UNIT 2 GNSS AND ITS COMPONENTS

Structure

2.1 INTRODUCTION

You have been introduced to the basic concepts of Global Navigation Satellite System (GNSS) and its examples viz., GPS, GLONASS and Galileo in the previous unit. You must be aware of the most spectacular technological developments in recent years and the enormous advances in the realm of satellite navigation or GNSS technologies. In a matter of a few years, satellite navigation has evolved to a dynamic and rapidly growing industry. This technology is devoted to the rapid and reliable determination of user's location and position. Let us discuss the satellite navigation methods in precisely determining the position of user's location anywhere on the Earth. Now in this unit, you will study about the components of GNSS and its different segments by specifically taking into account the GPS system. Further, we shall also discuss the principle of GPS operation and its function in determining the user coordinates and computing distances.

Objectives

After reading this unit you will be able to:

- discuss the three components of GPS segments;
- compute the distance between user and GPS satellites with the help of GPS receiver;
- recognise the principles of GPS operation;
- list out the types of GPS receivers and data formats; and
- identify the sources of errors in GPS data.

2.2 GPS SEGMENTS

During World War II GPS was used to locate the enemy, which was helpful in deciding whether to attack or retreat, depending on the size of forces.

In February 1978, the first experimental Block 1 GPS satellite was launched into space and the development of modern day GPS systems began.

You have been introduced to Global Positioning System in Unit 1 *Introduction to GNSS.* You have read that the GPS has made a significant impact on almost all positioning, navigation and monitoring applications. GPS enables us to estimate the position, velocity and timing information to the user with the suitable receiving equipment. The GPS satellite signals are used to compute positions in three dimensions and the time offset in the receiver clock. You should refer to Figs. 2.1 and 2.2, while reading this section. GPS comprises three main components:

1. Space segment (all operating GPS satellite vehicles)
2. Control segment (all ground stations involved in the monitoring of the system: master control stations, monitor stations, and ground antenna)
3. User segment (all civilian and military users with a GPS receiver)

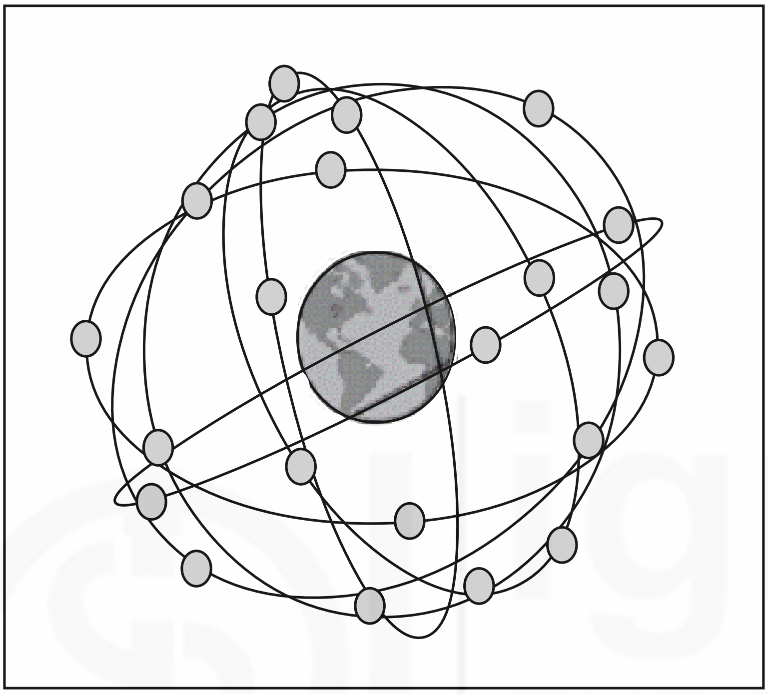
2.2.1 Space Segment

The space segment consists of the orbiting GPS satellites. The GPS design originally consists of 24 satellites, eight each in approximately three circular orbits. This had been later modified to six orbits with four satellites each (Fig. 2.1). The orbits are arranged so that at least six satellites are always within line of sight from almost anywhere on Earth's surface. The satellites are spaced so that GPS receiver, anywhere in the world, can receive the signals from at least four of them. The satellites are dispersed in six orbital planes on almost circular orbits with an altitude of about 20,200 km above the surface of the Earth, inclined by 55^{o} with respect to the equator and with orbital periods of approximately 11 h 58 m. The Space Vehicles (SVs) send radio signals from space as shown in Fig. 2.2. Each GPS satellite transmits a signal comprising:

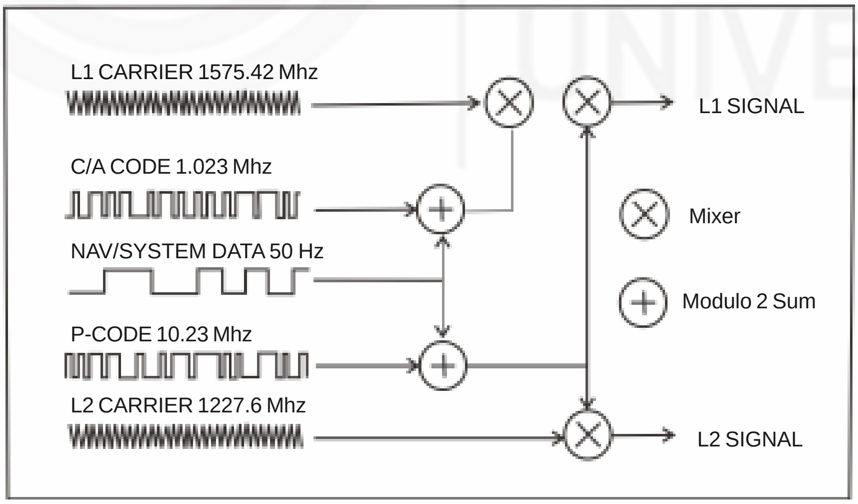
- carrier frequencies,
- two digital/ranging codes
- the navigation message.

