Module 11

Modern Navigation Systems

Navigating with GPS

Module 11A

The GPS Space Segment

Summary of Module 11

- **The module begins with a description of the GPS space segment (i.e., the satellite constellation). (11A)**
- This is followed by a description of the signal structure that provides the “ranging codes” used by GPS receivers in order to determine position, velocity, etc. (11B)
- Students will use actual GPS almanac data to compute azimuth (i.e., values for Hc) and elevation angles to GPS satellites from an assumed position on earth, as was done in Module 5. (11C)

Reading

- Read Chapter 5, “Satellite Navigation Systems,” of the primary text (Kayton & Fried).
- Download and peruse ICD 200, which describes the “space segment” and “navigation user interfaces”
  - Blackboard, or
  - http://www.gps.gov/technical/icwg/meetings/2010/03/10/AFD-100302-042.pdf

From Kayton and Fried, chap. 5

5.5.2 GPS Satellite Constellation and Coverage

GPS Satellite Constellation The fully operational GPS satellite constellation, as described in the 1992 Federal Radio Navigation Plan [24], comprises 24 satellites, four each in six 55°-inclined orbit planes spaced 60° apart in longitude. The nominal GPS 24 satellite constellation is given as orbit parameters for an epoch of July 1, 1993, at 0000 GMT [25] as follows: semimajor axis A = 26, 559.8 km; eccentricity $e = 0$; inclination $i = 55°$; argument of perigee $\omega = 0°$; right ascension of ascending nodes $\Omega = 272.847°$ (plane A), 332.847° (plane B), 32.847° (plane C), 92.847° (plane D), 152.847° (plane E), 212.847° (plane F); and mean anomalies M_0 that are nonuniform but nominally 90° between satellites within a plane and 15° between planes. The actual mean anomalies vary significantly from those nominal values in order to provide optimum coverage over regions of interest.

The GPS System Architecture

From Kayton & Fried

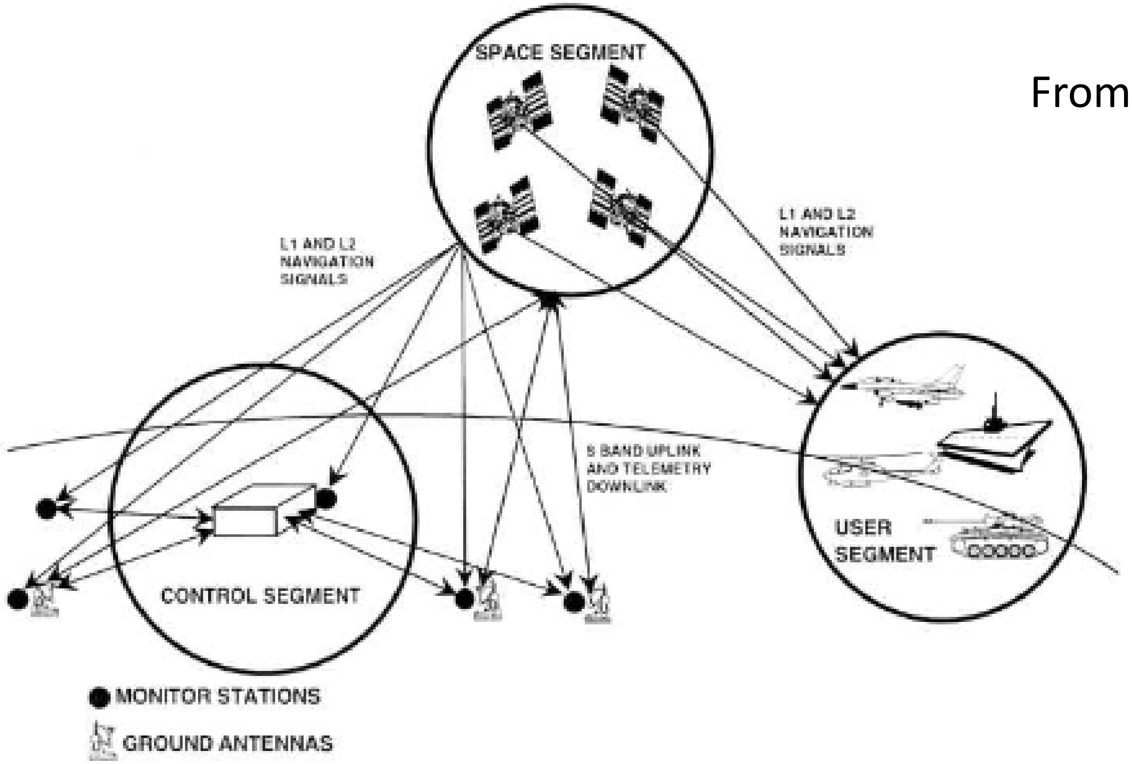

Figure 5.8 GPS system configuration.

