

Chapter Ten

Global positioning system (GPS)

10.1 Introduction to global positioning system

The Global positioning system (GPS) is a satellite based navigational system that was developed by U.S. Department of Defence (DOD) in the early 1970s. Initially, GPS was developed as a military system to fulfil U.S. military needs. However, it was later made available to civilians, and is now a dual system that can be accessed by both military and civilian uses. GPS is shortened form of **NAVSTAR – Navigation System with Time And Ranging Global Positioning system.**

GPS is a solution for one of man's longest and most troublesome problems. It provides an answer to the question '**Where on earth am I?**'

One can imagine that this is an easy question to answer. You can easily locate yourself by looking at objects that surround you and position yourself relative to them. But what if you have no objects around you? What if you are in the middle of desert or in the middle of the ocean ? For many centuries, this problem was solved by using the sun and stars to navigate. These methods worked well within certain boundaries. Sun and Stars cannot be seen when it is cloudy. Also positions cannot be determined very accurately.

GPS consists, normally of constellation of 24 – operational satellites. This constellation, known as **Initial Operational Capability (IOC)** was completed in July 1993. The official IOC announcement, however, was made on December 1993. To ensure continuous worldwide coverage, GPS satellites are arranged so that four satellites are placed in each of six orbital planes. With this constellation geometry, four to ten GPS satellites will be visible anywhere in

the world, if the elevation angle of 10^0 is considered. Only four satellites are needed to provide the positioning or location information in the form of precise estimation of position, velocity and time (PVT) by using a GPS receiver.

10.2 GPS an overview of & its basic principles

Objective of GPS

The main objectives of GPS System are: -

- ❑ GPS was developed with the objective to provide accurate estimates of PVT with root mean square errors of **10 m** in position, **0.1m/s** in velocity and **100ns** in time.
- ❑ These estimates are to be available to an unlimited number of users all over the globe continuously and nearly instantaneously.
- ❑ GPS was planned to offer two kinds of services:
 - Standard Positioning Services (SPS) for open, unrestricted civil use
 - Precise positioning services (PPS) for the DOD authorized users.
- ❑ Access to full capability of the system (i.e. PPS) is restricted by encryption in two ways:
 - By Selective Availability (S/A)
 - By Anti Spoofing (AS)

GPS Segments

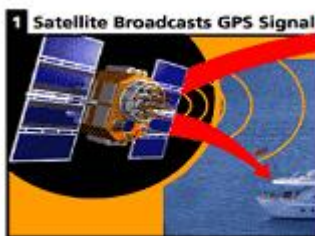
GPS consists of three distinct segments:

1. The space segments - Satellites orbiting the earth

2. The control segments - stationed positioned on the earth's equator to control the satellites.
3. The User segment - Any body that receives and uses the GPS signal.

1. Space Segment

- The space segment is designed to consist of 24 satellites orbiting the earth at approximately at height 20,200 km in every 12 hours.
- The satellites are arrayed in 6 orbital plane inclined 55° to the equator.
- The space segment is so designed that there will be a minimum of four satellites visible above a 15° cut - off angle at any point of the earth's surface at any time.
- Four satellites are the minimum that must be visible for most applications. Experience shows that there are usually at least 5 satellites visible for most of the time and quite often there are 6 or 7 satellites visible.



GPS satellite

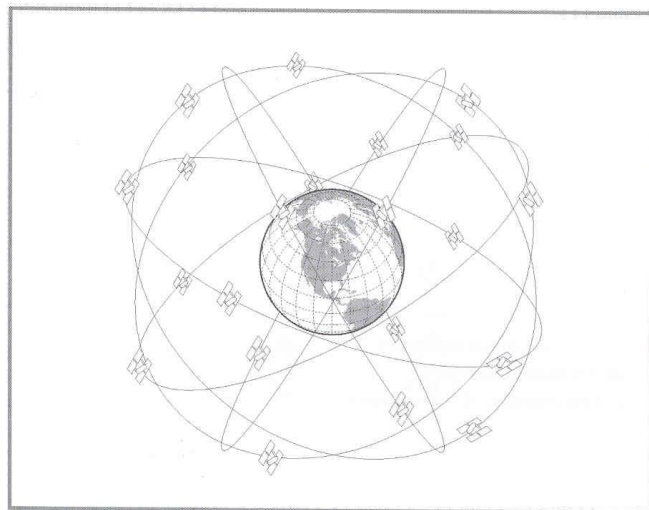


Figure 3.3. Satellite Coverage Constellation.

