Global Positioning System (GPS): Definition, Principles, Errors, Applications & DGPS

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Definition of GPS:

- *The GPS is a satellite-based navigation system made up of a network of 24 satellites placed into orbit by the U.S. Department of Defense*. *GPS was originally intended for military applications, but in the 1980s, the government made the system available for civilian use*. GPS works in any weather conditions, anywhere in the world, 24 hours a day. There are no subscription fees or setup charges to use GPS.
- *The global positioning system is a satellite-based navigation system consisting of a network of 24 orbiting satellites that are eleven thousand nautical miles in space and in six different orbital paths*. The satellites are constantly moving, making two complete orbits around the Earth in 24 hours i.e. 2.6 kilometers per second.
- *The Global Positioning System (GPS), originally NAVSTAR GPS, is a satellite-based radio navigation system owned by the United States government and operated by the United States Space Force (USSF)*. *It is one of the Global Navigation Satellite Systems (GNSS) that provides geo location and time information to a GPS receiver anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites*. Obstacles such as mountains and buildings block the relatively weak GPS signals.
- *The Global Positioning System is a space-based navigation and positioning system that was designed by the U.S. Military to allow a single soldier or group of soldiers to autonomously determine their position to within 10 to 20 meters of truth*. The concept of autonomy was important in that it was necessary to design a system that allowed the soldier to be able to determine where they were without any other radio (or otherwise) communications.
- *The GPS project was started by the U.S. Department of Defense in 1973, with the first prototype spacecraft launched in 1978 and the full constellation of 24 satellites operational in 1993*. Originally limited to use by the United States military, civilian use was allowed from the 1980s following an executive order from President Ronald Reagan. The system provides critical capabilities to military, civil and commercial users around the world. It is maintained by the United States government and is freely accessible to anyone with a GPS receiver.

Evolution of the GPS

Like so many other high-tech developments, GPS is maintained by the United States government and is freely accessible to anyone with a GPS receiver.

- During the late 1950's and early 1960's, the U.S. Navy sponsored two satellite-based positioning and navigation systems: *Transit and Timation*. *The Transit system became operational in 1964 and was made available to the public in 1969. Timation was a prototype system that never left the ground*. Simultaneously, the U.S. Air Force was conducting concept studies for a system called the System 621B. Ground tests were performed to validate the concept but before the system could be implemented, the

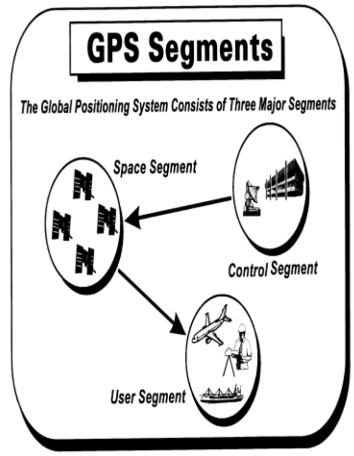
U.S. Deputy Secretary of Defense, in April 1973, designated the Air Force as the executive service to coalesce the Timation and 62 1B systems into a single Defense Navigation Satellite System (DNSS).

- From this emerged a combined system concept designated the NAVSTAR (Navigation System with Timing and Ranging) Global Positioning System, or simply GPS. *The 1970's saw the implementation of Phase I, the concept validation phase, during which the first prototype satellites were manufactured and tested.*
- In 1973, decision to development a satellite navigation system for military.
- In 1974-1979, conducted system tests US air force and navy.
- *The first functional NAVSTAR prototype satellite launch occurred in June 1977, and was called the NTS-2 (Navigation Technology Satellite 2, which was actually a modified Timation satellite).* While the NTS-2 only survived some 7 months, the concept was shown to be viable, and in February 1978 the first of the Block I NAVSTAR satellites was launched.
- *In 1977, first receiver test was conducted without placing the satellite in the orbit*. Signal received from pseudo- satellites. The concept started in the late '60s but the first satellite was launched in February 1978.
- In 1979, Phase II, full-scale development and testing of the system, was implemented with nine more Block I satellites launched during the following six years.
- This was followed in late 1985 by Phase III, the full-scale production and deployment of the next generation of Block II satellites.
- In 1978-85, a total of 11 Block I satellites were launched.
- In 1979, decision to expand GPS with 18 satellites in space.
- In 1980-1982, financial crisis occurs when the sponsors questioned the usefulness of the system.
- In 1983, civilian use of GPS was allowed after soviet union shot down Korean airplane that get lost over soviet territory.
- In 1986, GPS Programme suffered a setback due to the accident of challenger, which was supposed to carry block II satellites to the orbit. Then delta rockets were used for the purpose.
- In 1988, numbers of satellites were increased to 24.
- In 1989, First Block II satellites were installed and activated and The Magellan Corp. introduced the first hand-held GPS receiver.
- In 1990-1991, temporal deactivation of SA during Gulf War.
- In 1992 GPS was used in "Operation Desert Storm 1993- Initial operation capability (IOC) was announced and decided worldwide civilian use free of cost.
- In 1994, last block II satellites complete the satellite constellation.
- In 1995, fully operational capability was announced.
- On March 1996, the President decided to make GPS free for civilian users.
- In 2000, final deactivation of SA to give positional accuracy of 20m from 100m.
- In 2005, Launching of the II RM GPS satellite that supports the new military M signal and the second civil signal L2C. GPS project was developed in 1973, to overcome the limitations of previous navigation systems, integrating ideas from several predecessors, including a number of classified engineering design studies from the 1960s. The current system became operational on June 26, 1993 when the 24th satellite was launched. Bradford Parkinson, Roger L. Easton, and Ivan A. getting are credited for inventing the GPS.