GPS Constellation

- ~30 satellites in 12 hour orbits above the earth
- Each broadcasts a 1023 chip Pseudorandom noise sequences (PRNs)
- GPS receivers measure relative time delays of signals from 4 or more satellites
  - The PRNs are known ahead of time
  - As are their relative alignments
- This permits the position of a GPS receiver to be derived after correlation of the received signals with internally generated replicas of these signals inside a GPS receiver

Spread Spectrum CDMA

- GPS is a spread spectrum code division multiple access (CDMA) system
  - Each satellite transmits on the exact same frequencies (subject to Doppler shifts)
  - But each satellite transmits a different "spreading code", which is a pseudorandom noise sequence, or PRN
- This architecture permits the use of a single antenna, a single preamplifier, a single local oscillator, and a single IF amplifier while receiving signals from all of the visible satellites (typically 12 or more satellites)
- Separation of the aggregate signals into the codes for individual satellites is done in FPGAs and/or microprocessors within the GPS receiver.

Spreading of the GPS signal

- Spreading puts the signal below the radio noise floor
- De-spreading brings the signals back above the floor
- Spreading makes Time Difference of Arrival (TDOA) measurements more precise
- Spreading provides anti-jam capability
- Spreading simplifies receiver design

GPS Space Segment and Signal Design Details

- These are captured in a variety of GPS Program Office Interface Control Documents (ICDs), which are publically available to all
- ICD-200 is used for the discussion in Mod 11B.

GPS Documentation ICD-200

Navstar GPS Space Segment/Navigation User Interfaces

INTERFACE SPECIFICATION
IS-GPS-200

ICD = Interface Control Document

http://www.gps.gov/technical/icwg/meetings/2010/03/10/AFD-100302-042.pdf

(included with this module)

GPS satellites transmit on two main frequencies, at L-band

- L1 at 1575 MHz and L2 at 1227 MHz
  - By transmitting the same signal on two frequencies, it is possible to infer frequency dependent signal delays due to the ionosphere and troposphere, in which the speed of light is slightly different from its free space, vacuum value
  - These atmospheric and ionospheric delays can introduce errors of about 30 meters

The GPS satellites

- GPS satellites orbit at a height above ground of 10,000 miles in circular orbits that have a period of 12 hours
- They are in different orbital planes so as to provide visibility at most places on earth at most instants of time of 4 or more satellites
  - Thus permitting a navigation solution that include x, y, z, and time offset error (cf. Mod. 10)

