

Introduction to Global Positioning System

What is the Global Positioning System

The Global Positioning System was conceived in 1960 under the auspices of the U.S. Air Force, but in 1974 the other branches of the U.S. military joined the effort. The first satellites were launched into space in 1978. The System was declared fully operational in April 1995.

The Global Positioning System consists of 24 satellites, that circle the globe once every 12 hours, to provide worldwide position, time and velocity information. GPS makes it possible to precisely identify locations on the earth by measuring distance from the satellites. GPS allows you to record or create locations from places on the earth and help you navigate to and from those places.

Originally the System was designed only for military applications and it wasn't until the 1980's that it was made available for civilian use also.

The 3 segments of GPS

The Space segment: The space segment consists of 24 satellites circling the earth at 12,000 miles in altitude. This high altitude allows the signals to cover a greater area. The satellites are arranged in their orbits so a GPS receiver on earth can always receive a signal from at least four satellites at any given time. Each satellite transmits low radio signals with a unique code on different frequencies, allowing the GPS receiver to identify the signals. The main purpose of these coded signals is to allow for calculating travel time from the satellite to the GPS receiver. The travel time multiplied by the speed of light equals the distance from the satellite to the GPS receiver. Since these are low power signals and won't travel through solid objects, it is important to have a clear view of the sky.

The Control segment: The control segment tracks the satellites and then provides them with corrected orbital and time information. The control segment consists of four unmanned control stations and one master control station. The four unmanned stations receive data from the satellites and then send that information to the master control station where it is corrected and sent back to the GPS satellites.

The User segment: The user segment consists of the users and their GPS receivers.

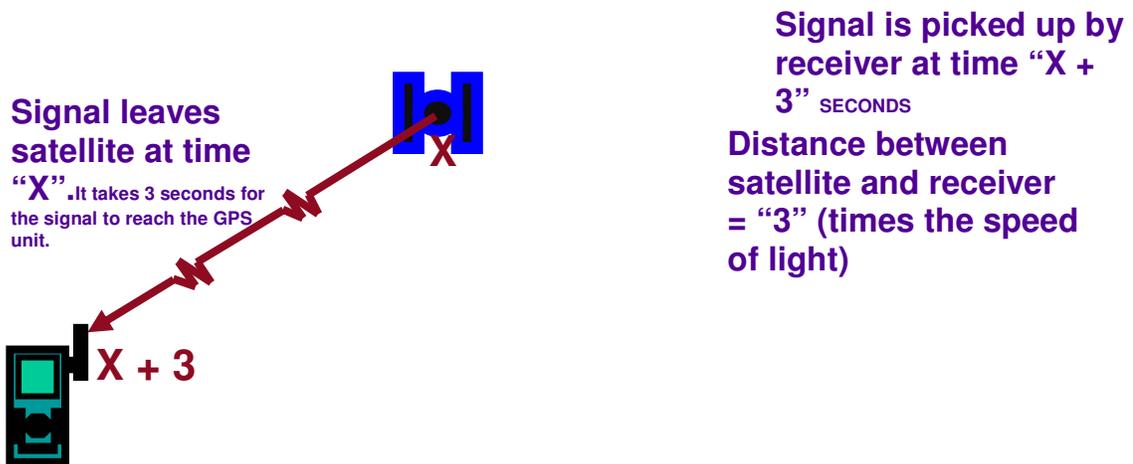
The number of simultaneous users is limitless.

How GPS Works

When a GPS receiver is turned on, it first downloads orbit information of all the satellites. This process, the first time, can take as long as 12.5 minutes, but once this information is downloaded, it is stored in the receivers memory for future use. Even though the GPS receiver knows the precise location of the satellites in space, it still needs to know the distance from each satellite it is receiving a signal from. That distance is calculated, by the receiver, by multiplying the velocity of the transmitted signal by the time it takes the signal to reach the receiver. The receiver already knows the velocity, which is the speed of a radio wave or 186,000 miles per second (the speed of light).