The carriers and the digital or ranging codes are mainly used to determine the distance from the user's receiver to the GPS satellites. The navigation message contains along with other information, the coordinates (the location) of the satellites as a function of time. The transmitted signals are controlled by highly accurate atomic clocks onboard the satellites.

The signals can pass through clouds, glass and plastic. Most solid buildings decrease the power of signals. The signals cannot pass through objects that contain lot of metals or objects that contain lot of water. Each GPS satellite is powered by solar energy. If solar energy is unavailable, suppose the satellite is in the Earth's shadow, it uses the backup batteries to continue running.



(a)



(b)

Fig. 2.1: (a) GPS constellations with 24 satellites (source: Leica Geosystems, 1999) and (b) GPS satellite signals (source: Kaplan, 2005)

2.2.2 Control Segment

The control segment consists of a system of tracking stations located around the world. It is responsible for constantly monitoring the satellite health, signal integrity and orbital configuration from the ground. The control segment comprises monitor station, master control station and ground antenna:

- **Monitor Stations**: It consists of six unmanned stations. Each station constantly monitors and receives information from GPS satellite vehicles and then sends the orbital and clock information to the master station.
- **Master Control Station (MCS)**: It constantly monitors and receives GPS satellite orbital and clock information from the monitoring stations. It contacts each GPS satellite regularly with a navigational update using dedicated or shared ground antennas. These update and coordinate the atomic clocks onboard the satellites within a few nanoseconds. The controllers in the MCS make precise correction to the data and send the information known as ephemeris data to the GPS satellite, using ground antenna.
- **Ground Antenna (GA):** Four ground antennas receive corrected orbital and clock information from the satellites.

The flight paths of the satellites are tracked by a number of dedicated U.S. Air Force monitoring stations along with shared Network Ground Antennas (NGA) monitoring stations operated in England, Argentina, Ecuador, Bahrain, Australia and Washington DC for the US-GPS constellation.

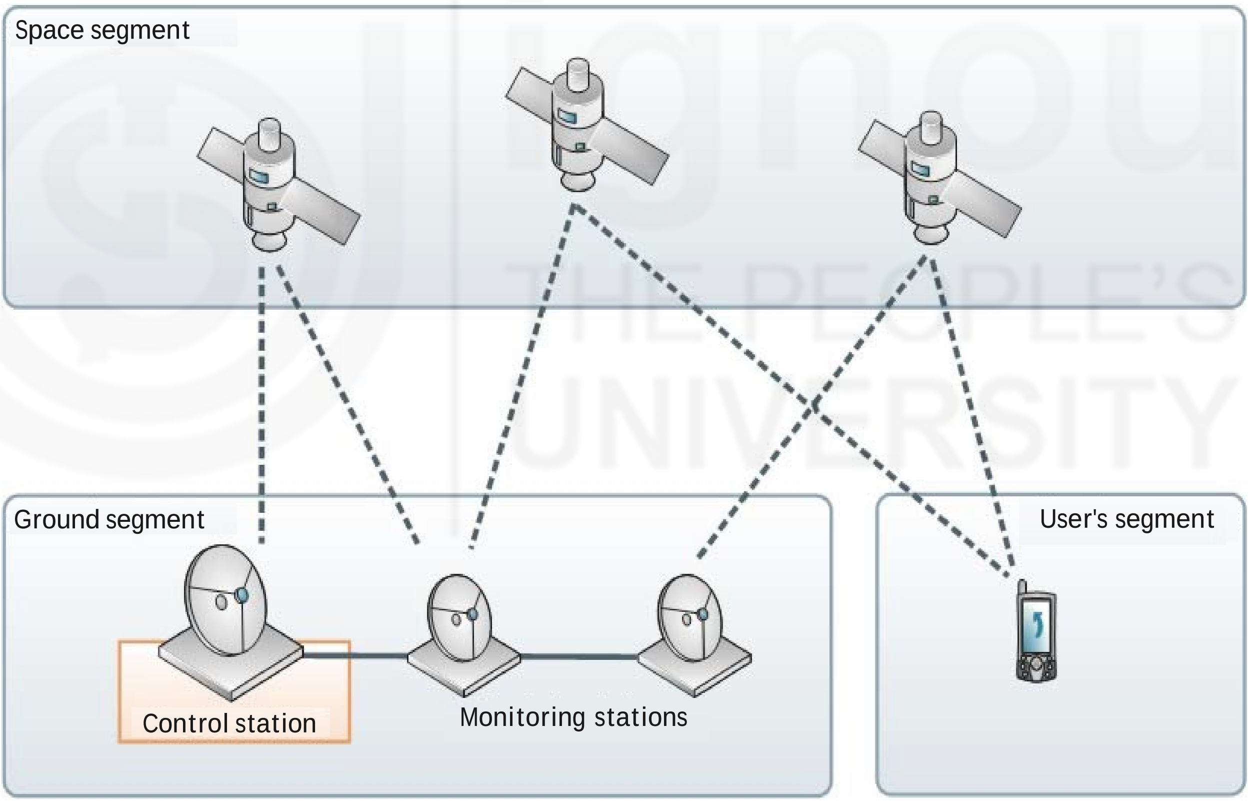


Fig. 2.2: GPS Segments-space segment, ground segment and user segment (source: www.kowoma.de/en/gps/errors.htm)

2.2.3 User Segment

The user segment consists of users like you, with the GPS receiver handset, which receives the signal broadcasted by the satellites (Fig. 2.3). The GPS receiver converts the signal into 3 dimensional positions (latitude, longitude and altitude). A receiver is mostly described by the number of channels / satellites, it can communicate simultaneously. You can opt for different types of receivers available in the market based on your requirement.

Fig. 2.3: A handheld GPS receiver

Check Your Progress I

Spend 5 mins

1) What are the three segments of GPS?

....

....

....

....

2) Name the source used to power GPS satellites.

....

....

....

....

3) What are the dimensional positions of GPS receiver?

