NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Computer Engineering
Department of Electrical and electronic Engineering

GLOBAL POSITIONING SYSTEM (GPS)

Graduation Project

COM/EE - 400

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ACKNOWLEDGMENT

Thanks God,

First of all we would like to thank our families that they were always helping us, supporting us and waiting for this long time.

Secondly, we would thank our supervisor Prof. Dr Fahreddin memedov his advices and being with us although he is so busy.

Thirdly, thanks for our instructors teaching us, standing next to us in our problems and advising us when we need.

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ABSTRACT

Over the past decade, the Global Positioning System has become increasingly advanced and useful. Today's capabilities are remarkable and stretch the boundaries for future innovation. In the report (and slide show), we have briefly covered the history of navigation, leading to GPS. We have then given a detailed explanation of how it works, mentioning the errors involved and correction techniques. This has leaded us to a discussion of where we are today, covering applications such as navigation, mapping, tracking, and timing. Moving on, we have taken a glance at where we are headed with this technology, considering such systems as Differential GPS. Regulations were placed on accuracy for security reasons, and only recently have they been removed. Now the envelope is being pushed to the point where engineering dreams of today will be a reality tomorrow.

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INTRODUCTION

This project is about the Global Positioning System (GPS) and its many applications. The history of navigation and how GPS works are important for understanding this project and so each has its own section within the project. How it compares to other navigational systems and its uses outside of navigation will be discussed as well. The goal of this project is to explain how GPS technology is affecting society. This project is intended for anyone who:

- uses GPS in their job.
- Uses GPS for leisure activities,
- is curious about the applications, or
- is curious about how it works,

actually, this project is for everyone since GPS affects us all whether we directly use it or not.

Ultimately, this project conveys that GPS is not just a navigational system. A good analogy is the clock which was originally used as a navigational tool. Since stars look different at different times, people who used celestial navigation needed to know what time of night it was. The market forecasters shortly after the invention of the clock probably could not have imagined the impact that timekeeping would have on the world or the other products and services that this technology would someday make possible. The same situation can be found now with GPS. In fact, it was first intended for military use but is now meeting numerous civilian needs as well. We can only guess at some of the eventual uses that this relatively new technology will bring about.

1- GPS OVERVIEW

1.1What is GPS?

The Global Positioning System (GPS) is a space age navigational system that can pinpoint your position anywhere on the globe, usually within a few yards or meters. This amazing technology is available to everyone, everywhere, day and night, and best of all, at no cost for use of the navigational data. GPS uses a constellation of 24 satellites in precise orbits approximately 11,000 miles above the earth. The satellites transmit data via high frequency radio waves back to Earth and, by locking onto these signals; a GPS receiver can process this data to triangulate its precise location on the globe.

GPS operates 24 hours a day, in all weather conditions, and can be used worldwide for precise navigation on land, on water and even in the air. Some of its many current applications include: boating, fishing, hunting, scouting on land or from the air, hiking, camping, biking, rafting, pack trips by horseback, hot air ballooning, general aviation, snowmobiling and skiing, search and rescue, emergency vehicle tracking, 4 wheeling, highway driving and a host of other outdoor activities where accurate positioning is required.

1.2 History of GPS

The global positioning system is designed by the Department of Defense and the Department of Transportation of the United States of America. On April 27, 1995 the system, containing 24 operational satellites, was formally declared as having met the requirement of Full Operation Capability. Since then, the system has been taken into full use. The US-DoD initially designed the GPS system for military use only, including some civil use on a subscription-like base in the beginning of 1978. In 1983 flight 007 of Korean Airlines crashed due to lack of accurate navigational equipment former President Reagan allowed the use of the SPS signal for use in aero planes and other transportation application

For the use of SPS system the differential GPS system (DGPS) was designed. In 1995 an agreement was made between the US-DoD and the US Department of Transportation regarding wide area broadcasts. Following this agreement, the Federal Aviation Administration (FAA) concluded negotiations regarding the development of an own DGPS service. The Wilcox Company got the $474 million contract for the Wide Area Augmentation System (WAAS). This system has typical DGPS classifications.

1.3 Who can use GPS?

GPS has a civilian and military user community. Although GPS is funded by the U.S. DoD, civilians worldwide can use GPS' Standard Positioning Service (SPS) provided a proper receiver is used. SPS provides positional accuracy of 10 meters in 2-D space with 95% confidence. The U.S. Military and its allies use a more highly accurate service called Precise Positioning Service (PPS) that is capable of accuracy within ten meters in 3-D space with 95% confidence.

1.4 Controlling the System

The GPS satellites are controlled by a master control station which is located at the Falcon Air Base in Colorado Springs, Colorado, USA. There are several other remote monitor stations, which send their information to the master control station. These stations are able to track and monitor each satellite for 21 hours a day, resulting in 2 periods of 1,5 hours when the satellite is on the other side of the earth, out of reach for that ground station The master station uploads the data which is necessary for proper operation of the satellite, like ephemeris and clock data to the satellites. The satellites send down subsets of the orbital ephemeris data.

1.5 The Russian Alternative for GPS

There is a Russian system similar to GPS, called GLONASS, which comes from GLObal NAvigational Satellite System. The GLONASS system has much in common with the GPS system. Both employ 24 satellites, are operated by the Departments of Defense of the two federations, and transmit spectrum signals at two frequencies and have pledged a partial signal available for civil use without any costs. Next to the similarities, there are some differences. The GPS system, for instance, uses

6 orbital planes, while the GLONASS system uses only 3. Also, the GPS system is fully operational, while GLONASS is not (yet).

1.6 What magic makes GPS work?

GPS is a second generation, satellite-based, positioning system that is available anywhere and anytime and is capable of measuring land, air and sea positions with millimeter accuracy. GPS is referred to as a system because it is an assemblage of three distinct components or segments: Space, Control, and User, see figure 1.1.

The Space Segment refers to the constellation of satellites and the navigational data they provide. The Control Segment refers to monitoring and updating of the satellites' clocks and navigational messages by a master control station that uses five regional monitoring stations distributed around the world. Lastly, the User Segment refers to the GPS receivers that calculate the time required for a radio signal to travel from the visible satellites to the receiver in order to measure its position using a technique called triangulation.

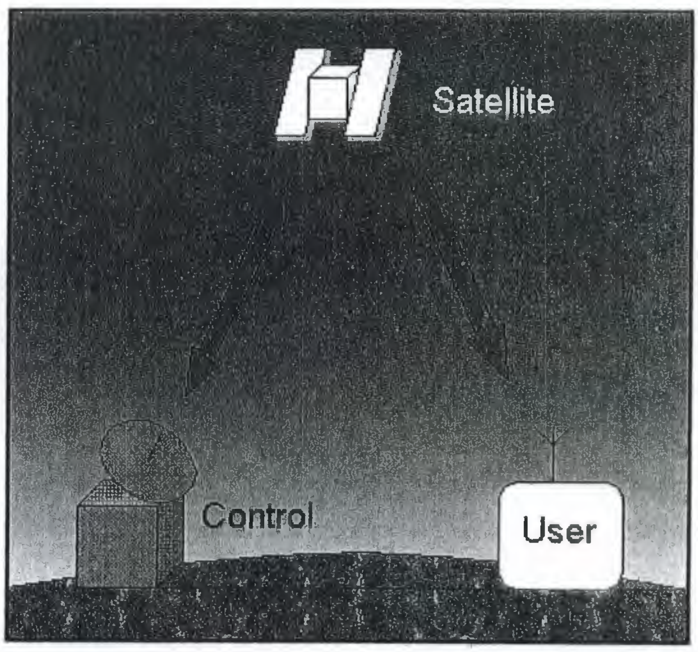


Fig 1.1 segments

1.7 How accurate is GPS?

Standard Positioning Service (SPS) provides civilians with positional accuracy of 100 meters in 2-D space with 95% confidence. Modified GPS, such as Differential GPS, can provide much greater accuracy than SPS, but has cost and feature limitations. The U.S. Military and its allies use a more highly accurate service called Precise Positioning Service (PPS) that is capable of accuracy within ten meters in 3-D space with 95% confidence.

2-DATA TRANSMISSION

2.1 Positioning with GPS

There are essentially two broad categories of GPS positioning which can be described as real-time navigation and high precision carrier phase positioning. Navigation uses a minimum of four pseudorange measurements to four satellites which are used to solve for the three-dimensional coordinates of the receiver and the clock offset between the receiver oscillator and GPS system time. An extension to this mode is differential GPS (DGPS) which again uses the pseudorange observable for positioning, but also incorporates real-time corrections for the errors inherent in the measurements.

The second category uses the much more precise carrier phase observations to compute baselines between two locations. Since the two carriers have short wavelengths (19 and 24 cm for L1 and L2 respectively), they cannot be used in the same manner as the pseudorange. The whole number of complete wavelengths (integer ambiguities) between the satellite and receiver must first be determined and this is carried out by post processing (static) or in Real-Time (RTK) using linear combinations of the two frequencies and differencing techniques.

Differences between these two modes are becoming less distinguishable. Combining the pseudorange with the phase data reduces the noise error within the pseudorange measurement resulting in a much higher positioning accuracy. New techniques are also being developed to solve for the integer ambiguities in a single epoch leading to very high baseline positioning in real-time. These are known as on-the-fly or fast ambiguity resolution techniques have already proved to provide accuracies of less than 1 cm on moving platforms over short baselines.

2.2 The Satellites

The satellites themselves are relatively large, using a multi-purpose military platform used for purposes other than global positioning, such as atomic flash detection. Each is designed to last $7^1/_2$ years, Twelve antennas point toward the Earth, and two solar arrays toward the Sun capable of generating 700 Watts, to drive the satellite's navigation transmitters, its four atomic clocks, and its momentum wheels. The latest generation of satellites are designated 'Block II'.

2.3 Navigation / Broadcast Data Message

The data message includes information describing the positions of the satellites, their health status, and the hand-over-word.

Each satellite sends a full description of its own orbit and clock data (within the ephemeris information) and an approximate guide to the orbits of the other satellites (contained within the almanac information).

The data is modulated at a much slower rate of 50 bps and thus it takes 12.5 minutes to transmit all of the information. To reduce the time it takes to obtain an initial position, the ephemeris and clock data is repeated every 30 seconds (Langley, 1990).

Parameters representing the delay caused by signal propagation through the ionosphere are also included within the data message.

2.4 The GPS data format & modulation

This section describes the format in which the GPS data is arranged when sent from the satellites to the GPS receivers.

- The data is split up in frames of 1500 bits.
- One frame exists of 5 subframes (300 bits).
- One subframe exists of 10 words (30 bits).

Suppose the datarate is 50 bits / second.

Then the duration becomes:

- Word = 0.6 seconds
- Subframe = 6 seconds
- Frame = 30 seconds

The databits are synchronized with the PRN-code. The PRN-code and the data are modulated with different frequencies on the carrierfrequency. Used in GPS this PRN-code (with a length of 1023 chips, and with a frequency of 1.023 MHz) has a duration of 1 millisecond, So with a datarate of 50 bits/s exactly 20 codes fit in one data bit. The PRN-code provides the system with a unambiguous >measurerange. 20 PRN-codes (take 20 ms) correspond therefore with (0.02 [s] * $300*10^6$ (speed of light [m/s]) =) 6000 km. Every subframe (300 bits) is preceded by a good recognizable word, so the unambiguous range becomes (300 * 6000 =) 1800000 km. In practice this means that the receiver on earth cannot be wrong measuring the phase of the GPS signal.

2.4.1 PRN codes

This section describes the principle of the PRN code that is used and its use for GPS.

PRN stands for Pseudo Random Noise. In normal language it means something like: "Random Noise at first sight, but in fact it's not". The code consists of a long series of bits (0's and 1's). At first sight there doesn't seem to be a regular pattern in the bits. But there is! The codes-patterns used for GPS repeat themselves after the 1023rd bit. These codes can be easily made with very few digital elements. For the 1023 bit pattern 10 shifting registers and some digital adders are needed. In general with n shifting registers a series of 2^n -1 bits can be generated. For n = 10 this will become 1024 (= 2^{10}) - 1 = 1023 bits. The codes are generated with a speed of 1.023 MHz (or 1023000 bits per second). An example with four shifting elements is given in figure2.1.

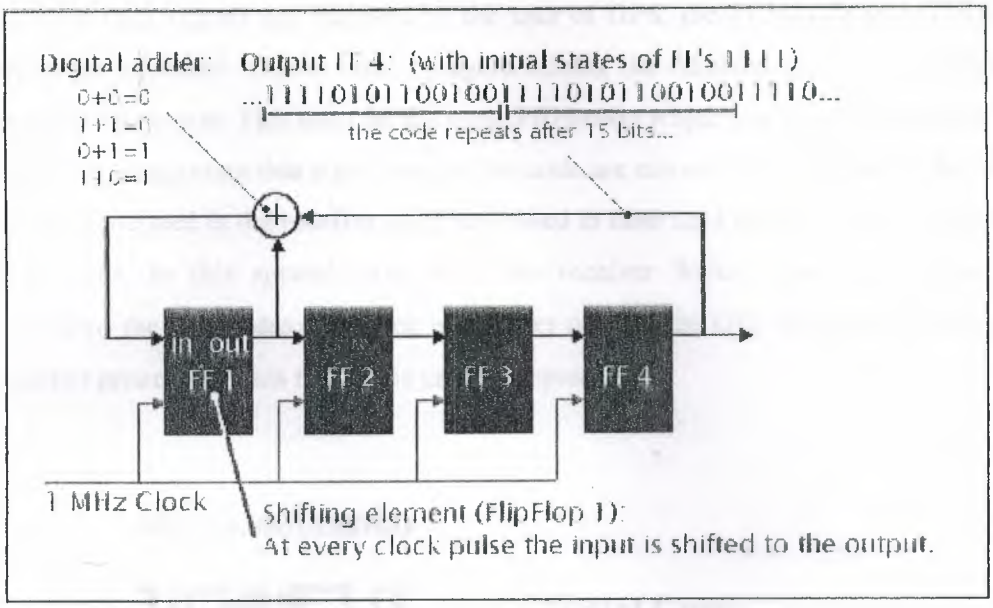


Fig 2.1 shifting element

The GPS satellites broadcast the PRN codes mixed (see the figure2.2) with the other GPS information, like orbital- (also called ephemeris-) and clock-parameters, but also parameters concerning the other satellites. By mixing the PRN-code with the 50 Hz data data the total signal is spread out over a broad part of the spectrum. This technique is called spread spectrum. This section won't go very deep in this complex matter, but the result is that the signal power is very low, even beneath the noise floor. In other words: it has become very hard to distinguish the signal from noise (that is always present on signals).

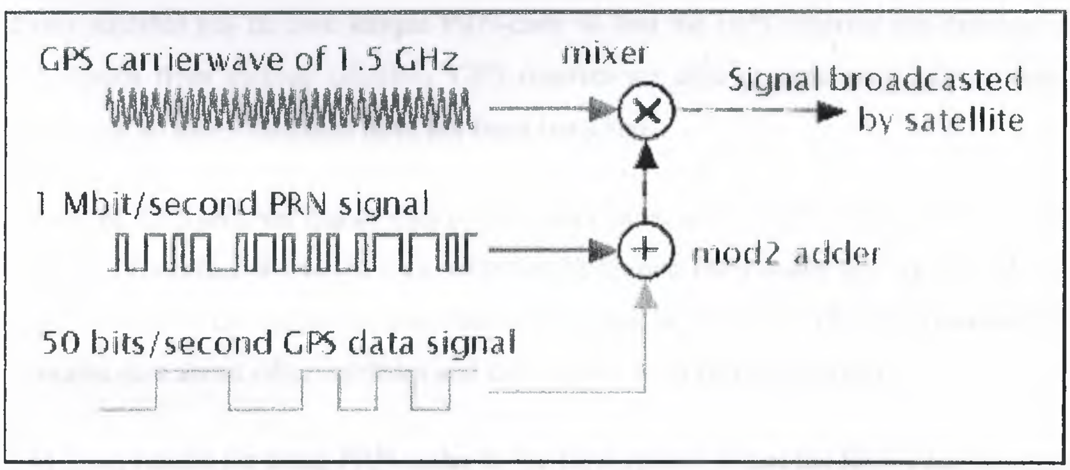


Fig 2.2 PRN codes mixed

When the GPS signals are received by the user of GPS, the PRN-code and GPS data have to be separated. This is done by again mixing the received signal with a locally generated PRN-code. This must be the same PRN-code which has been generated in the satellite. It is important that equal parts of the code are mixed with each other. Therefore the code generated in the receiver must be shifted in time until the two codes are exactly synchronous. In this special case when the receiver 'locks' (also referred as full correlation) the two codes can block each other out and the GPS-data remains and can be further processed. This method is called despreading.

