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

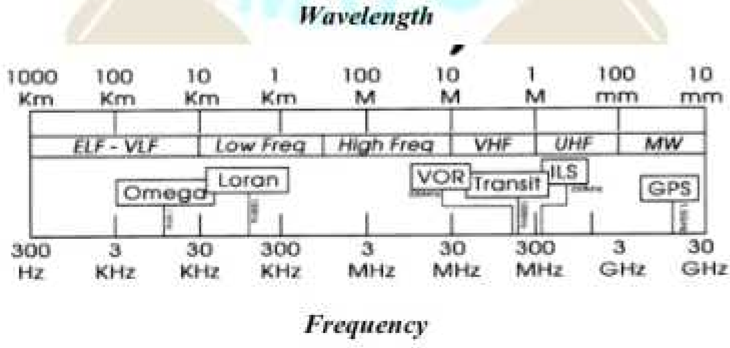
Lecture (2) GPS

4. Radio-Navigation Systems

GPS is far from being the only radio-navigation system that exists. Even before the Second World War, various schemes were attempted to provide crude positioning for ships and airplanes. Each new system built on the previous system, with each increasing the accuracy, and/or range of usability. Several systems developed during World War II are still in use today.

Today, there are at least a half-dozen different radio-navigation systems including *Omega, Loran, VOR/DME, ILS, Transit,* and, of course, the GPS, as show in Table 1. The first four are ground-based systems; the Transit and GPS systems are both space-based. The ground-based Omega and Loran systems are very similar in that they both employ difference-of-arrival techniques, with Omega measuring the phase difference and Loran measuring the time difference of the signals from two or more transmitters. These transmitters send out very low frequency carrier waves that are very long-26 kilometers for Omega; 2.5 kilometers for Loran. The advantage is that the long wavelength is able to "tunnel" through the atmosphere by "bouncing" off of the bottom of the ionosphere (a layer of electrically charged particles in the upper atmosphere) for great distances. This phenomenon is known as *"Wave Form Ducting."* In fact, this phenomenon is so effective, full global coverage is achieved by Omega with only eight transmitters. The disadvantage is low precision due to the long wavelength: six kilometers of potential error for Omega. While Loran's precision is as high as 450 meters, only some 10% of the globe is covered by Loran "Chains."

Table 1: Radio-Navigation Systems



Aviation systems such as the *VOR/DME* (Very High Frequency, Omnidirectional Ranging/Distance Measuring Equipment) and *ILS* (Instrument Landing System) systems operate at much higher frequencies and consequently provide much higher precision; on the order of 60-80 meters for VOR/DME, to less than 10 meters for ILS.

Note that:

OMEGA (**O**ptimized **M**ethod for **E**stimated **G**uidance **A**ccuracy)
LORAN (**LO**ng **RA**nge **N**avigation)
VOR (**V**ery High Frequency **O**mni-Directional **R**ange)
DME (**D**istance **M**easuring **E**quipment)
ILS (**I**nstrument **L**anding **S**ystem)
Transit (when two navigation marks line up and give a very accurate position line)

5. Frequency and Precision

Higher frequency produces higher precision. However, it also requires line-of sight since the higher frequency wavelengths "punch" right through the ionosphere rather than bounce off of it as do the longer wavelengths. The VOR/DME system covers essentially the entire United States, but this line-of-sight requirement makes it only useful in the air because the transmitters are all ground-based. The ILS is much more precise, but also suffers from the line-of-sight requirement and, in addition, provides only very limited coverage. Since it's designed for landing aircraft, *and* is very expensive, it's only located at the higher traffic airports.

Ever since the first Soviet Sputnik satellite in 1957, there have been attempts to use space-based platforms for radio-navigation to eliminate the line-of-sight requirement of high frequency, high accuracy systems. The U.S. Transit system, first launched in 1959, was the first successful such system and is still in operation today. The system includes six satellites (frequently referred to as SVs or Space Vehicles) in polar orbits some 360 kilometers high, and provides precision on the order of ½ kilometer or better, which is fine for coarse navigation and positioning, such as for ships at sea. The system relies on measuring the Doppler shift in the transmitted signal as the satellite passes from horizon to horizon. The drawback is that this occurs only about once an hour and requires some 15 minutes of reception to derive a fix. In addition, the system only provides two-dimensional fixes and gives no elevation information.

Enter the GPS, the highest frequency, shortest wavelength, and most precise system to date, with its full constellation of satellites providing total global coverage.