DOP (Dilution of Precision)

DOP is a value that shows the degree of degradation of the GPS positioning accuracy. *The smaller the value is, the higher the positioning accuracy is*. This value depends upon the positions of the GPS satellites tracked for positioning. If the tracked satellites spread evenly over the earth, the positioning accuracy would become higher, and *if the positions of tracked satellites are disproportionate, the positioning accuracy would become lower.*

GPS Segments/ Components of GPS/ Principles of GPS

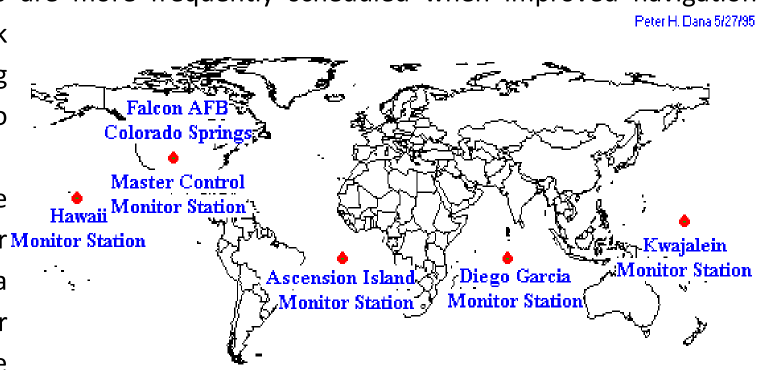


The Global Positioning System consists of three major segments: the Space Segment, the Control Segment, and the User Segment. The space and control segments are operated by the United States Military and administered by the U.S. Space Command of the U.S. Air Force. Basically, the control segment maintains the integrity of both the satellites and the data that they transmit. The space segment is composed of the constellation of satellites as a whole that are currently in orbit, including operational, backup and inoperable units. The user segment is simply all of the end users who have purchased any one of a variety of commercially available receivers. While the user segment obviously includes military users, this book will concentrate on the civilian uses only. Each of the segments will be examined more closely in the following pages.

The Control Segment

- *The control segment of the Global Positioning System consists of one Master Control Station (MCS) located at Falcon Air Force Base in Colorado Springs, Colorado, and four unmanned monitor stations located strategically around the world e.g. Hawaii Monitor Station, Ascension Monitor Station, Diego Garcia Monitor Station, Kwajalein Monitor Station.*
- In addition, the Air Force maintains three primary ground antennas, located more or less equidistant around the equator.
- *Observation and controlling the satellite system regularly.*
- *To check the satellite functions and it's accurate position in the space*.
- *To determine the time of GPS.*
- *Update periodically navigation messages for each satellite.*
- *In the event of some catastrophic failure, there are also two backup Master Control Stations, one located in Sunnyvale, California, and the other in Rockville, Maryland*.
- The unmanned monitor stations passively track all GPS satellites visible to them at any given moment, collecting signal (ranging) data from each. *This information is then passed on to the Master Control Station at Colorado Springs via the secure DSCS (Defense Satellite Communication System) where the satellite position ("ephemeris") and clock-timing data (more about these later) are estimated and predicted.*
- *The Master Control Station then periodically sends the corrected position and clock-timing data to the appropriate ground antennas which then upload those data to each of the satellites.*
- *Finally, the satellites use that corrected information in their data transmissions down to the end user*.
- *This sequence of events occurs every few hours for each of the satellites* to help insure that any possibility of error creeping into the satellite positions or their clocks is minimized.

- *The CS is responsible for maintaining the satellites and their proper functioning*. *This includes maintaining the satellites in their proper orbital positions (called station keeping)* and monitoring satellite subsystem health and status.
- *The CS also monitors the satellite solar arrays, battery power levels, and propellant levels used for maneuvers.* Furthermore, the CS activates spare satellites (if available) to maintain system availability.
- *The CS updates each satellite's clock, ephemeris, and almanac and other indicators in the navigation message at least once per day.* Updates are more frequently scheduled when improved navigation accuracies are required. (Frequent clock and ephemeris updates result in reducing the space and control contributions to range measurement error.
- Depending on the satellite block, the navigation message data can be stored for a minimum of 14 days to a maximum of a 210-day duration in intervals of 4 hours or 6 hours for uploads as infrequent as once per two weeks and intervals of greater than 6 hours in the event that an upload cannot be provided for over 2 weeks.



Global Positioning System (GPS) Master Control and Monitor Station Network

- *Furthermore, the CS resolves satellite anomalies*, controls SA and AS, and collects pseudo range and carrier phase measurements at the remote monitor stations to determine satellite clock corrections, almanac, and ephemeris. To accomplish these functions, the CS is comprised of three different physical components: the master control station (MCS), monitor stations, and the ground antennas.
- *Newly added control stations after 2005 are Washington DC England, Ecuador, Argentina, Bahrain and Australia.*
- *These Monitor stations measure signals from the SVs, which are incorporated into orbital models for each satellites.*
- *Master stations collect the data about the satellites of this system continuously from the other tracking stations.* MCS process the tracking data for computation of satellite ephemerides (or co-ordinate) & satellite clock parameters.
- The Master control station uploads ephemeris and clock data to the SVs. The SVs then send subsets of the orbital ephemeris data to GPS receivers over radio signals. The MCS also monitor the position of satellites at any instant of time, the functional capacity of the satellites & variation of the navigation data. The computation of satellite's Ephemeris & Clock errors are most important tasks of control stations, as both variables are important to get high accuracy.

The Space Segment

- *The space segment consists of the complete constellation of orbiting NAVSTAR GPS satellites*. The current satellites are manufactured by Rockwell International and cost approximately $40 million each.
- *To each satellite must be added the cost of the launch vehicle itself which may be as much as $100 million. To date, the complete system has cost approximately $10 billion*. *Each satellite weights approximately 900 kilograms and is about five meters wide with the solar panels fully extended. There were 11 Block I prototype satellites launched (10 successfully), followed by 24 Block II production units*. Currently, only one of the Blocks I satellites is still operational, while four Block II backups remain in ground storage. *The base*

size of the constellation includes 21 operational satellites with three orbiting backups, for a total of 24. They are located in six orbits at approximately 20,200 kilometers altitude.

- *Each of the six orbits is inclined 55 degrees up from the equator, and is spaced 60 degrees apart, with four satellites located in each orbit. The orbital period is 12 hours, meaning that each satellite completes two full orbits each 24-hour day.*
- The space segment is the constellation of satellites from which users make ranging measurements. *The SVs (i.e., satellites) transmit a PRN-coded signal from which the ranging measurements are made. This concept makes GPS a passive system for the user with signals only being transmitted and the user passively receiving the signals.*

- *The Space Segment of the system consists of the GPS satellites. These Space Vehicles (SVs) send radio signals from space. The Space Segments - consists of the group of minimum 24 Satellites & the signals -that are broadcast by them, which allow user to determine position velocity & time*. The basic functions of satellites are - To receive & store data uploaded by Control Segment. Maintain accurate time by means of on board ATOMIC CLOCKS & Transmit information & signals to users on TWO L- band frequencies. *Out of 52 constellations of GPS Satellites, the 11 were launched as an experimental satellite in Feb 1978 under so-called Block 1 Phase, Block 2 & Block 2 A were launched from 1989 onwards*. Full operational capability was declared on 17 July in 1995.
- Currently 12 of these satellites are re-designed as the part of GPS Modernisation Programme.