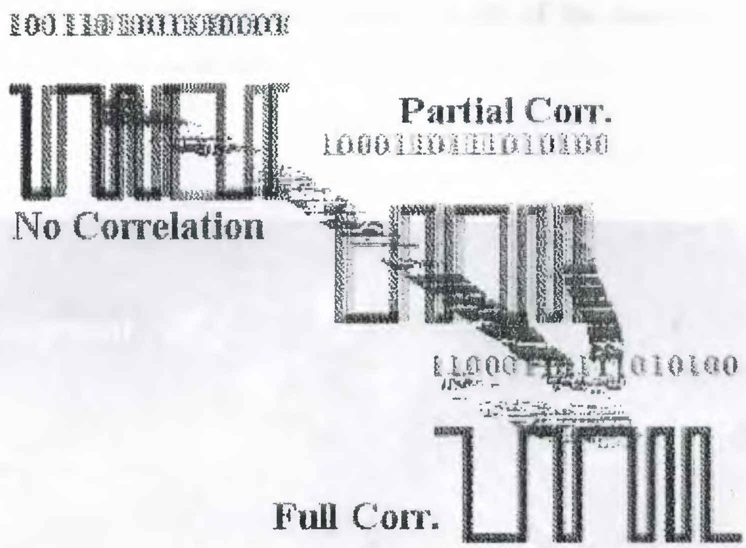


Fig 2.3 correlation

Every satellite has its own unique PRN-code so that the GPS receiver can distinguish the signals from various satellites. GPS receiver are able to generate 32 PRN-codes. Until now so many satellites have not been launched.

When the GPS receiver has to start up it doesn't know which GPS signal is from which satellite. Therefore it tries to lock with the 32 known PRN-codes one by one. If one code locks then the information of one satellite can be decoded. This information also contains data about other satellites and the rest can soon be received too.

The main reason for using PRN codes in the GPS system is that the PRN code enlarges the unambiguous measurement range. One must keep in mind that after 1023 bits the code is repeated. It is case that the GPS-receiver is aware it is 'looking' at the right code and not at its predecessor or successor. Looking at the wrong code gives a navigation error of 300 km (corresponding to the code length of 1 millisecond).

2.5 The Segments

The operation of GPS is split into three segments. The space segment is composed of the 24 Block II Navstar satellites that transmit precisely timed pulses of code and orbital data. The control segment helps keep track of the satellites with monitoring stations to find their exact orbit and any clock errors and hence correct the satellite's own data if necessary. Finally the user segment consists of all of the receivers located on the ground, or in aeroplanes, or in ships.

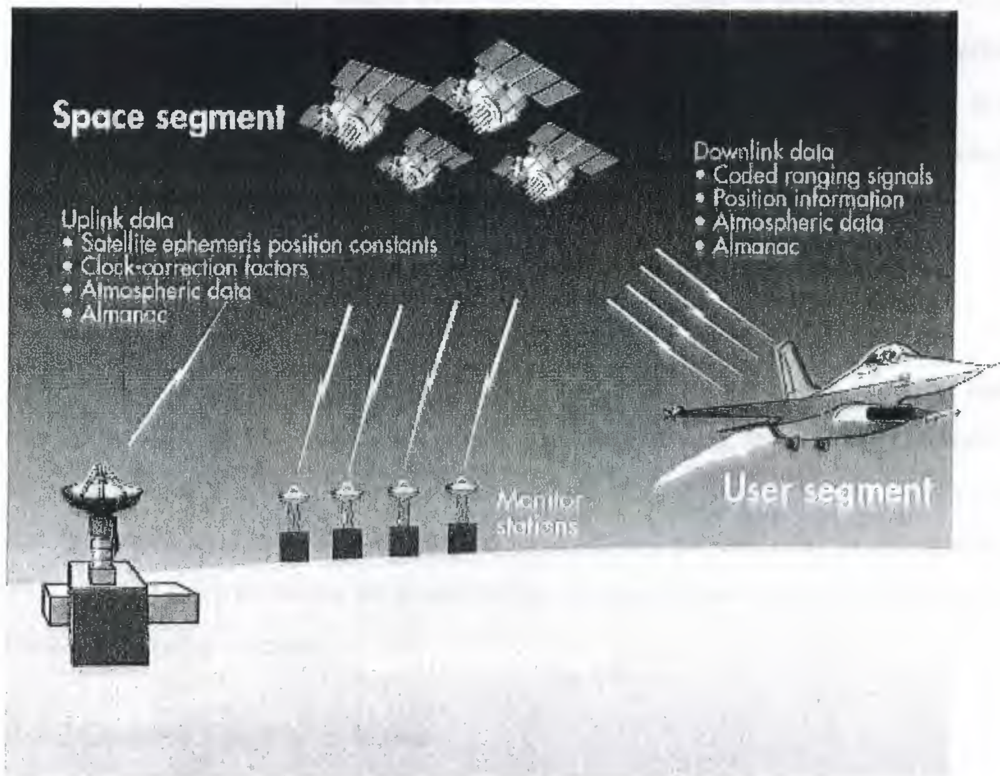


Fig 2.4 GPS consists of three major segments: the space segment, the user segment, and the control segment

2.6 Signals

GPS satellites transmit on two L-Band frequencies: 1.57542 GHz (L1) and 1.22760 GHz (L2). The L1 signal is modulated by two codes - the P-code (precise) and the C/A-code (coarse acquisition). The L2 carrier contains only P-code, which is encrypted. However there are some civilian receivers which have the capability of using the L1 P-code without decoding it.

The P-code is encrypted for use solely by authorized military users. The encryption is known as 'Anti-Spoofing' with the intention of preventing adversaries from sending out false signals to fool any military weapons or vehicles. Anti-spoofing was permanently implemented on January 31st 1994, with no prior announcement [1].

The C/A code is the standard freely available service for non-military users. It is, of course, less accurate and unlike the P-code, easier to jam. It uses only one frequency and so can't compensate for ionospheric delay as the P-code can. Therefore a mathematical model of the ionosphere is included in the data stream from the satellites reducing ionospheric error by as much as 50%. The C/A code is also degraded by a process known as 'Selective Availability'.

2.6.1 Antenna

The antenna is usually designed to be omni-directional with a gain of 3 dB, meaning that 50% of all surrounding signal is ignored (those coming from below the horizon, or antenna ground plane). The antenna is connected to the receiver by a coaxial cable through which a voltage is sent from the receiver to a pre-amplifier at the antenna end. This pre-amplifier increases the power of the detected signal so that it can be sent along the cable into the receiver.

2.6.2 Ground Control Stations

The GPS control, or ground, segment consists of unmanned monitor stations located around the world (Hawaii and Kwajalein in the Pacific Ocean; Diego Garcia in the Indian Ocean; Ascension Island in the Atlantic Ocean; and Colorado Springs, Colorado); a master ground station at Schriever (Falcon) Air Force Base in Colorado Springs, Colorado; and four large ground antenna stations that broadcast signals to the satellites. The stations also track and monitor the GPS satellites.

2.6.3 Receivers

GPS receivers can be hand carried or installed on aircraft, ships, tanks, submarines, cars, and trucks. These receivers detect, decode, and process GPS satellite signals. More than 100 different receiver models are already in use. The typical hand-held receiver is about the size of a cellular telephone, and the newer models are even smaller. The hand-held units distributed to U.S. armed forces personnel during the Persian Gulf war weighed only 28 ounces.

2.7 How does it Work?

Positions are determined by intersecting distances between the GPS satellites and the receiver. Traditionally, the technique is called trilateration.

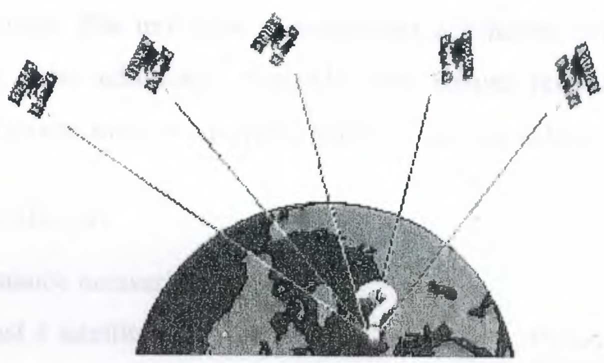


Fig 2.5 determine the position

Distances between the GPS satellites and the receiver are not measured directly and therefore must be derived. Typically the distances are derived from two fundamental GPS measurements:

There are two types of service available to GPS users - the SPS and the PPS.

2.8 How GPS Determines Your Position

GPS uses satellite ranging to triangulate your position. In other words, the GPS unit simply measures the travel time of the signals transmitted from the satellites, then multiplies them by the speed of light to determine exactly how far the unit is from every satellite it's sampling.

By locking onto the signals from a minimum of three different satellites, a GPS receiver can calculate a 2D (two-dimensional) positional fix, consisting of your latitude and longitude. By locking onto a fourth satellite, the GPS can compute a 3D (three-dimensional) fix, calculating your altitude as well as your latitude/longitude position.

In order to do this Lawrence uses a 12 parallel-channel receiver in all of its current products. Three of the channels lock on to satellites for triangulation. Another channel locks on to a fourth satellite for 3D navigation, which lets the unit calculate altitude in addition to latitude and longitude. These four channels continuously and simultaneously track the four satellites in the best geometrical positions relative to you. The additional eight channels track all other visible satellites, then add this data to the data from the original four satellites. The unit then over-resolves a solution, creating an accuracy-enhanced reading. The additional channels also ensure reliable, continuous and uninterrupted navigation, even in adverse conditions such as valleys or dense woods.

2.9 Position calculation

- Trilateration (distance measuring)
- In 3D with at least 4 satellites
- Alamanac and ehhemeris data

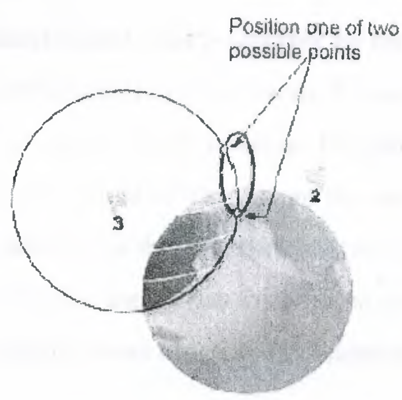


Fig 2.6 4 satellite

2.10 How the Current Locations of GPS Satellites are Determined

GPS satellites are orbiting the Earth at an altitude of 11,000 miles. The DOD 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. Think of the almanac as a "bus schedule" advising you of where each satellite will be at a particular time. Each GPS satellite continually broadcasts the almanac. Your GPS receiver will automatically collect this information and store it for future reference.

The Department of Defense constantly monitors the orbit of the satellites looking for deviations from predicted values. Any deviations (caused by natural atmospheric phenomenon such as gravity), are known as ephemeris errors. When ephemeris errors are determined to exist for a satellite, the errors are sent back up to that satellite, which in turn broadcasts the errors as part of the standard message, supplying this information to the GPS receivers.

By using the information from the almanac in conjunction with the ephemeris error data, the position of a GPS satellite can be very precisely determined for a given time.

2.11 Computing the Distance between Your Position and the GPS Satellites

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 about 186,000 miles per second. 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 x 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 synchronized so that they generate the same code at exactly the same time. The code received from the satellite can be compared with the code generated by the receiver. By comparing the codes, the time difference between when the satellite generated the code and when the receiver generated the code can be determined. This interval is the travel time of the code. Multiplying this travel time, in seconds, by 186,000 miles per second gives the distance from the receiver position to the satellite in miles.

2.12 Four (4) Satellites to give a 3D position

GPS needs a 4th satellite to provide a 3D position. Why??

Three measurements can be used to locate a point, assuming the GPS receiver and satellite clocks are precisely and continually synchronized, thereby allowing the distance calculations to be accurately determined. Unfortunately, it is impossible to synchronize 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.

The atomic clocks aboard the satellites maintain their time to a very high degree of accuracy. However, there will always be a slight variation in clock rates from satellite to satellite. Close monitoring of the clock of each satellite from the ground permits the control station to insert a message in the signal of each satellite which precisely describes the drift rate of that satellite's clock. The insertion of the drift rate effectively synchronizes all of the GPS satellite clocks.

The same procedure cannot be applied to the clock in a GPS receiver. Therefore, a fourth variable (in addition to x, y and z), time, must be determined in order to calculate a precise location. Mathematically, to solve for four unknowns (x,y,z, and t), there must be four equations. In determining GPS positions, the four equations are represented by signals from four different satellites.

2.13 Data Transformation

Because true position in the examples is defined in terms of a local coordinate system, the positions generated by the GPS receivers must be transformed using complex mathematical equations. Errors in the equations will result in inaccurate final positions stored in the GIS.

Most GPS field systems designed for GIS professionals include the ability to transform coordinates from one system to another--especially from WGS 1984 to other major coordinate systems. It's important, therefore, to consider the GPS field system as a whole when determining its accuracy and how well it transforms data to the coordinate system in which GIS positions will be stored.

If a GPS field system only can export positions in terms of the WGS 1984 reference system, then users will need to consider how well the GIS can conduct required coordinate transformations. The transformations don't have any effect on a GPS receiver's capabilities, but they affect the reliability of the data.

Several factors influence the accuracy of a GPS receiver. It's important to consider the reliability of each factor before making a judgment regarding the accuracy of GPS results. GPS receiver precision also is important, because a receiver that reliably derives positions close to each other typically will derive accurate positions. To determine a final accuracy level, however, transformation parameters used to derive final position coordinates must be reliably accurate. The best way to have "peace of mind" with regard to GPS field system accuracy is to test the equipment by collecting positions over a long period of time against a reliably defined reference position.

2.14 The radio signal

The current series of GPS satellites broadcast data using two distinct signals of accuracy. The first is for the standard positioning system (SPS). The second one is for the precise positioning system (PPS). The SPS signal is at the L1 frequency, which is 1547, 42MHz. The L2 frequency carries the PPS signal, and is at 1227,60MHz. The signal is shifted by 3 binary codes.

The signal can also be used for time, velocity and tracking. Time is an obvious option, because the signal is transmitted in periods of time with the atomic clock. Velocity is quite easy. The receiver calculates his position each time a signal is received. The difference in the place the signal is received gives the velocity. Tracking needs a bit more information. The tracking party needs to locate the vehicle that has to be tracked.

Then, using the information of where the vehicle is, by continuous updating of this information, the vehicle can be tracked.

The vehicle can also send the information up by it's own sender, after pinpointing it's location with the use of GPS and a digitized map. This way, the tracking party can use the power of the used receiving installation. This is reversing the original process, but it is a possible use of GPS.

2.15 The Precise Positioning System

The precise positioning system (PPS) is the encrypted military signal, which is designed to be accurate within 15 to 30 meters, but PPS has proven to be able to reach a resolution of 10 meters.
The PPS-system is used by authorised users only, they have cryptographic equipment and the keys to decode the PPS signal.

2.16 The Standard Positioning System

The standard positioning system has an accuracy of approximately 100 meters. Although the GPS system was originally designed for military use only, due to an airplane accident in 1983 this signal was released by President Reagan for aviation and other transportation applications.

The signal may be used by everyone without charges or restrictions. The signal can be supported by a ground station in order to create a higher accuracy. The exact location of the ground station is known, and it recalculates the signal, so that the error the US-DoD has put into the signal is gone, and it may even create a better signal than the original PPS signal.

This utilisation of GPS is called DGPS. The receiver used gets extra information through :

- A local support signal. This option can only be used for professional applications. A local station costs up to about 6.000 dollar (Dfl. 10.000). The low cost is an advantage and this option is used by several airports, to improve the control over flight traffic. The error that is made this way is usually less then 1 meter.

