Global Positioning System

(GPS) Lectures

References

1- L.F.Wiederholt,"GPS SYSTEM SEGMENTS " lecturer. 2012

2- E. Calais," The Global Positioning System" Purdue University - EAS Department, Civil 3273 – ecalais@purdue.edu

3- Elliott D. Kaplan," Understanding GPS Principles and Applications" © 2006 ARTECH HOUSE, INC. 685 Canton Street, Norwood, MA

Lecture (1) GPS

1. Introduction

The Global Positioning System (GPS) is a satellite-based navigation system, that was developed by the U.S. Department of Defense (DoD) in the early 1970s. Primarily, GPS was developed as a military system to fulfill U.S. military needs. However, it was later made available to civilians, and is now a dual-use system that can be accessed by both military and civilian users. GPS provides continuous positioning and timing information, anywhere in the world under any weather conditions. Because it serves an unlimited number of users as well as being used for security reasons, GPS is a one-way-ranging (passive) system. That is, users can only receive the satellite signals.

The types of satellites which are used to determine the location:

1. American satellites – GPS.
2. Russian satellites – GLONASS.
3. European satellites – Galileo.

2. Motivation

GPS satellites provide service to civilian and military users. The civilian service is freely available to all users on a continuous, worldwide basis. The military service is available to governments and allied armed forces as well as other Government agencies.

A variety of GPS augmentation systems and techniques are accessible to improve system performance to meet specific user requirements. The improved signal availability, accuracy, and integrity, allows even better performance than is possible using the basic GPS civilian service.

3. GPS Overview

The GPS is made up of three parts:

- Satellites orbiting the Earth;
- Control and monitoring stations on Earth; and
- The GPS receivers owned by users.

GPS satellites broadcast signals from space that are picked up and identified by GPS receivers. Each GPS receiver then provides three-dimensional location (latitude, longitude, and altitude) plus the time.

Furthermore GPS consist of three segments as shown in Figure1: *the space segment*, *the control segment* and *the user segment.*

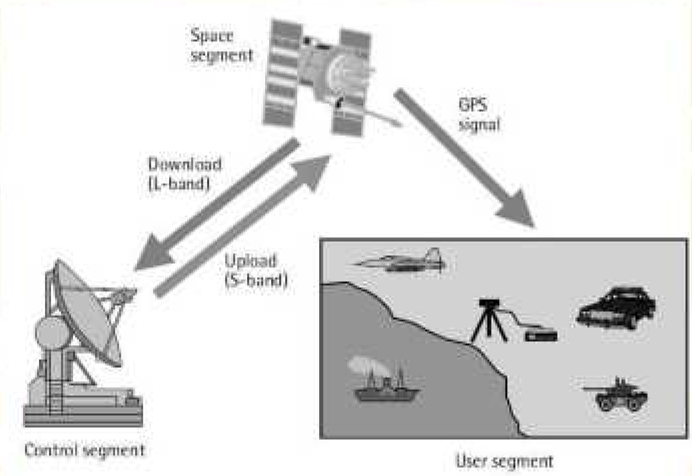


Fig. 1: GPS segments

- *The space segment* consists of a nominal constellation of 24 operating satellites that transmit one-way signals that give the current GPS satellite position and time. (all functional satellites).
- *The control segment* consists of worldwide monitor and control stations that maintain the satellites in their proper orbits through occasional command maneuvers, and adjust the satellite clocks. It tracks the GPS satellites, uploads updated navigational data, and maintains health and status of the satellite constellation. (All ground stations involved in the monitoring of the system: master control station, monitor stations, and ground control stations).
- *The user segment* consists of the GPS receiver equipment, which receives the signals from the GPS satellites and uses the transmitted information to calculate the user's three-dimensional position and time. (all civil and military GPS users).

3.1 Space Segment

The GPS Space Segment consists of **24** satellites in semi-synchronous (approximately 12- hour) orbits. The satellites are arranged in six orbital planes with four satellites in each plane. The orbital planes have an inclination angle of 55 degrees relative to the earth's equator as shown in figure (2).