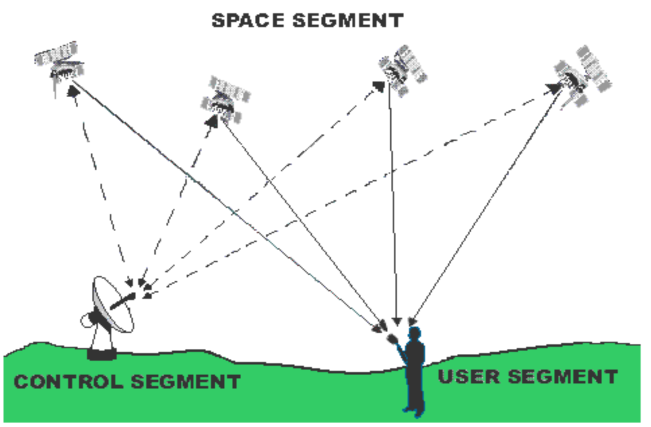
GPS Satellite Details

- *Name: NAVSTAR (The Navigation Satellite Timing and Ranging-USA)*
- *Galaxy: consist of 24 satellites.*
- *Manufacture: Rockwell International*
- *Altitude: 20200 km*
- *Weight: 845 kg*
- *Number of path or orbit: 6*
- *Number of satellite per path: 4*
- *Orbital inclination: 55 degree to equatorial plane*
- *Orbital spacing: 60 degree (360/6)*
- *Orbital period: 12 hours*
- *Planned life span: 7.5 years*

The User Segment

- Information that comes from space and sends to satellites is the most important part of GPS.
- The part that does this work is User Segment. It has the GPS receiver section.
- GPS collect and stored the all information that has come from space. For this, 4 satellites are required.

- The GPS user segment consists of the GPS receivers and the user community. *GPS receivers convert SV signals into position, velocity and time estimates. Four satellites are required to compute the four dimensions of X (latitude), Y (longitude), Z (altitude) and T (time)*. GPS receivers are used for navigation, positioning, time dissemination and other research
- *The user receiving equipment comprises the user segment*. Each set of equipment is typically referred to as a GPS receiver, which processes the L-band signals transmitted from the satellites to determine user PVT (Position, Velocity and Time).



- *While PVT determination is the most common use, receivers are designed for other applications, such as computing user platform attitude (i.e., heading, pitch, and roll) or as a timing source.*
- *Navigation in three dimensions is the primary function of GPS*. Navigation receivers are made for aircraft, ships, and ground vehicles and for hand carrying by individuals. Precise positioning is possible using GPS receivers at reference locations providing corrections and relative positioning, geodetic control and plate tectonic studies are example.
- *Time and frequency dissemination, based on the precise clocks on board the SVs and controlled by the monitor stations, is another use for GPS*, Astronomical observatories, telecommunications facilities, and laboratory standards can be set to precise time signals or controlled to accurate frequencies by special purpose GPS receivers. Research projects have used GPS signals to measure atmospheric parameters.

Working Functions of GPS

Generally the functions of a GPS are completed with 5 steps.

Step -1: Triangulating from Satellites:

- *GPS operation is based on the concept of ranging and Trilateration from a group of satellites*, which act as precise reference points. Each satellite broadcasts a Navigation Message that contains the following information;
- *A pseudo-random code called a Course Acquisition (CA) code, which contains orbital information about the entire satellite constellation (Almanac).*
- *Detail of the individual satellite's position (Ephemeris) that includes information used to correct the orbital data of satellites caused by small disturbances*.
- *The GPS system time, derived from an atomic clock installed on the satellite*, with clock correction parameters for the correction of satellite time due to differences between UTC and GPS time (the occasional 'leap' second added to a year) and delays (predicted by a mathematical ionospheric model) caused by the signal travelling through the ionosphiere.
- A GPS health message that is used to exclude unhealthy satellites from the position solution.
- *The GPS receiver in the aircraft takes 12.5 minutes to receive all of the data frames in the navigational message.* Once obtained, the receiver starts to match each satellite's CA code with an identical copy of the code contained in the receiver's database. By shifting its copy of the satellite's code, in a matching process, and by comparing this shift with its internal clock, the receiver can calculate how long it took the signal to travel from the satellite to the receiver. *The distance derived from this method of computing*

distance is called a Pseudo-range because it is not a direct measure of distance, but a measurement based on time. Pseudo-range is subject to several error sources, including atmospheric delays and multipath errors, but also due to the initial differences between the GPS receiver and satellite time references.

- *Using a process called Trilateration, the GPS receiver then mathematically determines its position by using the calculated pseudo-ranges and the satellite position information that has been supplied by the satellites.GPS_3D-Trilateration.*
- *If only one satellite is visible, position location is impossible* as the receiver location can be anywhere on the surface of a sphere with the satellite at its centre.
- *If two satellites are visible the receiver location can be anywhere on a circle where the surfaces of the two spheres intercept.* So position location is also impossible.
- *When a third satellite becomes visible, the GPS receiver can establish its position as being at one of two points on the previously derived circle where the third satellite sphere intercepts it*. So, whilst position fixing is possible, it is unreliable unless it is assumed that the receiver is at sea level on the surface of the Earth, because it is almost certain that only one of the two derived points would be near the surface of the Earth. So fixing is possible, but only in two dimensions (2D fixing): in latitude and longitude.
- *With at least four satellites visible, and their alignment good, the four spheres will intersect at only one point in space, so receiver position can be accurately fixed in three dimensions (3D fixing): in latitude, longitude and altitude.*
- *With five satellites visible, it is possible for the system to automatically detect an erroneous signal.*
- *With six satellites visible, it is possible for the system to automatically detect an erroneous signal, identify which satellite is responsible and exclude it from consideration*.
- *Altitudes derived from GPS positions are known as Geodetic altitudes and were not initially used for aircraft navigation*; PBN requires that they, and the navigational information presented by the system, are based on the World Geodetic System established in 1984, the WGS 84 coordinate system.
- As the GPS satellites provide a very accurate time reference as well as precise 3D position fixes, they can also calculate and provide accurate speed data.

