FUNDAMENTALS OF GPS

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Abstract : Conventional methods of surveying and navigation require tedious field and astronomical observations for deriving positional and directional information. Rapid advancement in higher frequency signal transmission and precise clock signals along with advanced satellite technology have led to the development of Global Positioning System (GPS). The outcome of a typical GPS survey includes geocentric position accurate to 10 m and relative positions between receiver locations to centimeter level or better. Technological aspect as well as applications of GPS in various fields are discussed in this paper.

INTRODUCTION

Traditional methods of surveying and navigation resort to tedious field and astronomical observation for deriving positional and directional information. Diverse field conditions, seasonal variation and many unavoidable circumstances always bias the traditional field approach. However, due to rapid advancement in electronic systems, every aspect of human life is affected to a great deal. Field of surveying and navigation is tremendously benefited through electronic devices. Many of the critical situations in surveying/navigation are now easily and precisely solved in short time.

Astronomical observation of celestial bodies was one of the standard methods of obtaining coordinates of a position. This method is prone to visibility and weather condition and demands expert handling. Attempts have been made by USA since early 1960's to use space based artificial satellites. System TRANSIT was widely used for establishing a network of control points over large regions. Establishment of modern geocentric datum and its relation to local datum was successfully achieved through TRANSIT. Rapid improvements in higher frequently transmission and precise clock signals along

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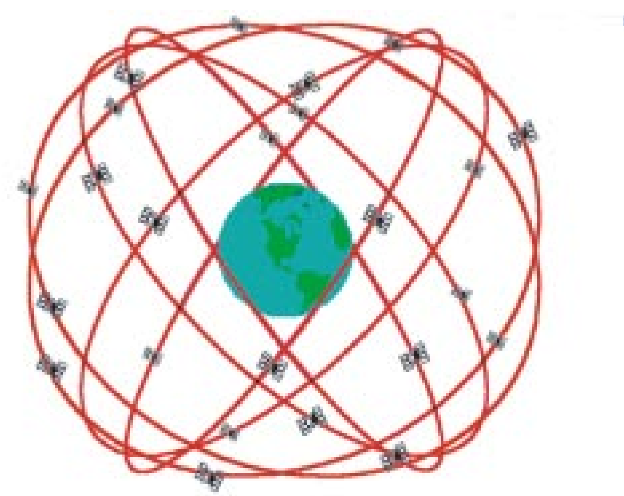
with advanced stable satellite technology have been instrumental for the development of global positioning system.

The NAVSTAR GPS (Navigation System with Time and Ranging Global Positioning System) is a satellite based radio navigation system providing precise three- dimensional position, course and time information to suitably equipped user.

GPS has been under development in the USA since 1973. The US department of Defence as a worldwide navigation and positioning resource for military as well as civilian use for 24 hours and all weather conditions primarily developed it.

In its final configuration, NAVSTAR GPS consists of 21 satellites (plus 3 active spares) at an altitude of 20200 km above the earth's surface (Fig. 1). These satellites are so arranged in orbits to have atleast four satellites visible above the horizon anywhere on the earth, at any time of the day. GPS Satellites transmit at frequencies L1=1575.42 MHz and L2=1227.6 MHz modulated with two types of code viz. P-code and C/A code and with navigation message. Mainly two types of observable are of interest to the user. In pseudo ranging the distance between the satellite and the GPS receiver plus a small corrective



GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

Figure 1: The Global Positioning System (GPS), 21-satellite configuration

term for receiver clock error is observed for positioning whereas in carrier phase techniques, the difference between the phase of the carrier signal transmitted by the satellite and the phase of the receiver oscillator at the epoch is observed to derive the precise information.

The GPS satellites act as reference points from which receivers on the ground detect their position. The fundamental navigation principle is based on the measurement of pseudoranges between the user and four satellites (Fig. 2). Ground stations precisely monitor the orbit of every satellite and by measuring the travel time of the signals transmitted from the satellite four distances between receiver and satellites will yield accurate position, direction and speed. Though three-range measurements are sufficient, the fourth observation is essential for solving clock synchronization error between receiver and satellite. Thus, the term “pseudoranges” is derived. The secret of GPS measurement is due to the ability of measuring carrier phases to about 1/100 of a cycle equaling to 2 to 3 mm in linear distance. Moreover the high frequency L1 and L2 carrier signal can easily penetrate the ionosphere to reduce its effect. Dual frequency observations are important for large station separation and for eliminating most of the error parameters.

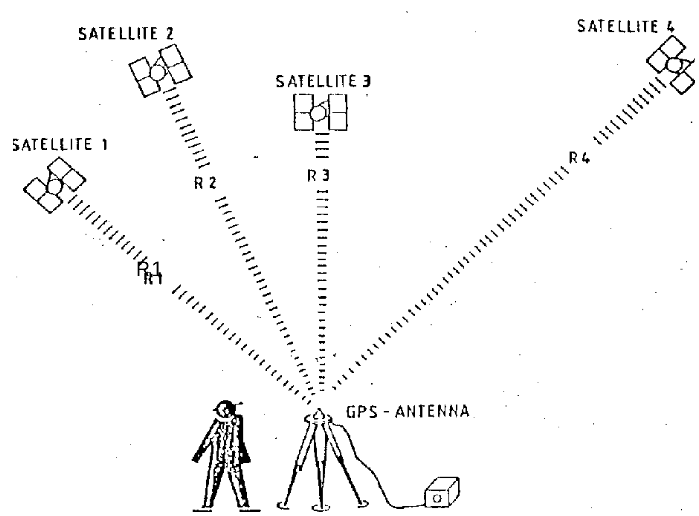


Figure 2: Basic principle of positioning with GPS

There has been significant progress in the design and miniaturization of stable clock. GPS satellite orbits are stable because of the high altitudes and no atmosphere drag. However, the impact of the sun and moon on GPS orbit though significant, can be computed completely and effect of solar radiation pressure on the orbit and tropospheric delay of the signal have been now modeled to a great extent from past experience to obtain precise information for various applications.

Comparison of main characteristics of TRANSIT and GPS reveal technological advancement in the field of space based positioning system (Table1).

Table 1. TRANSIT vs GPS

Details	TRANSIT	GPS
Orbit Altitude	1000 Km	20,200 Km
Orbital Period	105 Min	12 Hours
Frequencies	150 MHz 400 MHz	1575 MHz 1228 MHz
Navigation data	2D : X, Y	4D : X,Y,Z, t velocity
Availability	15-20 minute per pass	Continuously
Accuracy	ñ 30-40 meters (Depending on velocity error)	ñ15m (Pcode/No. SA 0.1 Knots
Repeatability	—	ñ1.3 meters relative
Satellite Constellation	4-6	21-24
Geometry	Variable	Repeating
Satellite Clock	Quartz	Rubidium, Cesium

GPS has been designed to provide navigational accuracy of ±10 m to ±15 m. However, sub meter accuracy in differential mode has been achieved and it has been proved that broad varieties of problems in geodesy and geodynamics can be tackled through GPS.

