



EEEN 567 – SATELLITE COMMUNICATION

GLOBAL NAVIGATION SATELLITE SYSTEMS (GNSS) STUDY GUIDE

I. FOUNDATIONAL CONCEPTS

1.1. What is GNSS?

1. **Definition:** A satellite-based system that provides geographic positioning anywhere on Earth.

2. **Key Systems**

- **GPS (U.S.):** The Global Positioning System is the most widely used.
- **GLONASS (Russia):** Global'naya Navigatsionnaya Sputnikovaya Sistema
- **Galileo (EU):** Civilian-controlled, offering high precision.
- **BDS (China):** BeiDou Navigation Satellite System.

3. **Core Components**

- **Space Segment:** The constellation of satellites.
- **Control Segment:** Ground stations that monitor and control the satellites.
- **User Segment:** The receivers (your phone, car navigation, specialized equipment).

1.2. **The Principle of Trilateration**

- **Not Triangulation:** Understand the difference. Trilateration uses distances, not angles.
- **Concept:** To find a 3D position (X, Y, Z), you need to know your distance to at least three known points (satellites).
- **Why Four Satellites?** A fourth satellite is required to solve for the receiver's clock error (dt), the critical fourth variable in the equations. This is because the receiver's clock is not atomic and has a significant bias.

1.3. **Measuring Distance: The Code Phase Method**

- **Pseudo-Range:** The fundamental measured quantity. It's a "pseudo" distance because it's contaminated by clock errors and atmospheric delays.
- **How it works:** The satellite transmits a known **Pseudo-Random Noise (PRN)** code at a precise time. The receiver generates an identical PRN code and shifts it in time until it correlates with the incoming signal.
- **The Measurement:** The time shift (Δt) between the received code and the local code, multiplied by the speed of light (c), gives the pseudo-range: $p = c * \Delta t$.

2. THE GNSS SIGNAL

This is the core for electrical engineers—understanding the physical signal.

2.1. Signal Structure (Using GPS L1 C/A as an example)

1. **Carrier Frequency:** L1 = 1575.42 MHz
2. **Modulation:**
 - **Binary Phase Shift Keying (BPSK):** The digital data is modulated onto the carrier using BPSK.
 - **Direct Sequence Spread Spectrum (DSSS):** The data signal (50 bps) is multiplied (XOR) by a high-rate PRN code (1.023 Mcps for C/A code). This "spreads" the signal's bandwidth, providing noise immunity and allowing multiple satellites to use the same frequency (CDMA).
3. **Components of the Signal:**
 1. **Navigation Data (D):** Contains the satellite's ephemeris (orbital parameters), clock corrections, and almanac (coarse orbital info for all satellites).
 2. **PRN Code (C):** A unique code for each satellite that allows the receiver to distinguish them.
 3. **Carrier Wave (L1):** The radio frequency wave.

2.2. Why These Frequencies?

- Penetration of the ionosphere is frequency dependent. L-band (~1-2 GHz) offers a good compromise between ionospheric penetration and antenna size.
- Understanding **Doppler Shift** is crucial, as it affects the received carrier frequency due to satellite and receiver motion.

3. RECEIVER OPERATION: THE SIGNAL PROCESSING CHAIN

A GNSS receiver is a sophisticated digital signal processing (DSP) system.

3.1. RF Front-End

1. **Function:** To receive, filter, down convert, and sample the analog RF signal.
2. **Key Components:** Antenna, Band-Pass Filter (BPF), Low-Noise Amplifier (LNA), Mixer (for down conversion to an Intermediate Frequency - IF), Analog-to-Digital Converter (ADC).
3. **EE Concepts:** Noise figure, gain, sampling theory, aliasing.

3.2. Baseband Processing (The Core DSP)

1. **Acquisition:**
 - **Goal:** A coarse search to find which satellites are visible and their approximate Doppler shift and code phase.