- Each GPS satellite has four very accurate and precise atomic clocks (**Rubidium** and **Cesium standards**) and has a microprocessor on board for limited self-monitoring and data processing.
- The satellites are equipped with thrusters, which can be used to maintain or modify their orbits.
- The clocks operate at a fundamental frequency of **10.23 MHz**. This is used to generate signals that are broadcast from the satellites.
- The satellites broadcast two carrier waves constantly. These carrier waves are in the L - Band (used for radio), and travel to the earth at the speed of light. These carrier waves are derived from the fundamental frequency, generated by a very precise atomic clock.

The GPS satellites essentially provide a platform for radio transceivers atomic clocks, computers and various ancillary equipments used to operate the system. The electronic equipments allow the measurement of pseudo range (R) from receiver to satellite, and each satellite broadcast a message, which allows the user to determine the spatial position of the satellite at any instant. With these data, the users are able to determine their position by resection.

2. Control Segment

- The control segment consists of one master control station, 5 monitor stations and 4 ground antennas distributed amongst 5 locations roughly on the earth's equator.
- These stations are at **Colorado Springs, Ascension Island, Diego Garcia, Hawai** and **Kwajalein Island**.
- The control segments track the GPS satellites, update their orbiting position and calibrate and synchronize their clocks.

- A further important function is to determine the orbit of each satellite and predict its path for following 24 hours.
- This information is uploaded to each satellite and subsequently broadcast from it. This enables the GPS receiver to know where each satellite can be expected to be found.
- The satellite signals are read at 5 monitor stations and measurements are then sent to the master control station in Colorado Springs.

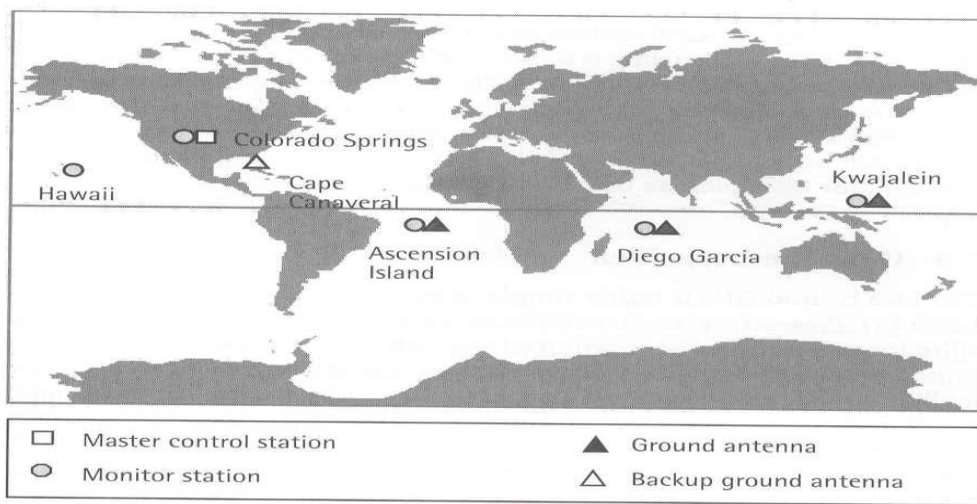
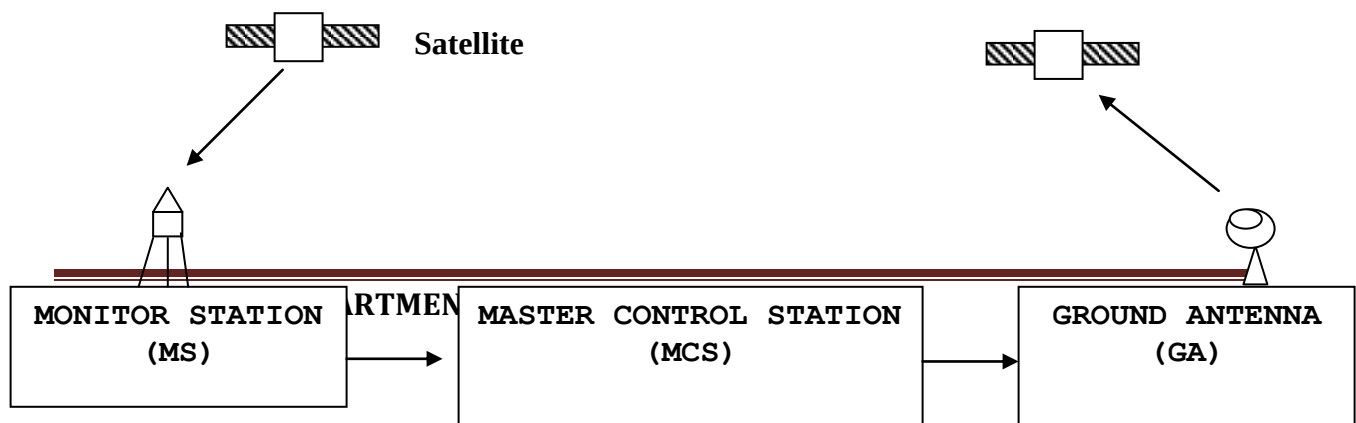