Step-2: Measuring distance from a Satellite:

- Normally distances are calculated on GPS is based on signals of a Satellite ranging.
- The easy formula to calculate the distance is:

Distance (d) = Speed of satellite ranging (3×10^8 m/second) x time

Time (Δt) = $t_2 - t_1$ where, t_1 = sending time, t_2 = receiving time

Step- 3: Getting Perfect Timing:

- If travel time measures through the radio signal are the basics of GPS, then stopwatch are very working instrument in this case. If their time is stopped for one thousandths of a second, then it will wrong at 200 miles.
- In terms of Satellites, timing is perfect because the Atomic clock is the compulsory element of Satellite systems.
- The key to accurate scheduling is to measure the distance to an extra satellite.
- If the three exact measurements can identify the three-dimensional position, then the fourth incorrect measure does the same thing.

Step-4: Knowing where a Satellite is in Space:

- We assume that we know the exact position of Satellites, for which we can used that satellites as a reference point.
- But how can we know that exactly where they are? After all, they float in the space of 11,000 miles.

Step-5: Correcting Errors:

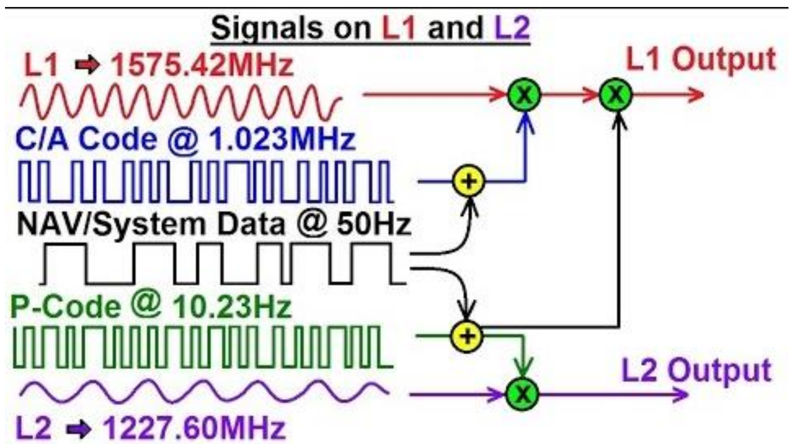
- So far, the calculation we are pointing to a GPS, that is sporadically. As if the whole thing was happening in a vacuum.
- But in reality, there are a lot of things which can be disrupt the GPS signals. To get the accurate results, this error likely to be corrected.
- For example, the ionosphere and atmosphere may be a reason for delay the whole function. Some error can be factored out by using arithmetic calculation and model.
- The relative position of the satellites in the sky can give rise to other errors.

Signals of GPS

GPS system sends their information through microwave signal. The signal systems are as below:

Pseudo Random Code (PRC):

- It is the prime part of GPS.
- It physically complicated digital number or complicated sequence of 'on' and 'off' pulse.
- There are 2 types of PRC signals generally found.
- *Coarse Acquisition Code (C/A):* (a) This contains L1 signals. (b) It repeats every 1023 bits & modulates at a 1 MHz rate. (c) C/A code is the basis for civilian GPS uses.
- *Precise Code (P):* (a) Modulate both L1 & L2 carries at a 10 MHz rate. (b) Used for Military purpose. (c) It is more complicated than C/A code.



There are 2 types of Signals: L1 & L2

- **L1 carries:** (a) L1 carries 1575.42 MHz. (b) L1 carries both the status message and a pseudo random code for timing.
- **L2 carries:** (a) L2 carries 1227.60 MHz. (b) Use for the more precise military pseudo random code.

Measurement of Errors of GPS

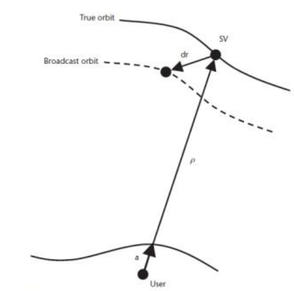
There are a number of sources of error that corrupt these measurements. An examination of these error sources is presented within this section.

1. Satellite Clock Error

The satellites contain atomic clocks that control all on board timing operations, including broadcast signal generation. Although these clocks are highly stable, the clock correction fields in the navigation data message are sized such that the deviation between SV time and GPS time may be as large as 1 ms. (An offset of 1 ms translates to a 300-km pseudo range error.) The MCS determines and transmits clock correction parameters to the satellites for rebroadcast in the navigation message. These correction parameters are implemented by the receiver using the second-order polynomial since these parameters are computed using a curve-fit to predicted estimates of the actual satellite clock errors, some residual error remains. *This residual clock error, δt, results in ranging errors that typically vary from 0.3–4m, depending on the type of satellite and age of the broadcast data. Range errors due to residual clock errors are generally the smallest following a control segment uploads to a satellite, and they slowly degrade over time until the next upload* (typically daily). At zero age of data (ZAOD), clock errors for a typical satellite are on the order of 0.8m. *Errors 24 hours after an upload are generally within the range of 1–4m. It is expected that residual clock errors will continue to decrease as newer satellites are launched with better performing clocks and as improvements are made to the control segment*. Errors were observed to be statistically independent from satellite to satellite with significant correlation over time.

2. Ephemeris Error

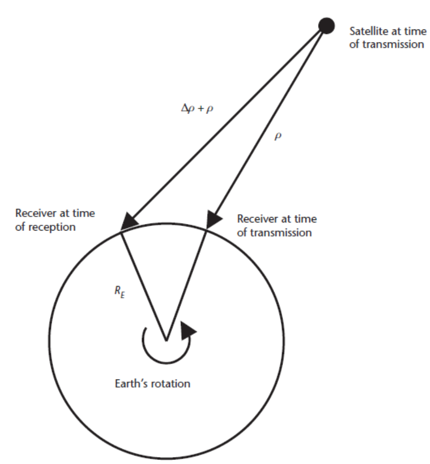
Estimates of ephemerides for all satellites are computed and uplinked to the satellites with other navigation data message parameters for rebroadcast to the user. As in the case of the satellite clock corrections, these corrections are generated using a curve fit of the control segment's best prediction of each satellite's position at the time of upload. The residual satellite position error is a vector with typical magnitudes in the range of 1–6m. The effective pseudo range and carrier-phase errors due to ephemeris prediction errors can be computed by projecting the satellite position error vector onto the satellite-to-user LOS vector. *Ephemeris errors are generally smallest in the radial (from the satellite toward the center of the Earth) direction. The components of ephemeris errors in the along-track (the instantaneous direction of travel of the satellite) and cross track (perpendicular to the along-track and radial) directions are much larger*. Along-track and cross-track components are more difficult for the control segment to observe through its monitors on the surface of the Earth, since these components do not project significantly onto LOSs toward the Earth. Fortunately, the user does not experience large measurement errors due to the largest ephemeris error components for the same reason.