This diagram illustrates two of the orbital planes of the space segment. For clarity. Only two orbits are shown, spaced 180° apart, whereas in reality there are six planes, spaced 60° apart. Each of the orbits has three or four satellites more or less equally spaced, for a total of 24. The Master Control Station can move any of the satellites at any time within their own orbits. They cannot, however, move a satellite from one orbit to another. The orbits are steeply inclined to the equator at 55°, being more than "halfway up." This is opposed to the polar, or "straight up" (north to south) orbits of the much lower orbiting Transit satellites.

The satellites have an average orbit altitude of **20,200 km** above the surface of the earth or about half the altitude of a geostationary satellite (a geostationary satellite, orbiting at about 40,000 kilometers altitude) as shown in figure (3).

The satellites complete one orbit in approximately **11 hours and 58 minutes**. Since the earth is rotating under the satellites, the satellites trace a track over the earth surface which repeats every **23 hours and 56 minutes**. A user at a fixed location on the ground will observe the same satellite each day passing through the same track in the sky, but the satellite will rise and set four minutes earlier each day, due to the 4 minute difference between the rotational period of the earth and two orbital periods of a satellite. The satellites are positioned in the orbital planes so that four or more satellites, with a good geometric relationship for positioning, will normally be observable at every location on earth.

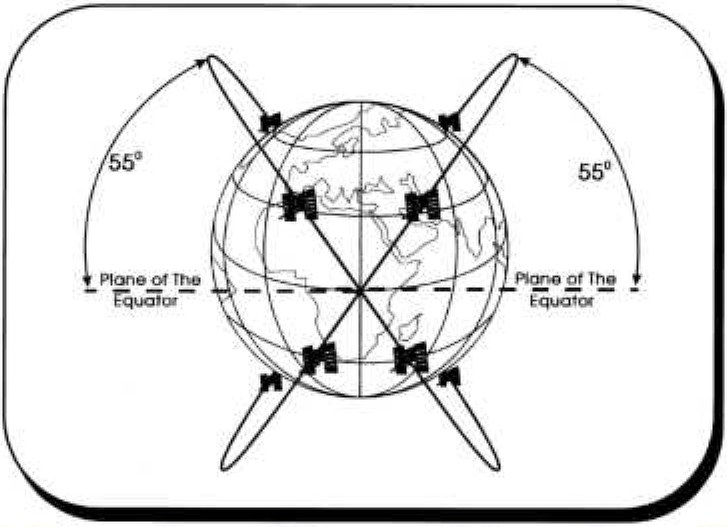
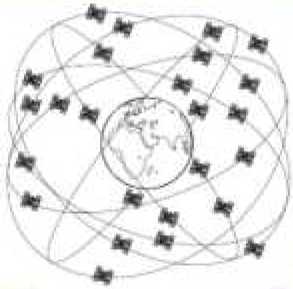
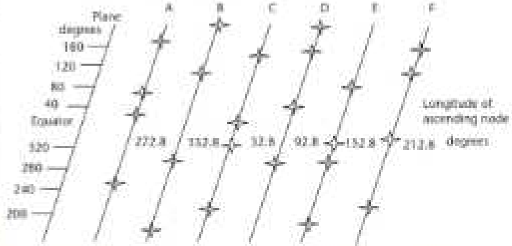


Fig. 2. The orbital planes have an inclination angle of 55 degrees relative to the earth's equator.

The satellites transmit ranging signals on two band frequencies: Link 1 (**L1**) Link 2 (**L2**). The satellite signals are transmitted using spread-spectrum techniques, employing two different ranging codes as spreading fictions (the clocks operate at a fundamental frequency), a **1.023 MHz** coarse/acquisition code (**C/A-code**) on **L1** and a **10.23 MHz** precision code (**P-code**) on both **L1** and **L2**. Either the C/A-code or the P-code can be used to determine the range between the satellite and the user, however, the P-code is normally encrypted and available only to authorized users. When encrypted, the P-code is known as the Y-code. A navigation message is superimposed on both the P(Y) -code and the C/A-code. The navigation message includes:

1. Satellite clock-bias data,
2. Satellite ephemeris (precise orbital) data for the transmitting satellite,
3. Ionospheric signal-propagation correction data, and
4. Satellite almanac (coarse orbital) data for the entire constellation.