Versatile use of GPS for a civilian need in following fields have been successfully practiced viz. navigation on land, sea, air, space, high precision kinematics survey on the ground, cadastral surveying, geodetic control network densification, high precision aircraft positioning, photogrammetry without ground control, monitoring deformations, hydrographic surveys, active control survey and many other similar jobs related to navigation and positioning,. The outcome of a typical GPS survey includes geocentric position accurate to 10 m and relative positions between receiver locations to centimeter level or better.

SEGMENTS OF GPS

For better understanding of GPS, we normally consider three major segments viz. space segment, Control segment and User segment. Space segment deals with GPS satellites systems, Control segment describes ground based time and orbit control prediction and in User segment various types of existing GPS receiver and its application is dealt (Fig. 3).

Table 2 gives a brief account of the function and of various segments along with input and output information.

Table 2. Functions of various segments of GPS

Segment	Input	Function	Output
Space	Navigation message	Generate and Transmit code and carrier phases and navigation message	P-Code C/A Code L1,L2 carrier Navigation message
Control	P-Code Observations Time	Produce GPS time predict ephemeris manage space vehicles	Navigation message
User	Code observation Carrier phase observation Navigation message	Navigation solution Surveying solution	Position velocity time

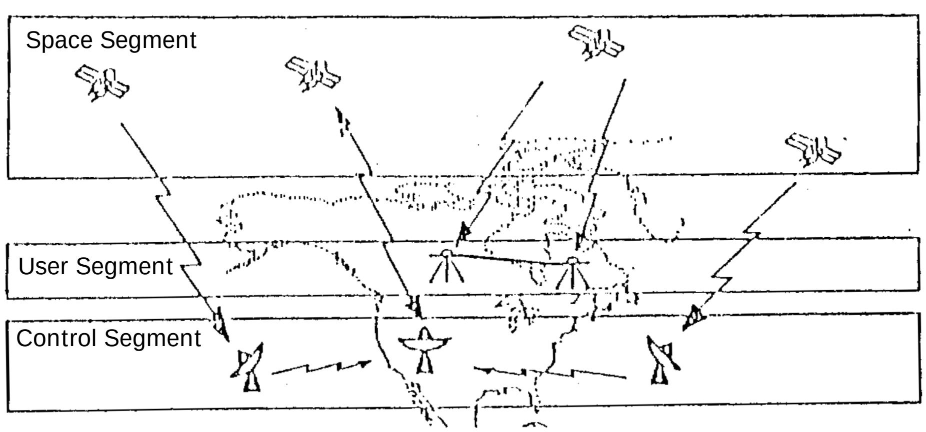


Figure 3: The Space, Control and User segments of GPS

GLONASS (Global Navigation & Surveying System) a similar system to GPS is being developed by former Soviet Union and it is considered to be a valuable complementary system to GPS for future application.

Space Segment

Space segment will consist 21 GPS satellites with an addition of 3 active spares. These satellites are placed in almost six circular orbits with an inclination of 55 degree. Orbital height of these satellites is about 20,200 km corresponding to about 26,600 km from the semi major axis. Orbital period is exactly 12 hours of sidereal time and this provides repeated satellite configuration every day advanced by four minutes with respect to universal time.

Final arrangement of 21 satellites constellation known as "Primary satellite constellation" is given in Fig. 4. There are six orbital planes A to F with a separation of 60 degrees at right ascension (crossing at equator). The position of a satellite within a particular orbit plane can be identified by argument of latitude or mean anomaly M for a given epoch.

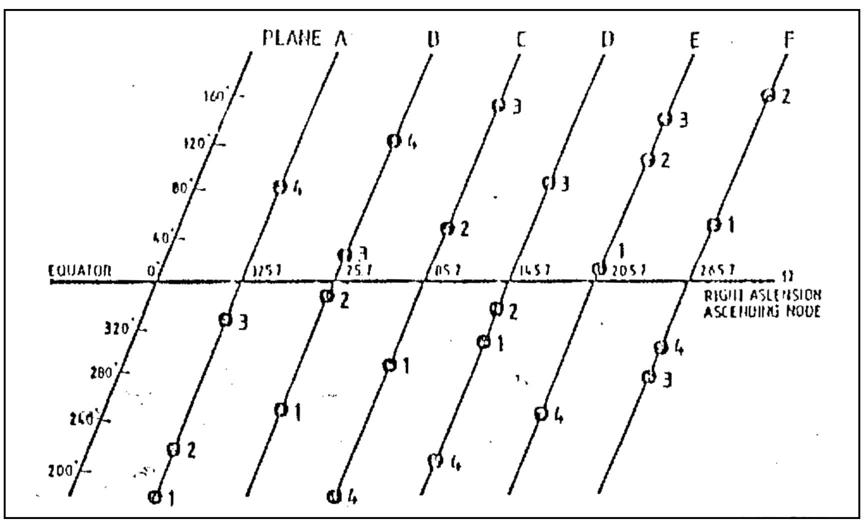


Figure 4: Arrangement of satellites in full constellation

GPS satellites are broadly divided into three blocks : Block-I satellite pertains to development stage, Block II represents production satellite and Block IIR are replenishment/spare satellite.

Under Block-I, NAVSTAR 1 to 11 satellites were launched before 1978 to 1985 in two orbital planes of 63-degree inclination. Design life of these prototype test satellites was only five years but the operational period has been exceeded in most of the cases.

The first Block-II production satellite was launched in February 1989 using channel Douglas Delta 2 booster rocket. A total of 28 Block-II satellites are planned to support 21+3 satellite configuration. Block-II satellites have a designed lifetime of 5-7 years.

To sustain the GPS facility, the development of follow-up satellites under Block-II R has started. Twenty replenishment satellites will replace the current block-II satellite as and when necessary. These GPS satellites under Block-IR have additional ability to measure distances between satellites and will also compute ephemeris on board for real time information.

Fig.5 gives a schematic view of Block-II satellite. Electrical power is generated through two solar panels covering a surface area of 7.2 square meter each. However, additional battery backup is provided to provide energy when the satellite moves into earth's shadow region. Each satellite weighs 845kg and has a propulsion system for positional stabilization and orbit maneuvers.