....

....

....

....

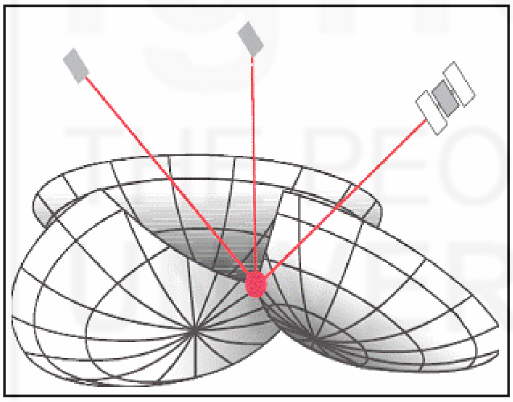
2.3 PRINCIPLE OF GPS OPERATION

You have learnt about the basics of GPS in the previous unit. If you are handling a GPS instrument then your location on Earth's surface could be known (Fig. 2.3). The idea behind the operation of GPS is rather simple. GPS positioning is based on the concept of *trilateration* which utilizes a basic geometric principle that allows computing a location. You could determine this by knowing distances from a point on the Earth (a GPS receiver i.e., your position) to three GPS satellites along with the satellite locations (Fig. 2.4). The location of the point or GPS receiver can be known by simply applying the well-known concept of resection which is used by many surveyors in their daily work. You would read in the following sections about knowing the distances to the satellites as well as the satellite locations. For using a GPS receiver to find your location, one has to determine the following:

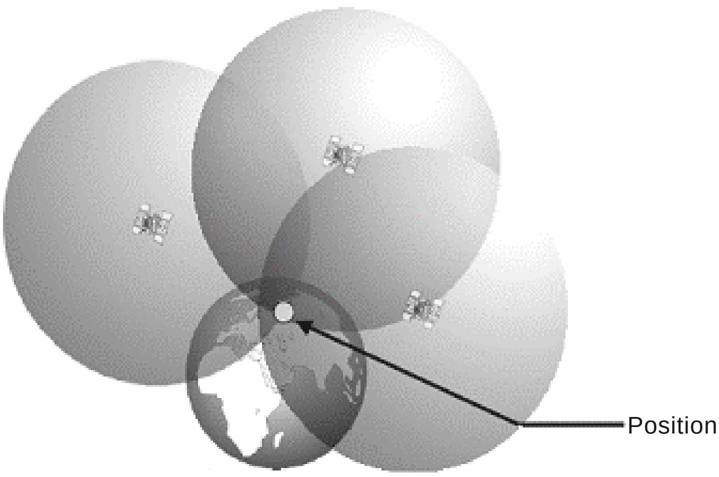
- precise location of at least four visible satellites
- distance between you and three of these satellites

As you have read earlier that each GPS satellite continuously transmits a microwave radio signal composed of two carriers, two codes and a navigation message. When you switch on your GPS receiver, it picks up the GPS signal through the receiver antenna. Once the receiver acquires the GPS signal, it will process using its in-built software. The outcome of the signal processing consists of the distances to the GPS satellites through the digital codes (known as the pseudoranges) and the satellite coordinates through the navigation message.

If you know the distance to three points relative to your own position, you can determine your own position relative to those three points. We know that the position of the receiver must be at some point on the surface of an imaginary sphere from the distance to one satellite. The sphere has its origin at the satellite with a radius equal to the distance of the user from the centre of the GPS satellite, which is assumed to be the centre of the sphere. By intersecting three imaginary spheres the receiver position can be determined (Fig. 2.4). From the practical point of view, however, a fourth satellite is needed to account for the receiver clock offset (Fig. 2.5).



(a)



(b)

Fig. 2.4: (a) Intersection of three imaginary spheres (Leica Geosystems, 1999) (b) GPS trilateration concept-position is determined at the point where three spheres intersect (source: www.zogg-jm.ch/Dateien/ GPS_ CompendiumGPS-X-02007.pdf)

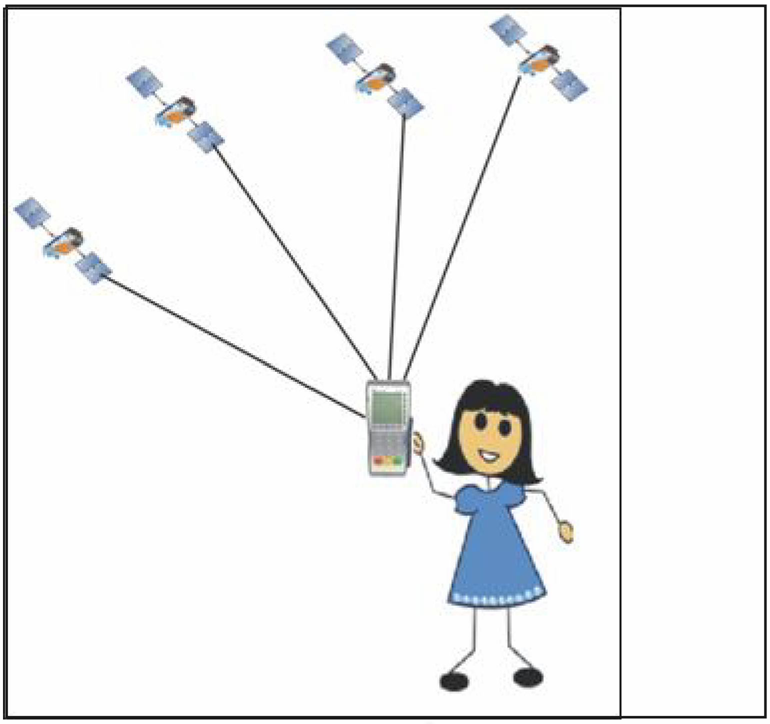


Fig. 2.5: You require at least four satellites to obtain a position and time in 3 dimensions

The accuracy obtained with the method described earlier was until recently limited to 100m for the horizontal component, 156m for the vertical component, and 340 nano second for the time component, all at the 95% level of confidence. The low accuracy level is due to the effect of the *selective availability*. This was a technique used to intentionally degrade the autonomous real-time positioning accuracy to unauthorised users.