- FM-transmitters with RDS With the help of the RDS signal a lot of information can be send over the FM band. This signal can also be used to send DGPS information. The use of this system is relatively simple, because a simple FM-receiver can be designed and build for use with this system. It does require a small number off DGPS transmitters is.
- Long wave transmitters with AMDS For the AM frequency band a RDS system was designed also, called AMDS. This system has the same possibilities as the FM system, only the amount of information is smaller than it is with the use of regular RDS. The range of an AM-transmitter is much larger, therefore the use of this system is a good option for cheap use of DGPS. A disadvantage of this system is the possible lower accuracy, because the distance from the ground station to the receiver is large.
- Long wave services Next to public DGPS services there is a possibility to use a signal created by a private company, for use with their equipment only.

By using the given options for DGPS, it is possible to accurately determine the position of a receiving party.

2.17 GPS Positioning Signals

GPS satellites transmit two L-Band signals which can be used for positioning purposes. The reasoning behind transmitting using two different frequencies is so that errors introduced by ionospheric refraction can be eliminated.

The signals, which are generated from a standard frequency of 10.23 MHz, are L1 at 1575.42 MHz and L2 at 1227.60 MHz and are often called the carriers.

The frequencies are generated from the fundamental satellite clock frequency of f=10.23 MHz.

Signal	Frequency (MHz)	Wavelength (cm)
L1	$154f_o = 1575.42$	~19
L2	$120f_o = 1227.60$	~24

Since the carriers are pure sinusoids, they cannot be used easily for instantaneous positioning purposes and therefore two binary codes are modulated onto them: the C/A (coarse acquisition) code and P (precise) code.

Also it is necessary to know the coordinates of the satellites and this information is sent within the broadcast data message which is also modulated onto the carriers.

For purposes of imposing the binary data onto the carriers, all of the codes are transferred from the 0 and 1 states to the -1 and 1 factors respectively.

The broadcast data message is then modulo-2 added to both the C/A code and the P code. This inverts the code and has the effect of also inverting the autocorrelation function.

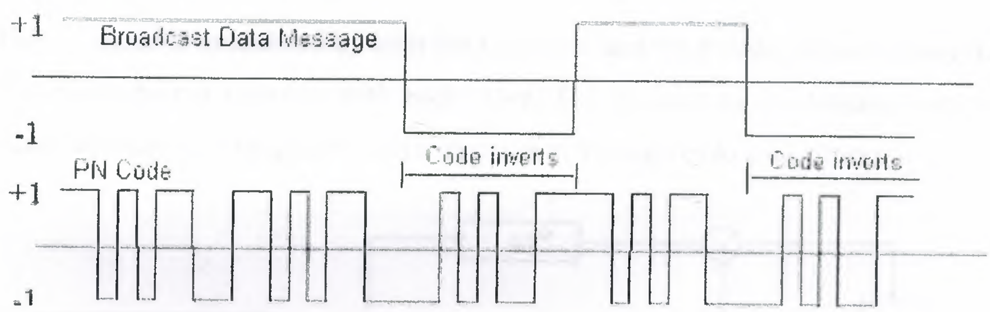


Fig 2.7 Modulo-2 Addition

Binary biphase modulation (also known as binary phase shift keying [BPSK]) is the technique that is used to modulate the codes onto the initial carrier waves.

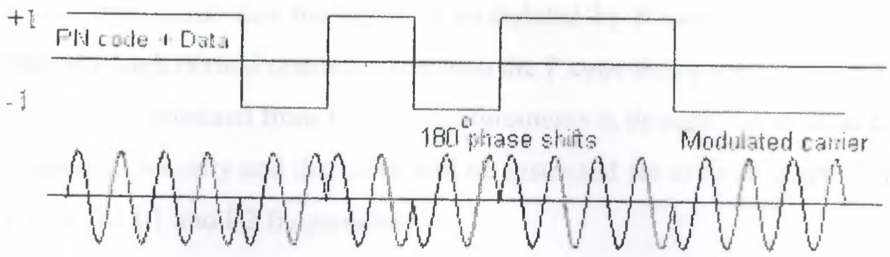


Fig 2.8 Binary Biphase Modulation

The codes are now directly multiplied with the carrier, which results in a 180 degree phase shift of the carrier every time the state of the code changes.

The modulation techniques also have the properties of widening the transmitted signal over a much wider frequency band than the minimum bandwidth required to transmit the information which is being sent (Pratt, 1992). This is known as spread spectrum modulation and has the benefits of developing processing gain in the de-spreading operation within the receiver, and it helps prevent possible signal jamming.

The L1 signal is modulated by both the C/A code and the P code, in such a way that the two codes do not interfere with each other. This is done by modulating one code in phase and the other in quadrature (ie they are at 90 degrees to each other).

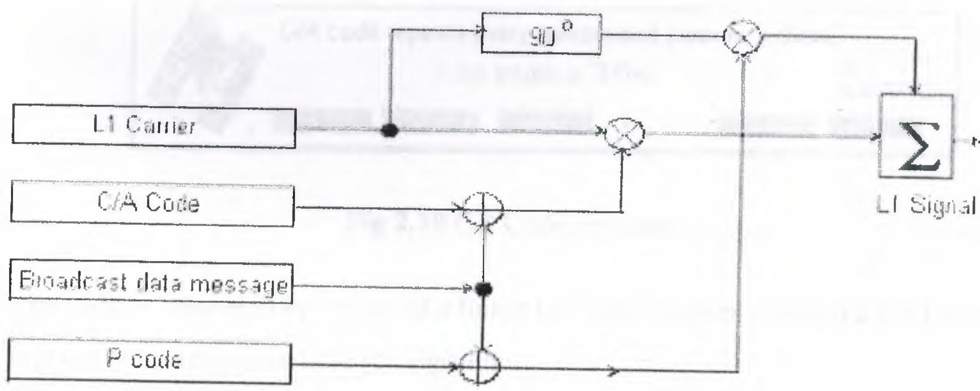


Fig 2.9 L1 Signal Structure

The C/A code is also amplified so that it is between 3 and 6 dB stronger than the P code.

For L2, it is stated that the signal is modulated by P code or the C/A code (Spilker, 1980) although normal operation has seen the P code being used. It should be noted that the precision obtained from P code measurements is thought not to be in the interests of US national security and therefore will be restricted for civilian users. This is the same for both the L1 and L2 frequencies.

2.18 C/A Code

The C/A code is a pseudo random (PN) binary code (states of 0 and 1) consisting of 1,023 elements, or chips, that repeats itself every millisecond.

The term pseudo random is used since the code is apparently random although it has been generated by means of a known process, hence the repeatability.

Due to the chipping rate (the rate at which each chip is modulated onto the carrier) of 1.023Mbps, the chip length corresponds to approximately 300m in length and due to the code length, the ambiguity is approximately 300km - ie the complete C/A code pattern repeats itself every 300km between the receiver and the satellite.

The C/A code can be thought of as a number of rulers extending from the satellite to the receiver. The length of each ruler is approximately 300km, and each graduation is 300m apart.

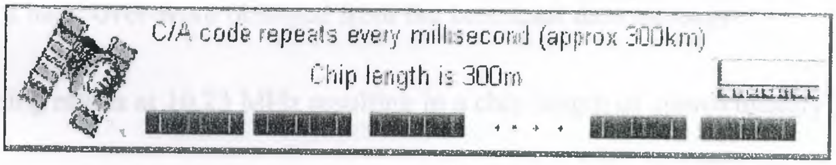


Fig 2.10 CA Code representation

The code is generated by means of a linear feedback register which is a hardware device representing a mathematical PN algorithm.

The sequences that are used are known as Gold codes which have particularly good autocorrelation and cross correlation properties. The cross correlation properties of the Gold codes are such that the correlation function between two different sequences is low - this is how GPS receivers distinguish between signals transmitted from different satellites.

2.19 P Code

The P code, or precise code, is a long binary code that would repeat only every 38 weeks (Pratt, 1992).

Despite the code being shortened to a one week repeatability because each satellite transmits a different weekly section of the code, there is still no ambiguity between the satellite and receiver.

The P code can be thought of as a ruler extending from the satellite to the receiver. The length of the ruler is approximately one week multiplied by the speed of light, and each graduation is 30m apart.

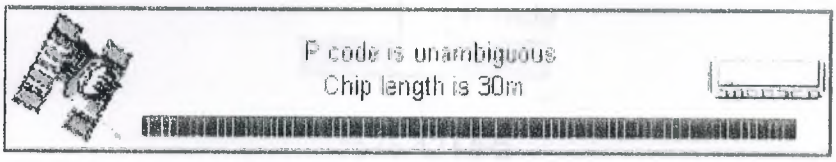


Fig 2.11 P code representation

Rapid access to the relevant part of the code for a particular satellite is carried out by means of a hand-over-word obtained from the broadcast data message.

The chipping rate is at 10.23 MHz resulting in a chip length of approximately 30 m.

2.20 Converting Noise to Signal

The signal is immediately passed through a high-pass filter that rejects all parts of the signal which are not within the L1 bandwidths (typically a filter with a central frequency of 1575.42 Mhz and bandwidth of 20 MHz) and this results in the radio frequency (RF) signal. The signal is then modulated with a sinusoid generated by the local oscillator, resulting in the generation of a signal with two different frequency components.

The frequency produced by the local oscillator is selected so that a signal at a low frequency (approximately 40 KHz) will be created. This lower frequency is then separated by passing the signal through a low-pass filter which will also eliminate some further noise. The bandwidth of this filter is dependent on the type of measurements that are required. If the P code is required, the bandwidth will be set to approximately 20 MHz (the distance between the first) and will be around 2 MHz if only the C/A code is tracked. The remaining analogue signal (known as the IF, or intermediate frequency signal) is then sampled as fast as possible to convert it to a digital form. An in-phase (I) and quadrature (Q) sample of the signal is generated by further sampling with an in-phase and a delayed (by 90deg) frequency from the local oscillator.

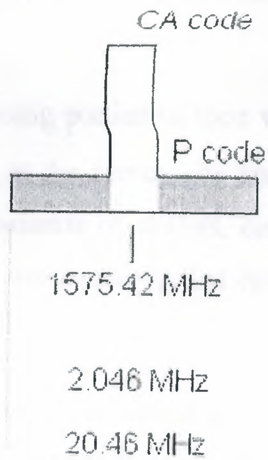


Fig 2.12 frequencies of P code and C/A code

3. APPLICATION OF GPS

3.1 Who uses GPS?

GPS has a variety of applications on land, at sea and in the air. Basically, GPS is usable everywhere except where it's impossible to receive the signal such as inside most buildings, in caves and other subterranean locations, and underwater. The most common airborne applications are for navigation by general aviation and commercial aircraft. At sea, GPS is also typically used for navigation by recreational boaters, commercial fishermen, and professional mariners. Land-based applications are more diverse. The scientific community uses GPS for its precision timing capability and position information.

Surveyors use GPS for an increasing portion of their work. GPS offers cost savings by drastically reducing setup time at the survey site and providing incredible accuracy. Basic survey units, costing thousands of dollars, can offer accuracies down to one meter. More expensive systems are available that can provide accuracies to within a centimeter.

Recreational uses of GPS are almost as varied as the number of recreational sports available. GPS is popular among hikers, hunters, snowmobiles, mountain bikers, and cross-country skiers, just to name a few. Anyone who needs to keep track of where he or she is, to find his or her way to a specified location, or know what direction and how fast he or she is going can utilize the benefits of the global positioning system.

GPS is now commonplace in automobiles as well. Some basic systems are in place and provide emergency roadside assistance at the push of a button (by transmitting your current position to a dispatch center). More sophisticated systems that show your position on a street map are also available. Currently these systems allow a driver to keep track of where he or she is and suggest the best route to follow to reach a designated location.

3.2 Tracking Vehicle using GPS

Vehicle tracking using GPS (Global Positioning System) is fully integrated into the VTS (Vehicle Tracking System).

The vehicle to be tracked is fitted with a GPS receiver and a small antenna. GPS satellites are continuously transmitting a radio message containing information including when the data was sent, which satellite sent it and the current reliability of the system. The GPS receiver fitted in the vehicle receives information from at least 4 satellites and carries out the necessary calculations to determine its current position.

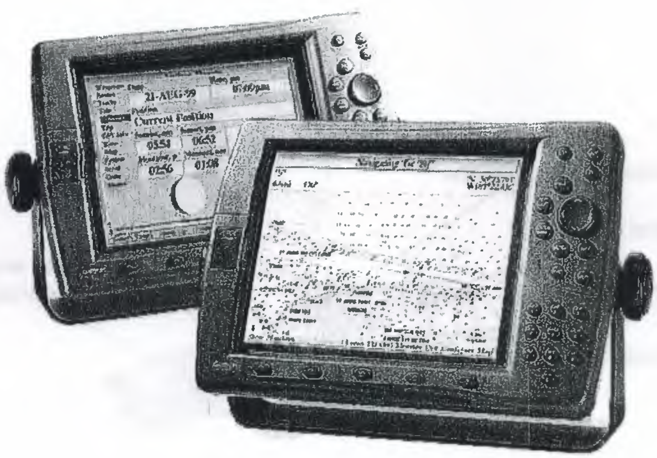


Fig 3.1. GPS 20102map receiver

3.3 GPS Applications

One of the fast-growing GPS applications is vehicle tracking. GPS-equipped fleet vehicles, public transportation systems, delivery trucks, and courier services use receivers to monitor their locations at all times. Public safety services, police, fire, and emergency medical services, are using GPS receivers to determine the nearest service vehicle to an emergency, enabling the quickest response in critical situations. Recently automobile manufacturers are installing moving-map displays guided by GPS receivers. For example, several Florida rental car companies are demonstrating GPS-equipped vehicles that give directions to drivers on display screens and through synthesized voice instructions.

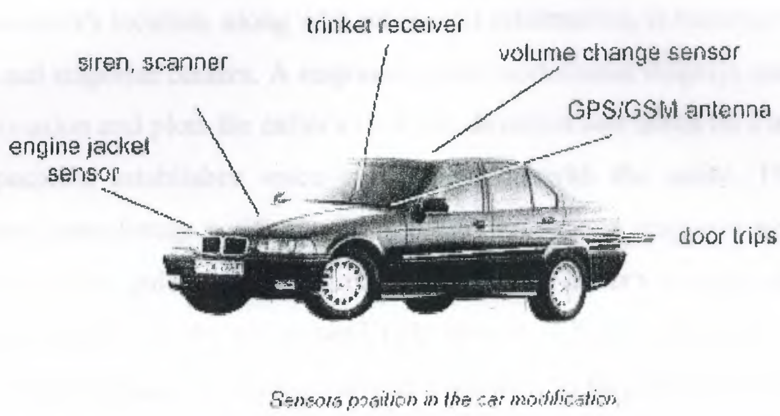


Fig 3.2 Sensors position in the car

3.3.1 Emergency services

When unexpected troubles threaten drivers, offering daily, around-the-clock service. Our response specialists are extensively trained and experienced in handling a variety of emergency situations.

3.3.2 Automatic Collision Notification:

If a vehicle's airbags or collision detection sensors are activated, ATX is automatically notified. The ATX national response centre then contact the vehicle occupants via the voice channel into the vehicle to ascertain if emergency assistance is required. If there is no response, an ATX response specialist will notify the appropriate 9-1-1 dispatch centre of the vehicle's location. Utilizing information from the vehicle's sensors such as the number and location (rear, front, or side) of airbags deployed and the type and severity of impact, ATX can provide immediate notification to emergency responders. Response specialists can also provide emergency agencies with life-critical information that can determine the emergency personnel needed -- even without the assistance of the vehicle's occupants. Automatic collision notification also holds tremendous promise in providing emergency responders with potentially quicker notification of an accident as well as additional crash data that can help determine and enhance the type of emergency rescue dispatched.