Table A: Frequency band designation

Frequency band	Designation	Typical service
3–30 kHz	Very low frequency (VLF)	Navigation, sonar
30–300 kHz	Low frequency (LF)	Radio beacons, navigational aids
300–3000 kHz	Medium frequency (MF)	AM broadcasting, maritime radio, Coast Guard communication, direction finding
3–30 MHz	High frequency (HF)	Telephone, telegraph, and facsimile; shortwave international broadcasting; amateur radio; citizen's band; ship-to-coast and ship-to-aircraft communication
30–300 MHz	Very high frequency (VHF)	Television, FM broadcast, air traffic control, police, taxicab mobile radio, navigational aids
300–3000 MHz	Ultrahigh frequency (UHF)	Television, satellite communication, radiosonde, surveillance radar, navigational aids
3–30 GHz	Superhigh frequency (SHF)	Airborne radar, microwave links, common-carrier land mobile communication, satellite communication
30–300 GHz	Extremely high frequency (EHF)	Radar, experimental

Table B: Microwave frequency band designation

	Microwave band designation	
Frequency	Old	New
500–1000 MHz	VHF	C
1–2 GHz	L	D
2–3 GHz	S	E
3–4 GHz	S	F
4–6 GHz	C	G
6–8 GHz	C	H
8–10 GHz	X	I
10–12.4 GHz	X	J
12.4–18 GHz	Ku	J
18–20 GHz	K	J
20–26.5 GHz	K	K
26.5–40 GHz	Ka	K

Table C: Radio frequency spectrum designation

AM Radio	535 - 1605 kHz
FM Radio	88 - 108 MHz
Broadcast TV (Channels 2-6)	54 - 88 MHz
Broadcast TV (Channels 7-13)	174 - 216 MHz
Broadcast TV (UHF)	470 - 806 MHz
Military air to air and air to ground communications	220 - 400 MHz
3G Broadband Wireless	746 - 764 MHz, 776 - 794 MHz
3G Broadband Wireless	1.7 - 1.85 MHz, 2.5 - 2.69 MHz
1G and 2G Digital Cellular Phones	806 - 902 MHz
Personal Communications Service (2G Cell Phones)	1.85 - 1.99 GHz
Wireless Communications Service	2.305 - 2.32 GHz, 2.345 - 2.36 GHz
Broadband Wireless Networking	2.3 - 2.7 GHz
Satellite Digital Radio	2.32 - 2.325 GHz
Multichannel Multipoint Distribution Service (MMDS)	2.15 - 2.68 GHz
Digital Broadcast Satellite	12.2 - 12.7 GHz
Local Multipoint Distribution Service (LMDS)	27.5 - 29.5 GHz, 31 - 31.3 GHz
Fixed Wireless Service	38.6 - 40 GHz

6. How GPS works?

The Global Positioning System (GPS) is a space based radio positioning/navigation system that will provide three-dimensional position, velocity and time information to suitably equipped users anywhere on or near the surface of the earth.

By using a timetable of satellite numbers and their orbits stored in the receiver's memory, the receiver can determine the distance and position of any GPS satellite and use this information to compute your position.

Satellites send radio signals to the receivers which are on earth surface. Using these signals receiver calculates its location on earth.

A GPS receiver needs ***four*** satellites to provide a three-dimensional (3D) fix and ***three*** satellites to provide a two-dimensional (2D) fix. A three-dimensional (3D) fix means the unit knows its ***latitude, longitude and altitude***, while a two-dimensional (2D) fix means the unit knows only its ***latitude and longitude***.

The satellites share a common time system known as **'GPS time'** and transmit (broadcast) a precise time reference as a spread spectrum signal at two frequencies in **L-Band**: **L1=1575,42 MHz, L2=1227,6 MHz**.

Two spread spectrum codes are used:

- A civil coarse acquisition (C/A) code and
- A military precise (P) code.
- **L1** contains both a P code and a C/A code, while
- **L2** contains only the P code.

7. GPS Addresses

The system is fully operational, providing positioning and navigation service to virtually anyone anywhere on the globe. In a sense, it has allowed us to give every centimeter of the surface of the planet its own unique address that can be understood by anybody through the use of a universal geocoordinate system. It could be in the not too distant future that you'll find yourself inviting a friend to your home by saying something like ". . . sure, come on over. My address is

39°45' 16.174634"N by

77°22'37.582062"W,

You can't miss it." And the fact is they couldn't, because *on the entire planet there is no other place that shares that same address.* It is yours, yours alone, and there's no mistaking it.

8. Levels of GPS Service

Two levels of navigation and positioning are offered by the Global Positioning System: The *Standard Positioning Service* (SPS), and the *Precise Positioning Service* (PPS).

The *Precise Positioning Service* (PPS) is a highly accurate positioning, velocity and timing service that is designed primarily for the military and other authorized users, although under certain conditions can be used by civilians who have specialized equipment.

The *Standard Positioning Service* (SPS) offers a base-line accuracy that is much lower than the PPS, but is available to all users with even the most inexpensive receivers. As we will see, there are various techniques available that substantially increase the SPS accuracy, even well beyond that which is offered by the PPS.

The standard positioning service (SPS) provides the lowest accuracy GPS position measurements, normally in the region of 3–10 meters. To make SPS measurements the GPS receiver locks onto four or more satellites, as show in figure (6), and then uses the C/A code to estimate the distance to each satellite. These estimates are called *pseudo-range measurements*.