Selective Availability is a process applied by the U.S. Department of Defence to the GPS signals, intended to deny civilian and hostile foreign users the full accuracy of GPS by subjecting the satellite clocks to a process known as *dithering* which alters their time slightly.

With the recent decision of terminating the selective availability, the obtained horizontal accuracy is expected to improve to about 22m.

You would be curious to know about the other uses of GPS apart from the one discussed above. You can read about the useful information provided by GPS receivers mentioned below:

You will read about applications of GPS and GPS survey in Unit 3, *GPS Survey and Applications*, of MGY-003.

- **Location:** GPS provides information about your location in three dimensions:

  1) Latitude (x coordinate)

  2) Longitude (y coordinate)

  3) Elevation

- **Speed:** When you're in motion, a GPS receiver displays your speed.
- **Direction of travel:** GPS receiver can display your direction of travel.
- **Time:** GPS receiver receives time information from atomic clocks.
- **Stored locations:** You can store locations of interest in the GPS.
- **Cumulative data:** GPS receiver can also keep track of information such as the total distance travelled, average speed, maximum speed, minimum speed, elapsed time and time of arrival at a specified location.

2.3.1 GPS Signal Structure

You have learnt that the GPS satellites transmit radio signals. There are two types of radio signals:

- C/A-code (Coarse/Acquisition GPS code)
- P-code (Precise GPS code)

Pseudorandom noise (PRN) code is any group of binary sequences that appear to be randomly distributed like noise, but which can be exactly distributed.

Each code consists of a stream of binary digits, zeros and ones, known as *bits* or *chips*. The codes are commonly known as *Pseudorandom Noise (PRN) codes* because they look like random or noise-like signals. The codes are generated using a mathematical algorithm. You will read here about the characteristics (Table 2.1) and differences of these two types of signals:

Coarse Acquisition Code (C/A-code)

Jam and Spoof means to broadcast false signals to mislead the receiver.

C/A- code is the type of signal that GPS units receive. C/A-code is sent on the L1 band at a frequency of 1575.42 MHz (Fig. 2.1). C/A broadcasts are known as the Standard Positioning Service (SPS), about which you will read in next section. It is easier for U.S. military forces to *jam and spoof* C/A-code. The advantage of C/A-code is that it is quicker to use for acquiring satellite data and getting an initial position fixed. C/A-code is less accurate than P-code. The C/A-code is a stream of 1,023 binary digits (i.e., 1,023 zeros and ones) that repeats itself every millisecond. This means that the chipping rate of the C/A-code is 1.023 Mbps. In other words, the duration of one bit is approximately 1μs, or equivalently 300m.

Precision Code (P-code)

P-code provides highly precise location information. The P-code is difficult to jam and spoof. The U.S. military is the primary user of P-code transmissions and it uses an encrypted form of the data known as Y-code so that only special receivers can access the information. The P-code signal is broadcasted on both the L1 band at 1575.42MHz and the L2 band at 1227.6 MHz (Table 2.1). Two military codes (m-code) are now available on L1 and L2 frequency. P-code broadcasts are known as the Precise Positioning Service (PPS), about which you will read in next section. It takes the P-code to repeat itself in 266 days, by its rate of 10.23 Mbps. The 266-day-long code is divided into 38 segments; each one is 1 week long. Of these, 32 segments are assigned to the various GPS satellites. That is, each satellite transmits a unique 1-week segment of the P-code, which is initialised every Saturday/Sunday midnight crossing. The remaining six segments are reserved for other uses. The P-code is designed primarily for military purposes. It was available to all users until January 31, 1994. P-code was encrypted by adding to it an unknown W-code. This encryption is known as the *Antispoofing* (AS).

Antispoofing is a mechanism intended to defeat *deception jamming* through encryption of the military signals. It is similar to selective availability, in that its intention is to deny civilian and hostile powers access to the P-code part of the GPS signal.

Differences between C/A-code and P-code

Let us read about the differences between C/A-code and P-code. Presently, the C/A-code is modulated onto the L1 carrier only, while the P-code is modulated onto both the L1 and the L2 carriers. This modulation of P code is called biphase modulation because the carrier phase is shifted by 180° when the code value changes from zero to one or from one to zero. Each satellite is assigned a unique C/A-code, which enables the GPS receivers to identify the satellite transmitting that particular code. The C/A-code range measurement is relatively less precise compared to that of the P-code. However C/A code is less complex and is available to all users. The P-code is a very long sequence of binary digits that repeats itself after 266 days. It is also 10 times faster than the C/A-code (i.e., its rate is 10.23 Mbps).

Navigation Message

GPS navigation message is a data stream added to both the L1 and the L2 carriers as binary biphase modulation. The navigation message along with other information contains the coordinates of the GPS satellites as a function of time, the satellite health status, the satellite clock correction, the satellite almanac and atmospheric data. Each satellite transmits its own navigation message with information on the other satellites, such as the approximate location and health status.

Table 2.1: GPS frequencies and their codes

Carrier	Frequency	Code\Signal
L1	1575.42 MHz	C\A & P(Y)
L2	1227.60 MHz	P(Y)

2.3.2 GPS Positioning Service

You have earlier read in this unit that GPS was originally developed as a military system. Later on it was made available for civilian uses as well. However, to maintain the military advantage, the U.S. Department of Defense provides two levels of GPS positioning and timing services:

- Precise Positioning Service (PPS)
- Standard Positioning Service (SPS)

Precise Positioning Service

Precise Positioning Service (PPS) is primarily intended for military and selected government agency users. Civilian use is permitted but only with special approval of U.S. Department of Defense. It is the most precise autonomous positioning and timing service. It uses one of the transmitted GPS codes, known as P(Y)-code, which is accessible to authorised users only.