To determine the time part of the formula, the receiver matches the satellites transmitted code to its own code, and by comparing them determines how much it needs to delay its code to match the satellites code. This delayed time is multiplied by the speed of light to get the distance.

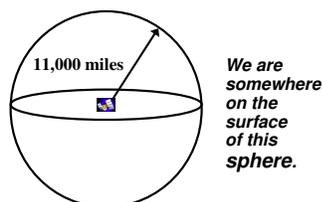
The GPS receivers clock is less accurate than the atomic clock in the satellite, therefore, each distance measurement must be corrected to account for the GPS receivers internal clock error.



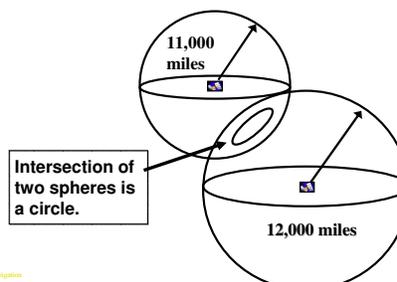
Triangulation

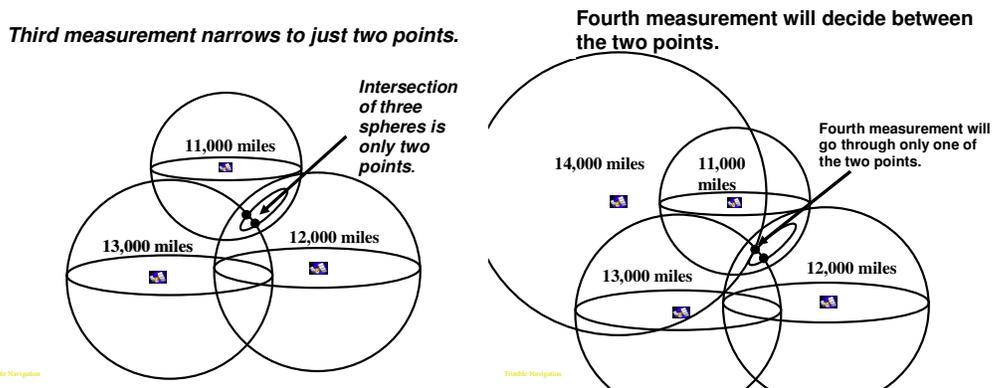
Once both satellite and position are known for at least 4 satellites, the receiver can determine a position by triangulation.

One measurement narrows down our position to the surface of a sphere



Second measurement narrows it down to the intersection of two spheres.





Sources of GPS Error

GPS receivers have potential position errors due to some of the following sources:

User mistakes account for most GPS errors. Incorrect datum and typographic errors when inputting coordinates into a GPS receiver can result in errors up to many kilometers. Unknowingly relying on less than four satellites for determining position coordinates can also result in unreliable position fixes that can easily be off by a distance in excess of a mile. Even the human body can cause signal interference. Holding a GPS receiver close to the body can block some satellite signals and hinder accurate positioning. If a GPS receiver must be hand held without benefit of an external antenna, facing to the south can help to alleviate signal blockage caused by the body because the majority of GPS satellites are oriented more in the earth's southern hemisphere. A GPS receiver has no way to identify and correcting user mistakes.

Satellite clock errors: Caused by slight discrepancies in each satellite's four atomic clocks. Errors are monitored and corrected by the Master Control Station.

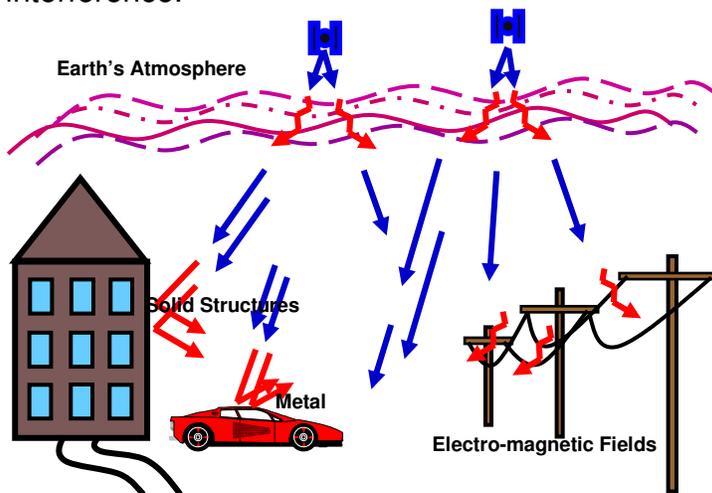
Orbit errors: Satellite orbit (referred to as "satellite ephemeris") pertains to the altitude, position and speed of the satellite. Satellite orbits vary due to gravitational pull and solar pressure fluctuations. Orbit errors are also monitored and corrected by the Master Control Station.

