What is the Global Positioning System?

The Global Positioning System was conceived in 1960 under the auspices of the U.S. Air Force, but in 1974 the other branches of the U.S. military joined the effort. The first satellites were launched into space in 1978. The System was declared fully operational in April 1995.

The Global Positioning System consists of 24 satellites, that circle the globe once every 12 hours, to provide worldwide position, time and velocity information. GPS makes it possible to precisely identify locations on the earth by measuring distance from the satellites. GPS allows you to record or create locations from places on the earth and help you navigate to and from those places.

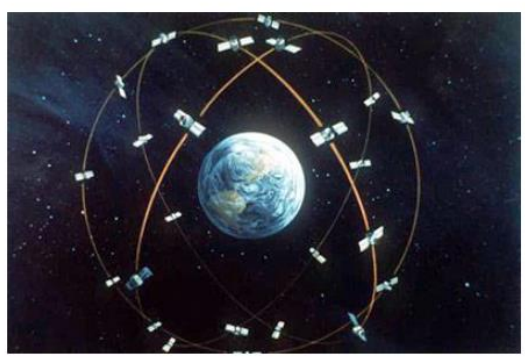
Originally the System was designed only for military applications and it wasn't until the 1980's that it was made available for civilian use also.

Presently, GPS is fully operational and meets the criteria established in the 1960s for an optimum positioning system. The system provides accurate, continuous, worldwide, three-dimensional position and velocity information to users with the appropriate receiving equipment. GPS also disseminates a form of Coordinated Universal Time (UTC). The satellite constellation nominally consists of 24 satellites arranged in 6 orbital planes with 4 satellites per plane.

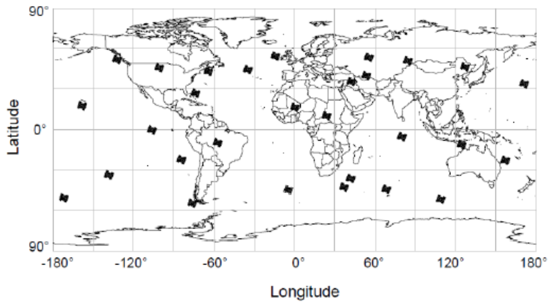
The satellites broadcast ranging codes and navigation data on two frequencies using a technique called code division multiple access (CDMA); that is, there are only two frequencies in use by the system, called L1 (1,575.42 MHz) and L2 (1,227.6 MHz). Each satellite transmits on these frequencies, but with different ranging codes than those employed by other satellites. These codes were selected because they have low cross-correlation properties with respect to one another.

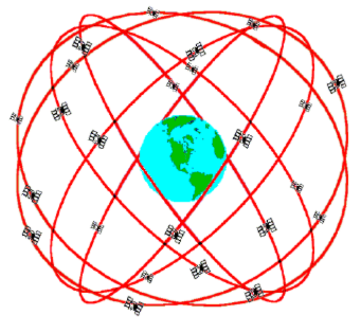
The Launch of GPS

- DOD sponsored project puts satellites into orbit
- First Sat launched in 1978
- 24 Sats by mid 1990s
- 31 Currently operational in orbit, with more coming
- A fundamental change in how positioning is done



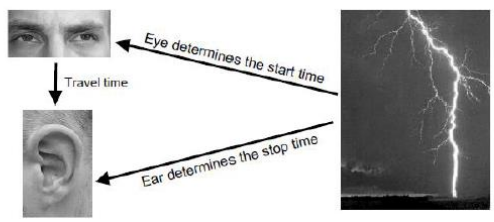
GPS Constellation





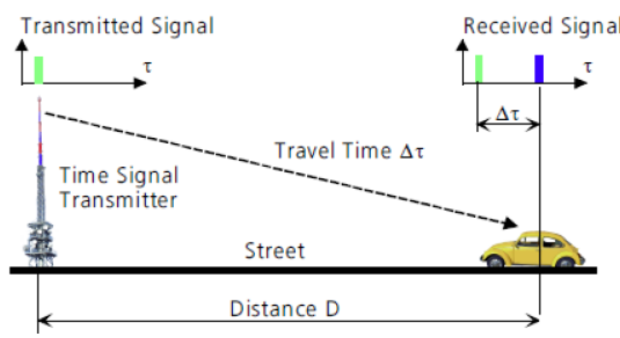
- All GPS satellites are placed in 6 MEO (Medium Earth Orbits) s.