3.3.3 Emergency Response:

In the event of an emergency, a subscriber activates the emergency button in their vehicle. The caller's location, along with other vital information, is transmitted to one of ATX's national response centers. A response center workstation displays the customer's profile information and plots the caller's location, direction and speed on a map, while a response specialist establishes voice communication with the caller. The response specialist can immediately notify the appropriate emergency response agency in the vicinity of the caller, guide emergency responders to the caller's location and maintain direct voice contact with the caller until help arrives. All of this occurs without the driver ever having to pick up a handset or dial a number. In fact, they don't even need to know where they are. According to a study by Driscoll-Wolfe Marketing Research, of the 83,000 wireless phone users placing 9-1-1 wireless calls, a third are from callers who don't know their location.

With any emergency response or roadside assistance call, ATX response specialists can notify third parties, such as a family member or friend, that a subscriber has been involved in an emergency. In the event of an automatic collision notification, third party notification is automatic. Subscribers designate third-party contacts upon enrolment.

3.3.4 Basic Roadside Assistance:

When motorists experience a problem with a vehicle's mechanical system, a flat tire, or empty gas tank, they simply push a button to summon help. An ATX Response Specialist makes voice contact with the driver and directs the driver's roadside assistance provider to the vehicle's exact location.

3.3.5 Enhanced Roadside Assistance:

When in trouble, a caller can press a special roadside-assist button, which takes ATX's ability to integrate voice and geographic data to a higher informational level. ATX appends the subscriber's profile and location with mapping details and routes them directly to the roadside assistance provider, alleviating the need for intervention by an ATX response specialist, on-line transfers or extended holding times. This feature offers more efficient customer service and greater operational effectiveness.

3.3.6 Remote Door Unlock:

Drivers monitored by ATX don't have to wait for a locksmith to arrive. They simply phone ATX to request remote unlocking service through our automated voice response system. We then send a signal to unlock the car door at the exact time the driver has indicated.

3.3.7 Stolen vehicle Tracking:

When a vehicle is reported stolen or missing, the basic features of the system allow the ATX response specialist to locate and check on the automobile. Once the vehicle is confirmed stolen and appropriate police involvement is engaged, ATX can lead the police directly to the missing vehicle. For legal and safety reasons, ATX will not lead the vehicle owner to a suspected stolen car without police involvement.

3.3.8 Security System Notification:

ATX can notify a subscriber when his or her vehicle's security system has been activated and can initiate tracking upon verification of the theft. This service has both business and consumer applications.

The general purposes of security subsystem are:

- · Sensors controlling.
- · Checking sensors state
- · Checking sensors integrity.
- · Converting analog signals (from analog sensors) to digital.
- · Collecting data from sensors.
- · Packing data and transmitting to the main system.
- · Receiving command from main system.
- · Controlling the vehicle manipulators.

The security subsystem provides large opportunities against hijacking your car. It consists of group of different sensors and manipulators. SYNAPSE (kind of GPS equipment) provides possibility of long distance control of security subsystem through WEB interface or GSM/GPRS network.

What could be included?

- · Lock unlock door sensors
- · Field disturbance sensor
- · Electronic hood lock
- · Audio sensor
- · Control start system
- · Electronic gasoline valve
- · Infrared based remote control system with dynamic floating key code
- · Different kinds of wireless sensors

3.3.9 Geo-Fencing:

An ATX subscriber can request placement of an electronic "fence" around their vehicle for theft protection. If the vehicle moves out of the "fenced area," the ATX Response Center will be notified and take appropriate action.

3.4 Information Services:

An individual's need for information doesn't end just because he or she has left the office. ATX sees mobile individuals as "nodes on a network," and we're developing services to help keep customers connected and informed at any time and under any circumstance.

3.4.1 Messaging Services:

ATX is developing a connectivity service where email, pages or other short messages may be sent to a vehicle or mobile device. This feature operates like those that exist today using technologies like SMS (a.k.a. Short Messaging Services) or other similar types of messaging technologies that many cellular service providers use today. This option may be activated or non-active based on the user's preference. The user may also have the option of defining the number of characters to be sent as well as block emails or messages from individuals that do not wish to have forwarded or sent to their vehicles or mobiles.

3.4.2 Vehicle Operating Information:

Vehicle Operating Information benefits both subscribers and the automobile OEM. This service gives customers the ability to schedule simple diagnostics such as notification of service needs or recalls. They can also get these messages on-demand. In addition to the convenience and safety benefits, vehicle operating information services can provide real-time maintenance and repair to the manufacturer, which will reduce the cost of vehicle warranty coverage and provide unique dealer sales and relationship marketing opportunities. ATX is working with its automotive OEM customers to develop and offer other such services.

3.4.3 Information Services:

Information Services like news, weather, financial and sports are designed to meet the mobile individual's need for timely, location-enhanced information. Utilizing an Internet interface, users will be able to select and set up a personalized set of information services from their personal web page. Based on their customized profile settings, ATX will deliver the requested information to the vehicle, mobile device, or home email or web page.

These services will also be connected to an internet profile where the user can set up routine delivery times, select information to be sent in-vehicle, and make requests for other specific non-time sensitive information to be sent to their vehicle at a later time. Additionally, requests for more time-critical information will also be taken into account.

3.5 Military Uses for GPS

Although the GPS satellite constellation was completed only recently, it has already proved to be a most valuable aid to U.S. military forces. Picture the desert, with its wide, featureless expanses of sand. The terrain looks much the same for miles. Without a reliable navigation system, U.S. forces could not have performed the maneuvers of Operation Desert Storm. With GPS, the soldiers were able to go places and maneuver in sandstorms or at night when even the troops who lived there couldn't. Initially, more than 1,000 portable commercial receivers were purchased for their use. The demand was so great that, before the end of the conflict, more than 9,000 commercial receivers were in use in the Gulf region. They were carried by foot soldiers and attached to vehicles, helicopters, and aircraft instrument panels. GPS receivers were used in several aircraft, including F-16 fighters, KC-135 aerial refuelers, and B-2 bombers; Navy ships used them for rendezvous, minesweeping, and aircraft operations.

GPS has become important for nearly all military operations and weapons systems. In addition, it is used on satellites to obtain highly accurate orbit data and to control spacecraft orientation.

GPS is based on a system of coordinates called the World Geodetic System 1984 (WGS 84), similar to the latitude and longitude lines you see on wall maps in school. The WGS 84 system provides a built-in frame of reference for all military activities, so units can synchronize their maneuvers

Fig 3.3 More than 9,000 GPS receivers were used by U.S. and coalition forces during Gulf war

3.6 Example of GPS receivers

3.6.1 Handheld

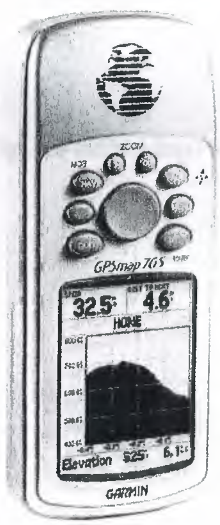


Fig 3,4 GPS Map 76

Fig 3.5 GPS III P

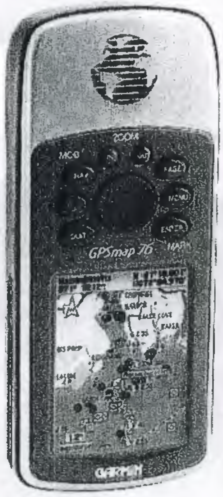


Fig 3.6 GPS Map76s

3.6.2 Sounder

Fig 3.7 GPS Map 188188c

Fig 3.8 GPS map 238s

3.6.3 Fishfinder

Fig 3.9 Findfisher160

Fig 3.10 Findfisher 100 PIC

3.6.4 2 way communication

Fig 3.11 rino110

4-DIFFERENTIAL GPS SYSTEM

4.1 What is DGPS?

Differential GPS is a method of increasing the accuracy of positions derived from GPS receivers. With DGPS receivers, position accuracy is improved, going from 30 metres to better than 10 metres.

This method has been found to overcome these induced errors and also to improve natural ones (mainly ionospheric). This technique is known as Differential GPS (DGPS). DGPS uses a separate static base station; since this station knows its own co-ordinates precisely it can look at the transmitted GPS data telling it where it is and see how much error has been induced. It then transmits this new information from the base so that real GPS users can receive this and use it to increase the accuracy of their own co-ordinates to a considerably better degree.

Differential GPS (DGPS) is the blanket term for a number of different systems that have evolved to overcome the inaccuracies caused by SA and the physics involved in sending radio signals through the earth's atmosphere. These systems are separated into two classifications:

Real-Time Differential, and Post Processed Differential

- Real-Time Differential, is correction where signals are received from the differential provider, and used by the receiver at the same time as signals from the GPS satellite are received to calculate a much more precise position instantaneously.

- Post Processing, is Differential correction that takes place after the fact: the GPS data collected in the field is saved, and the Differential correction is added at a later date.

4.1.1 Real Time Differential

Real time Differential correction requires a receiver designed for use with a real time differential service. Often different service providers have their own receiver, or they supply an auxiliary unit which will feed the Differential correction into the receiver. Real time Differential services broadcast an extra signal, which allows a GPS receiver to cancel out many of the errors inherent in GPS signals. Some of these services use their own satellites, and some have ground stations sprinkled around the covered area. Some services combine the two. Unlike GPS itself, Real time Differential services do not necessarily provide a global blanket.

Real time Differential provides some significant gains in accuracy, with sub-meter accuracy available. Because of this accuracy, some issues come to light. HDOP is an acronym for *Horizontal Dilution of Precision.* This is caused when the satellites are in a poor geometric configuration. By setting an HDOP mask, signals can be ignored if they don't satisfy a minimum requirement. Latency is the amount of time since the last Differential correction signal was received. By setting a maximum latency, old signals can be disallowed. Finally, with high accuracy, antenna height must be taken into account, if the position of the ground is the intended location.

4.1.2 Post Processing

Post Processing works on the principle that if the exact location of a place is known, then the size of the SA distortion can be determined for each GPS signal. If correction information is then broadcast to local receivers set up to deal with it, significant improvement in accuracy can be achieved by storing GPS readings for subsequent computerized correction. This FieldWorker screen shot illustrates some common options when saving GPS data.

The disadvantage of post processing is that it is not as reliable as real time. While the field workers are out collecting data, the base station may go down without their knowledge. They would then return from their trip to find that there are no correction signals. At this point, they would have to go back into the field and redo their data collection. Another disadvantage is that post processing software has to be set up on a desktop machine, someone has to be trained to operate it, and then all of the data has to be processed. With real time, the data is already stored with the high accuracy positions. Real time is just like having a highly accurate normal receiver.

We have compiled information on real time Differential service coverage, including maps where possible, that we try to keep as complete as we can. They are only to give an indication of the extent of GPS coverage. For up-to-date information, contact the service providers directly.

4.2 DGPS Broadcast Standard for Marine Navigation in Canada

The Canadian Coast Guard Differential Global Positioning System (DGPS) Broadcast Standard is a reference document which specifies the format, information content, modulation parameters, coverage area, and use of the signal which is broadcast from a network of Canadian Coast Guard operated marine radio beacons. This network is planned to primarily provide coverage to coastal areas, major Canadian waterways, Vessel Traffic Services zones and ports. It will also overlap US DGPS coverage of contiguous waters.

This Standard also specifies the system performance which can be achieved with the use of proper DGPS user equipment. Key performance and functional elements essential for the user equipment suite are addressed.

4.2.1 Signal Scope

The Canadian DGPS Navigation Service augments the Navstar Global Positioning System (GPS) by providing localized pseudo range correction factors and ancillary information which are broadcast over a network of strategically located MF marine radio beacons. This service will provide the mariner with a horizontal accuracy of 10 meters or better, 95 % of the time in all coverage areas.

The user equipment receives system status and data updates on a continuous basis. The DGPS Reference Station utilizes a NAD 83 datum for its antenna surveyed position. Therefore, the user equipment suite will compute the NAD 83 Datum when operating in the differential mode. The DGPS Navigation Service not only enhances the accuracy of the Standard Positioning Service (SPS), but also provides a real time integrity, monitoring and reporting (for further information on the SPS, see the Global Positioning System Standard Positioning Service Signal Specification dated November 5, 1993, published by the US Department of Defense).

DGPS transmissions will be broadcast in the 285 KHz to 325 KHz band which is allocated for maritime radio navigation (radio beacons). Marine radio beacons will be exclusively used to broadcast DGPS signals on the main carrier using Minimum Shift Keying (MSK) Modulation. There will be no radiobeacon identity tone. The modulated signal will contain DGPS information and the identification of the transmitting DGPS station.

Figure 4.1 contains a system concept of the DGPS Navigation Service. A typical DGPS station comprises control stations (CSs), reference stations (RSs), their associated integrity monitors (IMs) to ascertain the status and the integrity of the broadcast, and the MF radio beacon transmitter to broadcast DGPS information to users. A control monitor (CM) located at a 24 hour staffed Coast Guard operational site maintains two way communications via dial up lines with the DGPS stations. The CM monitors the status of the system.

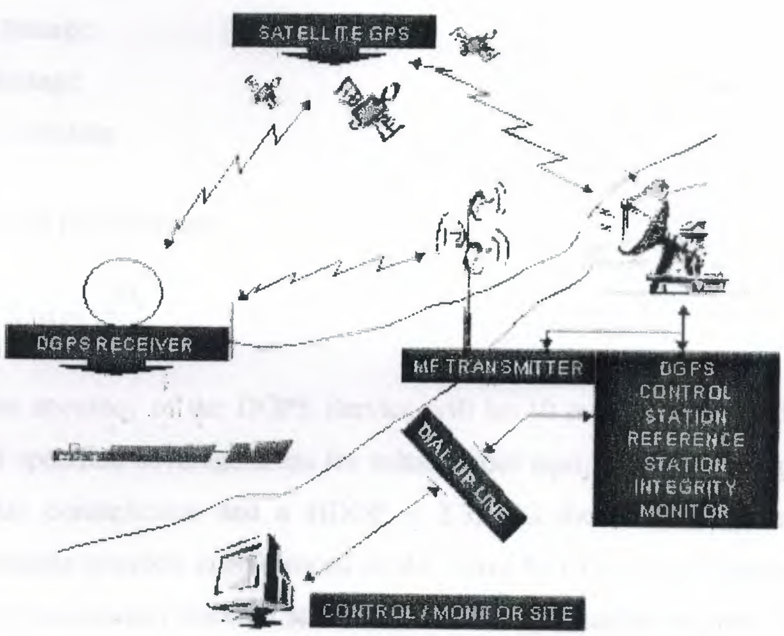


Fig 4.1 DGPS System

4.2.2 Signal Format

The broadcast data consists of a selected subset of the message types contained in the RTCM Special Committee No. 104, "Recommended Standards for Differential Navstar GPS Service", dated January 3, 1994 herein referred to as "RTCM SC104". All selected message types will be broadcast in the format of this document unless otherwise noted or amended by a later version.

Message Types

Message Header

Type 3 Message

Type 5 Message

Type 7 Message

Type 9 Message

Type 9-1 Message

Type 9-3 Message

Type 16 Message

Message Scheduling

4.2.3 System Performance

4.2.3.1 Accuracy

The position accuracy of the DGPS Service will be 10 meters (95% of the time), or better in all specified coverage areas for suitable user equipment (assuming the full 24 GPS satellite constellation and a HDOP < 2.3). As the DGPS Reference Station surveyed antenna position is referenced to the NAD 83 Coordinate System, the user's differentially determined position solution is inherently transformed into the NAD 83 Coordinate System. The user equipment suite need not perform any datum conversion from WGS-84 when working with NAD 83 Charts within the service area.

4.2.3.2 Availability

A satisfactory DGPS broadcast is defined as one that is

- healthy,
- the PRC time out limit for at least four satellites has not been reached, and
- the DGPS Station ID number checks out against that in the beacon almanac.

A user is primarily concerned with being able to receive a satisfactory DGPS broadcast with minimal disruption. Known as user availability, this parameter is a function of three components:

- the reliability of the DGPS station;
- the effect of atmospheric noise preventing user equipment from receiving an otherwise healthy DGPS broadcast.
- whether a user is in a standard/enhanced coverage or in a multiple coverage area.