Ephemeris error. (*After:* [9].)

3. Relativistic Effects

Both Einstein's general and special theories of relativity are factors in the pseudo range and carrier-phase measurement process. *The need for Special Relativity (SR) relativistic corrections arises any time the signal source (in this case, GPS satellites) or the signal receiver (GPS receiver) is moving with respect to the chosen isotropic light speed frame, which in the GPS system is the ECI frame*. The need for general relativity (GR) relativistic corrections arises any time the signal source and signal receiver are located at different gravitational potentials. *The satellite clock is affected by both SR and GR. In order to compensate for both of these effects, the satellite clock frequency is adjusted to 10.22999999543 MHz prior to launch*. The frequency observed by the user at sea level will be 10.23 MHz; hence, the user does not have to correct for this effect. *The user does have to make a correction for another relativistic periodic effect that arises because of the slight eccentricity of the satellite orbit*. Exactly half of the periodic effect is caused by the periodic change in the speed of the satellite relative to the ECI frame and half is caused by the satellite's periodic change in its gravitational potential. *Due to rotation of the Earth during the time of signal transmission, a relativistic error is introduced, known as the* ***Sagnac***



3 The Sagnac effect.

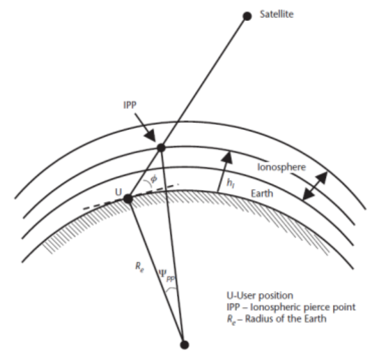
***Effect**, when computations for the satellite positions are made in an ECEF coordinate system*. During the propagation time of the SV signal transmission, a clock on the surface of the Earth will experience a finite rotation with respect to an ECI coordinate system. *Figure illustrates clearly, if the user experiences a net rotation away from the SV, the propagation time will increase, and vice versa. If left uncorrected, the Sagnac Effect can lead to position errors on the order of 30m. Corrections for the Sagnac Effect are often referred to as Earth rotation corrections.*

4. Atmospheric Effects

The propagation speed of a wave in a medium can be expressed in terms of the index of refraction for the medium. *The index of refraction is defined as the ratio of the wave's propagation speed in free space to that in the medium by the formula n= c/v* Where c is the speed of light equal to 299,792,458 m/s as defined within the WGS-84 system. The medium is dispersive if the propagation speed (or, equivalently, the index of refraction) is a function of the wave's frequency.

4.1 Ionospheric Effects

The ionosphere is a dispersive medium located primarily in the region of the atmosphere between about 70 km and 1,000 km above the Earth's surface. Within this region, ultraviolet rays from the sun ionize a portion of gas molecules and release free electrons. These free electrons influence electromagnetic wave propagation, including the GPS satellite signal broadcasts.



Ionospheric modeling geometry.

4.2 Tropospheric Delay

The troposphere is the lower part of the atmosphere that is non dispersive for frequencies up to 15 GHz. Within this medium, the phase and group velocities associated with the GPS carrier and signal information (PRN code and navigation data) on both L1 and L2 are equally delayed with respect to free-space propagation. *This delay is a function of the tropospheric refractive index, which is dependent on the local temperature, pressure, and relative humidity.* Left uncompensated, the range equivalent of this delay can vary from about 2.4m for a satellite at the zenith and the user at sea level to about 25m for a satellite at an elevation angle of approximately 5º.

5. Receiver Noise and Resolution

Measurement errors are also induced by the receiver tracking loops. In terms of the DLL, dominant sources of pseudo range measurement error (excluding multipath) are thermal noise jitter and the effects of interference. *The C/A code composite receiver noise and resolution error contribution will be slightly larger than that for P(Y) code because the C/A code signal has a smaller RMS bandwidth than the P(Y) code*. Typical modern receiver 1σ values for the noise and resolution error are on the order of a decimeter or less in nominal conditions (i.e., without external interference) and negligible compared to errors induced by multipath. Receiver noise and resolution errors affect carrier phase measurements made by a PLL.

6. Multipath and Shadowing Effects

One of the most significant errors incurred in the receiver measurement process is multipath. *Multipath errors vary significantly in magnitude depending on the environment within which the receiver is located, satellite elevation angle, receiver signal processing, antenna gain pattern, and signal characteristics*.

7. Hardware Bias Errors

7.1 Satellite Biases

Upon signal transmission, the GPS signals on each carrier frequency and among frequencies are imperfectly synchronized due to the different digital and analog signal paths corresponding to each signal. *The timing bias between the L1 and L2 P(Y) code signals is inconsequential for most dual-frequency users since the broadcast clock corrections compensate for this bias under the presumption that the user is combining L1 and L2 pseudo range measurements via the Ionospheric-free pseudo range equation*. Single-frequency users (L1 or L2) employing the broadcast clock corrections, however, must correct for the L1-L2 timing bias by using a broadcast correction, TGD, contained in word 7 of sub frame 1 of the GPS navigation message. *The absolute value of the uncorrected L1-L2 group delay bias is specified to be less than 15 ns with random variations about the mean less than 3 ns (2 sigma). Observed values are generally less than 8 ns in magnitude. Until 1999, broadcast TGD values were derived from factory measurements*. Since April 1999, the broadcast TGD values have been provided to the Air Force by JPL. At present, the accuracy of the broadcast values is limited by a nearly 0.5-ns message quantization error. C/A code users have an additional timing bias of the transmitted signals to account for, which is the bias between the L1 C/A code and P(Y) code signals. This bias is specified to be less than 10 ns (2 sigma). Typical observed magnitudes are less than 3 ns. Although various organizations, including JPL, routinely estimate this bias, the present GPS navigation message does not include a field for this data. Future GPS navigation messages, however, will disseminate corrections for the L1 C/A code to P(Y) code bias, as well as a number of additional group delay corrections, referred to as inter signal corrections (ISCs) that will be introduced on future satellites (i.e., Blocks IIR-M and beyond) that will broadcast the new L2C,M code, and L5 signals.