Ionospheric interference: The ionosphere is the layer of the atmosphere from 50 to 500 km altitude that consists primarily of ionized air. Ionospheric interference causes the GPS satellite radio signals to be refracted as they pass through the earth's atmosphere – causing the signals to slow down or speed up. This results in inaccurate position measurements by GPS receivers on the ground. Even though the satellite signals contain correction information for ionospheric interference, it can only remove about half of the possible 70 nanoseconds of delay, leaving potentially up to a ten meter horizontal error on the ground. GPS receivers also attempt to "average" the amount of signal speed reduction caused by the atmosphere when they calculate a position fix. But this works only to a point. Fortunately, error caused by atmospheric conditions is usually less than 10 meters. This source of error has been further reduced with the aid of the Wide Area Augmentation System (WAAS), a space and ground based augmentation to the GPS (to be covered later).

Tropospheric interference: The troposphere is the lower layer of the earth's atmosphere (below 13 km) that experiences the changes in temperature, pressure, and humidity associated with weather changes. GPS errors are largely due to water vapor in this layer of the atmosphere. Tropospheric interference is fairly insignificant to GPS.

Receiver noise is simply the electromagnetic field that the receiver's internal electronics generate when it's turned on. Electromagnetic fields tend to distort radio waves. This affects the travel time of the GPS signals before they can be processed by the receiver. Remote antennas can help to alleviate this noise. This error cannot be corrected by the GPS receiver.

Multipath interference is caused by reflected radio signals from surfaces near the GPS receiver that can either interfere with or be mistaken for the true signal that follows an uninterrupted path from a satellite. An example of multipath is the ghosting image that appears on a TV equipped with rabbit ear antennas. Multipath is difficult to detect and sometimes impossible for the user to avoid, or for the receiver to correct. Common sources of multipath include car bodies, buildings, power lines and water. When using GPS in a vehicle, placing an external antenna on the roof of the vehicle will eliminate most signal interference caused by the vehicle. Using a GPS receiver placed on the dashboard will always have some multipath interference.



Selective Availability (S/A) was the intentional degradation of the satellite signals by a time varying bias. Selective Availability is controlled by the DOD to limit accuracy for non - U.S. military and government users and was originally instituted for security reasons. In May, 2000, bowing to pressure from business and the White House, the Pentagon set Selective Availability to zero. The Pentagon did not turn S/A off, but rather merely reduced the amount of signal interference to zero meters, effectively eliminating intentional position errors.

The Pentagon retains the ability to reactivate S/A without notice to non government GPS users. So it's important to understand what Selective Availability is, and to be aware that it could be reactivated by the U.S. military at any time without prior notification.

Number of satellites visible: The more satellites the receiver can "see", the better

the accuracy. Signal reception can be blocked by buildings, terrain, electronic interference and sometimes dense foliage. The clearer the view, to the receiver, the better the reception.

Satellite geometry: This refers to the relative position of the satellites at any given time. Ideal satellite geometry exists when the satellites are located at wide angles relative to each other. Poor geometry exists when the satellites are located in a line or in a tight grouping.

GPS Terminology

2D Positioning: In terms of a GPS receiver, this means that the receiver is only able to lock on to three satellites which only allows for a two dimensional position fix. Without an altitude, there may be a substantial error in the horizontal coordinate.