The first component of user availability depends on the reliability of the entire set of DGPS broadcast station equipment. Known as broadcast reliability, it is specified to be at least 99.7%. A user may view this reliability as the probability that the DGPS broadcast is providing healthy DGPS corrections at a specified power when a user selects that particular broadcast.

The second component of user availability is called broadcast availability. As atmospheric noise varies over time and region, modeling to derive signal availability's at the various DGPS broadcast station sites using CCIR noise. This process also estimates the required effective radiated power for each radiobeacon transmitter and the coverage region in which this availability is assured. Broadcast availability will be at least 99% at the edge of the advertised coverage area for a DGPS station.

The third component will provide the best service availability since service will still be available from an alternate DGPS station in the event of a total DGPS station failure.

Prolonged empirical DGPS data collection and operational experience will be needed in order to arrive at an accurate user availability figure.

A DGPS broadcast is considered to be healthy if it meets the following requirements:

1. The protection limit has not been exceeded;
2. The broadcast is monitored;
3. The RS receives a correct RS ID;
4. The IM position error is within the position threshold.

4.2.4 DGPS Broadcast station design

Redundancy of equipment is provided in order to attain the 99.7% equipment reliability. Figure 4.2 is a representative DGPS Station configuration.

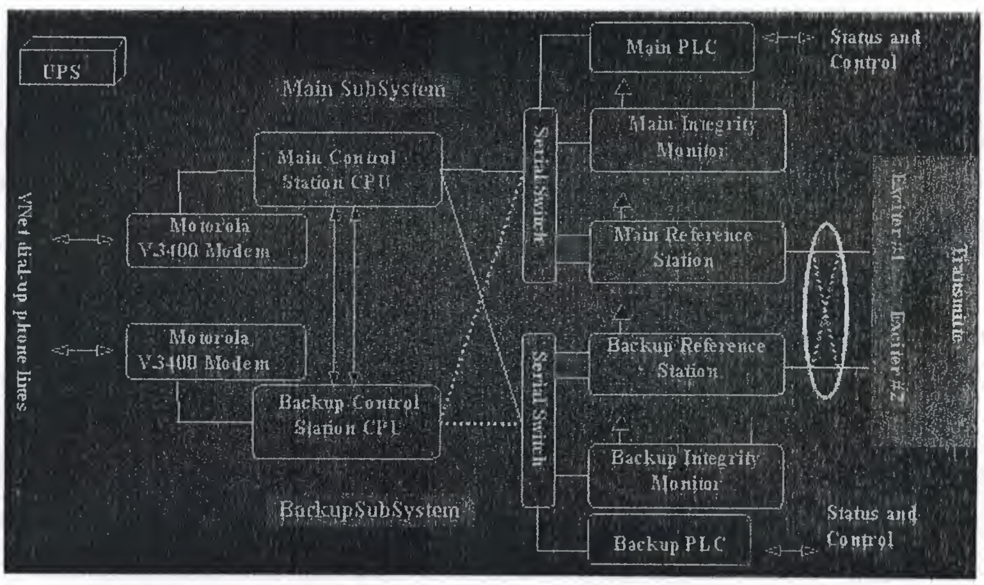


Fig 4.2 DGPS Station Configuration

The Reference Station (RS) and Integrity Monitor (IM) operate autonomously. In the event of a RS or IM malfunction, the redundant equipment should come on line either through the control station (CS) or by commands from the control monitor (CM). Restoration of DGPS signal transmission in the latter case will take longer as it requires operator instructions.

4.2.5 DGPS Broadcast coverage

4.2.5.1 Broadcast Coverage

DGPS coverage performance is adversely affected by atmospheric and man-made noise that falls within the radiobeacon's bandwidth. Experience has shown that the noise level in inland areas is considerably higher than in offshore areas. Therefore, two levels of advertised coverage are provided:

4.2.5.2 Offshore Coverage

The service area of each DGPS broadcast will be defined as the area within which the DGPS signal strength is at least 75 mv/m or signal availability is at least 99% in average yearly noise conditions, whichever is the more stringent criteria.

4.2.5.3 Inland Coverage

The service area of each DGPS broadcast will be defined as the area within which the DGPS signal strength is at least 100 mv/m or signal availability is at least 99% in average yearly noise conditions, whichever is the more stringent criteria.

All Canadian radiobeacons broadcast at 200 bits per second, regardless of whether they provide inland or offshore coverage.

Overlapping coverage from adjacent Canadian and American radiobeacons is available in many areas.

A list containing details of DGPS broadcast stations and their respective *advertised* coverage areas are given in *DGPS Reference Stations Table*

4.3 Station Selection

The latency of a pseudorange correction increases and the position accuracy consequently degrades, when there is a weak and less reliable DGPS signal. This will usually occur when a vessel navigates beyond the edge of an advertised DGPS coverage. Another error contribution due to spatial decorrelation, becomes pronounced when a broadcast emanating from a DGPS Station more than 260 nautical miles from the vessel is used. The user should be aware of these factors when using a broadcast from a DGPS Station.

An unhealthy broadcast should not be used under any circumstances.

The user equipment suite will encounter three DGPS station selection scenarios in Canadian waters:

- user is within the advertised coverage of one CG designated DGPS Station.
- user is within the advertised coverage of two or more CG designated DGPS Stations.
- user is outside the advertised coverage of any DGPS Station.

In the first scenario, the user equipment suite should use the broadcast from the designated DGPS station and continually monitor its health and various parameters.

The second scenario occurs in a multiple coverage area. In a limited number of locations where several broadcasts are available, the closest one may not necessarily be the one with the highest received power. The closest station, provided it is healthy, should be used even if it&'s signal strength is low relative to other received signals. The alternate designated DGPS Station(s) will be selected in the event that the broadcast from the closest station becomes unhealthy or unmonitored. If the alternate designated DGPS Station also becomes unhealthy, it should attempt to check out the status of the "faulty" designated DGPS Station(s) before attempting to scan for a satisfactory broadcast from a non-designated DGPS Station, as in the guidelines described below.In the third scenario where there are no designated DGPS Stations, the user equipment suite should use a satisfactory broadcast from the nearest DGPS Station, subject to the applicable constraints in the guidelines described below.

The following guidelines should be used in seeking a satisfactory broadcast:

- scan for and use a satisfactory broadcast from the nearest non-designated DGPS Station);
- a satisfactory broadcast emanating from a DGPS Station more than 260 nautical miles away should be used with caution.; and
- an unmonitored broadcast of any DGPS Station should be used with caution.

4.4 System Operation

4.4.1 System Integrity

System Integrity depends on the ability of:

- the DGPS station to provide a satisfactory broadcast;
- the system to alert the user of any out of tolerance or unhealthy conditions in the DGPS corrections; and
- the user equipment suite to process the DGPS alarms.

The reference station is augmented by a collocated integrity monitor (IM). The IM verifies the accuracy of the broadcast PRCs at the pseudorange and positional levels. In essence, by knowing its own surveyed (GPS antenna) location, the IM is able to assess whether the broadcast PRCs and derived DGPS positions are within certain specified limits, and if not, will alert the 24 hour staffed control monitor (CM) and the user. As part of augmenting system integrity, the DGPS station sends routine station status messages every half hour and any alarm messages to the CM.

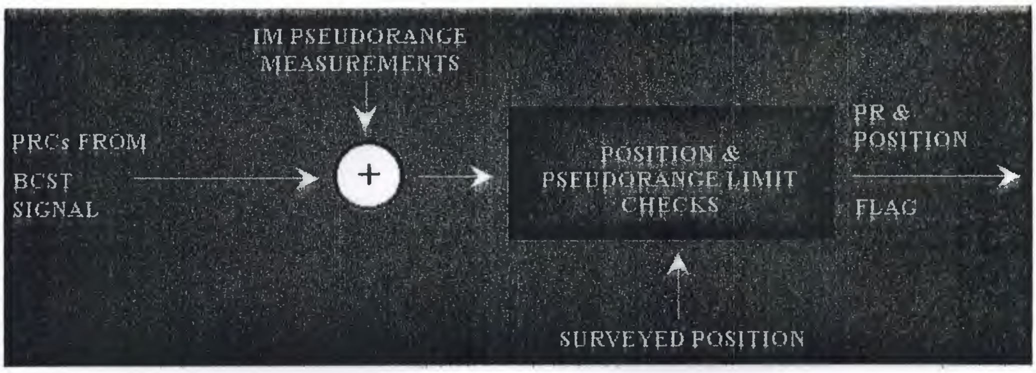


Fig 4.3 Integrity Monitor Process

The integrity monitor (IM) performs integrity verification of pseudorange and positional accuracies, and takes appropriate action as described below:

1. If the pseudorange residual is high, a pseudorange alarm is broadcast by the setting of the PRC(to) Field to a value of binary 1000 0000 0000 0000 along with the setting of the RRC Field to a value of 1000 0000. Should the user equipment suite detect either one of these settings it should immediately stop applying any PRC derived information for that satellite until the alarm condition ends. This broadcast will occur for a maximum thirty second period.
2. For positional verification, a protection limit for the over determined (position) solution shall be set at the IM to warn the user in the event that the accuracy is out of specified tolerance. The IM utilizes the broadcast UDRE values to weight the pseudoranges in computing the over determined solution. The known position of the IM is not included in the overdetermined solution which it computes. If the set value is exceeded after a defined interval, the broadcast will become unhealthy. The time from when a protection limit is exceeded to when the user equipment suite/user is alarmed by the broadcast will not exceed ten seconds. This time includes the length of the longest possible message and the header of the following message. The use of the Type 9 message as the exclusive PRC message results in these low time to alarm values.

4.4.2 DGPS System Failure / Default Mode

A system failure is said to occur when any one of the following conditions apply:

- unhealthy broadcast;
- absence of pseudo range corrections in message transmission;
- unmonitored broadcast (e.g. integrity monitor failure);
- no broadcast.

If the reference station receiver can no longer generate pseudo range corrections, a Type 6 Message will be broadcast in which the message header will be set to indicate an unhealthy condition. A Type 16 message will also be issued. In the case where the reference receiver cannot generate Type 6 Messages, a single tone will be broadcast.

If a radio beacon can no longer transmit any information, this condition will be broadcast to the user as a Type 16 Message via adjacent marine radio beacons. Should any of the above mentioned system failure conditions occur, an updated Type 7 Message for all surrounding DGPS stations will be generated and broadcast by the appropriate marine radio beacons in the area.

Modulator failures may result in the broadcast of alternating ones and zeros, a single carrier tone, or no output at all.

Table 4.1 Summary of the abnormal conditions

Abnormal Conditions at Reference Station	Reference Station Action	Adjacent Reference Station Action
No PRC	Issue Type 6, 16 & Updated 7	Issue Updated Type 7, 16
No RTCM messages	Issue Single Tone	Issue Updated Type 7, 16
No Output e.g. Cable Cut	-	Issue Updated Type 7, 16
Modulator Failure	Issue Tone Or Alt. 1s/ 0s, Or No Output	Issue Updated Type 7, 16
Unmonitored	Issue Info. in Header & Type 7, 16	Issue Updated Type 7, 16
Unhealthy	Issue Info. in Header & Type 7, 16	Issue Updated Type 7, 16
Low signal power	Issue Type 16	Issue Updated Type 16

The failures described above will be indicated in the header of all messages broadcast

By the affected station(s) where possible and in an updated Type 7 message by adjacent DGPS stations.A summary of the abnormal conditions described above is provided in Table 4.1 The user equipment should therefore need to be able to process all the messages outlined in Table 4.1.

If an out of tolerance condition is expected to continue for more than two hours a "Notice To Mariners" and/or "Notice to Shipping" will be issued as appropriate.

4.5 User Equipment Capabilities

In order to ensure end to end system integrity, the user equipment suite should have the following capabilities:

- receive and process all the various types of messages broadcast by the DGPS station.
- receive and process all the various messages at 200 bps, 100 bps and 50 bps;
- receive and process the various messages arising from out of tolerance and alarm conditions detected at the broadcast station site as described above;
- alert the user for pseudo range level alarms if an inadequate satellite constellation exists at that time in that user location;
- alert the user when the protection limit is exceeded.
- select automatically the appropriate radio beacon with priority given to proximity first and signal strength second;
- have a minimum of nine parallel channels to be used for GPS reception (recommended for navigation in restricted waterways); otherwise a minimum five channel receiver should be used for normal navigation;
- combine the UDRE values with localized error factors such as user receiver noise, interference, multipath, HDOP, and PRC latency in order to provide a confidence level about the user's displayed position;
- detect the absence of RTCM messages containing pseudo range corrections in the data stream and if available tune to a different marine radio beacon in advance of the "PRC Time Out Limit". The broadcast of alternating ones and zeros should not cause any false acquisitions since the subject broadcast will be listed as unhealthy by the Type 7 Message;
- display a textual message based on information in the header of any broadcast DGPS type message concerning unhealthy or unmonitored conditions existing at the reference station. Additionally, unhealthy or unmonitored conditions should cause a visual alarm to activate;
- Type 16 messages should also be treated in the same manner as in j);
- if a marine radiobeacon is utilized beyond 260 nautical miles the user equipment suite should display this condition in order to indicate that additional unaccounted for error components are present.

- retain the ability to process Type 9-1 messages at 50 bps rate in the event that SA is withdrawn permanently;
- retain the ability to process Type 1 messages in the event that SA is withdrawn permanently;
- discard all pseudo range corrections from the previous broadcast when switching broadcasts before utilizing any pseudorange corrections from the new broadcast;
- immediately stop applying any PRC derived information for a satellite until the alarm condition ends, when any pseudorange alarm messages are received from the DGPS station. This is accomplished by the setting of the PRC(to) field to a value of binary 1000 0000 0000 0000 and the RRC field to a value of 1000 0000;
- alert the user of positional alarms generated by the DGPS station due to a lack of healthy pseudo ranges because of insufficient satellites or a failure of the pseudo range weighting or monitoring functions. These conditions are indicated by the message header which allows the broadcast of an alarm without breaking frame synchronization;
- alert the user of an unmonitored condition alarm. This is indicated by the message header and will generally occur for duration's of only several minutes. During this time the redundant IM is used to perform an initial assessment of the broadcast before the status of the system returns to the monitored condition. As the hot and standby reference stations usually maintain a time base to within 15 ns of each other, the IM may be able verify the broadcast health status for the new reference station in a few seconds. However, if both IMs malfunction, the unmonitored condition can last for a prolonged period;
- stop using the pseudorange correction if its age exceeds 30 seconds since this PRC should not be applied to the user's navigation solution. When Type 9-3 Messages are broadcast at 200 bps the user would have to miss nine consecutive updates before the time out limit is reached for a given pseudo range; and
- exit the differential navigation mode and revert to GPS if there are insufficient satellites with valid pseudorange corrections

4.6 Reference Stations Table

In August 1996, the initial operational service (DGPS) of the CCG DGPS system began. DGPS corrections are broadcast from medium frequency radiobeacon transmitters located to cover selected marine areas and waterways. The broadcasts are in accordance with international standards for radiobeacon DGPS. DGPS provides continuous precision (better than 10 metres 95% of the time) positioning with suitable user receiver equipment properly installed and maintained. The broadcasts are continuously monitored for integrity. The performance of the DGPS service has not been validated and it should be used with caution. Validation testing will take place until late 1997 after which full operational service (FOS) will be declared. Additional stations are in the process of being added to the system. In addition, some test bed stations remain in operation. These signals are experimental and should not be used under any circumstances where system failure or inaccuracy could constitute a safety hazard.

Additional information on the use and operation of DGPS will be announced through *Notices to Mariners.*

The differential corrections are based on the North American Datum 1983 (NAD 83). Positions obtained using DGPS should be referenced to this datum.

Follow the links below to view maps showing station coverage and caracteristics. For practical reasons coverage is divided in following segments:

- Pacific Coast
- Great Lakes and St. Lawrence River
- Atlantic Coast

4.6.1 Station Coverage -Pacific Coast

This figure shows nominal coverage from DGPS broadcasts. Users should be aware that coverage is subject to short and long term variation due to environmental and seasonal conditions. Please note that the following map is not at scale and the coverage represented is approximate.