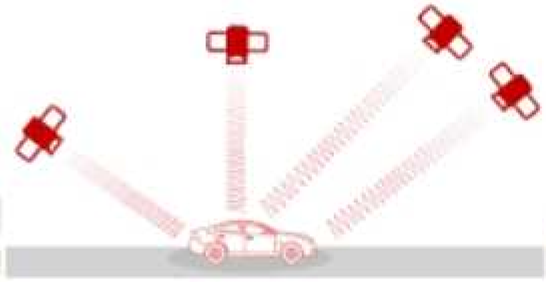


Figure (6)

9. Basic Signal Structure

By itself, the carrier wave carries no information other than its frequency, wavelength, and amplitude. If we want to transmit any useful information on that carrier wave, we have to modulate or vary it at a regular rate. The second line in the figure (7) represents a string of zeros (offs) and ones (on's) that we want to send on the carrier wave, much like Morse-code. There are several methods of transmitting that information on a carrier wave. The first is by varying (modulating) the amplitude, or how "high' and "low" the sine "humps" go. If you've ever listened to AM radio, you've heard Amplitude Modulation.

You could also vary, just slightly, the frequency of the carrier wave around a central "flat" frequency. That concept is illustrated by the line second from the bottom in the figure (7). This is how FM, or Frequency Modulation, radio works.

Finally, you could modulate the *phase* of the carrier. The phase is the relative up/down position of the sine "humps." By regularly reversing the ups and downs you can transmit your "Morse-code" information. This is how GPS transmits data on its two carriers. This is illustrated in the bottom line of the figure (7).

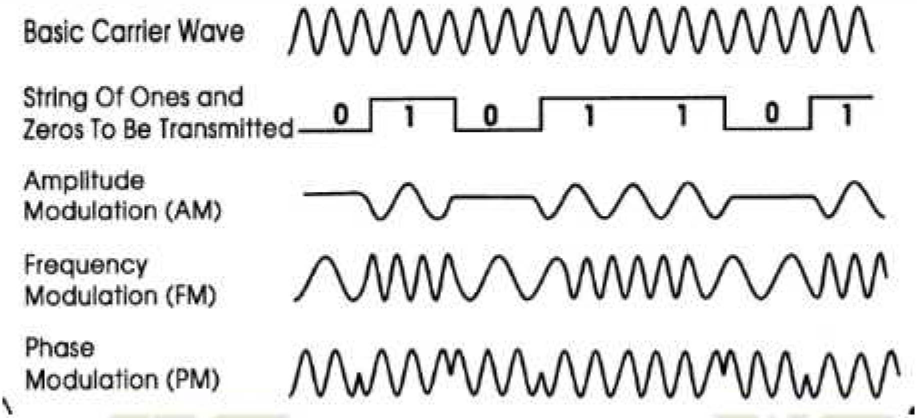


Figure (7). Basic Signal Structure

10. Pseudo-Random Codes

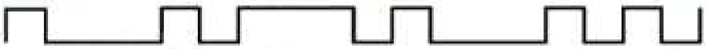
Two Morse-code-like signal strings are transmitted by each satellite. They are the *Coarse Acquisition*, or *C/A-code*, and the *Precise*, or *Protected Code* (*P-Code).*

The C/A-code is a sequence of 1,023 bi-phase modulations of the carrier wave. Each opportunity for a phase-reversal modulation, or switch from a zero to a one, is called a *"Chip"* (whether or not the phase is actually reversed at that moment). This entire sequence of 1,023 chips is repeated 1,000 times each second, resulting in a "Chip-Rate" of 1.023 MHz or one (opportunity for a) phase switch (chip) every one-millionth of a second. Each satellite carries its own unique code string. The C/A code is the code used for the Standard Positioning Service (SPS).

The Precise (P) code is similar to the C/A-code, but instead of a sequence of 1023 chips, the chip-count runs to the millions. As a result, *the complete sequence for the P-code takes 267 days to complete*, rather than the one one-thousandth of a second for the C/A-code. ***One-week segments of the 267-day string are assigned to each satellite and are changed weekly***. The P-code is the code used for the Precise Positioning Service (PPS).

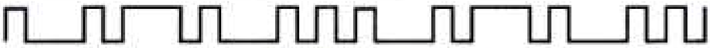
The chip rate of the P-code is an order of magnitude higher than for the C/A-code, running at phase-reversal chip rate of 10.23 MHz, or one phase switch (chip) opportunity every one ten-millionth of a second. This means that there are ten million individual opportunities for a phase reversal each and every second. Since distance is a direct function of time, the radio wave clearly can't travel very far in only one ten-millionth of a second.

Consequently, the P-code is considerably more precise than C/A code. As we'll see, this fact is critical in understanding how GPS determines distance and why one service is so much more accurate than the other.



(a) Coarse Acquisition (C/A) Code

Coarse Acquisition (C/A) Code: A sequence of 1023 Bi-Phase Modulation of the carrier, Repeated 1000 x sec. With A "Chip Rate of 1.023 MHz (SPS)



(b) Precise (P) Code

Precise (or Protected) (P) Code: A Very long sequence of Bi-phase modulations of the carrier, repeated every 267 days with a "Chip rate" of 10.23 MHz (PPS)

Figure (8): C/A code and P Code