Concept of GPS



Distance = Travel Time x Speed of Sound

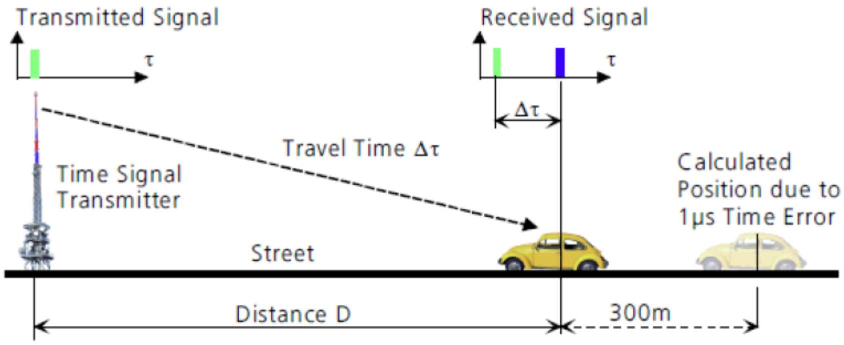
Speed of sound= 340.29 m/s



Distance = Travel Time x Speed of radio wave

Speed of radio waves (~speed of light in vacuum) = 3 x 10^8 m/s

The Clock Problem - Simplified



- There is 300m error if time is off in 1 micro seconds

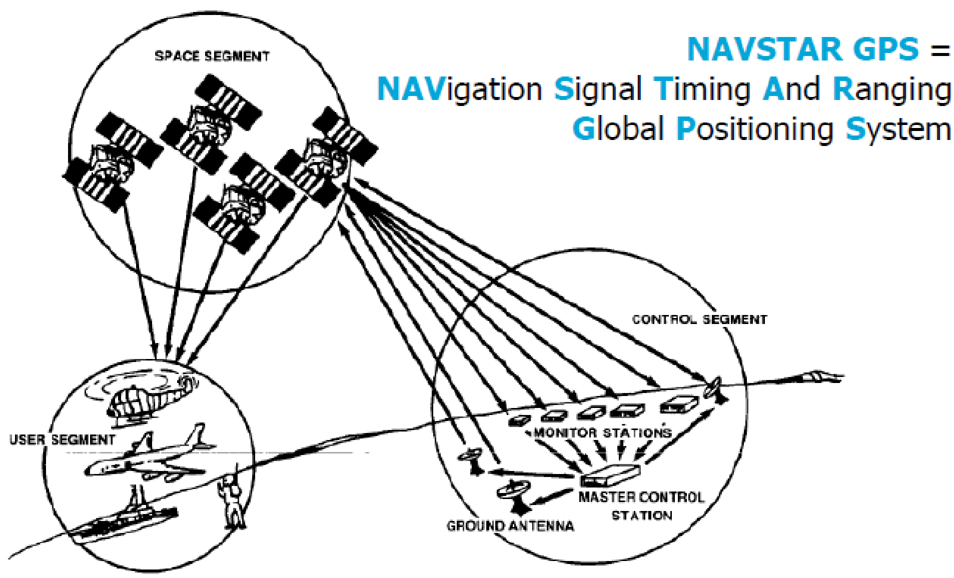
What are pseudoranges?

Time that the signal is transmitted from the satellite is encoded on the signal, using the time according to an atomic clock onboard the satellite. Time of signal reception is recorded by receiver using an atomic clock. A receiver measures difference in these times:

pseudorange = (time difference) . (speed of light)

Note that pseudorange is almost like range, except that it includes clock errors because the receiver clocks are far from perfect.