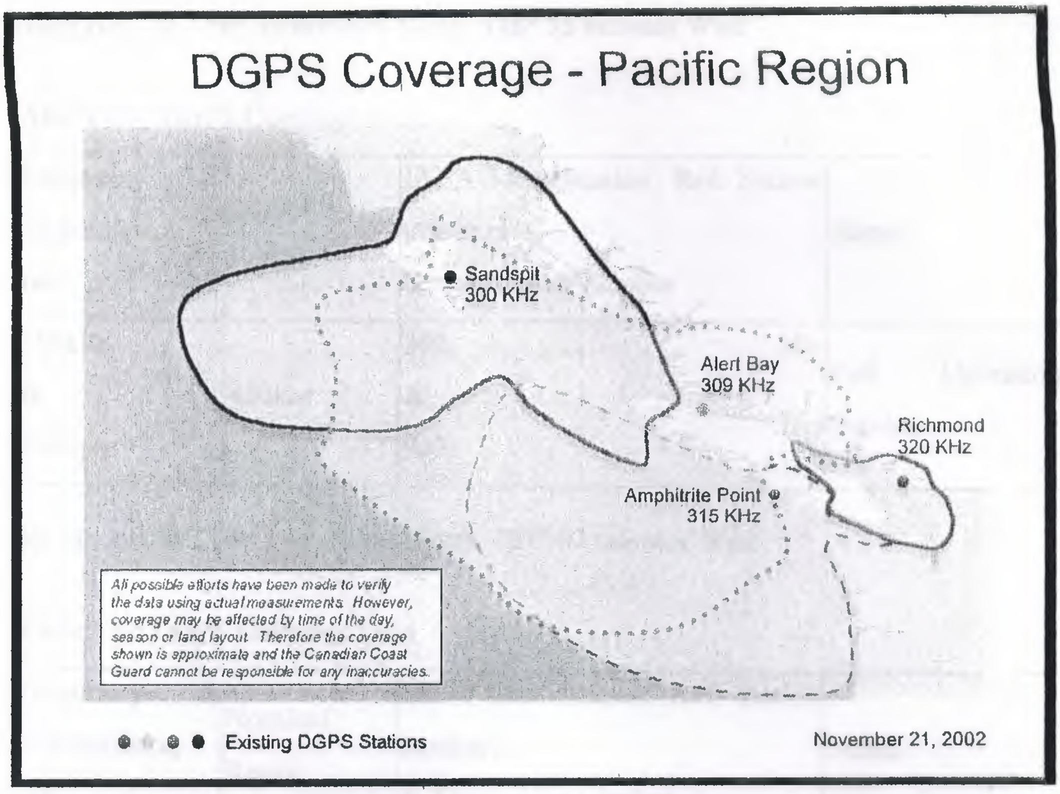


Fig 4.4 DGPS Coverage -Pacific Coast

Sandspit, BC, 53° 14 minutes North, 131° 49 minutes West

Sandspit DGPS Coverage Data

Frequency & Transmission rate	Nominal Range	IALA Identification, Ref. Station numbers & Transmitter number	Status
300khz & 200bps	350km	306, 307 & 906	Full Operational Service

Alert Bay, BC, 50° 35 minutes North, 126° 55 minutes West

Albert Bay DGPS Coverage Data

Frequency & Transmission rate	Nominal Range	IALA Identification, Ref. Station numbers & Transmitter number	Status
309khz & 200bps	450km	300, 301 & 909	Full Operational Service

Richmond, BC, 49° 11 minutes North, 123° 07 minutes West

Richmond DGPS Coverage Data

Frequency & Transmission rate	Nominal Range	IALA Identification, Ref. Station numbers & Transmitter number	Status
320khz & 200bps	170km	304, 305 & 907	Full Operational Service

Amphitrite Point, BC, 48° 55 minutes North, 125° 33 minutes West

Amphitrite Point DGPS Coverage Data

Frequency & Transmission rate	Nominal Range	IALA Identification, Ref. Station numbers & Transmitter number	Status
315khz & 200bps	350km	302, 303 & 908	Full Operational Service

4.6.2 Station Coverage Atlantic Coast

This figure shows nominal coverage from DGPS broadcasts. Users should be aware that coverage is subject to short and long term variation due to environmental and seasonal conditions. Please note that the following map is not at scale and the coverage represented is approximate.

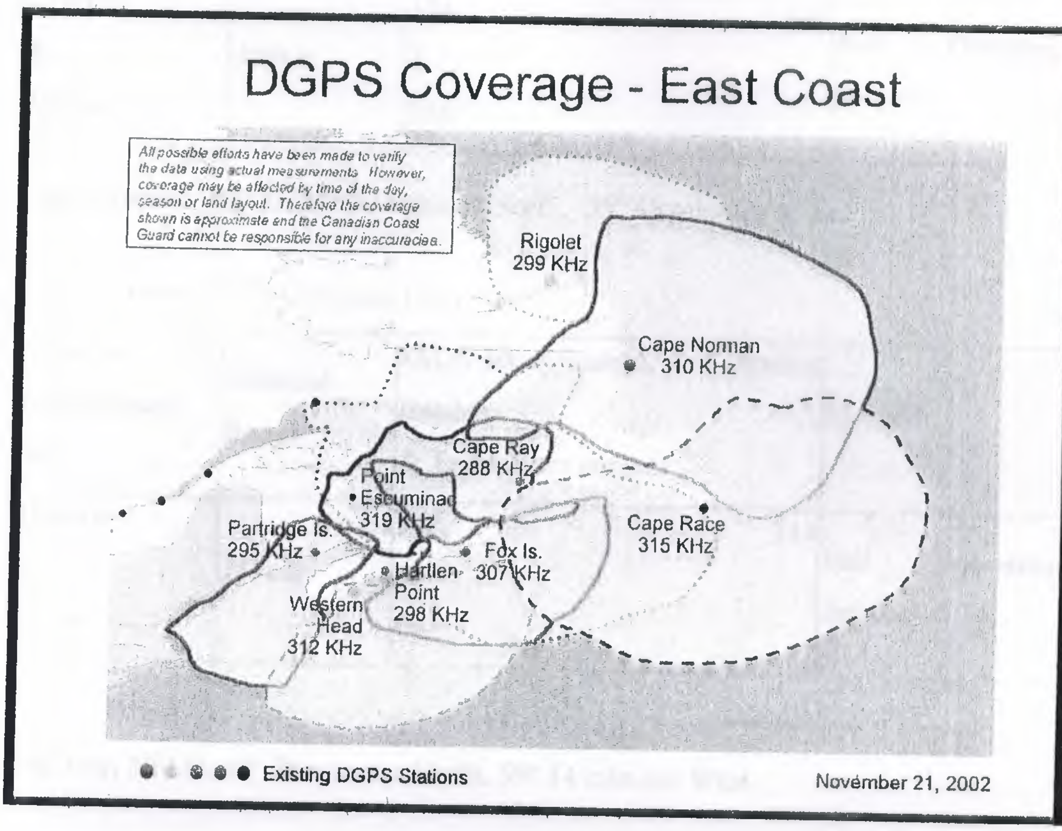


Fig 4.5 DGPS coverage – East coast

Rigolet, NFLD, 54° 11 minutes North, 58° 27 minutes West

Rigolet DGPS Coverage Data

Frequency & Transmission rate	Nominal Range	IALA Identification, Ref. Station numbers & Transmitter number	Status
299khz & 200bps	300km	344, 345 & 946	Full Operational Service

Cape Norman, NFLD, 51° 30 minutes North, 55° 49 minutes West

Cape Norman DGPS Coverage Data

Frequency & Transmission rate	Nominal Range	IALA Identification, Ref. Station numbers & Transmitter number	Status
310khz & 200bps	350km	342, 343 & 944	Full Operational Service

Cap Ray, NFLD, 47° 38 minutes North, 59° 14 minutes West

Cape Ray DGPS Coverage Data

Frequency & Transmission rate	Nominal Range	IALA Identification, Ref. Station numbers & Transmitter number	Status
288khz & 200bps	350km	340, 341 & 942	Full Operational Service

Cape Race, NFLD, 46° 46 minutes North, 53° 11 minutes West

Cape Race DGPS Coverage Data

Frequency & Transmission rate	Nominal Range	IALA Identification, Ref. Station numbers & Transmitter number	Status
315khz & 200bps	525km	338, 339 & 940	Full Operational Service

Point Escuminac, NB, 47° 04 minutes North, 64° 48 minutes West

Point Escuminac DGPS Coverage Data

Frequency & Transmission rate	Nominal Range	IALA Identification, Ref. Station numbers & Transmitter number	Status
319khz & 200bps	300km	332, 333 & 936	Full Operational Service

Fox Island, NS, 45° 20 minutes North, 61° 05 minutes West

Fox Island DGPS Coverage Data

Frequency & Transmission rate	Nominal Range	IALA Identification, Ref. Station numbers & Transmitter number	Status
307khz & 200bps	300km	336, 337 & 934	Full Operational Service

Partridge Island, NB, 45° 14 minutes North, 66° 03 minutes West

Partridge Island DGPS Coverage Data

Frequency & Transmission rate	Nominal Range	IALA Identification, Ref. Station numbers & Transmitter number	Status
295khz & 200bps	300km	326, 327 & 939	Full Operational Service

Hartlen Point, NS, 44° 36 minutes North, 63° 27 minutes West

Hartlen Point DGPS Coverage Data

Frequency & Transmission rate	Nominal Range	IALA Identification, Ref. Station numbers & Transmitter number	Status
298khz & 200bps	300km	330, 331 & 937	Full Operational Service

Western Head, NS, 43° 59 minutes North, 64° 40 minutes West

Western Head DGPS Coverage Data

Frequency & Transmission rate	Nominal Range	IALA Identification, Ref. Station numbers & Transmitter number	Status
312khz & 200bps	300km	334, 335 & 935	Full Operational Service

5-GPS ACCURACY AND ERRORS

5.1 GPS Accuracy

GPS was conceived in the 1970s, and is controlled by the United States Department of Defence. Although GPS was initially envisioned for military use, the Government realized early on that there would be numerous civilian applications as well. Subsequently, the Department of Defence (DOD) created two transmission codes; the P code (Precision code) for military use, and the C/A code (Civilian Access code) for civilian use.

The highest accuracy levels were to be reserved for the military so as to prevent hostile enemy attacks against the U.S. using our own navigational system. However, once in operation, the civilian GPS receivers using the C/A code proved to be more accurate than the DOD had intended. Consequently, the military developed a system for randomly degrading the accuracy of the signals being transmitted to civilian GPS receivers. This intentional degradation in accuracy is called Selective Availability or S/A. This reduced the civilian GPS accuracy levels to being within 100 meters or less, 95% of the time. However, typical accuracy for most users averaged between 20 and 50 meters the majority of the time. You could easily see the effects of S/A on a GPS receiver when you were not moving. Typically, there would be random movements in speed, altitude and position readings, along with slow position "wandering" on the plotter trail. This was easily seen when you were on a .1 or .2 mile zoom range and not moving. For example, while parked at the dock in your boat, you would see unexplainable changes in your digital speed readings up to a few miles per hour, even though you were not moving.

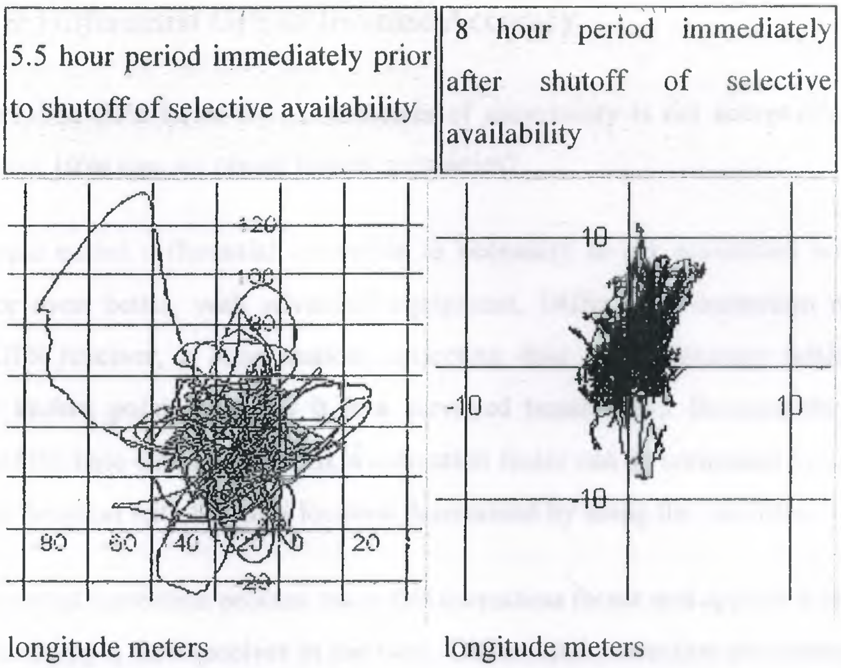


Fig 5.1 Plot of position accuracy using standard Lawrence GPS receiver (stationary). Note the differences in scale.

Effective May 2, 2000 selective availability (S/A) has been eliminated. The United States Department of Defense now has the technology to localize the control system to deny GPS signals to selected areas. It is not often that your electronics products increase in value after you've purchased them. Now boaters, aviators, drivers, hikers, hunters, and outdoor enthusiasts of all types can locate their position up to ten times more precisely (within 10 to 20 meters) and navigate their way through unfamiliar terrain. Anglers can now return to their favorite spot on a lake or river instead of just their favorite area. A Lawrence GPS receiver in combination with advanced technology of today's GPS management will take you anywhere you want to go.

The decision to allow civilians so much accuracy in location information was finally made because GPS is continually playing a more important role in the lives of people around the world - it's becoming a national utility. GPS is the global standard in navigation because it is completely free of charge to the public.

5.2 Using Differential GPS to Increase Accuracy

As powerful as GPS is, +/-50 - 100 meters of uncertainty is not acceptable in many applications. How can we obtain higher accuracies?

A technique called differential correction is necessary to get accuracies within 1 -5 meters, or even better, with advanced equipment. Differential correction requires a second GPS receiver, a *base station,* collecting data at a stationary position on a precisely known point (typically it is a surveyed benchmark). Because the physical location of the base station is known, a correction factor can be computed by comparing the known location with the GPS location determined by using the satellites.

The differential correction process takes this correction factor and applies it to the GPS data collected by a GPS receiver in the field. Differential correction eliminates most of the errors listed in the GPS Error Budget discussed earlier. After differential correction, the GPS Error Budget changes as follows;

5.3 GPS Error Budget

Source	Uncorrected	With Differential
Ionosphere	0-30 meters	Mostly Removed
Troposphere	0-30 meters	All Removed
Signal Noise	0-10 meters	All Removed
Ephemeris Data	1-5 meters	All Removed
Clock Drift	0-1.5 meters	All Removed
Multipath	0-1 meters	Not Removed
SA	0-70 meters	All Removed

By eliminating many of the above errors, differential correction allows GPS positions to be computed at a much higher level of accuracy.

5.4 Real-Time Differential Correction

Because of errors associated with GPS, users must employ methods to improve the accuracy of GPS. This correction can occur while the points are being collected, a process known as Real-Time Differential Correction, or after the collection of points, which is known as Post-Processing.

Real-time differential correction provides GPS users a fast and convenient way to get accurate GPS readings. However, because of the additional hardware that is usually required, the costs for this process can be high.

While the specifics of Real-Time correction can vary, this approach generally requires the user to receive a second signal in addition to the one from the GPS satellites.The GPS receiver can uses this second signal to calculate the error present in the GPS signal.

This correctional signal usually emanates from a base station. A base station is simply a GPS receiver at a precisely surveyed location. Because the base station is at a known location, it can calculate the error present in the GPS signal, by comparing its real location with the location the GPS provides. The base station can then send this error amount to other receivers who will then be able to use it to calculate *their* position. This corrected position will then be stored or displayed by the unit and no further processing of the GPS points will be needed.

While this option is quick and convenient since no additional work is needed, it is usually costly. In addition to the GPS receiver, users must also purchase an additional receiver for the correctional signals, or purchase a GPS model with the Real-Time receiver built in. Not surprisingly, this can be costly. Furthermore, unless users set up their own base station, they will have to pay a subscription fee to one of the companies that provide a correctional signal.