Figure 1.4 GPS control sites.

- Here they are processed to determine any errors in each satellite. The new ephemerides (satellite position as a function of time), Clock corrections and other broadcast message data are then sent back to three monitoring stations (Diego Garcia, Ascension & Kwajalein) equipped with ground antennas and uploaded to the satellites and broadcasted.



MASTER CONTROL STATION (MCS) - Prediction of ephemerides and clock behavior

MONITOR STATION (MS) - Control of ephemerides and satellite clocks.

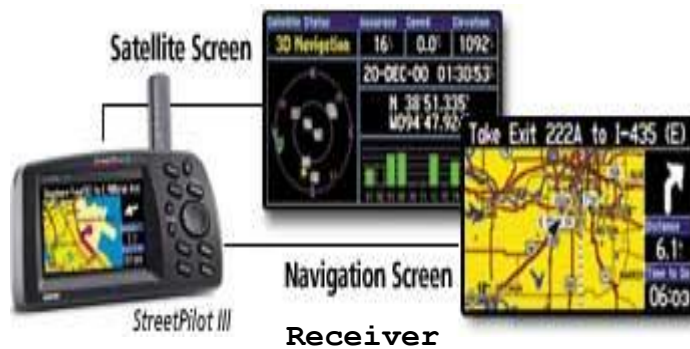
GROUND ANTENNA GA) - Uplink of Navigation Message to Satellites

The main operational tasks of the control systems are:

- Tracking of the satellite for the orbit and clock determination and prediction modeling.
- Time synchronization of the satellites
- Upload of the data message to the satellites.

3. User Segment

- The user segment comprises of anyone using GPS receiver to receive GPS signals and determine their position and /or their time.
- Typical applications within the user segment are Land Navigation for vehicle location, surveying, marine navigation, areal navigation, machine control etc.
- GPS receivers vary greatly in size and complexity. The typical receiver is composed of an antenna and preamplifier, radio signal microprocessor, control and display device, data recording unit and power supply.
- The GPS receiver decodes the timing of signals from the visible satellites and calculates their distances. This is used to compute its own latitude, longitude, elevation and time. This is a continuous process and generally the position is updated on a second by second basis.



Basic Principles of GPS

- GPS is based on the principle of resection i.e. Receiver's position (x,y,z) can be determined given the distances from objects whose positions are known.
- Analytically, from the known positions of three objects and their distance from unknown position, we get three-distance equation involving three unknown corresponding to the unknown position of the receiver.
- These three equations can be solved for three unknowns (x,y,z) .