7.2 User Equipment Biases

User equipment bias errors introduced by the receiver hardware are often ignored because they are relatively small in comparison to other error sources, especially when cancellation is considered. *GPS signals are delayed as they travel through the antenna, analog hardware (e.g., RF and IF filters, low-noise amplifiers, and mixers) and digital processing until the point where pseudo range and carrier-phase measurements are physically made within the digital receiver channels*. Although the absolute delay values for propagation from the antenna phase center until the digital channels may be quite large (over 1 µs with long antenna-receiver cable runs or when SAW filters are employed), for similar signals on the same carrier frequency the delays experienced for the set of visible signals are nearly exactly equal. *The absolute delay is important for timing applications and must be calibrated out*. For many applications, however, the common delay does not affect performance, since it does not influence positioning accuracy, but rather directly appears only in the least-squares estimate of receiver clock bias.

8. Pseudo range Error Budgets

Based on the earlier discussion regarding error constituents, we can develop pseudo range error budgets to aid our understanding of stand-alone GPS accuracy. *These budgets are intended to serve as guidelines for position error analyses.* Position error is a function of both the pseudo range error (UERE) and user/satellite geometry (DOP).

Applications or Uses of GPS:

The United States government created the system, maintains it and makes it freely accessible to anyone with a GPS receiver. The global positioning system provides critical capabilities to military, civil and commercial users around the world.

- **GPS and Satellite Image:** GPS has been widely used to prepare map from Satellite images especially topographic surveys and thematic mapping.
- **Road Traffic Congestion:** A navigation device has a GPRS receiver for receiving real time information about or slow average speed on a stretch of motorway, indicating congestion. The device calculates a new itinerary to avoid the congestion, based on historically record speeds on secondary roads weighed by the current average speed in the congestion area.
- **GPS and Defense**: Corps use GPS as a modern defensive purpose like trending and rescued.
- **Accidental Purpose**: To find and rescue any crashes ship and airplanes, GPS Plays very important role.
- **Tectonics:** GPS enables direct fault motion measurement of earthquake between earthquake GPS can be used to measure crustal motion and deformation to estimate seismic strain build up for creating seismic hazard maps.
- **GPS and Terrorism:** GPS is very important to determine the location of terrorist attacks. For example, on the surgical strike, Indian intelligence agencies had using the GPS and Indian Army carried out surgical strike against terror launch pads on and along the Line of Control (LoC) on 2016.
- **GPS of Mining:** The use of RTK GPS has significantly improved several mining operations such as drilling, shoveling, vehicle tracking and surveying, RTK GPS provides centimetre-level positioning accuracy.
- **GPS and Climatology:** GPS plays very important role to prepare weather map and computerized map.
- **GPS and Tours:** Location determines what content to display, for instance, information about an approaching point of interest.
- **Navigation:** Navigators value digitally precise velocity and orientation measurements. With the help of GPS roads or paths available, traffic congestion and alternative routes, roads or paths that might be taken to get to the destination. If some roads are busy then the best route to take, The location of food, banks, hotels, fuel, airports or other places of interests, the shortest route between the two locations, the different options to drive on highway or back roads etc. are easily getting better result using GPS.
- **Disaster Relief:** GPS gives us the facility to measure the capabilities of earthquake, flood wildfires.
- **GPS-Equi Radio Sondes and Dropsondes:** GPS Measure and calculate the Atmospheric pressure, wind speed and direction up to 27 km from the earth's surface.
- **Fleet Tracking:** The use of GPS technology to identify, locate and maintain contact reports with one or more fleet vehicles in real time.
- **Robotics:** Self-navigation, autonomous robots using GPS sensors, which calculate Latitude, Longitude, Time, speed and heading.
- **Sport:** GPS also used in footballs and rugby and different sports for control and analysis of the training load.

- **Surveying:** Surveyors use absolute locations to make maps and determines property boundaries. The surveying and mapping community was one of the first to take advantage of GPS because it dramatically increased the productivity and resulted in more accurate and reliable data. Today, GPS is a vital part of surveying and mapping activities around the world.

- **Distance and Height Measurement:** GPS helps to calculate the distances and heights of different places on the earth surface.

- **Automated Vehicle:** With the help of GPS location and routes for cars and trucks to function without a human driver.

- **Agriculture:** GPS-based applications in precision farming are being used for farm planning, field mapping, soil sampling, tractor guidance, crop scouting, variable rate applications, and yield mapping. GPS allows farmers to work during low visibility field conditions such as rain, dust, fog, and darkness.

- **GPS and Fishing:** Synoptic maps of the main concentrations of fisherman villages, fishing ports and beach landing points, markets, processing, freezing and transshipment points, coastal landforms can be studied with the help of GPS.

- **GPS and Oil Leak:** GPS tracking technology is helping with the study by examining how currents are influence by winds and waves and measuring wind speed to find out how oil would spread from the ocean, onto the beach. Many instruments are being used in the study to gather as much data as possible. After data is collected, researchers plan to use 3D pictures of oil transports and hope to come up with more information about oil spills, how to mitigate their damage, and how to protect the environment.

- **Astronomy:** Both positional and clock synchronization data is used in astrometry and celestial mechanics calculations. It is also used in amateur astronomy using small telescope to professionals observations, for example, which finding extra solar planets.

- **GPS and Forestation:** GPS Technology Makes Tree Planting More efficient. Deforestation and disappearing wildlife habitats are a big problem in the modern world. Manufacturing industries use state-of-the- art technologies to produce and sell more paper and wood products, but there is growing concern over the devastation wrought by their methods of obtaining materials. The rate with which large, luscious forests are being cut down. The trees are being removed much more quickly than we can hope to replant, as trees take many years to grow to their full potential. One solution-orientated man is leading team, developing ways to replant forests as quickly and efficiently as possible, using GPS technology.

- **Topographic Mapping:** In a Ground Control Point (GCP) system, GPS tool use to prepare the topographic mapping of real world.

- **GPS and Urban Planning:** A special GPS technology has been used in urban planning and engineering survey.

- **Cartography:** Both civilian and military cartographers use GPS extensively.

Global Navigation Satellite System

GPS (USA)

The United States Global Positioning System (GPS) consists of up to 32 medium Earth orbit satellites in six different orbital planes with the exact number of satellites varying as older satellites are retired and replaced. Operational since 1978 and globally available since 1994, GPS is the world's most utilized satellite navigation system.