Standard Positioning Service

Standard Positioning Service (SPS) is less precise than PPS. The SPS is available to all users worldwide free of direct charges. There are no restrictions on SPS usage. It uses the second transmitted GPS code, known as the C/A-code, which is available free of charge to all users worldwide, authorised and unauthorised. This was achieved under the effect of Selective Availability (SA).

2.3.3 Pseudorange Measurements

The *pseudorange* is a measure of the range, or distance, between the GPS receiver and the GPS satellite. You can say more precisely, it is the distance between the GPS receiver's and the GPS satellite's antenna. You have learnt earlier that the ranges from the receiver to the satellites are required for the position computation. Either the P-code or the C/A-code can be used for measuring the pseudorange.

2.3.4 Carrier-phase Measurements

Now you would learn about another way of determining the GPS ranges. They can be obtained through the carrier phase measurements. The range would simply be the sum of the total number of full carrier cycles plus fractional cycles at the receiver and the satellite, multiplied by the carrier wavelength. The ranges determined with the carrier phase parameters are far more accurate than those obtained with the codes (i.e., the pseudoranges).

2.3.5 Trilateration

Now you know that GPS is based on satellite ranging. It requires calculation of the distances between the receiver and the position of 3 or more satellites (4 or more if elevation is desired) and then applying simple mathematics. Assuming that the positions of the satellites are known, subsequently the location of the receiver can be calculated by determining the distance from each of the satellites to the receiver. GPS takes 3 or more known references and measured distances and then triangulates an additional position.

2.3.6 Determination of the Current Locations of GPS Satellites

You know that the GPS satellites are orbiting the Earth at an altitude of 20,200 km. The US Department of Defense can predict the paths of the satellites vs. time with great accuracy. Furthermore, the satellites can be periodically adjusted by huge land-based radar systems. Therefore, the orbits and thus the locations of the satellites are known in advance. Today's GPS receivers store this orbit information for all of the GPS satellites in what is known as an *almanac data*. Each GPS satellite continually broadcasts the almanac. Your GPS receiver will automatically collect this information and store it for future reference.

Almanac data contains the approximate positions of the satellites. The data is constantly being transmitted and is stored in the GPS receiver's memory.

The US Department of Defense constantly monitors the orbits of the satellites looking for deviations from predicted values. Any deviations caused by natural atmospheric phenomenon such as gravity are known as *ephemeris errors*.

By using the information from the almanac together with the ephemeris error data, the position of a GPS satellite can be very precisely determined.

2.3.7 Computing Distance Between User's Position and GPS Satellites

You have read that the GPS determines distance between a GPS satellite and a GPS receiver by measuring the amount of time it takes a radio signal (the GPS signal) to travel from the satellite to the receiver. Radio waves travel at the speed of light, which is $\sim 3 \times 10^8$ m/s. So, if the amount of time it takes for the signal to travel from the satellite to the receiver is known, the distance from the satellite to the receiver (distance = speed × time) can be determined. If the exact time when the signal was transmitted and the exact time when it was received are known, the signal's travel time can be determined. In order to do this, the satellites and the receivers use very accurate clocks which are synchronised so that they generate the same code at exactly the same time.

2.3.8 Requirement of Four Satellites for Determination of 3D Position

In the previous example, you saw that it took only 3 measurements to triangulate a 3D position. You must be thinking that GPS needs a 4^{th} satellite to provide a 3D position. Let us discuss why does it require the 4^{th} satellite?

Three measurements can be used to locate a point, assuming the GPS receiver and satellite clocks are precisely and continually synchronised. This allows the distance calculations to be accurately determined. Unfortunately, it is impossible to synchronise these two clocks, since the clocks in GPS receivers are not as accurate as the very precise and expensive atomic clocks in the satellites. The GPS signals travel from the satellite to the receiver very fast, so if the two clocks are off by only a small fraction, the determined position data may be considerably distorted.

2.3.9 Position Calculations

The GPS calculation in the receiver uses four equations in the four unknowns x, y, z and t_c, where x, y, z are the receiver's coordinates and t_c is the time correction for the GPS receiver's clock. The four equations are:

$$d_1 = c(t_{t,1} - t_{r,1} + t_c) = \sqrt{(x_1 - x)^2 + (y_1 - y)^2 + (z_1 - z)^2}$$
$$d_2 = c(t_{t,2} - t_{r,2} + t_c) = \sqrt{(x_2 - x)^2 + (y_2 - y)^2 + (z_2 - z)^2}$$
$$d_3 = c(t_{t,3} - t_{r,3} + t_c) = \sqrt{(x_3 - x)^2 + (y_3 - y)^2 + (z_3 - z)^2}$$
$$d_4 = c(t_{t,4} - t_{r,4} + t_c) = \sqrt{(x_4 - x)^2 + (y_4 - y)^2 + (z_4 - z)^2}$$

where

- c = speed of light (3×10^8 m/s),
- $t_{t,1}$, $t_{t,2}$, $t_{t,3}$, $t_{t,4}$ = times that GPS satellites 1, 2, 3, and 4, respectively, transmitted their signals (these times are provided to the receiver as part of the information that is transmitted).
- $t_{r,1}$, $t_{r,2}$, $t_{r,3}$, $t_{r,4}$ = times that the signals from GPS satellites 1, 2, 3, and 4, respectively, are received (according to the inaccurate GPS receiver's clock), and
- x_1, y_1, z_1 = coordinates of GPS satellite 1 (these coordinates are provided to the receiver as part of the information that is transmitted); similar meaning for x_2, y_2, z_2, etc.

The receiver solves these equations simultaneously to determine x, y, z and t_c.

Check Your Progress II

Spend 5 mins

1) List the differences between C/A-code and P-code.

....

....

....

....

....

2) Name the two levels of GPS positioning services provided by US Department of Defense.

....

....

....

....

3) What is Trilateration?

....

....

....

....

2.4 TYPES OF GPS RECEIVER AND DATA FORMATS

You will read about GPS receivers and Data formats in this section.