Because of these additional costs, Real-Time Differential correction might be best suited for those projects where cost is less important than convenience.

5.5 Differential Correction

Of all the post-processing techniques, *Differential Correction*, may provide the most accurate results. However it can also require more work than Point Averaging.

The error that is present in GPS signal is random. The user never knows if their reading is 1 meter off or 100 meters off. However, even though it is random it is consistent, so every GPS receiver in the area picking up a signal at that moment is going to have the same error present in its readings. Therefore, if the user could collect readings in two places at once, one at a known location and another at the unknown location he or she could use the error present in the known location's GPS coordinate to determine the error present in the unknown location's coordinate.

This is the principle behind differential correction. Throughout the world people have set up GPS receivers at known locations solely for the purpose of collecting points to be used for differential correction. Known as *Base Stations*, these receivers record their GPS coordinates and time of day and then store the file to be used for differential correction. Many people make these files available over the internet so they can be used by anyone.

While there are many benefits to using differential correction, there are many caveats that users need to be aware of as they plan their GPS collection methodology. The first concerns the availability of base stations. A base station's files are only suitable for use within a 300 mile radius of the base station. If a GPS user is outside of this 300 mile zone, it is likely the base station is receiving signals from different satellites than the user and therefore the error present in the signals won't be the same. This potential difference in error signals also means that the user must collect their points at the exact same time as the base station is collecting its points.

5.6 Point Averaging

Because of a variety of factors, all GPS collected points have a certain amount of error. This means that the location on the screen will not reflect the real location, in fact it could be off as much as 100 meters. Therefore, users who wish to increase the accuracy of their GPS coordinates must take steps to minimize the error. Post-processing techniques offers GPS users an affordable and relatively easy means for correcting GPS points. It provides a reasonable alternative to Real-Time Differential Correction which can be expensive.

The simplest post processing technique is *Point Averaging*, and it relies on simple arithmetic to correct GPS errors., the GPS user stood in one spot and recorded the coordinates on the GPS display once a minute. When the results were plotted, the wide spread of points was evident. Even though the user stood perfectly still, the GPS recorded locations as far as 100 meters away, but most points are closely clustered around the true location.

Because a user never knows whether the single point they just collected is 1 meter or 100 meters from the true location, collecting one GPS reading for a location may not provide accurate results. However, if the user collected many points and then averaged them together, they could feel confident that the majority of points were fairly close to the real location and the effects of any outliers would be minimal.

While there is no set number of points a user needs to collect in order to do Point Averaging, there is a point where diminishing returns set in. The Spatial Analysis Unit typically recommends collecting points once a second for 20 minutes. Collecting more points than that does not dramatically increase the accuracy and simply uses more time, which might be more effectively spent collecting other points.

Different GPS receivers have different ways to perform averaging. Some models will collect readings for a set period of time and then calculate the average and store it in memory, while other models can not perform averaging and require the user to manually store points over a period of time and then perform the averaging after these points have been downloaded.

Regardless of the approach of the GPS unit, Point Averaging can improve the accuracy of GPS readings and the Spatial Analysis Unit suggests that it be a part of all GPS projects.

5.7 GPS Accuracy factors

5.7.1 Basic factors of GPS accuracy

There are two factors that determine the accuracy of a GPS position:

- Error on Range Measurement (Noise + Systematic)
- Geometry to the Satellites

The first factor, the error on a measurement, has may components that are controlled by the receiver and the local environment of the system. The geometry to the satellites is basically not under the control of the user, except by using a receiver with more channels. The two effects enter as two factors in an equation for the position error. The commonly quoted parameter is the "DOP" (dilution of precision). This represents the geometric factor.

Position Error = DOP x Range Error

5.7.2 receiver range error

The true range to the satellites is about 20,000 km (3 times the radius of the earth). While the true range is the major component of a range measurement, it is rivalled by the effects of the local receiver clock error. Clearly this enormous error must be carefully measured and eliminated. This is done by including the receiver clock error as an unknown that is estimated at the same time as the position of the receiver. This is what makes a GPS solution a 4 dimensional problem. This estimation is done at every timeline that a position is computed.

The remainder of the errors in the range signal contribute directly to the position error. They are all very small compared to the range and receiver clock error, but very important to accuracy. These are contained in the small sliver on the top line which is expanded on the lower line. Several are variable, depending on the local time, and the receiver.

5.8 Error Sources

Single receiver GPS positioning is capable of horizontal accuracies of 20 meters (or better), 95% of the time simply due to the effect of hardware, environmental and atmospheric error sources. However, due to past US national security concerns, much larger intentional errors had (or may be again) been placed on the GPS system thus limiting accuracies obtainable from civilian users, The use of 'intentional signal degredation' has reduced the GPS accuracy to between 30 to 100 meters (95%) but has had the effect of rapidly advancing modern day DGPS techniques. The two aspects of this degradation are known as selective availability (SA) and anti-spoofing

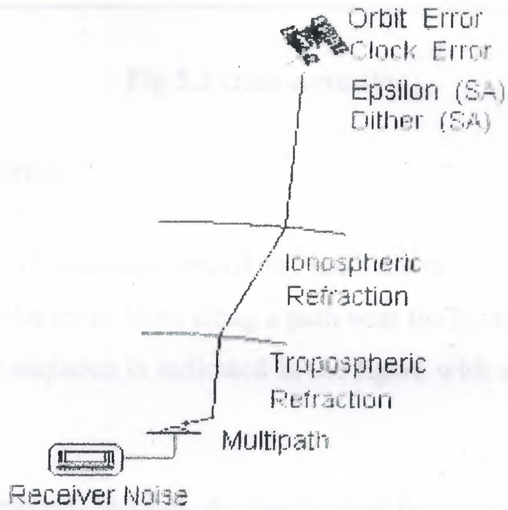


***Fig 5.2** error source*

5.8.1 Selective Availability (S/A)

This error was intentionally injected onto the GPS signals at the satellites. It was turned off on May 1, 2000.

5.8.2 Anti-spoofing

AS further alters the GPS signal by changing the characteristics of the P code by mixing it with a so-called W code resulting in the Y code. It is the latter that is modulated onto the carriers and is thus designed to prevent the ability of the receiver to make P code measurements. Many receiver manufacturers have already developed techniques to still make P code measurements with only a small addition in added noise (cross correlation techniques), see for instance Talbot (1992)or Ashjaee and Lorenz (1992).

5.8.3 Cross correction

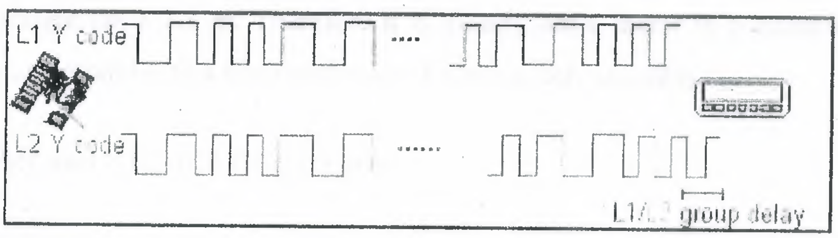


Fig 5.3 cross correction

5.8.4 Ionospheric Error

This error is a function of the local time of day and latitude. It is largest in the tropics in afternoon where it can be up to 30 m along a path near the horizon. Late at night it may be under a meter. The variation is indicated in the figure with a vertical bar within this component.

The ionosphere is eliminated through the use of dual frequency receivers. The second signal frequency, denoted L2, is present on GPS satellites precisely to remove the ionospheric effects. Most PPS receivers types are dual frequency. (The PLGR is an exception.)

Unfortunately the L2 frequency does not currently have the signal intended for use by the Standard Positioning Service (the CA code). Thus all CA receivers must deal with the ionospheric error. In the future (about 2003-2005) new satellites will begin to have the CA signal on L2 as well as a new frequency for civilian use, named L5. When this happens, the ionosphere will effectively be removed as an error source except for older receivers.

Several hardware techniques have been developed in the civilian community to receive L2 range signals despite them being encrypted. These receivers are usually more expensive than CA receivers ($10,000 in 2000 and decreasing.)

5.8.5 Atmospheric Error

This error is essentially a function of the weight of the atmosphere above the user. It is therefore easily modeled using the atmospheric pressure. The total value of this error looking straight up is 2.3 m. Therefore it is usually not a factor in position accuracy. Receivers can model it to a few centimeters knowing only the altitude.

5.8.6 Orbit and Satellite Clock Error

In order to navigate, the user needs to know the origin of the ranges he is measuring, that is the satellite position. The satellites broadcast this. However this information is just read out of a memory on the satellite. It is usually loaded in once a day from the computation center in Colorado Springs. Therefore this will be a *prediction* of where the satellite *will be*. It is in error due to many factors. In discussing this error, the selective availability is not considered, as it was included above.

In addition to the satellite position, the satellite clock offsets are also broadcast. The satellite atomic clocks drift off, but the Air Force GPS Ground system monitors this error and includes in the broadcast of the satellite position, the precise offset of each satellites clock from Universal Time (UTC).

These two components are currently the limiting error components in the GPS receivers using the Precise Positioning System. If Selective Availability is removed, this will be true for all real time users.

For very precise work, both civilian science workers and the military produce post fit orbit and satellite clock estimates. These usually are available one to two weeks after the fact. Several civilian Precise Ephemeris (PE's) are available on the internet.

5.8.7 Multipath

The signal from the satellite comes along the direct line of sight between the user's antenna and the satellite. As the satellites can be anywhere in the upward hemisphere. Most GPS antennas can receive signals from anywhere above the horizon or above some low elevation angle .

In addition to this direct path, the signal can bounce off metal surfaces and reach the antenna along other paths. This is multipath. In practice antennas have some sensitivity to signals even from below, so multipath can be quite extensive. The receiver can only measure the sum of all these signals, and will have some error due to the antenna picking up this reflected energy.

It is important to note that this is a function of how 'clean' the antenna location is. Therefore it is highly variable. Multipath *often is the dominate error source in DGPS applications.*

In addition to the antenna siteing, the user has several other hardware options. Antennas are available that reject most of the multipath. They do this at the expense of seeing any satellites at low elevation angles. Since 1993, there have been receiver techniques that minimize multipath. These are usually available only in the more expensive receivers and then only at extra cost.

5.9 Examples of Errors

This example of the latitude error from two receivers on the same antenna. This data was taken while SA was on. One receiver was a civilian SPS receiver, the other a military PPS receiver. The larger errors going up to 50 m are the civilian SPS results. The small error are the PPS ones.

The PPS errors exhibit jumps that correspond to the shifting of the set of satellites tracked. The noise within each small track segment is much less than a meter, but there is a bias of a few meters in each segment. This 'bias' seems to have a slow drift with time in some cases. This is due to the orbit and satellite clock errors. The error is essentially a random number for each satellite that slowly varies with time. It is smallest at satellite data upload (about 1.5 m one standard deviation) and grows to about a 4 m standard deviation after 24 hours.

Other Sources of Error in GPS

• Signal Delay caused by the Ionosphere

• Signal Delay caused by the Troposphere

• Orbit Errors (GPS satellite position inaccuracy)

• Receiver Noise

5.10 Receiver Noise

Every object that is not at absolute zero radiates electromagnetic energy over a broad band. Some of this is at the GPS frequencies. This will contribute a range error to the measurement. It is called "thermal noise". For GPS in the most precise receivers it use to be about 1 m. This is now only true of receivers that use technology from the first two generations of receivers. The newer technology is generally not usually used on the least expensive receivers.

The new receiver technology, usually called 'narrow correlator' technology, has thermal noise range errors one tenth that of the original GPS receiver. That is 10 cm or less.

5.11 Measuring GPS Accuracy

As discussed above, there are several external sources which introduce errors into a GPS position. While the errors discussed above always affect accuracy, another major factor in determining positional accuracy is the alignment, or geometry, of the group of satellites (constellation) from which signals are being received. The geometry of the constellation is evaluated for several factors, all of which fall into the category of Dilution Of Precision, or DOP.

5.12 DOP

DOP is an indicator of the quality of the geometry of the satellite constellation. Your computed position can vary depending on which satellites you use for the measurement. Different satellite geometries can magnify or lessen the errors in the error budget described above. A greater angle between the satellites lowers the DOP, and provides a better measurement. A higher DOP indicates poor satellite geometry, and an inferior measurement cofiguration.

Some GPS receivers can analyze the positions of the satellites available, based upon the almanac, and choose those satellites with the best geometry in order to make the DOP as low as possible. Another important GPS receiver feature is to be able to ignore or eliminate GPS readings with DOP values that exceed user-defined limits. Other GPS receivers may have the ability to use all of the satellites in view, thus minimizing the DOP as much as possible.

5.13 Levels of GPS Accuracy

There are three types of GPS receivers which are available in today's marketplace. Each of the three types offers different levels of accuracy, and has different requirements to obtain those accuracies. To this point, the discussion in this book has focused on Coarse Acquisition (C/A code) GPS receivers. The two remaining types of GPS receiver are Carrier Phase receivers and Dual Frequency receivers.

5.13.1 C/A Code receivers

C/A Code receivers typically provide 1-5 meter GPS position accuracy with differential correction. C/A Code GPS receivers provide a sufficient degree of accuracy to make them useful in most GIS applications.

C/A Code receivers can provide 1-5 meter GPS position accuracy with an occupation time of 1 second. Longer occupation times (up to 3 minutes) will provide GPS position accuracies consistently within 1-3 meters. Recent advances in GPS receiver design will now allow a C/A Code receiver to provide sub-meter accuracy, down to 30 cm.

5.13.2 Carrier Phase receivers

Carrier Phase receivers typically provide 10-30 cm GPS position accuracy with differential correction. Carrier Phase receivers provide the higher level of accuracy demanded by certain GIS applications.

Carrier Phase receivers measure the distance from the receiver to the satellites by counting the number of waves that carry the C/A Code signal. This method of determining position is much more accurate; however, it does require a substatially higher occupation time to attain 10-30 cm accuracy. Initializing a Carrier Phase GPS job on a known point requires an occupation time of about 5 minutes. Initializing a Carrier Phase GPS job on an unknown point requires an occupation time of about 30-40 minutes.

Additional requirements, such as maintaining the same satellite constellation throughout the job, performance under canopy and the need to be very close to a base station, limit the applicability of Carrier Phase GPS receivers to many GIS applications.

5.13.3 Dual-Frequency receivers

Dual-Frequency receivers are capable of providing sub-centimeter GPS position accuracy with differential correction. Dual-Frequency receivers provide "survey-grade" accuracies not often required for GIS applications.

Dual-Frequency receivers receive signals from the satellites on two frequencies simultaneously. Receiving GPS signals on two frequencies simultaneously allows the receiver to determine very precise positions.

5.14 What affects GPS accuracy?

Many factors affect how accurate your GPS is. The atmosphere, the ionosphere and the position of your receiver could all affect GPS accuracy. Any buildings, natural structures or heavy foliage that obstruct the GPS' view of the sky may decrease the position accuracy. Your GPS accuracy will also depend on your level of clearance with the US DOD. There are two available radio signals that receivers can use: the Standard

Positioning Service (SPS) for civilians and the Precise Positioning Service (PPS) for military and authorized personnel. The DOD occasionally jams the GPS signals for civilians on a short-term basis. Precision and Accuracy

Although precision and accuracy are often assumed to be the same thing, technically they are slightly different. Precision refers to the closeness to the mean of observations and accuracy refers to the closeness to truth.

Care must be taken particularly when using differential GPS to the accuracy of the results (closeness to truth) as reference points used can and often are inconsistent with truth.

The precision or accuracy quoted by many GPS manufacturers is often done using a statistic known as CEP (Circular Error Probable) and are usually tested under ideal conditions.

sp = standard deviation of latitude

sl = standard deviation of longitude

CEP = 0.59[sp + sl]

CEP is the radius of the circle that will contain approximately 50 percent of the horizontal position measurements reported by the GPS receiver. This also means that 50% of the positions reported by your GPS will be outside of this circle.

Another common measure of accuracy is 2DRMS (Distance Root Mean Squared).