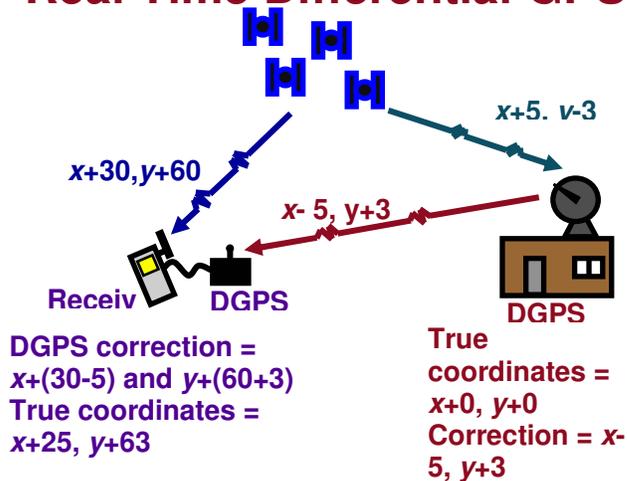
3D Positioning: Position calculations in three dimensions. The GPS receiver has locked on to 4 satellites. This provides an altitude in a addition to a horizontal coordinate, which means a much more accurate position fix.

Real Time Differential GPS: Real-time DGPS employs a second, stationary GPS receiver at a precisely measured spot (usually established through traditional survey methods). This receiver corrects any errors found in the GPS signals, including atmospheric distortion, orbital anomalies, Selective Availability (when it existed), and other errors. A DGPS station is able to do this because its computer already knows its precise location, and can easily determine the amount of error provided by the GPS signals. DGPS corrects or reduces the effects of:

- Orbital errors
- Atmospheric distortion
- Selective Availability
- Satellite clock errors
- Receiver clock errors

DGPS cannot correct for GPS receiver noise in the user's receiver, multipath interference, and user mistakes. In order for DGPS to work properly, both the user's receiver and the DGPS station receiver must be accessing the same satellite signals at the same time.

Real Time Differential GPS



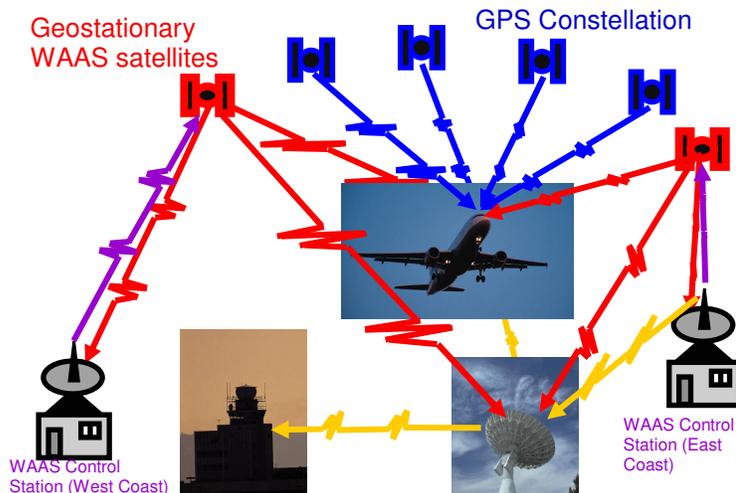
Wide Area Augmentation System:

The Wide Area Augmentation System (WAAS) is an experimental system designed to enhance and improve satellite navigation over the continental United States, and portions of Mexico and Canada.

Think of WAAS as a highly advanced real-time differential GPS. But instead of using ground based transmitters to broadcast position correction information, WAAS uses its own geostationary satellites in fixed orbit over North America. There are 25 ground reference stations positioned across the United States (including three in southern Alaska, and one each in Puerto Rico and Hawaii) that monitor GPS satellite signals. These stations continuously receive and correct GPS satellite information against their own known precise positions. Each WAAS ground station (referred to as a Wide Area Reference Station, or WRS) then sends its corrected GPS data to one of two master control stations located on the Pacific and Atlantic coasts of the U.S. These master control stations create a correction message that weeds out atmospheric distortion, GPS satellite orbit and clock errors and time errors. This message is then broadcast to the two WAAS satellites. These in turn re-broadcast the correction information using the basic GPS signal structure to any WAAS capable GPS receiver.