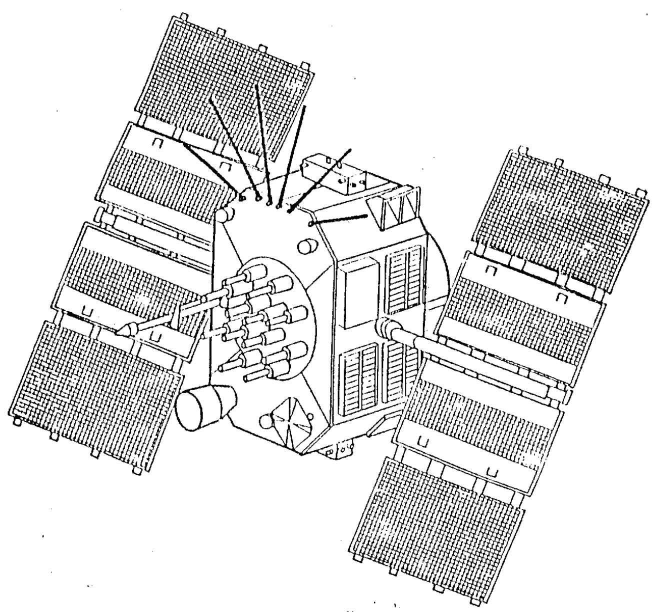


Figure 5: Schematic view of a Block II GPS satellite

GPS satellites have a very high performance frequency standard with an accuracy of between $1X10^{-12}$ to $1X10^{-13}$ and are thus capable of creating precise time base. Block-I satellites were partly equipped with only quartz oscillators but Block-II satellites have two cesium frequency standards and two rubidium frequency standards. Using fundamental frequency of 10.23 MHz, two carrier frequencies are generated to transmit signal codes.

Observation Principle and Signal Structure

NAVSTAR GPS is a one-way ranging system i.e. signals are only transmitted by the satellite. Signal travel time between the satellite and the receiver is observed and the range distance is calculated through the knowledge of signal propagation velocity. One way ranging means that a clock reading at the transmitted antenna is compared with a clock reading at the receiver antenna. But since the two clocks are not strictly synchronized, the observed signal travel time is biased with systematic synchronization error. Biased ranges are known as pseudoranges. Simultaneous observations of four pseudoranges are necessary to determine X, Y, Z coordinates of user antenna and clock bias.

Real time positioning through GPS signals is possible by modulating carrier frequency with Pseudorandom Noise (PRN) codes. These are sequence of binary values (zeros and ones or +1 and -1) having random character but identifiable distinctly. Thus pseudoranges are derived from travel time of an identified PRN signal code. Two different codes viz. P-code and C/A code are in use. P means precision or protected and C/A means clear/acquisition or coarse acquisition.

P- code has a frequency of 10.23 MHz. This refers to a sequence of 10.23 million binary digits or chips per second. This frequency is also referred to as the chipping rate of P-code. Wavelength corresponding to one chip is 29.30m. The P-code sequence is extremely long and repeats only after 266 days. Portions of seven days each are assigned to the various satellites. As a consequence, all satellite can transmit on the same frequency and can be identified by their unique one-week segment. This technique is also called as Code Division Multiple Access (CDMA). P-code is the primary code for navigation and is available on carrier frequencies L1 and L2.

The C/A code has a length of only one millisecond; its chipping rate is 1.023 MHz with corresponding wavelength of 300 meters. C/A code is only transmitted on L1 carrier.

GPS receiver normally has a copy of the code sequence for determining the signal propagation time. This code sequence is phase-shifted in time step-by-step and correlated with the received code signal until maximum correlation is achieved. The necessary phase-shift in the two sequences of codes is a measure of the signal travel time between the satellite and the receiver antennas. This technique can be explained as code phase observation.

For precise geodetic applications, the pseudoranges should be derived from phase measurements on the carrier signals because of much higher resolution. Problems of ambiguity determination are vital for such observations.

The third type of signal transmitted from a GPS satellite is the broadcast message sent at a rather slow rate of 50 bits per second (50 bps) and repeated every 30 seconds. Chip sequence of P-code and C/A code are separately combined with the stream of message bit by binary addition ie the same value for code and message chip gives 0 and different values result in 1.

The main features of all three signal types used in GPS observation viz carrier, code and data signals are given in Table 3.

Table 3. GPS Satellite Signals

Atomic Clock (G, Rb) fundamental frequency	10.23. MHz
L1 Carrier Signal	154 X 10.23 MHz
L1 Frequency	1575.42 MHz
L1 Wave length	19.05 Cm
L2 Carrier Signal	120 X 10.23 MHz
L2 Frequency	1227.60 MHz
L2 Wave Length	24.45 Cm
P-Code Frequency (Chipping Rate)	10.23 MHz (Mbps)
P-Code Wavelength	29.31 M
P-Code Period	267 days : 7 Days/Satellite
C/A-Code Frequency (Chipping Rate)	1.023 MHz (Mbps)
C/A-Code Wavelength	293.1 M
C/A-Code Cycle Length	1 Milisecond
Data Signal Frequency	50 bps
Data Signal Cycle Length	30 Seconds

The signal structure permits both the phase and the phase shift (Doppler effect) to be measured along with the direct signal propagation. The necessary bandwidth is achieved by phase modulation of the PRN code as illustrated in Fig. 6.

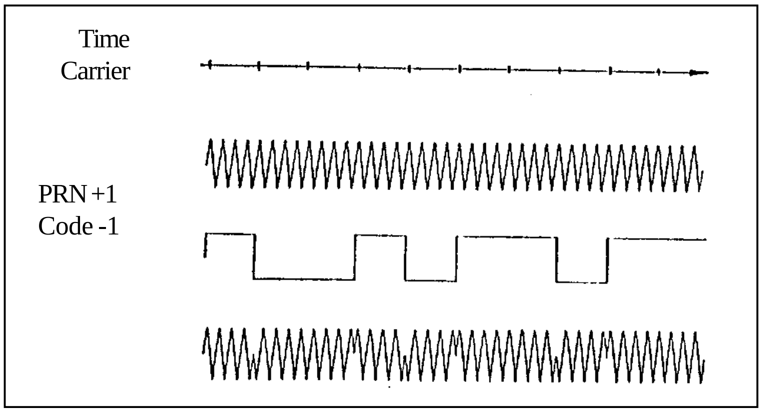


Figure 6: Generation of GPS Signals

Structure of the GPS Navigation Data

Structure of GPS navigation data (message) is shown in Fig. 7. The user has to decode the data signal to get access to the navigation data. For on line navigation purposes, the internal processor within the receiver does the decoding. Most of the manufacturers of GPS receiver provide decoding software for post processing purposes.