The GPS system at the time of publication of the text by Kayton & Fried

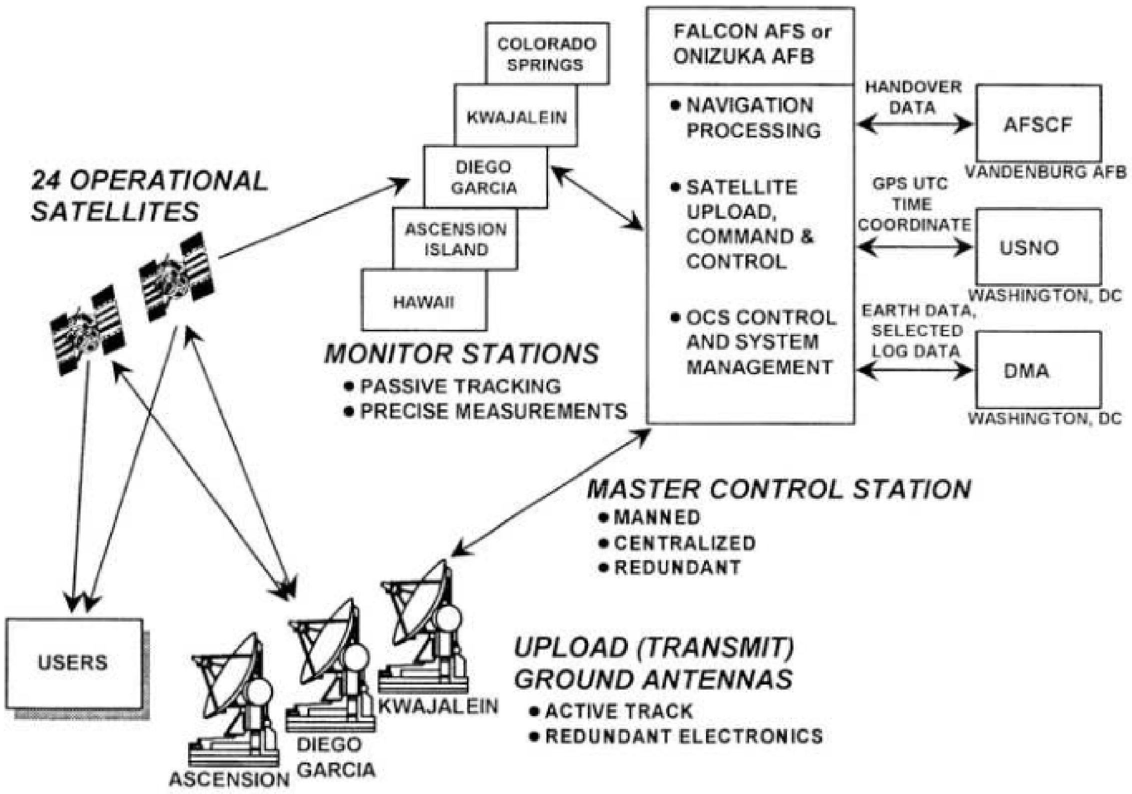

Figure 5.11 GPS control segment configuration.

There are more than 24 Satellites; Block II satellites will be replaced by Block III satellites (eventually).

The ground segment is an evolving system with regular improvements such as networking, modernization of equipment, changes and increases in locations, etc.

C/A, Y/P, and M codes

- Commercial GPS receivers depend on the Coarse/Acquisition, or C/A codes.
- There is a precision code used by privileged users (e.g., the military) called the P code
- When encrypted, the P code is called the Y code
- There is also an M code, for privileged users.
- Some of this is described in the text. Other details can be found in specialized GPS textbooks and documents.

The navigation message

- The C/A code transmits it PRNs at 1,023,000 code ‘chips” per second.
- Superimposed on this is a 50 bit per second “navigation” message, which provides the orbital parameters and clock error estimates for each of the satellites
- This message permits ranging information derived from reception of the prn codes to be converted into a navigation fix using the trigonometry described in the previous modules (e.g., the equations of Richharia, et al.)

From chapter 5 of Kayton and Fried

The GPS navigation message is the information supplied to the GPS users from a GPS satellite. These data are provided via the 50-bps data bit stream modulated on the PRN codes described in Section 5.5.5, providing the user with the information needed to navigate [34]. Among other data, the user is provided with information from which can be computed the position and velocity of the satellite and the time and frequency offset of its clock, as well as information to resolve ambiguities in the received C/A code. The other information includes almanacs for determining the position, velocity, and clock offsets of the other satellites, an ionosphere model and a description of the time offset between GPS system time and universal coordinated time (UTC).

Frames, Subframes, and TLM and HOW Words The GPS navigation message consists of a frame of five 300-bit subframes spanning 30 seconds of time as illustrated in Figure 5.16 [7, 8]. Each six-second subframe consists of ten

The Navigation Processor

- GPS receivers measure the relative offsets of the PRNs received from each satellite
- These are turned into relative time delays
- These are turned into “pseudoranges” by scaling via the speed of light
- Three-dimensional trigonometry is used to turn these ranges into a GPS receiver position fix.

Typical C/A accuracy

- A low cost C/A code GPS receiver moving slowly (e.g., automotive speeds) can provide 3D RMS accuracy of about 14 feet
- Careful long-term signal integration techniques for stationary receivers can provide sub-centimeter accuracy

Use of GPS

- 40 – 60% of 911 calls in the United States are made from cell phones
    - E911, an FCC requirement, has led to the inclusion of GPS chips in essentially all smart phones
- But, the bulk of GPS use is for precision time and time interval (PTTI) uses, such as synchronizing cell phone networks and web-based networking activities, and not for navigation

The GPS signal and GPS receivers

- More details of the GPS signal structure and a description of a typical GPS receiver architecture are given in Mod 11B.

Assignment 11-1

1. Using material from earlier modules, compute the orbital radius and height above the earth for a GPS satellite based on its orbital period of 12 hours.
2. Estimate the ground footprint, in square miles, of a single satellite using simple trigonometry to determine what percentage of the earth's surface can be "seen" from a single satellite.
3. Continue this "back of the envelope" analysis to estimate the total number of GPS satellites that are needed in order for a GPS receiver to have visibility of at least four satellite simultaneously for "almost" 100% of the time from "almost" anywhere on earth.

End of Mod 11A