Types of GPS Receivers

You know that in the determination of a geographical position, the GPS receiver is significant since it catches and recognises the signals and decodes them according to the three-dimensional factors: latitude, longitude and altitude. This special radio receiver returns the output to the user in a usable form. It is composed of an antenna, tuned to the satellite frequencies, a processor and in most consumer units a keypad and display navigational information to the operator. The GPS receivers have been classified on the basis of the number of frequencies that the receiver can track:

- Single Frequency Code Receivers
- Single Frequency Carrier Smoothed Code
- Single Frequency Code and Carrier receivers
- Dual Frequency Receivers (L1/L2)

GPS receiver can also be classified on the level of accuracy as given below:

- **C/A Code Receivers:** This type of receiver provides 1-5 m GPS accuracy with differential correction, with an occupation time of 5 sec.
- **Carrier Phase Receivers:** This type of receiver provides 10-30 cm GPS Position accuracy with differential correction.
- **Dual-Frequency Receivers:** This type of receiver provides sub-centimeter GPS position accuracy with differential correction and survey grade accuracies.

Formats of GPS Data

GPS accuracy and data standards are influenced by the type of data being collected. The following is a brief list of some standard formats of data collection:

- RINEX
  - o Raw GPS static data format for data processing and archive
- NMEA
  - o Standard related to data communication between marine electronic devices
  - o Transmission of GPS position from GPS receiver to other devices (e.g. GPS receiver to PDA)
  - o For real time positioning
- RTCM SC-104
  - o Transmission of GPS correction from GPS reference station to GPS Rover
  - o For DGPS/RTK surveys

Accuracy of GPS

You have read that GPS is the best navigation and tracking technology available so far. It demonstrates the accuracy levels of within 4-20 meters or so of the actual position of the object being tracked. In Table 2.2 are given the four basic levels of accuracy that you can obtain with your real-time GPS system.

Table 2.2: Basic Levels of Accuracy in GPS Real Time System

GPS Type	Accuracy
Autonomous	15-100 meters
Differential GPS (DGPS)	0.5-5 meters
Real-Time Kinematic Float (RTK Float)	20 cm-1 meter
Real-Time Kinematic Fixed (RTK Fixed)	1 cm - 5 cm

A standard GPS receiver for civil use offers an accuracy down to a few meters. More sophisticated GPS receivers providing an accuracy of few centimetres cost several lakhs. They are normally used for land survey. The receivers achieve accuracies of approximately 100 m with the activation of selective availability. The accuracy enhances to approximately 15 m after the deactivation of the selective availability. This depends on the number and position of available satellites.

In order to further improve the GPS positioning accuracy, the differential method is used, which employs two receivers simultaneously for tracking the same GPS satellites. You have read about differential GPS in Unit 1, *Introduction to GNSS* of MGY-003. In this case, positioning accuracy level of the order of a subcentimeter to a few meters can be achieved.

2.5 SOURCES OF ERROR IN GPS OBSERVATION

You have read about the positioning accuracy of all measurements. Different sources can contribute to the total error in GPS measurements. You will read about the causes of errors in GPS in the following section:

2.5.1 Selective Availability

You have read earlier that *selective availability (SA)* for civil GPS receivers lead to a less accurate position determination. In this way an inaccuracy of the position of 50 – 150 m can be achieved for several hours. While in times of selective availability the position determination with civil receivers had an accuracy of approximately 100 m, nowadays 20 m or even less is usual. The reasons for selective availability were safety concerns. Do you know that the terrorists should not be provided with the possibility of locating important buildings with homemade remote control weapons. Paradoxically, during the first Gulf war in 1990, SA had to be deactivated partially, as not enough military receivers were available for the American troops. 10000 civil receivers were acquired (Magellan and Trimble instruments), making a very precise orientation possible in a desert with no landmarks.

2.5.2 Satellite Geometry

Let us look at the factors influencing the accuracy of the position determination in the satellite geometry. Simplified, satellite geometry describes the position of the satellites to each other from the view of the receiver (Fig. 2.6).

If a receiver sees 4 satellites and all are arranged e.g. in the north-west direction, this leads to a "bad" geometry. In the worst case, no position determination is possible at all, when all distance determinations point to the same direction. Even if a position is determined, the error of the positions may be up to 100 –150 m.

If, on the other hand, the 4 satellites are well distributed then the determined position will be much more accurate. Let us assume the satellites are positioned in the north, east, south and west in 90° steps. The distances can be measured in four different directions, reflecting good satellite geometry. You can see in Fig. 2.6, where the two satellites are in an advantageous position, from the view of the receiver they can be seen in an angle of approximately 90° to each other. The possible positions are marked by the grey circles. The point of intersection A of the two circles is a rather small and the determined position will be rather accurate.

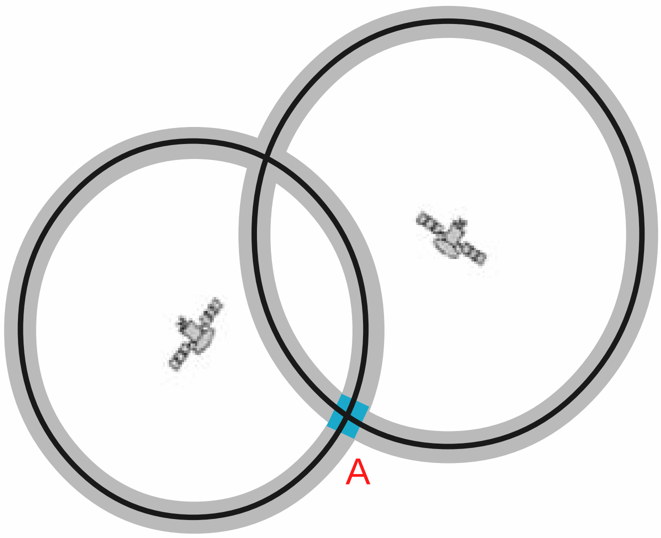


Fig. 2.6: Good geometrical alignment of two satellites (source: www.kowoma.de/en/gps/errors.htm)

If the satellites are more or less positioned in one line from the view of the receiver, the plane of intersection of all the possible positions is considerably larger and elongated and thus the determination of the position is less accurate (Fig. 2.7).