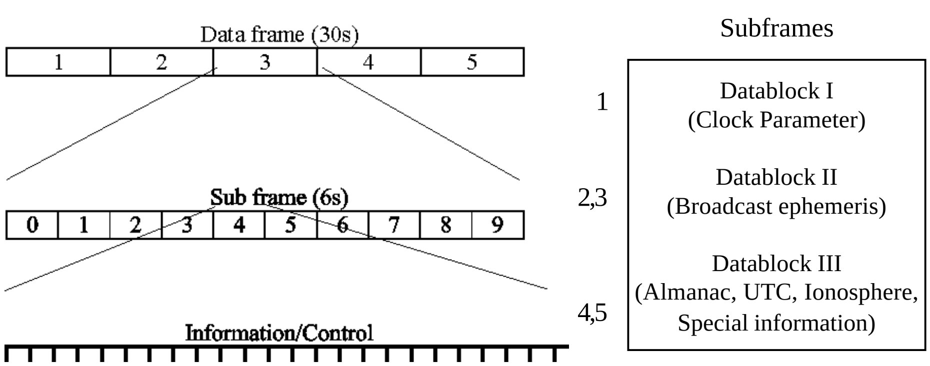


Figure 7: Structure of Navigation data

With a bit rate of 50 bps and a cycle time of 30 seconds, the total information content of a navigation data set is 1500 bits. The complete data frame is subdivided into five subframes of six-second duration comprising 300 bits of information. Each subframe contains the data words of 30 bits each. Six of these are control bits. The first two words of each subframe are the Telemetry Work (TLM) and the C/A-P-Code Hand over Work (HOW). The TLM work contains a synchronization pattern, which facilitates the access to the navigation data.

The navigation data record is divided into three data blocks:

Data Block I	appears in the first subframe and contains the clock coefficient/bias.
Data Block II	appears in the second and third subframe and contains all necessary parameters for the computation of the satellite coordinates.
Data Block III	appears in the fourth and fifth subframes and contains the almanac data with clock and ephemeris parameter for all available satellite of the GPS system. This data block includes also ionospheric correction parameters and particular alphanumeric information for authorized users.

Unlike the first two blocks, the subframe four and five are not repeated every 30 seconds.

International Limitation of the System Accuracy

Since GPS is a military navigation system of US, a limited access to the total system accuracy is made available to the civilian users. The service available to the civilians is called Standard Positioning System (SPS) while the service available to the authorized users is called the Precise Positioning Service (PPS). Under current policy the accuracy available to SPS users is 100m, 2D-RMS and for PPS users it is 10 to 20 meters in 3D. Additional limitation viz. Anti-Spoofing (AS), and Selective Availability (SA) was further imposed for civilian users. Under AS, only authorized users will have the means to get access to the P-code. By imposing SA condition, positional accuracy from Block-II satellite was randomly offset for SPS users. Since May 1, 2000 according to declaration of US President, SA is switched off for all users.

The GPS system time is defined by the cesium oscillator at a selected monitor station. However, no clock parameter are derived for this station. GPS time is indicated by a week number and the number of seconds since the beginning of the current week. GPS time thus varies between 0 at the beginning of a week to 6,04,800 at the end of the week. The initial GPS epoch is January 5, 1980 at 0 hours Universal Time. Hence, GPS week starts at Midnight (UT) between Saturday and Sunday. The GPS time is a continuous time scale and is defined by the main clock at the Master Control Station (MCS). The leap seconds is UTC time scale and the drift in the MCS clock indicate that GPS time and UTC are not identical. The difference is continuously monitored by the control segment and is broadcast to the users in the navigation message. Difference of about 7 seconds was observed in July, 1992.

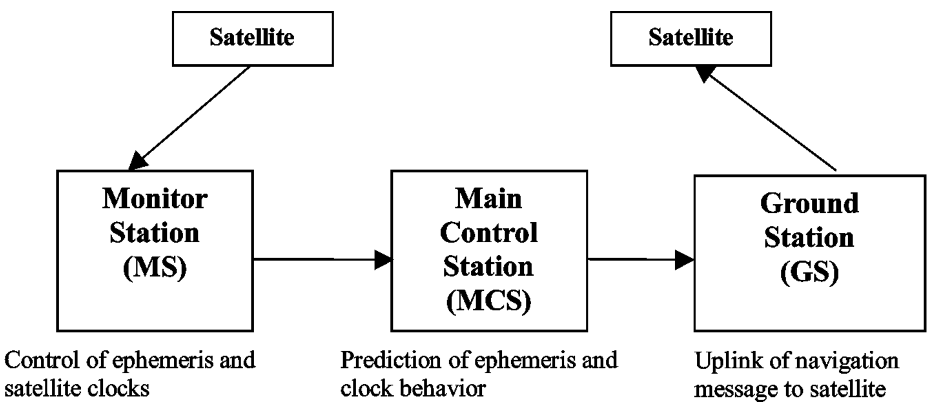


Figure 8: Data Flow in the determination of the broadcast ephemeris

GPS satellite is identified by two different numbering schemes. Based on launch sequence, SVN (Space Vehicle Number) or NAVSTAR number is allocated. PRN (Pseudo Random Noise) or SVID (Space Vehicle Identification) number is related to orbit arrangement and the particular PRN segment allocated to the individual satellite. Usually the GPS receiver displays PRN number.

Control Segment

Control segment is the vital link in GPS technology. Main functions of the control segment are:

- Monitoring and controlling the satellite system continuously
- Determine GPS system time
- Predict the satellite ephemeris and the behavior of each satellite clock.
- Update periodically the navigation message for each particular satellite.

For continuos monitoring and controlling GPS satellites a master control stations (MCS), several monitor stations (MS) and ground antennas (GA) are located around the world (Fig. 9). The operational control segment (OCS) consists of MCS near Colorado springs (USA), three MS and GA in Kwajaleian Ascension and Diego Garcia and two more MS at Colorado Spring and Hawai.

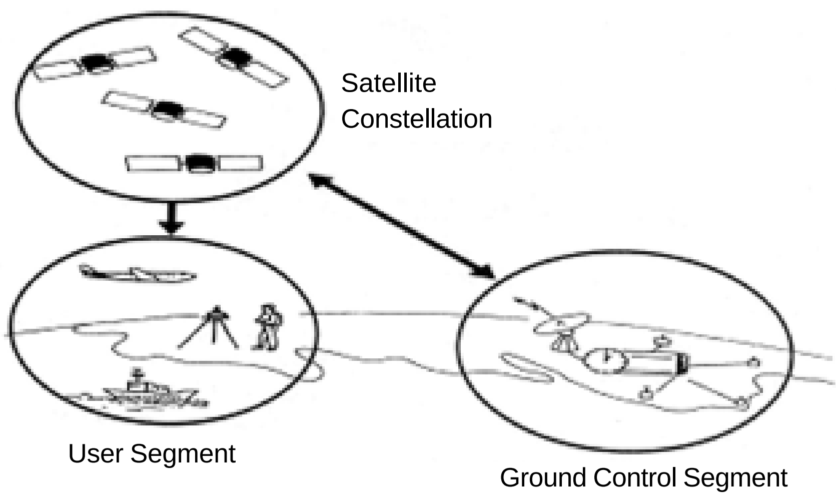


Figure 9: Control segment with observation stations

The monitor station receives all visible satellite signals and determines their pseudorages and then transmits the range data along with the local meteorological data via data link to the master control stations. MCS then precomputes satellite ephemeris and the behaviour of the satellite clocks and formulates the navigation data. The navigation message data are transmitted to the ground antennas and via S-band it links to the satellites in view. Fig. 9 shows this process schematically. Due to systematic global distribution of upload antennas, it is possible to have atleast three contacts per day between the control segment and each satellite.