GLONASS (Russia)

The formerly Soviet, and now Russian, Global'naya Navigatsionnaya Sputnikovaya Sistema, (Global Navigation Satellite System or GLONASS), is a space-based satellite navigation system that provides a civilian radio navigation-satellite service and is also used by the Russian Aerospace Defense Forces and is the Second alternative navigational system in operation. GLONASS became operational in year 1993 with 12 satellites in 2 orbits at the height of 19,130 km. At present, there are total 27 satellites in orbit and all are operational.

Galileo (EU)

The European Union and European Space Agency agreed in March 2002 to introduce their own alternative to GPS, called the Galileo positioning system. Galileo became operational on 15 December 2016 (global Early Operational Capability (EOC)). At an estimated cost of €10 billion, the system of 30 MEO satellites was originally scheduled to be operational in 2010. The original year to become operational was 2014. The first experimental satellite was launched on 28 December 2005. Galileo is expected to be compatible with the modernized GPS system. The receivers will be able to combine the signals from both Galileo and GPS satellites to greatly increase the accuracy. Galileo is expected to be in full service in 2020 and at a substantially higher cost. Galileo is global navigation system available for civilian and commercial use. *The fully deployed Galileo system will consist of 30 operational satellites and 6 in-orbit spares. As of now 22 out of 30 satellites are in orbit.* Galileo started offering Early Operational Capability from 2016 and is expected to reach full operational capability by 2020.

BeiDou (China)

BeiDou is Satellite Navigation System of China. It has total 22 Operational satellites in orbit and the full constellation is scheduled to comprise 35 satellites. *BeiDou has two separate constellations, BeiDou-1 and BeiDou-2. BeiDou-1 also known as first generation was a constellation of three satellites. BeiDou-2, also known as COMPASS, is the second generation of the system*. Beidou started as the now-decommissioned Beidou-1, an Asia-Pacific local network on the geostationary orbits. China has indicated their plan to complete the entire second generation Beidou Navigation Satellite System (BDS or BeiDou-2, formerly known as COMPASS), by expanding current regional (Asia-Pacific) service into global coverage by 2020. This BeiDou-3 system is proposed to consist of 30 MEO satellites and five geostationary satellites (IGSO). A 16-satellite regional version (covering Asia and Pacific area) was completed by December 2012. Global service was completed by December 2018. It became operational in year 2000 and offered limited coverage and navigation services, mainly for users in China and neighboring regions. Beidou-1 was decommissioned at the end of 2012. It became operational in the year 2011 with a partial constellation of 10 satellites in the orbit. Next generation of it is BeiDou-3. The first BDS-3 satellite was launched in March 2015. As of January 2018, nine BDS-3 satellites have been launched. BeiDou-3 is expected to be fully functional by the end of 2020

Regional Navigation Satellite Systems

NavIC (India)

The Indian Regional Navigation Satellite System (IRNSS), which was later given the operational name of NavIC or Navigation with Indian Constellation (NavIC), is the regional satellite navigation system of India. Launched and operated by the Indian Space Research Organization (ISRO), IRNSS covers India and nearby regions extending up to 1,500 km.

The NavIC or Navigation with Indian Constellation is an autonomous regional satellite navigation system developed by Indian Space Research Organisation (ISRO) which would be under the total control of Indian government. *The government approved the project in May 2006, with the intention of the system completed and* *implemented on 28 April 2016. It consists of a constellation of 7 navigational satellites. 3 of the satellites are placed in the Geostationary orbit (GEO) and the remaining 4 in the Geosynchronous orbit (GSO) to have a larger signal footprint and lower number of satellites to map the region*. It is intended to provide an all-weather absolute position accuracy of better than 7.6 meters throughout India and within a region extending approximately 1,500 km around it. *A goal of complete Indian control has been stated, with the space segment, ground segment and user receivers all being built in India. All 7 satellites, IRNSS-1A (1 July 2013), IRNSS-1B (4 April 2014), IRNSS-1C (16 October 2014), IRNSS-1D (28 March 2015), IRNSS-1E (20 January 2016), IRNSS-1F (10 March 2016), and IRNSS-1G (28 April 2016) of the proposed constellation were precisely launched from Satish Dhawan Space Centre.*

It covers India and a region extending 1,500 km (930 mi) around it, with plans for further extension. An Extended Service Area lies between the primary service area and a rectangle area enclosed by the 30th parallel south to the 50th parallel north and the 30th meridian east to the 130th meridian east, 1,500–6,000 km beyond borders. The system at present consists of a constellation of seven satellites, with two additional satellites on ground as stand-by.

The constellation was in orbit as of 2018, and the system was operational from early 2018 after a system check. NavIC provides two levels of service, the "standard positioning service", which will be open for civilian use, and a "restricted service" (an encrypted one) for authorized users (including military). There are plans to expand NavIC system by increasing constellation size from 7 to 11.

QZSS (Japan)

The Quasi-Zenith Satellite System (QZSS) is the regional satellite navigation system from Japan which is still under construction by the Satellite Positioning Research and Application Center, Japan. *As per plans, the QZSS constellation will have 7 satellites, out of which 4 are already in orbit. The Quasi-Zenith Satellite System (QZSS) is a four-satellite regional time transfer system and enhancement for GPS covering Japan and the Asia-Oceania regions.* QZSS services were available on a trial basis as of January 12, 2018, and were launched in November 2018. The first satellite was launched in September 2010. An independent satellite navigation system (from GPS) with 7 satellites is planned for 2023.

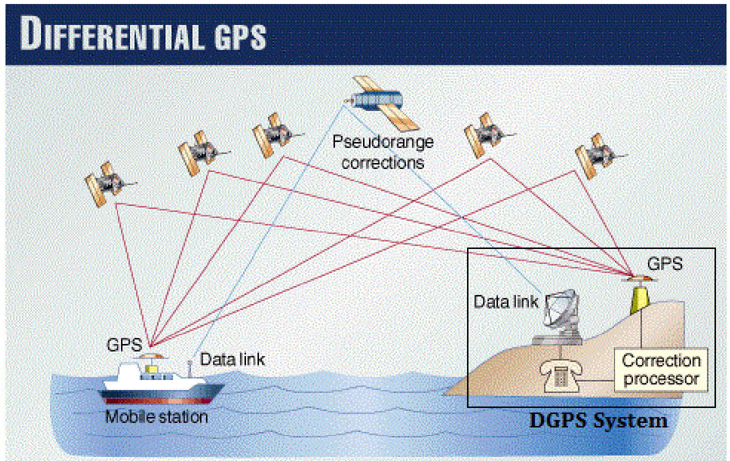
Augmentation

GNSS augmentation is a method of improving a navigation system's attributes, such as accuracy, reliability, and availability, through the integration of external information into the calculation process, for example, the Wide Area Augmentation System, the European Geostationary Navigation Overlay Service, the Multi-functional Satellite Augmentation System, Differential GPS, GPS-Aided GEO Augmented Navigation (GAGAN) and inertial navigation systems.