(a) GPS Satellite Constellation (b) GPS Constellation Planar Projection

Fig. 3. GPS Satellite Constellation and Planar Projection.

3.2 Control Segment

The Control Segment primarily consists of a Master Control Station (**MCS**) (**1 Master Control Station**), at Falcon Air Force Base (AFB) in Colorado Springs, USA, plus monitor stations (**MS**) and ground antennas (**GA**) at various locations around the world. The monitor stations are located at Falcon AFB, Hawaii, Kwajalein, Diego Garcia, and Ascension (**5 Monitor Stations**). All monitor stations except Hawaii and Falcon AFB are also equipped with ground antennas as shown in figures (4) & (5). The Control Segment includes a Prelaunch Compatibility Station (PCS) located at Cape Canaveral, USA, and a back-up MCS capability.

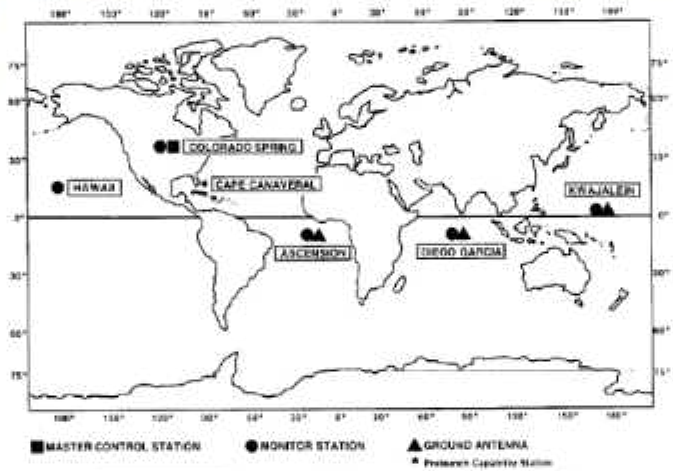


Fig. 4. GPS Control Segment Locations

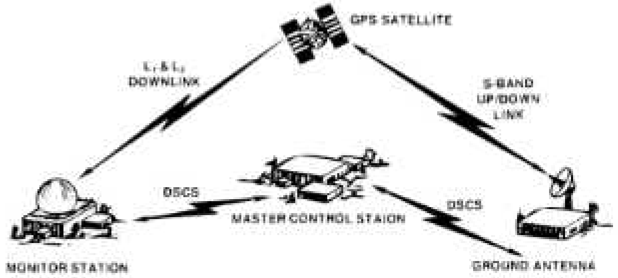


Fig. 5. Monitor Station and Ground Antenna

The MCS uplinks data to GPS satellites which includes:

- **Almanac**, which is a log of all GPS satellite positions and health and allows a GPS receiver to identify which satellites are in its hemisphere, and at what times.

  An almanac is like a schedule telling a GPS receiver when and where satellites will be overhead. Transmitted continuously by all satellites, the almanac allows GPS receivers to choose the best satellite signals to use to determine position.

- **Ephemeris data** is unique to each satellite and provides highly accurate satellite position (orbit) information for that GPS satellite alone. It does not include information about the GPS constellation as a whole. Ephemeris information is also transmitted as a part of each satellite's time signal.

By using the information from the GPS satellite constellation **almanac** in conjunction with the **ephemeris** data from each satellite, the position of a GPS satellite can be very precisely determined for a given time.

- **Clock-correction factors** for each satellite; necessary to ensure that all satellites are operating at the same precise time (known as "GPS Time").
- **Atmospheric data** (to help correct most of the distortion caused by the GPS satellite signals passing through the ionosphere layer of the atmosphere).

3.3 User Segment

The User Segment consists of receivers specifically designed to receive, decode, and process the GPS satellite signals. Receivers can be stand-alone, integrated with or embedded into other systems. GPS receivers can vary significantly in design and function, depending on their application for navigation, accurate positioning, time transfer, surveying and attitude reference.