User Segment

Appropriate GPS receivers are required to receive signal from GPS satellites for the purpose of navigation or positioning. Since, GPS is still in its development phase, many rapid advancements have completely eliminated bulky first generation user equipments and now miniature powerful models are frequently appearing in the market.

BASIC CONCEPT OF GPS RECEIVER AND ITS COMPONENTS

The main components of a GPS receiver are shown in Fig. 10. These are:

- Antenna with pre-amplifier
- RF section with signal identification and signal processing
- Micro-processor for receiver control, data sampling and data processing
- Precision oscillator
- Power supply
- User interface, command and display panel
- Memory, data storage

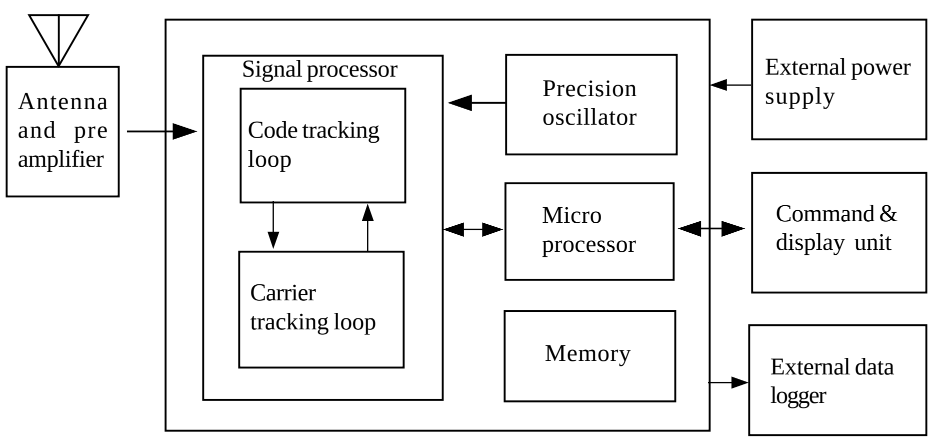


Figure 10: Major components of a GPS receiver

Antenna

Sensitive antenna of the GPS receiver detects the electromagnetic wave signal transmitted by GPS satellites and converts the wave energy to electric current] amplifies the signal strength and sends them to receiver electronics.

Several types of GPS antennas in use are mostly of following types (Fig. 11).

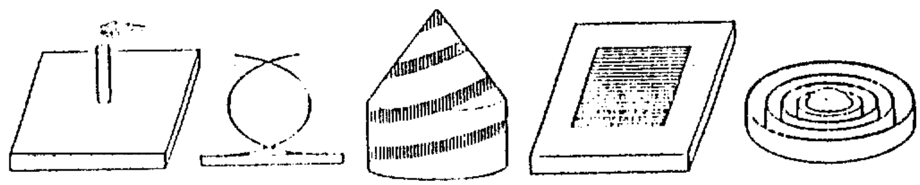


Figure 11: Types of GPS Antenna

- Mono pole or dipole
- Quadrifilar helix (Volute)
- Spiral helix
- Microstrip (patch)
- Choke ring

Microstrip antennas are most frequently used because of its added advantage for airborne application, materialization of GPS receiver and easy construction. However, for geodetic needs, antennas are designed to receive both carrier frequencies L1 and L2. Also they are protected against multipath by extra ground planes or by using choke rings. A choke ring consists of strips of conductor which are concentric with the vertical axis of the antenna and connected to the ground plate which in turns reduces the multipath effect.

RF Section with Signal Identification and Processing

The incoming GPS signals are down converted to a lower frequency in the RS section and processed within one or more channels. Receiver channel is the primary electronic unit of a GPS receiver. A receiver may have one or more channels. In the parallel channel concept each channel is continuously franking one particular satellite. A minimum of four parallel channels is required to determine position and time. Modern receivers contain upto 12 channels for each frequency.

In the sequencing channel concept the channel switches from satellite to satellite at regular interval. A single channel receiver takes atleast four times of 30 seconds to establish first position fix, though some receiver types have a dedicated channel for reading the data signal. Now days in most of the cases fast sequencing channels with a switching rate of about one-second per satellite are used.

In multiplexing channel, sequencing at a very high speed between different satellites is achieved using one or both frequencies. The switching rate is synchronous with the navigation message of 50 bps or 20 milliseconds per bit. A complete sequence with four satellites is completed by 20 millisecond or after 40 millisecond for dual frequency receivers. The navigation message is continuous, hence first fix is achieved after about 30 seconds.

Though continuous tracking parallel channels are cheap and give good overall performance, GPS receivers based on multiplexing technology will soon be available at a cheaper price due to electronic boom.

Microprocessor

To control the operation of a GPS receiver, a microprocessor is essential for acquiring the signals, processing of the signal and the decoding of the broadcast message. Additional capabilities of computation of on-line position and velocity, conversion into a given local datum or the determination of waypoint information are also required. In future more and more user relevant software will be resident on miniaturized memory chips.

Precision Oscillator

A reference frequency in the receiver is generated by the precision oscillator. Normally, less expensive, low performance quartz oscillator is used in receivers since the precise clock information is obtained from the GPS satellites and the user clock error can be eliminated through double differencing technique when all participating receivers observe at exactly the same epoch. For navigation with two or three satellites only an external high precision oscillator is used.

Power Supply

First generation GPS receivers consumed very high power, but modern receivers are designed to consume as little energy as possible. Most receivers have an internal rechargeable Nickel-Cadmium battery in addition to an external power input. Caution of low battery signal prompts the user to ensure adequate arrangement of power supply.

Memory Capacity

For port processing purposes all data have to be stored on internal or external memory devices. Post processing is essential for multi station techniques applicable to geodatic and surveying problems. GPS observation for pseudoranges, phase data, time and navigation message data have to be recorded. Based on sampling rate, it amount to about 1.5 Mbytes of data per hour for six satellites and 1 second data for dual frequency receivers. Modern receivers have internal memories of 5 Mbytes or more. Some receivers store the data on magnetic tape or on a floppy disk or hard-disk using external microcomputer connected through RS-232 port.