2DRMS = 2*sqrt(sp*sp + sl*sl)

2DRMS is the 95-98% probability that the position will be within the stated 2 dimensional accuracy. The probability varies between 95-98% because the standard deviation of latitude and longitude may not always match.

Each has been created using 24 hours of data taken at 20 second intervals in the south western USA.

There are 4 techniques commonly used for GPS Navigation: Autonomous, WADGPS and RTK. Surveying applications usually require the use of RTK or Post Processing.

When used properly under ideal conditions, the CEP precisions for each method will depend on the quality of the GPS equipment in use and is approximated below:

Autonomous <10m

WADGPS 0.3-2m

RTK 0.05 - 0.5 m

Post Processed 0.02 - 0.25 m

Accuracy (closeness to truth) of differential systems is relative to the accuracy of the reference points used.

When used in less than ideal conditions, the accuracy and precision of any GPS system can be degraded significantly.

Ideal Conditions

Ideal conditions for GPS Surveying or Navigation are a clear view of the sky with no obstructions from about 5 degrees elevation and up.

Any obstructions in the area of the GPS antenna can cause a very significant reduction in accuracy. Examples of interfering obstructions include: buildings, trees, fences, cables etc. Obstructions may have the following effects thereby reducing accuracy:

• Reduced number of satellites seen by the receiver

• Reduced strength of satellite geometry (Dilution of Precision (DOP) values)

• Satellite signal multipath

• Corruption of GPS measurements

Multipath is caused by GPS signals being reflected from surfaces near the GPS antenna that can either interfere with or be mistaken for the signal that follows the straight line path from the satellite. In order to get an accurate measurement from a GPS satellite, it is necessary that the signal from the GPS satellite travels directly from the satellite to the GPS antenna. If the signal has been reflected off of another surface prior to being received at the antenna, its length will be greater than was anticipated and will result in positioning error. Multipath is difficult to detect and sometimes hard to avoid.

5.15 Common GPS Surveying and Navigation Techniques and Associated Errors

5.15.1 Autonomous or Stand Alone

The method involves using a GPS on its own with no additional correction information other that what is broadcast by the GPS system. Prior to May 2, 2000 accuracies obtained using this method weren't usually much better than 100m due to a US Department of Defense induced error called Selective Availability (SA). On May 2 SA was turned off and now accuracies are usually better than 10m.

Autonomous receivers will attempt to correct the Ionospheric and Tropospheric errors bases on mathematical models which are very limited in their accuracy. They have no way of correcting for orbit errors, multipath or receiver noise.

5.15.2 Wide Area Differential GPS (WADGPS)

Examples of Systems that use WADGPS include:

WAAS (Wide Area Augmentation System)

- OMNIStar
- Racal
- Navcom Starfire

These systems receive an additional satellite signal that contains more accurate information about GPS Ionosphere and Orbit errors allowing the GPS receiver to determine a more accurate position. These systems have no way of correcting for multipath or receiver noise. Accuracies of WADGPS are often better than 2-3 meters. Although multipath can cause very large errors as is the case in the Autonomous positioning. A solar maximum of a an 11 year solar cycle occurred near the year 2000 which can also have dramatic and unpredictable effects on the accuracy of WADGPS systems.

5.16 Real-Time Kinematic (RTK)

RTK is a process where GPS signal corrections are transmitted in real time from a reference receiver at a known location to one or more remote rover receivers. The use of an RTK capable GPS system can compensate for atmospheric delay, orbital errors and other variables in GPS geometry, increasing positioning accuracy up to within a centimeter. Used by engineers, topographers, surveyors and other professionals, RTK is a technique employed in applications where precision is paramount. RTK is used, not only as a precision positioning instrument, but also as a core for navigation systems or automatic machine guidance, in applications such as civil engineering and dredging. It provides advantages over other traditional positioning and tracking methods, increasing productivity and accuracy.

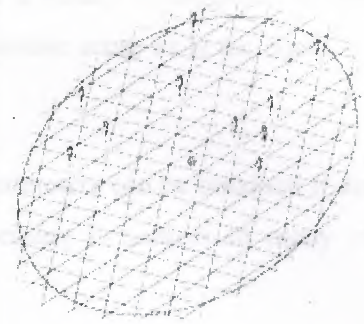
Using the code phase of GPS signals, as well as the carrier phase, which delivers the most accurate GPS information, RTK provides differential corrections to produce the most precise GPS positioning.

This technique can result in accuracies as good as 0.05 m - 0.10 m if used properly and in ideal conditions.

Thales Navigation has developed two innovative, high-performance technology solutions for RTK ambiguity resolution; KART (Kinematic Applications in Real Time) for single-frequency receivers and LRK® (Long Range Kinematic) for dual-frequency receivers.

KART technology does not depend on an a priori stochastic model to achieve and confirm a kinematic solution, making it a faster, easier, more reliable and cost-effective method. KART makes real-time kinematic operation possible with single-frequency receivers in applications otherwise impossible without dual-frequency measurements.

Conventional ambiguity resolution with multiple computations



RTK convergence with a single solution

Fig 5.4 Real-Time Kinematic

The limitations of an RTK system include the following:

• *Initialization* - The receiver must be initialized in good GPS conditions for up to 15 minutes before achieving sub-meter accuracy. If the receiver sees less than 4 satellites at any given time after being initialized, the receiver must re-initialize before again achieving sub-meter accuracy.

• *Baseline Length* - As the distance between the Base and Remote receivers grows larger, the errors observed between the GPS receivers becomes less and less common degrading accuracy at the remote. Good accuracies can normally be achieved with baselines (line between base and remote) in the order of 10 - 15 km. Baseline lengths can be reduced considerably when strong ionospheric conditions exist.

• *Radio Transmission* - The base and remote must maintain communications at all times in order to maintain good accuracy. Terrain, distance and interference all have effects on the distance in which the base and remote are able to maintain communications.

• *Visibility* and Multipath - Usually at least 5 satellites must be available in order to achieve good results. Although less susceptible to multipath after initialization compared to other techniques, RTK results can seriously be degraded by obstructions such as trees, fences and buildings.

• *Accuracy of Reference Point* - The absolute accuracy of the position reported by the Remote receiver is only as accurate in an absolute sense as is the position of the base station coordinates.

Post accurate results in the order of a few centimeters can be obtained if done properly and the conditions are good but post-processing is subject to many of the same limitations as RTK.Processing

This technique of GPS is used mostly used for Surveying and is not used for navigation. It is similar to RTK in that a base station must be placed at a known reference point and a rover is used for gathering new positions. Instead of obtaining accurate results in real-time, accurate coordinates are generated by taking data stored from the receivers and processing them using special software on a computer. Extremely.

5.17 Long Range Kinematic (LRK)

Thales Navigation's LRK technology is a sophisticated kinematic method that optimizes the advantages of dual-frequency GPS operation. Other conventional methods use the dual-frequency only during initialization. LRK makes solving ambiguities during initialization easy and continuous dual-frequency kinematic operation possible at distances up to 40 kilometers.

Conventional dual-frequency kinematic operation is limited to about 10 kilometers, using a combined observation on GPS L1 and L2 frequencies to produce an initial wide lane solution, ambiguous to around 86 centimeters. During a second phase, the conventional kinematic method uses measurements from the L1 frequency only. This method only allows for kinematic operation as long as the de-correlation of atmospheric errors is compatible with a pure phase single-frequency solution.

Similar to the KART process, LRK is a simple and reliable method that allows any initialization mode, from a static or fixed reference point, to On The Fly ambiguity resolution, when performing dual-frequency GPS positioning. LRK technology reduces initialization times to a few seconds by efficiently using L2 measurements in every mode of operation. LRK maintains optimal real-time positioning accuracy to within a centimeter at a range up to 40 kilometers, even with a reduced number of visible satellites.

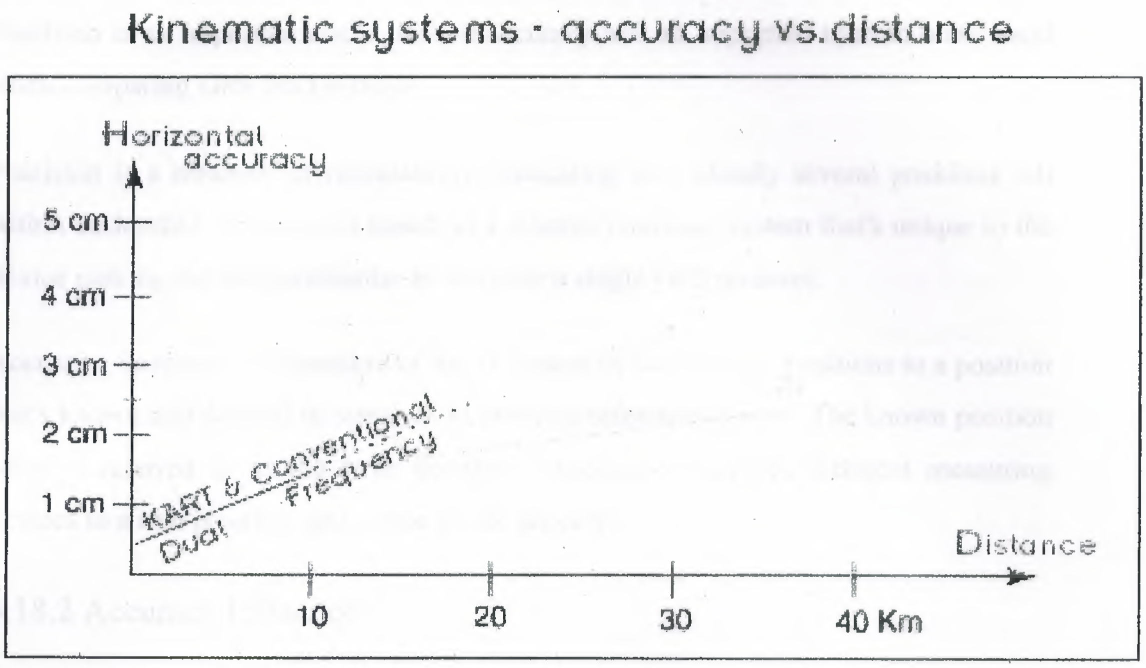


Fig 5.5 Kinematic systems – Accuracy and distance

5.18 What's the Difference Between Accuracy and Precision?

I recently was asked, "How can you say that your Global Positioning System (GPS) is accurate to better than one meter when three parameter transformations can't always accommodate that level of accuracy?" That's a valid question and one that many people misunderstand--especially when the terms "accuracy" and "precision" often are used interchangeably in common language. Because GPS manufacturers routinely refer to a GPS receiver's accuracy in technical specifications, it's important to understand what helps determine the accuracy level of a GPS receiver as well as the differences between accuracy and precision.

5.18.1 Standard Definitions

Precision is easier to understand, although it's less commonly used than accuracy. Precision is an important component of accuracy and an important term to understand when comparing GPS field systems.

Precision is a measure of repeatability, indicating how closely several positions fall within each other. Precision is based on a relative reference system that's unique to the device making the measurements--in this case a single GPS receiver.

Accuracy, however, is a measure of the closeness of one or more positions to a position that's known and defined in terms of an absolute reference system. The known position often is referred to as the "true position." Accuracy compares different measuring devices to a true position, and hence to one another.

5.18.2 Accuracy Influences

To determine equipment accuracy, several factors must be taken into account. Each factor has an important effect on a GPS field system's final accuracy specification. These factors include the following:

- Equipment precision
- Reference system and reliability of true position
- Transformation parameters used to determine final coordinates

These factors can explain why GPS-B in the example provides better accuracy results than GPS-A. In some instances, the precision specification also can be considered exactly the same as the accuracy specification. This situation occurs when accuracy is defined with direct reference to the WGS 1984 ellipsoid or geodetic reference system. The positions are provided as latitudes, longitudes and height above the WGS 1984 ellipsoid. the average position for GPS-A and GPS-B should be much closer to each other as well as the true position. A GPS receiver that's very precise in this system should also be very accurate.

But why is GPS-B more accurate than GPS-A? Perhaps because GPS-A's accuracy is in terms of a local coordinate system and not the WGS 1984 system. Or perhaps the true position's reference system is different than the one used to determine the GPS-based positions. This situation can occur when a local coordinate system is similar to, but not the same as, the WGS 1984 reference system.

5.18.3 Data Transformation

The positions generated by the GPS receivers must be transformed using complex mathematical equations. Errors in the equations will result in inaccurate final positions stored in the GIS.

Most GPS field systems designed for GIS professionals include the ability to transform coordinates from one system to another--especially from WGS 1984 to other major coordinate systems. It's important, therefore, to consider the GPS field system as a whole when determining its accuracy and how well it transforms data to the coordinate system in which GIS positions will be stored.

If a GPS field system only can export positions in terms of the WGS 1984 reference system, then users will need to consider how well the GIS can conduct required coordinate transformations. The transformations don't have any effect on a GPS receiver's capabilities, but they affect the reliability of the data.

5.19 The radio signal

The current series of GPS satellites broadcast data using two distinct signals of accuracy. The first is for the standard positioning system (SPS). The second one is for the precise positioning system (PPS). The SPS signal is at the L1 frequency, which is 1547,42MHz, the L2 frequency carries the PPS signal, and is at 1227,60MHz. The signal is shifted by 3 binary codes.

The signal can also be used for time, velocity and tracking. Time is an obvious option,because the signal is transmitted in periods of time with the atomic clock. Velocity is quite easy. The receiver calculates his position each time a signal is received. The difference in the place the signal is received gives the velocity. Tracking needs a bit more information. The tracking party needs to locate the vehicle that has to be tracked. Then, using the information of where the vehicle is, by continuous updating of this information, the vehicle can be tracked.

The vehicle can also send the information up by it's own sender, after pinpointing it's location with the use of GPS and a digitized map. This way, the tracking party can use the power of the used receivig installation. This is reversing the original process, but it is a possibile use of GPS.

5.20 The Precise Positioning System

The pecise positioning system (PPS) is the encrypted military signal, which is designed to be accurate within 15 to 30 meters, but PPS has proven to be able to reach a resolution of 10 meters. The PPS-system is used by authorised users only, they have cryptographic equipment and the keys to decode the PPS signal

5.21 The Standard Positioning System

The standard positioning system has an accuracy of approximately 100 meters. Although the GPS system was originally designed for military use only, due to an airplane accident in 1983 this signal was released by President Reagan for aviation and other transportation applications.

The signal may be used by everyone without charges or restrictions. The signal can be supported by a ground station in order to create a higher accuracy. The exact location of the ground station is known, and it recalculates the signal, so that the error the US-DoD has put into the signal is gone, and it may even create a better signal than the original PPS signal.

This utilisation of GPS is called DGPS. The receiver used gets extra information through :

- A local support signal This option can only be used for professional applications. A local station costs up to about 6.000 dollar (Dfl. 10.000). The low cost is an advantage and this option is used by several airports, to improve the control over flight traffic. The error that is made this way is usually less then 1 meter.

- FM-transmitters with RDS With the help of the RDS signal a lot of information can be send over the FM band. This signal can also be used to send DGPS information. The use of this system is relatively simple, because a simple FM-receiver can be designed and build for use with this system. It does require a small number off DGPS transmitters is.
- Long wave transmitters with AMDS For the AM frequency band a RDS system was designed also, called AMDS. This system has the same possibilities as the FM system, only the amount of information is smaller than it is with the use of regular RDS. The range of an AM-transmitter is much larger, therefore the use of this system is a good option for cheap use of DGPS. A disadvantage of this system is the possible lower accuracy, because the distance from the ground station to the receiver is large.
- Long wave services Next to public DGPS services there is a possibility to use a signal created by a private company, for use with their equipment only.

By using the given options for DGPS, it is possible to accurately determine the position of a receiving party.

CONCLUSION

The technology of the Global Positioning System is allowing for communicate in society. The applications using GPS are constantly growing. The cost of the receivers is dropping while at the same time the accuracy of the system is improving. This affects everyone with things such as faster Internet speed and safer plane landings.

Even though the system was originally developed for military purposes, civil sales now exceed military sales.

Today's capabilities are remarkable and stretch the boundaries for future innovation.

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