System architecture



From: "NAVSTAR GPS User Equipment Introduction", DoD, 1996

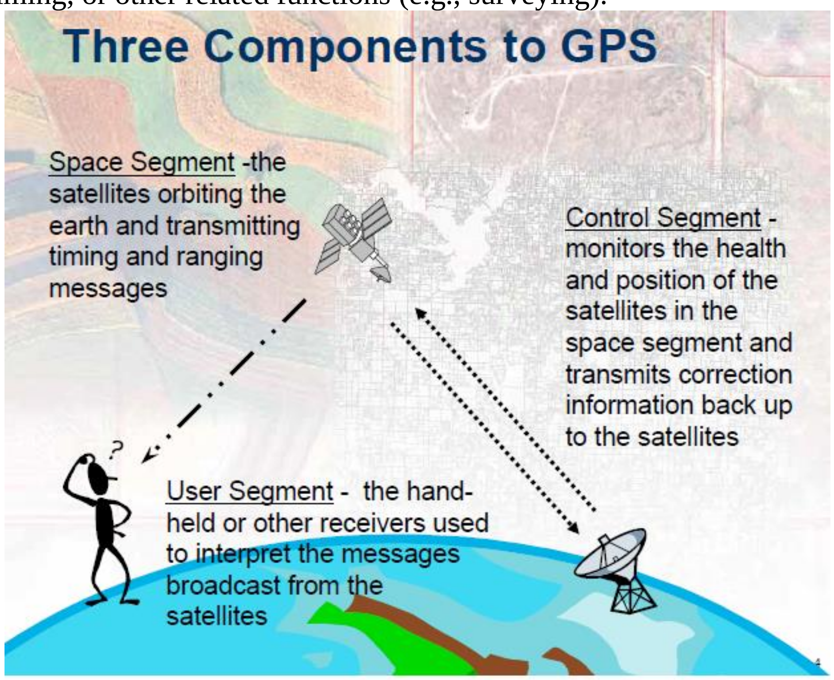
Orbit Design

The satellite constellation is designed to have at least 4 satellites in view anywhere, anytime, to a user on the ground. For this purpose, there are nominally 24 GPS satellites distributed in 6 orbital planes. So that we may discuss the orbit design and the implications of that design, we must digress for a short while to explain the geometry of the GPS constellation.

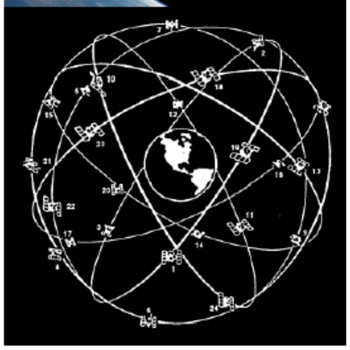
The 6 orbital planes rise over the equator at an inclination angle of 55° to the equator. The point at which they rise from the Southern to Northern Hemisphere across the equator is called the "Right Ascension of the ascending node". Since the orbital planes are evenly distributed, the angle between the six ascending nodes is 60°.

GPS segments:

GPS is comprised of three segments: satellite constellation, ground-control/monitoring network, and user receiving equipment. The satellite constellation is the set of satellites in orbit that provide the ranging signals and data messages to the user equipment. The control segment (CS) tracks and maintains the satellites in space. The CS monitors satellite health and signal integrity and maintains the orbital configuration of the satellites. Furthermore, the CS updates the satellite clock corrections and ephemerides as well as numerous other parameters essential to determining user PVT. Finally, the user receiver equipment (i.e., user segment) performs the navigation, timing, or other related functions (e.g., surveying).



Space segment



Satellite constellation:

- 24 nominal satellites
- orbital period 11 hour 58 min
- 6 orbital planes, 55^o inclination
- nearly circular orbits, radius 26,560 km (~20,200 km altitude)

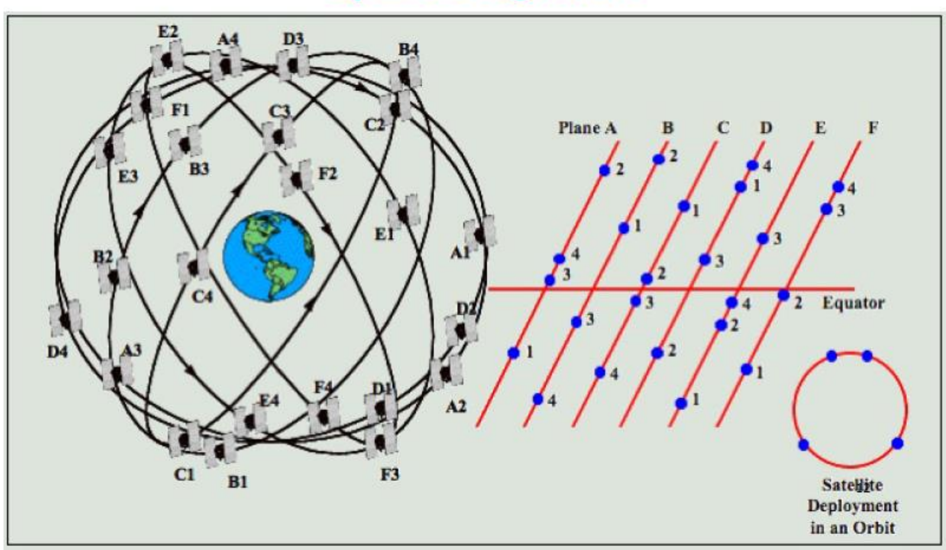
Space segment

Different schemes to identify GPS satellites

	example:
• Orbital position: <*letter*><*number*>	D-4
• Satellite vehicle number: SVN <*number*>	**SVN 34**
• PRN code number: PRN <*number*>	**PRN 04**
• Launch sequence number	II-23
• NASA catalogue number	22877
• International ID	1993-068A