Most modern receivers have a keypad and a display for communication between the user and the receivers. The keypad is used to enter commands, external data like station number or antenna height or to select a menu operation. The display indicates computed coordinates, visible satellites, data quality indices and other suitable information. Current operation software packages are menu driven and very user friendly.

Classification of GPS Receivers

GPS receivers can be divided into various groups according to different criteria. In the early stages two basic technologies were used as the classification criteria viz. Code correlation receiver technology and sequencing receiver technology, which were equivalent to code dependent receivers and code free receivers. However, this kind of division is no longer justifiable since both techniques are implemented in present receivers.

Another classification of GPS receivers is based on acquisition of data types e.g.

- C/A code receiver
- C/A code + L1 Carrier phase
- C/A code + L1 Carrier phase + L2 Carrier phase
- C/A code + p_code + L1, L2 Carrier phase
- L1 Carrier phase (not very common)
- L1, L2 Carrier phase (rarely used)

Based on technical realization of channel, the GPS receivers can be classified as:

- Multi-channel receiver
- Sequential receiver
- Multiplexing receiver

GPS receivers are even classified on the purpose as :

- Military receiver
- Civilian receiver
- Navigation receiver
- Timing receiver
- Geodetic receiver

For geodetic application it is essential to use the carrier phase data as observable. Use of L1 and L2 frequency is also essential along with P-code.

Examples of GPS Receiver

GPS receiver market is developing and expanding at a very high speed. Receivers are becoming powerful, cheap and smaller in size. It is not possible to give details of every make but description of some typical receivers given may be regarded as a basis for the evaluation of future search and study of GPS receivers.

Classical Receivers

Detailed description of code dependent T1 4100 GPS Navigator and code free Macrometer V1000 is given here:

T1 4100 GPS Navigator was manufactured by Texas Instrument in 1984. It was the first GPS receiver to provide C/A and P code and L1 and L2 carrier phase observations. It is a dual frequency multiplexing receiver and suitable for geodesist, surveyor and navigators. The observables through it are:

- P-Code pseudo ranges on L1 and L2
- C/A-Code pseudo ranges on L1
- Carrier phase on L1 and L2

The data are recorded by an external tape recorder on digital cassettes or are downloaded directly to an external microprocessor. A hand held control display unit (CDU) is used for communication between observer and the receiver. For navigational purposes the built in microprocessor provides position and velocity in real time every three seconds. T1 4100 is a bulky instrument weighing about 33 kg and can be packed in two transportation cases. It consumes 90 watts energy in operating mode of 22V - 32V. Generator use is recommended. The observation noise in P-Code is between 0.6 to 1 m, in C/A code it ranges between 6 to 10 m and for carrier phase it is between 2 to 3 m.

T1 4100 has been widely used in numerous scientific and applied GPS projects and is still in use. The main disadvantages of the T1 4100 compared to more modern GPS equipment's are

- Bulky size of the equipment
- High power consumption
- Difficult operation procedure
- Limitation of tracking four satellites simultaneously
- High noise level in phase measurements

Sensitivity of its antenna for multipath and phase centre variation if two receivers are connected to one antenna and tracking of seven satellites simultaneously is possible. For long distances and in scientific projects, T1 4100 is still regarded useful. However, due to imposition of restriction on P-code for civilian, T1 4100 during Anti Spoofing (AS) activation can only be used as a single frequency C/A code receiver.

The MACROMETER V 1000, a code free GPS receiver was introduced in 1982 and was the first receiver for geodetic applications. Precise results obtained through it has demonstrated the potential of highly accurate GPS phase observations. It is a single frequency receiver and tracks 6 satellites on 6 parallel channels. The complete system consists of three units viz.

- Receiver and recorder with power supply
- Antenna with large ground plane
- P 1000 processor

The processor is essential for providing the almanac data because the Macrometer V 1000 cannot decode the satellite messages and process the data. At pre determined epoches the phase differences between the received carrier signal and a reference signal from receiver oscillator is measured. A typical baseline accuracy reported for upto 100 km distance is about 1 to 2 ppm (Parts per million).

Macrometer II, a dual frequency version was introduced in 1985. Though it is comparable to Macrometer V 1000, its power consumption and weight are much less. Both systems require external ephemeredes. Hence specialized operators of few companies are capable of using it and it is required to synchronize the clock of all the instruments proposed to be used for a particular observation session. To overcome above disadvantages, the dual frequency Macrometer II was further miniaturized and combined with a single frequency C/A code receiver with a brand name MINIMAC in 1986, thus becoming a code dependent receiver.

Examples of present Geodetic GPS Receivers

Few of the currently available GPS receivers that are used in geodesy surveying and precise navigation are described. Nearly all models started as single frequency C/A-Code receivers with four channels. Later L2 carrier phase was added and tracking capability was increased. Now a days all leading manufacturers have gone for code-less, non sequencing L2 technique. WILD/ LEITZ (Heerbrugg, Switzerland) and MAGNAVOX (Torrance, California) have jointly developed WM 101 geodetic receiver in 1986. It is a four channel L1 C/A code receiver. Three of the channels sequentially track upto six satellites and the fourth channel, a house keeping channels, collects the satellite message and periodically calibrates the inter channel biases. C/A-code and reconstructed L1 carrier phase data are observed once per second.

The dual frequency WM 102 was marketed in 1988 with following key features:

- L1 reception with seven C/A code channel tracking upto six satellites simultaneously.
- L2 reception of upto six satellites with one sequencing P- code channel
- Modified sequencing technique for receiving L2 when P-code signals are encrypted.

The observations can be recorded on built in data cassettes or can be transferred on line to an external data logger in RS 232 or RS 422 interface. Communication between operator and receiver is established by alpha numerical control panel and display WM 101/102 has a large variety of receiver resident menu driven options and it is accompanied by comprehensive post processing software.

In 1991, WILD GPS system 200 was introduced. Its hardware comprises the Magnavox SR 299 dual frequency GPS sensor, the hand held CR 233 GPS controller and a Nicd battery. Plug in memory cards provide the recording medium. It can track 9 satellites simultaneously on L1 and L2. Reconstruction of carrier phase on L1 is through C/A code and on L2 through P-code. The receiver automatically switches to codeless L2 when P-code is encrypted. It consumes 8.5 watt through 12-volt power supply.