DORIS

Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS) is a French precision navigation system. Unlike other GNSS systems, it is based on static emitting stations around the world, the receivers being on satellites, in order to precisely determine their orbital position. The system may be used also for mobile receivers on land with more limited usage and coverage. Used with traditional GNSS systems, it pushes the accuracy of positions to centimetric precision (and to millimetric precision for altimetric application and also allows monitoring very tiny seasonal changes of Earth rotation and deformations), in order to build a much more precise geodesic reference system Global Positioning System (United States)

Differential Global Positioning System (DGPS)



A Differential Global Positioning System (DGPS) is an enhancement to the Global Positioning System (GPS) which provides improved location accuracy, in the range of operations of each system, from the 15-meter nominal GPS accuracy to about 1-3 cm in case of the best implementations.

The United States Coast Guard (USCG) and the Canadian Coast Guard (CCG) each run DGPSes in the United States and Canada on long wave radio frequencies between 285 kHz and 325 kHz near major waterways and harbors. *The USCG's DGPS was named NDGPS (Nationwide DGPS)* and was jointly administered by the Coast Guard and the U.S. Department of Defense's Army Corps of Engineers (USACE). It consisted of broadcast sites located throughout the inland and coastal portions of the United States including Alaska, Hawaii and Puerto Rico.[2] Other countries have their own DGPS.

A similar system which transmits corrections from orbiting satellites instead of ground-based transmitters is called a Wide-Area DGPS (WADGPS) or Satellite Based Augmentation System.

Differential Global Positioning Systems (DGPS) are GPS systems that use fixed reference locations on Earth to calculate positioning errors transmitted by the satellites in view. Since the location of these reference points in already knows, they can easily calculate any positioning errors that are being transmitted by the GPS constellation. This error information is then transmitted out to GPS devices, which use this information to calculate their accurate position.

Difference between GPS and DGPS

GPS: GPS known as Global Positioning System is a collection of number of satellites in the space sending the precise location details in the space back to Earth. *Signals are obtained by the GPS instrument which uses to calculate its location, speed, and time at the location, height of the location and other info*. It is very popular in the military world and was first developed by the USA military during the Cold war period. After early 1980 GPS technology is available to the public. Before the military use, 1960 was the year when GPS was first used for ship navigation by USA navy.

DGPS: Differential Global Positioning System (DGPS) is an enhancement to the GPS (Global Position System). *GPS system based on the satellite technology can have the nominal accuracy of 15 meter whereas DPGS can bring accuracy around 10 cm*. DGPS uses the fixed ground based reference stations to broadcast the difference between the coordinates from the GPS and from the fixed position from the base station. The digital correction signal is transmitted to all ground based transmitters called rovers. DGPS rely on two stations one is base station and next is rover.

- In GPS world, handheld device receive signal from the satellite for the position where as in DGPS world hand held device (rover) receives calibrated signal from the ground based transmitter.

- GPS accuracy is around 15 meters whereas DGPS is around 10 cm.
- GPS instrument can be used globally where as DGPS are meant locally may be within 100km. DGPS accuracy will start to degrade once instrument distance from ground based transmitters start to increase. Best results by the United States Department of Transportation were 0.67 m error growth within 100 km.
- GPS system is affordable compare to DGPS system which is why all smart phones have built-in GPS system.
- In GPS satellite transmit signal in frequency ranging from 1.1 to 1.5 GHz. In DGPS frequency varies by agencies, here is the list of frequency used by different agency.
- GPS accuracy is highly depending upon the number of satellites used for the calculation, for example there will be better accuracy on open space compare to the forested area. DGPS accuracy is not affected by these variables. It might be affected by the distance between transmitters and the instrument (rover).
- Most of the time coordinate system used in GPS will be WGS84 in Longitude and Latitude format where as DGPS might have local coordinate system.
- GPS instruments cover the wide range and can be used globally while DGPS instruments cover a short range up to 100 km, but this range could change according to the frequency band.
- GPS system is less expensive as compared to DGPS system.
- The factors that affect the accuracy of the GPS system are selective availability, satellite timing, atmospheric conditions, ionosphere, troposphere and multipath. In contrast, the DGPS system is affected by the distance between the transmitter and rover, ionosphere, troposphere and multipath but at less extent.

Basis for Comparison	**GPS**	**DGPS**
Number of receivers used	Only one, i.e., Stand-alone GPS receiver	Two, Rover and stationary receivers
Accuracy	15-10 m	10 cm
Range of the instruments	Global	Local (within 100 km)
Cost	Affordable as compared to DGPS	Expensive
Frequency range	1.1 - 1.5 GHz	Varies according to agency
Factors affecting the Accuracy	Selective availability, satellite timing, atmospheric conditions, ionosphere, troposphere and multipath.	Distance between the transmitter and rover, ionosphere, troposphere and multipath.
Time coordinate system used	WGS84	Local coordinate system
Range	GPS's instruments range is global.	While DGPS's instruments range is local.

Applications of DGPS

- **Air Navigation:** One of its more popular applications is in air navigation. By using it a pilot can receive constant information about where the plane is in 3 dimensions.
- **Farming:** It is also becoming a hot topic in precision farming. Farmers can use DGPS to map out their crops, map crop yields, and control chemical applications and seeding.
- **Hydrographic Survey:** It is also proving to be useful in ground and hydrographic surveying.
- **Weather forecast:** Another application is in weather forecasting, where atmospheric information can be gained from its effects on the satellite signals.
- **Coastal Monitoring:** There has also been at least one experiment where it was used for beach morphology and monitoring.
- **Transport:** DGPS can also be used for train control for such things as avoiding collisions and routing.
- **City Administrative:** There is even been research into using it to help the visually impaired in getting around in cities.
- **Car Navigation:** There is also at least one project that is working on using DGPS for car navigation.
- **Sports field:** In the sports world it is finding a place in balloon and boat racing. It will eventually become an integral part of much of our technology.

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