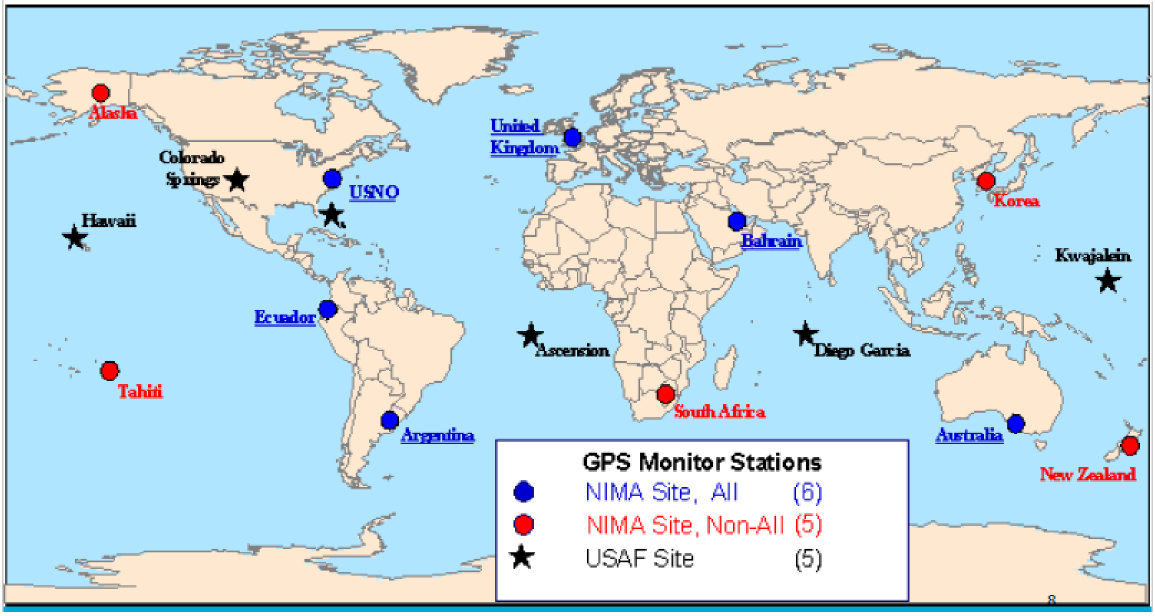
If not mentioned otherwise we will use the assigned satellite **PRN** number (range 1 – 32)

Space segment



Baseline GPS Satellite Constellation

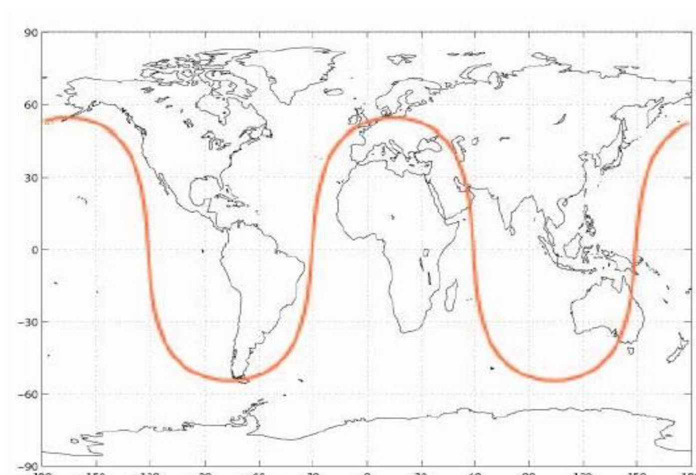
Control segment



Control segment

- Monitor satellite orbits
- Monitor and maintain satellite health
- Maintain GPS time
- Predict satellite ephemerides and clock parameters
- Update satellite navigation messages
- Command maneuvres, relocations of satellites

GPS Satellite ground track



All the prototype satellites, known as Block I, have been decommissioned. Between 1989 and 1994, 24 Block II (1989-1994) were placed in orbit. From 1995 onwards, these have started to be replaced by a new design known as Block IIR. The nominal specifications of the GPS satellites are as follows:

- Life goal: 7.5 years
- Mass: ~1 tonne (Block IIR: ~2 tonnes)
- Size: 5 metres
- Power: solar panels 7.5 m^2 + Ni-Cd batteries
- Atomic clocks: 2 rubidium and 2 cesium