TRIMBLE NAVIGATION (Sunny vale, California) has been producing TRIMBLE 4000 series since 1985. The first generation receiver was a L1 C/A code receiver with five parallel channels providing tracking of 5 satellites simultaneously. Further upgradation included increasing the number of channels upto tweleve, L2 sequencing capability and P-code capability. TRIMBLE Geodatic Surveyor 4000 SSE is the most advanced model. When P-Code is available, it can perform following types of observations, viz.,

- Full cycle L1 and L2 phase measurements
- L1 and L2, P-Code measurements when AS is on and P-code is encrypted
- Full cycle L1 and L2 phase measurement
- Low noise L1, C/A code
- Cross-correlated Y-Code data

Observation noise of the carrier phase measurement when P-code is available is about ñ 0-2mm and of the P-code pseudoranges as low as ñ 2cm. Therefore, it is very suitable for fast ambiguity solution techniques with code/ carrier combinations.

ASHTECH (Sunnyvale, California) developed a GPS receiver with 12 parallel channels and pioneered current multi-channel technology. ASHTECH XII GPS receiver was introduced in 1988. It is capable of measuring pseudoranges, carrier phase and integrated dopler of up to 12 satellites on L1. The pseudoranges measurement are smoothed with integrated Doppler. Postion velociy, time and navigation informations are displayed on a keyboard with a 40-characters display. L2 option adds 12 physical L2 squaring type channels.

ASHTECH XII GPS receiver is a most advanced system, easy to handle and does not require initialization procedures. Measurements of all satellites in view are carried out automatically. Data can be stored in the internal solid plate memory of 5 Mbytes capacity. The minimum sampling interval is 0.5 seconds. Like many other receivers it has following additional options viz.

- 1 ppm timing signal output
- Photogrammetric camera input
- Way point navigation
- Real time differential navigation and provision of port processing and vision planning software

In 1991, ASHTECH P-12 GPS receiver was marketed. It has 12 dedicated channels of L1, P-code and carrier and 12 dedicated channels of L2, P-code and carrier. It also has 12 L1, C/A code and carrier channels and 12 code less squaring L2 channels. Thus the receiver contains 48 channels and provides all possibilities of observations to all visible satellites. The signal to noise level for phase measurement on L2 is only slightly less than on L1 and significantly better than with code-less techniques. In cases of activated P-code encryption, the code less L2 option can be used.

TURBO ROGUE SNR-8000 is a portable receiver weighing around 4 kg, consumes 15-watt energy and is suitable for field use. It has 8 parallel channels on L1 and L2. It provides code and phase data on both frequencies and has a codeless option. Full P-code tracking provides highest precision phase and pseudo rages measurements, codeless tracking is automatic “full back” mode. The code less mode uses the fact that each carrier has identical modulation of P-code/Y-code and hence the L1 signal can be cross-correlated with the L2 signal. Results are the differential phase measurement (L1-L2) and the group delay measurement (P1-P2)

Accuracy specifications are :

P-Code pseudo range	1cm (5 minutes integration)
Codeless pseudo range	10cm (5 minutes integration)
Carrier phase	0.2 - 0.3 mm
Codeless phase	0.2 - 0.7 mm

One of the important features is that less than 1 cycle slip is expected for 100 satellite hours.

Navigation Receivers

Navigation receivers are rapidly picking up the market. In most cases a single C/A code sequencing or multiplexing channel is used. However, modules with four or five parallel channels are becoming increasingly popular. Position and velocity are derived from C/A code pseudoranges measurement and are displayed or downloaded to a personal computer. Usually neither raw data nor carrier phase information is available. Differential navigation is possible with some advanced models.

MAGELLAN NAV 1000 is a handheld GPS receiver and weighs only 850 grams. It was introduced in 1989 and later in 1990, NAV 1000 PRO model was launched. It is a single channel receiver and tracks 3 to 4 satellites with a 2.5 seconds update rate and has a RS 232 data port.

The follow up model in 1991 was NAV 5000 PRO. It is a 5-channel receiver tracking all visible satellites with a 1-second update rate. Differential navigation is possible. Carrier phase data can be used with an optional carrier phase module. The quadrifilar antenna is integrated to the receiver. Post processing of data is also possible using surveying receiver like ASHTECH XII located at a reference station. Relative accuracy is about 3 to 5 metres. This is in many cases sufficient for thematic purposes.

Many hand held navigation receivers are available with added features. The latest market situation can be obtained through journals like GPS world etc.

For most navigation purpose a single frequency C/A code receiver is sufficient. For accuracy requirements better than 50 to 100 meters, a differential option is essential. For requirement below 5 meters, the inclusion of carrier phase data is necessary. In high precision navigation the use of a pair of receivers with full geodetic capability is advisable.

The main characteristics of multipurpose geodetic receiver are summarized in Table 4.

Table 4. Overview of geodetic dual-frequency GPS satellite receiver (1992)

Receiver	Channel		Code		Wavelength		Anti-spoofing
	L1	L2	L1	L2	L1	L2	
TI 4100	4	4	P	P			Single frequency
MACROMETER	6	6	-	-		/2	No influence
ASHTECH XII	12	12	C/A	-		/2	No influence
ASHTECH P 12	12	12	C/A, P	P			Squaring
TRIMBLE SST	8-12	8-12	C/A	-		/2	No influence
TRIMBLE 4000	9-12	9-12	C/A, P	P			Codeless SSE
WM 102	7 par	1 seq	C/A	P			Squaring
WILD GPS 200	9	9	C/A	p			Codeless
TURBO ROGUE	8	8	C/A, P	P			Codeless

Some of the important features for selecting a geodetic receiver are :

- Tracking of all satellites
- Both frequencies
- Full wavelength on L2
- Low phase noise-low code noise
- High sampling rate for L1 and L2
- High memory capacity

- Low power consumption
- Full operational capability under anti spoofing condition

Further, it is recommended to use dual frequency receiver to minimize ion-spherical influences and take advantages in ambiguity solution.

Accuracy

In general, an SPS receiver can provide position information with an error of less than 25 meter and velocity information with an error less than 5 meters per second. Upto 2 May 2000 U.S Government has activated Selective Availability (SA) to maintain optimum military effectiveness. Selective Availability inserts random errors into the ephemeris information broadcast by the satellites, which reduces the SPS accuracy to around 100 meters.

For many applications, 100-meter accuracy is more than acceptable. For applications that require much greater accuracy, the effects of SA and environmentally produced errors can be overcome by using a technique called Differential GPS (DGPS), which increases overall accuracy.

Differential Theory

Differential positioning is technique that allows overcoming the effects of environmental errors and SA on the GPS signals to produce a highly accurate position fix. This is done by determining the amount of the positioning error and applying it to position fixes that were computed from collected data.

