ECE 514E – RADAR & SATELLITE ENGINEERING

GLOBAL NAVIGATION SATELLITE SYSTEMS (GNSS) – STUDY GUIDE/REVISION

I. FUNDAMENTAL CONCEPTS

1. **GNSS Definition**
   - Global Navigation Satellite Systems (GNSS) are satellite-based systems providing geospatial positioning, navigation, and timing.
   - Key systems: GPS (USA), GLONASS (Russia), Galileo (EU), BeiDou (China).
2. **Trilateration Principle:**
   - Position calculated using distances (pseudoranges) from ≥4 satellites.
   - **Equation**: d=c·(trx−ttx), where cc = speed of light, t*t* = signal transmission/reception time.
3. **Key Parameters:**
   - **Accuracy**: Horizontal (5–10 m civilian GPS), vertical (10–20 m).
   - **Precision**: Repeatability of measurements under identical conditions.

II. GNSS SYSTEM ARCHITECTURE

1. **Space Segment**:
   - **Orbits**:
     - MEO (Medium Earth Orbit): 20,200 km (GPS), 11.5-hour period.
     - Inclination: 55° (GPS), 64.8° (GLONASS).
   - **Satellite Components**: Atomic clocks (Rb/Cs), solar panels, transmitters.
2. **Control Segment**:
   - Master Control Stations (e.g., Colorado Springs for GPS) monitor satellite health, upload ephemeris/clock data.
   - Global network of monitoring stations.
3. **User Segment**:
   - Receivers (chipsets, antennas), applications (aviation, smartphones).

III. SIGNAL STRUCTURE & MODULATION

1. **Carrier Frequencies**

- **GPS L1**: 1575.42 MHz (civilian C/A code), **L2**: 1227.60 MHz (military P(Y) code).
- **Galileo E1**: 1575.42 MHz (interoperable with GPS).

2. **Modulation Schemes**
   - **BPSK**: Used in GPS C/A code.
   - **BOC (Binary Offset Carrier)**: Galileo E1 (reduces interference).
3. **Spreading Codes:**
   - **C/A Code**: 1023-chip Gold code (1.023 Mbps chipping rate).
   - **P(Y) Code**: 10.23 Mbps (encrypted).
4. **Navigation Message:**
   - Broadcasts ephemeris (satellite position), almanac (constellation health), clock corrections.

IV. RECEIVER OPERATION

1. **Signal Acquisition:**
   - Parallel code search (correlators) to align receiver-generated code with satellite code.
   - **Doppler Shift Compensation**: ±5 kHz due to satellite motion.
2. **Tracking Loops:**
   - **Delay-Locked Loop (DLL)**: Tracks code phase.
   - **Phase-Locked Loop (PLL)**: Tracks carrier phase.
3. **Position Calculation:**
   - Solve ρ=(xs−xu)2+(ys−yu)2+(zs−zu)2+c⋅δt

     where δt = receiver clock bias.

V. ERROR SOURCES & MITIGATION

Error Type	Magnitude	Mitigation Techniques
Ionospheric Delay	5–30 m	Dual-frequency receivers (L1/L2), models
Tropospheric Delay	2–20 m	Empirical models (Hopfield)
Multipath	1–5 m	Choke-ring antennas, signal processing
Satellite Clock	1–3 m	Control segment corrections
Ephemeris Errors	2–5 m	Real-time precise orbit products

VI. AUGMENTATION SYSTEMS

1. **SBAS (Satellite-Based Augmentation)**

- WAAS (USA), EGNOS (EU): Correct errors via geostationary satellites (accuracy <1 m).

2. **GBAS (Ground-Based Augmentation):**
    - Local ground stations (e.g., airports) provide corrections for aircraft landing.
3. **RTK (Real-Time Kinematics):**
    - Carrier-phase ambiguity resolution (cm-level accuracy).

VII. KEY APPLICATIONS

1. **Transportation**:
    - Aviation (ILS approach), maritime navigation, autonomous vehicles.
2. **Timing**:
    - Network synchronization (5G, power grids) using GNSS-disciplined oscillators.
3. **Geodesy**:
    - Tectonic plate monitoring (mm/year precision).
4. **Emergency Services**:
    - E911 location (3GPP standards).

VIII. EMERGING TECHNOLOGIES

1. **Multi-Constellation Receivers**:
    - Combine GPS + Galileo + BeiDou (improves urban canyon availability).
2. **Anti-Jamming Techniques**:
    - Null-steering antennas, encryption (M-Code).
3. **Quantum GNSS**:
    - Quantum accelerometers for inertial navigation during signal loss.

IX. EQUATIONS TO MEMORIZE

1. **Pseudorange**:
2. **Dilution of Precision (DOP)**:
    - $GDOP=\sigma x2+\sigma y2+\sigma z2+\sigma ct2$ (lower = better).
3. **Ionospheric Delay**: $I=40.3f2\cdot TEC I=f240.3\cdot TEC$ (TEC = Total Electron Content).

1. **Pseudorange:**
2. **Dilution of Precision (DOP):**
   - $\text{GDOP} = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2 + \sigma_{ct}^2}$ (lower = better).
3. **Ionospheric Delay:** $I = \frac{40.3}{f^2} \cdot \text{TEC}$ (TEC = Total Electron Content).

X. STUDY RESOURCES

1. **Textbooks**:
   - *Global Positioning System: Signals, Measurements, and Performance* (Misra & Enge).
   - *Principles of GNSS, Inertial, and Multisensor Navigation* (Groves).
2. **Tools**:
   - MATLAB GNSS Toolbox, GNSS-SDR (open-source software-defined radio).
3. **Online**:
   - ESA GNSS Academy, GPS.gov.

X1. KEY STUDY TIPS:

- Master signal processing concepts (correlation, PLL/DLL).
- Understand error propagation in position solutions.
- Experiment with low-cost SDR kits to capture real GNSS signals.