The orientation of the satellites is always changing, such that the solar panels face the sun, and the antennas face the centre of the Earth. Signals are transmitted and received by the satellite using microwaves. Signals are transmitted to the User Segment at frequencies L1 = 1575.42 MHz, and L2 = 1227.60 MHz. We discuss the signals in further detail later on. Signals are received from the Control Segment at frequency 1783.74 Mhz. The flow of information is a follows: the satellites transmit L1 and L2 signals to the user, which are encoded with information on their clock times and their positions. The Control Segment then tracks these signals using receivers at special monitoring stations. This information is used to improve the satellite positions and predict where the satellites will be in the near future. This orbit information is then uplinked at 1783.74 Mhz to the GPS satellites, which in turn transmit this new information down to the users, and so on. The orbit information on board the satellite is updated every hour.

GPS Satellites

- Maintain accurate time by means of rubidium and cesium clocks
- Broadcast the time information to the user by means of
  - Two/three carrier frequencies:
    L1 (1575.42 MHz) ; L2 (1227.60 MHz) ; L5 (1176.45 MHz)
  - Pseudo random noise (PRN) codes
- Broadcast its position (satellite ephemeris), clock corrections and health information by means of data message
- Receive and store satellite ephemeris and other data regularly uploaded by the Control Segment

Block I satellites:
- 11 satellites launched (1978-1985), one launch failure
- in 1995 last Block I stopped functioning after 11 years (4.5 year design life!)
- mass 845 kg, inclination 63^0, 2 orbital planes (A+C)

Block II and **IIA** satellites:
- 28 satellites built and launched
- first launch 1989, last launch 1997
- design life 7.5 years
- mass 1500 kg, inclination 55^0, 6 orbital planes
- Anti-Spoofing (A-S) and Selective Availability (SA) implemented

11 Block IIA in orbit
oldest launched Nov-1990

Block IIR and **IIR-M** satellites:

- replacement for block II satellites
- first successful launch 1998 (1 launch failure)
- IIR-M transmit L2C signal

12 Block IIR and 8 Block IIR-M in orbit

Block IIF satellites (first launch in 2010):

- third frequency (L5)

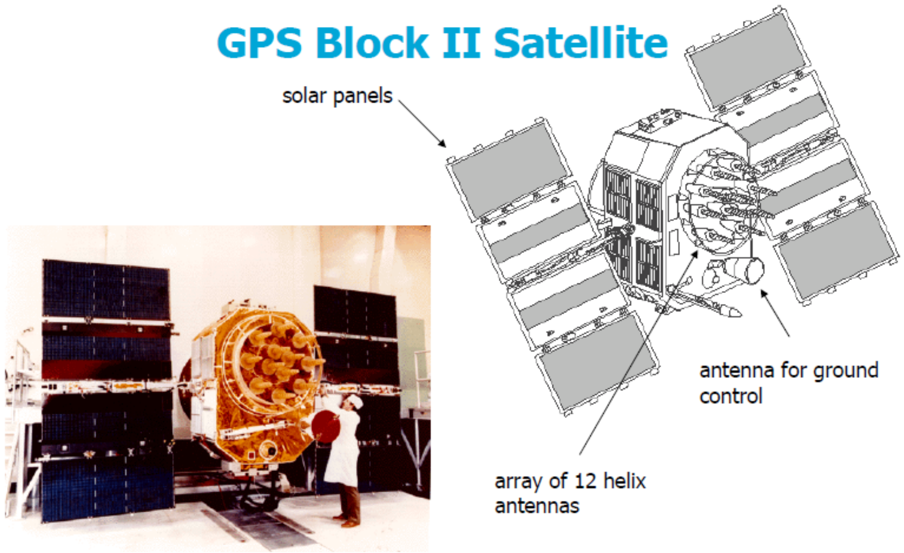
1 Block IIF in orbit
11 more to be launched, First Feb-2011

Block III

- additional civil signal on L1 (L1C)

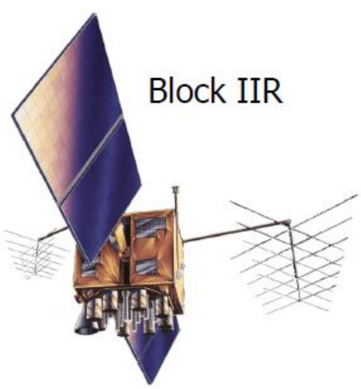
30 to be launched

GPS Block II Satellite



GPS Block IIR and IIF Satellite

Block IIR



Block IIF