Typically, the horizontal accuracy of a single position fix from a GPS receiver is 15 meter RMS (root-mean square) or better. If the distribution of fixes about the true position is circular normal with zero mean, an accuracy of 15 meters RMS implies that about 63% of the fixes obtained during a session are within 15 meters of the true position.

Types of Errors

There are two types of positioning errors: correctable and non-correctable. Correctable errors are the errors that are essentially the same for two GPS receivers in the same area. Non-correctable errors cannot be correlated between two GPS receivers in the same area.

Correctable Errors

Sources of correctable errors include satellite clock, ephemeris data and ionosphere and tropospheric delay. If implemented, SA may also cause a correctable positioning error. Clock errors and ephemeris errors originate with the GPS satellite. A clock error is a slowly changing error that appears as a bias on the pseudorange measurement made by a receiver. An ephemeris error is a residual error in the data used by a receiver to locate a satellite in space.

Ionosphere delay errors and tropospheric delay errors are caused by atmospheric conditions. Ionospheric delay is caused by the density of electrons in the ionosphere along the signal path. A tropspheric delay is related to humidity, temperature, and altitude along the signal path. Usually, a tropospheric error is smaller than an ionospheric error.

Another correctable error is caused by SA which is used by U.S Department of Defence to introduce errors into Standard Positioning Service (SPS) GPS signals to degrade fix accuracy.

The amount of error and direction of the error at any given time does not change rapidly. Therefore, two GPS receivers that are sufficiently close together will observe the same fix error, and the size of the fix error can be determined.

Non-Correctable Errors

Non-correctable errors cannot be correlated between two GPS receivers that are located in the same general area. Sources of non-correctable errors include receiver noise, which is unavoidably inherent in any receiver, and multipath errors, which are environmental. Multi-path errors are caused by the receiver "seeing" reflections of signals that have bounced off of surrounding objects. The sub-meter antenna is multipath-resistant; its use is required when logging carrier phase data. Neither error can be eliminated with differential, but they can be reduced substantially with position fix averaging. The error sources and the approximate RMS error range are given in the Table 5.

Table 5. Error Sources

Error Source	Approx. Equivalent Range Error (RMS) in meters
Correctable with Differential	
Clock (Space Segment)	3.0
Ephemeris (Control Segment)	2.7
Ionospheric Delay (Atmosphere)	8.2
Tropospheric Delay (Atmosphere)	1.8
Selective Availability (if implemented)	27.4
Total	28.9
Non-Correctable with Differential	
Receiver Noise (Unit)	9.1
Multipath (Environmental)	3.0
Total	9.6
Total user Equivalent range error (all sources)	30.5
Navigational Accuracy (HDOP = 1.5)	45.8

DIFFERENTIAL GPS

Most DGPS techniques use a GPS receiver at a geodetic control site whose position is known. The receiver collects positioning information and calculates a position fix, which is then compared to the known co-ordinates. The difference between the known position and the acquired position of the control location is the positioning error.

Because the other GPS receivers in the area are assumed to be operating under similar conditions, it is assumed that the position fixes acquired by other receivers in the area (remote units) are subject to the same error, and that the correction computed for the control position should therefore be accurate for those receivers. The correction is communicated to the remote units by an operator at the control site with radio or cellular equipment. In post-processed differential, all units collect data for off-site processing; no corrections are determined in the field. The process of correcting the position error with differential mode is shown in the Figure 12.

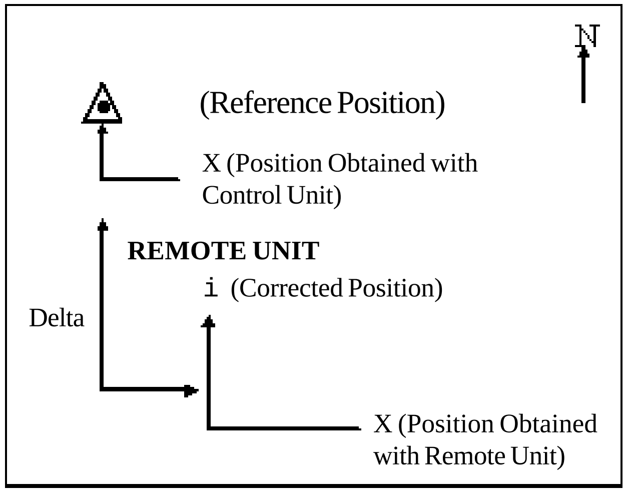


Figure 12: A Position Error Corrected with Differential

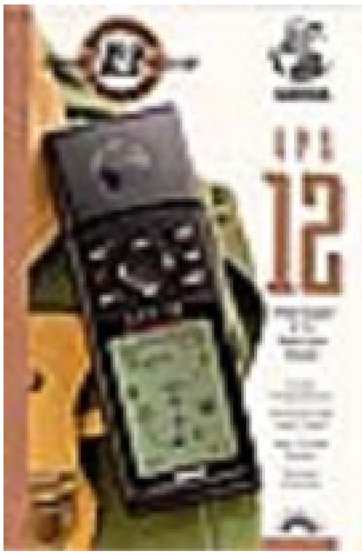
The difference between the known position and acquired position at the control point is the DELTA correction. DELTA, which is always expressed in meters, is parallel to the surface of the earth. When expressed in local co-ordinate system, DELTA uses North-South axis (y) and an East-West axis (x) in 2D operation; an additional vertical axis (z) that is perpendicular to the y and x is used in 3D operation for altitude.

APPLICATIONS OF GPS

- Providing Geodetic control.
- Survey control for Photogrammetric control surveys and mapping.
- Finding out location of offshore drilling.
- Pipeline and Power line survey.
- Navigation of civilian ships and planes.
- Crustal movement studies.
- Geophysical positioning, mineral exploration and mining.
- Determination of a precise geoid using GPS data.
- Estimating gravity anomalies using GPS.
- Offshore positioning: shiping, offshore platforms, fishing boats etc.

VARIOUS MAKES OF GPS

TRIMBLE GPS AS A ROVER



GARMIN 12 CHANNEL GPS

MAGELLAN GPS - 315 SERIES

CONCLUSIONS

Global Positioning System (GPS) is currently designed to provide navigational accuracy of ±10 m to ±15 m. However, sub meter accuracy in differential mode has been achieved and it has been proved that broad varieties of problems in geodesy and geo-dynamics can be tackled through GPS. GPS service consists of three components, viz. space, control and user.

REFERENCES

GPS Positioning Guide: A user guide to the Global Positioning System. Natural Resources, Canada. URC : uttp://www.geod.nrcan.gc.ca

GPS World Periodicals.

Proceedings of ION, GPS, 2002. Portland, Oregon, USA Sept. 2002.

Seeber, Gunter 2003. Satellite Geodesy (2nd Edition). Walter de Gruyter Inc. ISBN : 31101 75495.