figure-of-merit.
    - d: Path length (≈38,500 km), L: Losses (atmospheric, polarization).
  - **Noise Sources**: Thermal noise (N=kTB), interference.
- **Modulation & Multiple Access:**
  - Digital: QPSK, 8PSK, 16APSK.
  - Access Methods: FDMA, TDMA, DVB-S2 for broadcast.

4. ELECTRICAL SUBSYSTEMS

- **Power Systems**:
  - Solar Arrays: Triple-junction GaAs cells (efficiency ~30%).
  - Batteries: Li-ion for eclipse operation (70 mins/day).
  - Power Regulation: DC-DC converters, bus voltage (28–100 V).
- **Antennas**:
  - Reflector types: Parabolic, shaped beams.
  - Gain: $G = \eta\left(\frac{\pi D}{\lambda}\right)^2$

    Where η = efficiency and D = diameter.

- **Thermal Control**:
  - Passive: Multi-layer insulation (MLI), radiators.
  - Active: Heaters for battery/critical components.
- **Attitude Control**:
  - Sensors: Sun sensors, star trackers.
  - Actuators: Reaction wheels, magnetorquers.

5. CHALLENGES & EE SOLUTIONS

- **Latency**: 240–280 ms round-trip → Unsuitable for real-time apps (e.g., gaming).

- **Interference Mitigation**:
    - Polarization diversity (LHCP/RHCP), frequency coordination.
- **High-Power Amplifiers (HPAs)**:
    - Traveling-wave tube amplifiers (TWTAs) for efficiency (60–70%).
    - Solid-state power amplifiers (SSPAs) for lower bands.
- **Radiation Hardening**:
    - Shielding, radiation-tolerant ICs (e.g., FPGA/CPU).

6. DESIGN PROBLEMS & EQUATIONS

1. **Orbit Calculation**:
    - Given, $M_{Earth} = 5.972\ kg$, calculate GEO altitude.
    - *Solution*:
    - $r = \left(\frac{GMT^2}{4\pi^2}\right)^{1/3} \approx 42{,}164\ km$
    - Taking the radius of the earth to be $r_e = 6{,}378$, we get altitude, h = 35786 km

2. **Link Budget**:
    - Compute C/N for a Ku-band downlink (12 GHz) with:
      EIRP = 50 dBW, Gr/T= 20 dB/K, distance = 38,500 km, bandwidth = 36 MHz, losses = 2 dB.
    - Steps:

$$FSPL = 20log_{10}\left(\frac{4\pi}{\lambda}\right)$$

$$\frac{C}{N} = EIRP + \left(\frac{G_r}{T}\right) - FSPL - k - B - L$$

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    - *Steps*: Calculate FSPL $= 20\log_{10}(4\pi d/\lambda)$, then $C/N = \mathrm{EIRP} + G_r/T - \mathrm{FSPL} - k - B - L$.

7. CASE STUDIES

- **Intelsat 38**: C/Ku-band, 7.5 kW power, 50+ transponders.
- **GOES-R**: Weather imaging, 10-year design life, X-band telemetry.

8. FUTURE TRENDS

- **High-Throughput Satellites (HTS)**: Spot beams, frequency reuse.
- **Electric Propulsion**: Xenon ion thrusters for station-keeping (reduced fuel mass).
- **LEO Competition**: Starlink (low latency) vs. GEO (broadcast advantage).