Fig: 1

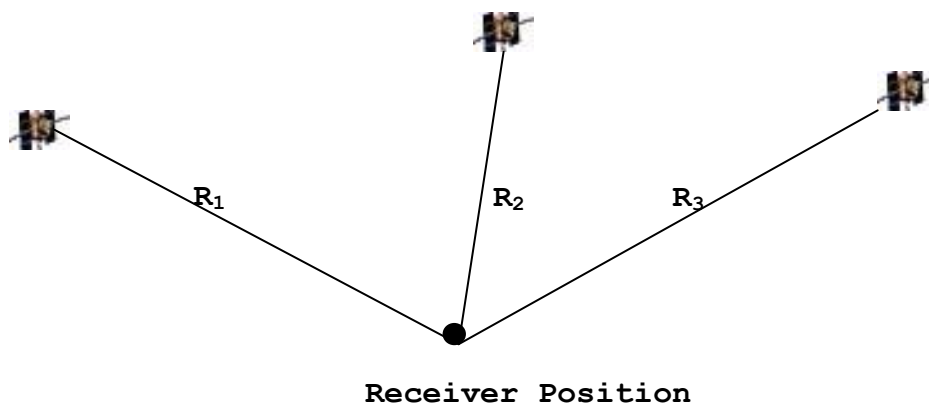
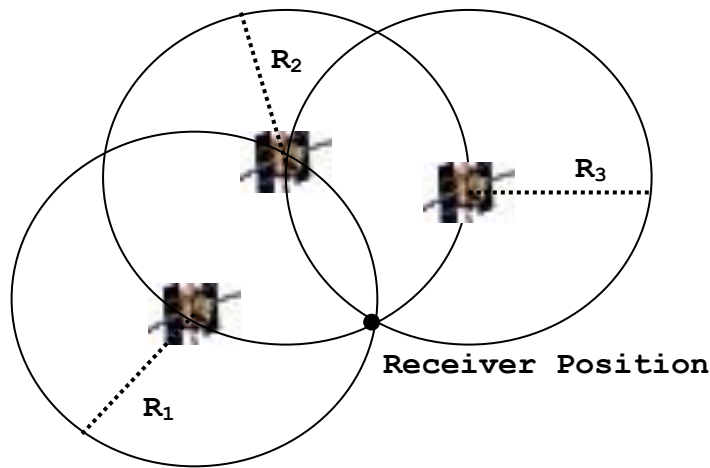


Fig: 2

- ❑ Theoretically, only three distances to three simultaneously tracked satellites are needed. R_1 , R_2 and R_3 in **Fig: 1**
- ❑ In this case the Receiver would be located at the intersection of three spheres – each has a radius of one receiver-satellite distance. **Fig: 2**
- ❑ Fourth satellite is required to account for Receiver clock offset.
- ❑ Then the intersection of three distances from satellite to the receiver would be the position of receiver.
- ❑ Satellites broadcast their position as a function of time in WGS-84 Coordinates system.
- ❑ Therefore, the position of receiver is determined in WGS-84 coordinate system, which later converted into local coordinate system.

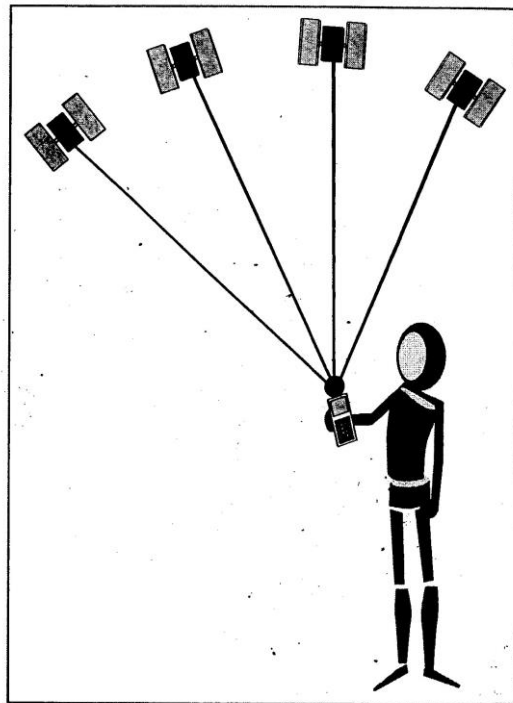
How to calculate Distance from Satellite to Receiver?

- ❑ In GPS, the satellites, which broadcast their positions, are the objects at known locations.

- ❑ The distance between the receiver and a satellite is measured in terms of transit time of the signal multiplied by velocity of light.

$$\text{i.e. Distance} = \text{Velocity} \times \text{Time}$$

- ❑ The velocity is the velocity of radio signal broadcasted by the satellite at the speed of light (3×10^{10} cm/sec).
- ❑ There is the time taken for the radio signal to travel from the satellite to the GPS receiver.
- ❑ This is little harder to calculate, since you need to know when the radio signals left the satellite and when it reached the receiver.
- ❑ Therefore the travel time is fourth unknown to be estimated in addition to the three coordinates of receiver's position.
- ❑ A user, therefore, needs a minimum of four satellites in view to estimate his four-dimensional position: three coordinates for spatial position plus time bias.



At least four satellites are required to obtain a position and time in 3 dimensions