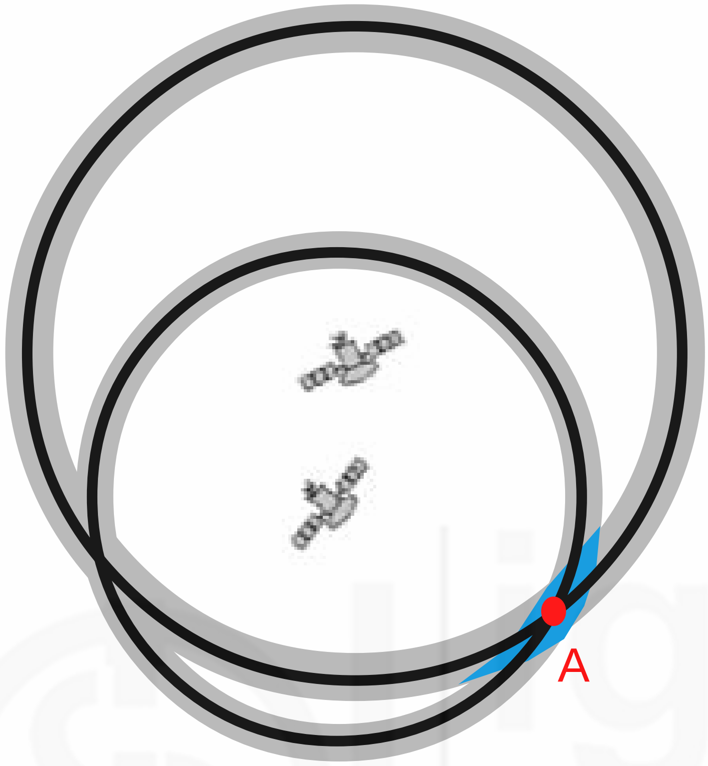


Fig. 2.7: Bad geometrical alignment of two satellites (source: www.kowoma.de/en/gps/errors.htm)

The satellite geometry is also relevant when the receiver is used in vehicles or close to high buildings. If some of the signals are blocked off, the remaining satellites determine the quality of the position.

2.5.3 Satellite Orbits

You know that although the satellites are positioned in very precise orbits but slight shifts of the orbits are possible due to gravitational forces. Sun and Moon have a weak influence on the orbits. The orbit data are controlled and corrected regularly that is sent to the receivers in the package of ephemeris data. Therefore the influence on the correctness of the position determination is rather low, the resulting error being not more than 2 m.

2.5.4 Multipath Effect

The multipath effect is caused by reflection of satellite signals (radio waves) on the objects. It was the same effect that caused ghost images on television when antennae on the roof were still more common instead of today's satellite dishes.

For GPS signals this effect mainly appears in the neighbourhood of large buildings or other elevations (Fig. 2.8). The reflected signal takes more time to reach the receiver than the direct signal. The resulting error typically lies in the range of a few meters.

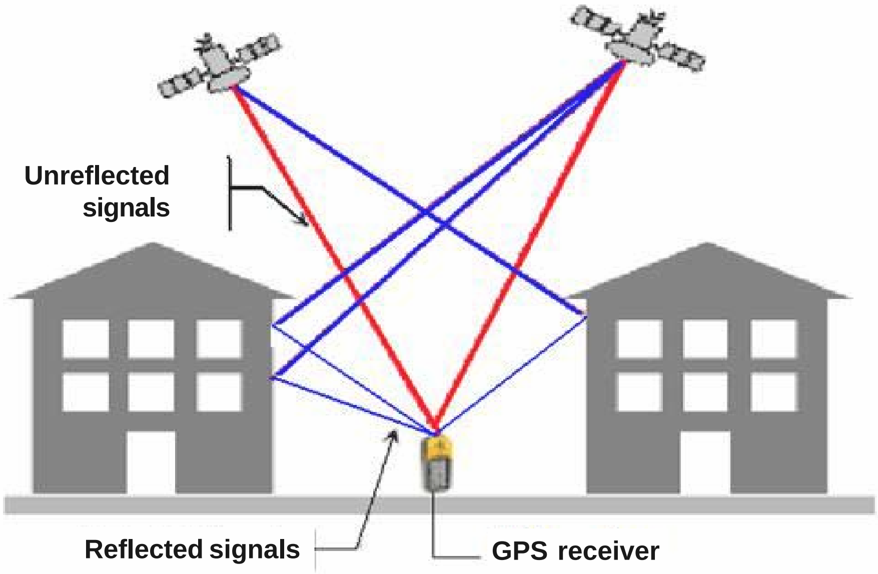


Fig. 2.8: Interference Caused by Reflection of the Signals (source: www.kowoma.de/en/gps/errors.htm)

2.5.5 Atmospheric Effects

You will find that another source of inaccuracy that is the reduced speed of propagation of the radio signals in the troposphere and ionosphere. While radio signals travels with the velocity of light in the outer space, their propagation in the ionosphere and troposphere is slower (Fig. 2.9). In the ionosphere at a height range of 80 – 400 km a large number of electrons and positively charged ions are formed by the ionising force of the Sun. The electrons and ions are concentrated in four concentric layers in the ionosphere. These layers refract the electromagnetic waves from the satellites, resulting in an elongated runtime of the signals. These errors are mostly corrected by the receiver through calculations.