Unlike differential GPS which requires additional equipment to work, the WAAS is available to anyone equipped with a WAAS capable GPS receiver in much of the United States and portions of Mexico. However, the System has its limitations at this time, including poor coverage over portions of the northern United States, and very slow signal acquisition time. WAAS capable GPS receivers are now widely available.

Wide Area Augmentation System



Waypoint (Landmark)

A waypoint is based on geographic coordinate values entered into the receiver's memory. These coordinates represent either a saved receiver position fix, or user-entered coordinates. A Waypoint will have a designated alphanumeric name, or a user-supplied name. Once entered and saved, it remains static in the GPS receiver's memory until edited or deleted.

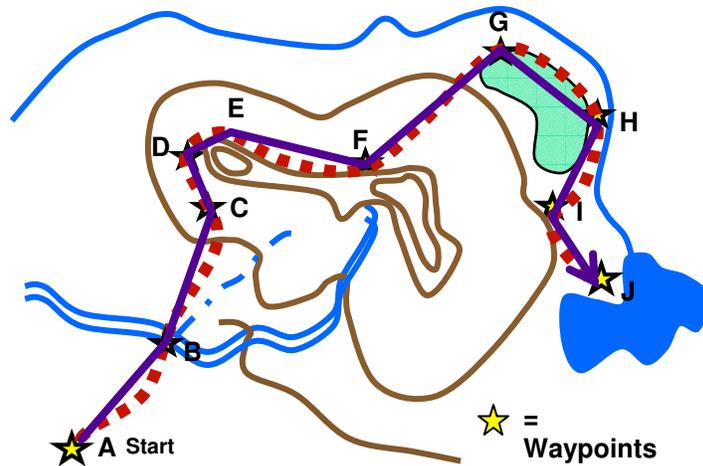
To turn a position fix into a waypoint is simply a matter of saving the receiver's current position as a waypoint. The receiver must be locked on to enough satellites to provide at least a two-dimensional (2D), or three-dimensional (3D) fix. The receiver will give the position coordinates an alpha-numeric name, or the user can designate a unique name. Once this happens, the position fix becomes a waypoint with static coordinates saved in memory.

A waypoint can also be created from coordinates derived other than by GPS. Coordinates on a map can become a waypoint. Coordinates radioed from a person in a remote location to another person can also become a waypoint once they are programmed into a GPS receiver.

Route

Routes are just a sequence of waypoints. Once you pass one waypoint, the next waypoint will be navigated to. When you first activate a route, the GPS receiver will assume that the first leg is A to B. B is the waypoint being navigated to and A is the anchor point that defines the first leg of the route.

A Route



Track Log

A track log is the GPS units' record of your travel or where you have been. As you move along your every movement is being stored. Receivers with a TracBack feature, will allow you to reverse your route taking you back the same way you originally traveled. Most GPS receivers show you your track as you move along on a map screen.

Goto Function

The Goto function gives GPS receivers the capability of leading you to any place you have specified. You simply enter the coordinate of your desired destination into the GPS receiver as a waypoint and then, by using the Goto function, you tell the receiver to guide you there. The receiver guides you to your destination using a steering screen. There are several different versions of a steering screen, but they do the same thing of pointing you in the direction you need to go to get from your present position to the waypoint you selected.

Note: The following terms are used by Garmin in its GPS manuals. Other GPS receiver manufacturers may use different terminology.

Active from waypoint is your starting waypoint, or the receiver's last waypoint in an active route.

Active GOTO waypoint is your designated destination in the receiver, whether in an active route, or as a single waypoint.

Active leg is always a straight line between the last waypoint and the GOTO waypoint. A GPS receiver always plots the most efficient, straight-line course of travel between two points - the active leg. If the receiver is following a route, the active leg will be the desired track between the last waypoint in the route, and the next waypoint in the route. If the receiver has deviated from the route, the receiver selects the closest leg to its position and makes it the active leg in the route (the next waypoint in the route list becomes the GOTO destination waypoint).