- **How:** The receiver performs a 2D search (across all possible PRN codes and across frequency bins) using correlation techniques (e.g., Matched Filter, FFT-based parallel search).

2. Tracking:

- **Goal:** Once acquired, track the precise code phase and carrier frequency of each satellite.
- **How:** Uses Phase-Locked Loops (PLL) for the carrier and Delay-Locked Loops (DLL) for the code.
- **EE Concepts:** Control theory, loop filters, discriminators, lock detectors.

3.3. Navigation Solution

- The tracked parameters (pseudo-range and carrier phase) are passed to the navigation processor.
- This processor solves a system of equations to compute the user's position, velocity, and time (PVT).

4. KEY ERROR SOURCES AND MITIGATION

Understanding errors is critical for designing robust systems.

Error Source	Approximate Range Error	Cause	Mitigation Techniques
Satellite Clock	± 2 m	Imperfections in satellite's atomic clock	Ground monitoring and clock correction parameters in data message.
Orbital (Ephemeris)	± 2.5 m	Difference between satellite's actual and reported position	Ground monitoring and precise ephemeris data.
Ionospheric Delay	± 5 m (Varies)	Signal slowing through ionized layers. Frequency-dependent.	Dual-Frequency Receivers (L1 & L2): Measure and cancel delay. Using models.
Tropospheric Delay	± 0.5 m	Signal slowing through the neutral atmosphere (weather).	Using standardized models (e.g., Hopfield, Saastamoinen).
Receiver Noise	± 0.3 m	Thermal noise in the receiver electronics.	Better front-end design, wider bandwidth, longer integration time.
Multipath	± 1 m	Signals reflecting off buildings, ground, etc., before reaching antenna.	Advanced antenna design (choke rings), signal processing techniques (narrow correlator, MEDLL).

5. ADVANCED CONCEPTS

5.1. Carrier Phase Positioning

- Using the phase of the carrier wave itself, not just the PRN code. Provides centimeter-level accuracy.
- **Challenge:** Requires resolving the integer "**phase ambiguity.**"
- **Application: Real-Time Kinematic (RTK)** and **Precise Point Positioning (PPP)**, used in surveying, agriculture, and autonomous vehicles.

5.2. Differential GPS (DGPS)

- A method where a stationary base station at a known location calculates error corrections and broadcasts them to nearby mobile receivers.
- Dramatically reduces common errors (ionospheric, tropospheric, ephemeris).

5.3. Inertial Navigation System (INS) Integration

- GNSS has high long-term accuracy but can have dropouts (tunnels, urban canyons).
- INS (accelerometers + gyroscopes) has high short-term accuracy but drifts over time.
- **Sensor Fusion:** Combining GNSS and INS using a **Kalman Filter** provides a robust, continuous, and accurate navigation solution. This is critical for automotive and aerospace applications.

6. STUDY & PROJECT SUGGESTIONS

1. **Simulate:** Use MATLAB or Python to simulate a simple GPS signal, generate PRN codes, and implement a basic correlation-based acquisition algorithm.
2. **Experiment:** Buy a low-cost software-defined radio (SDR) dongle (e.g., RTL-SDR). You can use open-source software (e.g., gnss-sdr) to actually receive and decode live GPS signals.
3. **Build:** Interface a hobbyist-grade GNSS module (e.g., u-blox NEO, Trimble) with a microcontroller (Arduino, Raspberry Pi) to log data and display position.
4. **Explore:** Research a specific error mitigation technique (e.g., implementing a basic Kalman filter for sensor fusion or studying multipath rejection algorithms).

7. KEY RESOURCES

- **Textbook:** *Understanding GPS/GNSS: Principles and Applications* by Elliott D. Kaplan and Christopher J. Hegarty. (The definitive text).
- **Online:** Stanford University's free online course "GPS: Theory and Practice" (recorded lectures are available).
- **Standards:** GPS Interface Control Documents (ICDs) – publicly available technical specifications of the GPS signals.