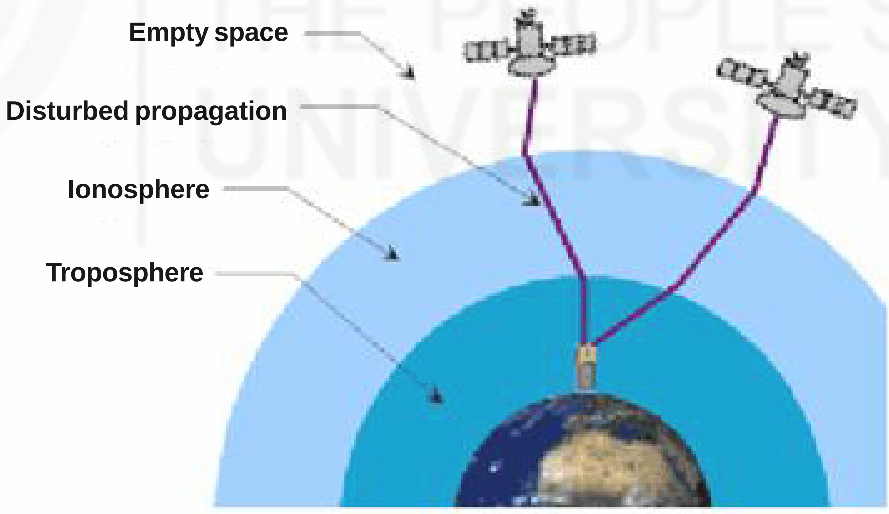


Fig. 2.9: Effect of ionosphere on the propagation of radio waves through the Earth's atmosphere (source: www.kowoma.de/en/gps/errors.htm)

2.5.6 Clock Inaccuracies and Rounding Errors

Despite the synchronisation of the receiver clock with the satellite time during the position determination, the remaining inaccuracy of the time still leads to an error of about 2 m in the position determination. Rounding and calculation errors of the receiver sum up approximately to 1 m.

2.5.7 Relativistic Effects

As you have already learnt that the time is a relevant factor in GPS navigation and must be accurate to 20 - 30 ns to ensure the necessary accuracy. Therefore, the fast movement of the satellites themselves (nearly 12000 km/h) must be considered.

If you have dealt with the theory of relativity you must know that time runs slower during very fast movements. For satellites moving with a speed of 3874 m/s, clocks run slower when viewed from Earth. This relativistic time dilation leads to an inaccuracy of time of approximately 7.2 microseconds per day. There is another relativistic effect, which is not considered for routine position determinations by GPS called *Sagnac-Effect*. The influence of this effect is very small and complicated to be calculated as it depends on the directions of the movement. Therefore, it is only considered in special cases.

Albert Einstein's *theory of relativity* states that objects will move slower and shorten in length from the point of view of an observer on Earth. Einstein also derived the famous equation, $E = mc^2$, which reveals the equivalence of mass and energy.

The errors of the GPS system are summarised in Table 2.2.

Sagnac-Effect is caused by the movement of the observer on the Earth surface, who also moves with a velocity of up to 500 m/s (at the equator) due to the rotation of the globe.

Table 2.2: Errors of the GPS system

Ionospheric effects	± 5 meters
Shifts in the satellite orbits	± 2.5 meters
Clock errors of the satellites' clocks	± 2 meter
Multipath effect	± 1 meter
Tropospheric effects	± 0.5 meter
Calculation and rounding errors	± 1 meter

2.6 SUMMARY

GNSS is a space-based radio positioning system that includes one or more satellite constellations, augmented as necessary, to support the intended operation. This provides 24-hour three-dimensional position, velocity and time information to suitably equipped users anywhere on or near the surface of the Earth. It is a generic term covering a number of existing and planned constellations of satellites together with supporting infrastructural systems used for determining positions across the globe. They are coordinated with data communication methods, such as radio or the internet, playing key role in the operation of powerful, integrated information management and control systems with a diverse range of applications affecting many parts of the national and regional economies. Let us summarise about what we have read in this unit:

- GPS comprises three main components, space segment, control segment and user segment.
- GPS satellite continuously transmits a microwave radio signal composed of two carriers, two codes and a navigation message.
- When you switch on a GPS receiver, it picks up the GPS signal through the receiver antenna. Once the receiver acquires the GPS signal, it will process it using its in-built software.
- The outcome of the signal processing consists of the distances to the GPS satellites through the digital codes (known as the pseudoranges) and the satellite coordinates through the navigation message.
- If you know the distance to three points relative to your own position, you can determine your own position relative to those three points.

- GPS satellites transmit two types of radio signals: C/A-code and P-code. GPS positioning service can be -Precise Positioning Service (PPS) and Standard Positioning Service (SPS).
- There are many sources of errors in GPS data which have been discussed elaborately.

Spend 30 mins

2.7 UNIT END QUESTIONS

1) Discuss three components of GPS.
2) What is GPS signals structure?
3) Explain the sources of errors in the GPS data.

2.8 REFERENCES

- Kaplan E.D. (2005), *Understanding GPS Principle and Applications*, Artech House, 706p.
- Leica Geosystems AG (1999), *GPS Basics 1.0.0en*, Heerbrugg, Switzerland, 64p.
- www.kowoma.de/en/gps/errors.htm
- www.zogg-jm.ch/Dateien/ GPS_ CompendiumGPS-X-02007.pdf

(Data from above websites have been retrieved between 1st September and 30th September 2011)

2.9 FURTHER/SUGGESTED READING

- Kaplan E.D. (2005), *Understanding GPS Principle and Applications*, Artech House, 706p.
- Mc Namara J. (2008), *GPS for Dummies*, 2nd Ed., Willey Publishing Inc., River Street Hoboken, 408p.

2.10 ANSWERS

Check Your Progress I

1) Space, Ground and User
2) Solar energy and suppose the satellite is in Earth’s shadow, it used the backup batteries to continue running.
3) Latitude, longitude and altitude

Check Your Progress II

1) Refer to sub-section 2.3.1
2) Precise positioning service and standard position service
3) Refer to sub-section 2.3.5

Unit End Questions

1) Refer to all the subsections of section 2.2
2) Refer to sub-section 2.3.1
3) Refer to section 2.5