Bearing (BRG)/Desired Track (DTK): In GPS the term bearing is used in place of

azimuth. As used in GPS, bearing is the compass direction (expressed in degrees) from your present position to your desired destination waypoint, or the compass direction between any two waypoints.

Tracking (TRK)/ Heading (HDG) is the direction you are moving, expressed in degrees from north. The direction you are actually traveling.

Course Made Good (CMG) or Course Over Ground (COG) is your present direction of travel expressed in degrees from north. It is not necessarily the most direct path to a GOTO waypoint. If traveling from one waypoint to another (using GOTO), then XTE (see below) will show the distance of deviation of your actual route from the active leg (a straight line) between those waypoints.

Crosstrack Error (XTE) is the distance off the desired track (active leg) on either side of the active leg. It's the linear difference between the Desired Track (DTK) and your actual Course Made Good (CMG).

Course Deviation Indicator (CDI) graphically shows the amount and direction of XTE.

Desired track (DTK) is shown in degrees from north. It's a function of GOTO. DTK is measured along the active leg (a straight line between two waypoints in a route), or from your current position to a designated GOTO waypoint (when not navigating a route).

Speed Over Ground (SOG) is the velocity you are traveling.

Velocity Made Good (VMG): Velocity made good is the speed at which you approach your destination. If you are directly on course, VMG is the same value as SOG, but if you stray from course, VMG decreases and is less than SOG.

Estimated Position Error (EPE)

A measurement of horizontal position error in feet or meters based upon a variety of factors including DOP and satellite signal quality.

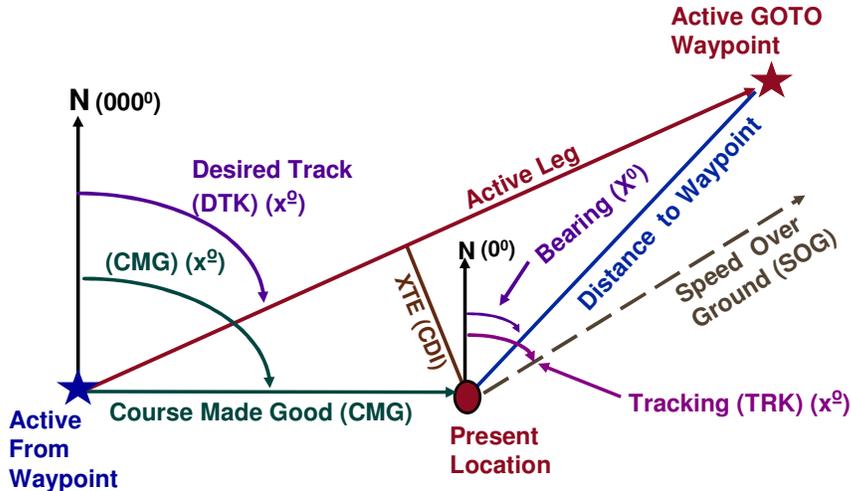
Estimated Time Enroute (ETE)

The time left to your destination based upon your present speed and course.

Estimated Time of Arrival (ETA)

The time of day of your arrival at a destination

GPS Navigation Terminology



GPS Receiver Inputs

The following are inputs that are needed before you use your GPS receiver.

Position Format: Input what units you want your position.

Examples: Latitude and Longitude

Degrees – Minutes – Seconds (hddd mm' ss.s°, N 43 - 40' - 55.8" E)

UTM (11T 0557442m E 4836621m N)

Map Datum:

Make sure the map datum in your GPS receiver matches the map datum of the map you are using when you are going to plot points on that map.

Some common map datums used are WGS 84, NAD 27 and NAD 83.

Distance:

Input distance units such as: Nautical or Statute miles, Metric, Yards

Elevation:

Input elevation units in feet or meters

North Reference: Input the North reference you want to use. Examples: True, Magnetic or Grid

Time: Input time format for 12 or 24 hour and input the correct time zone.