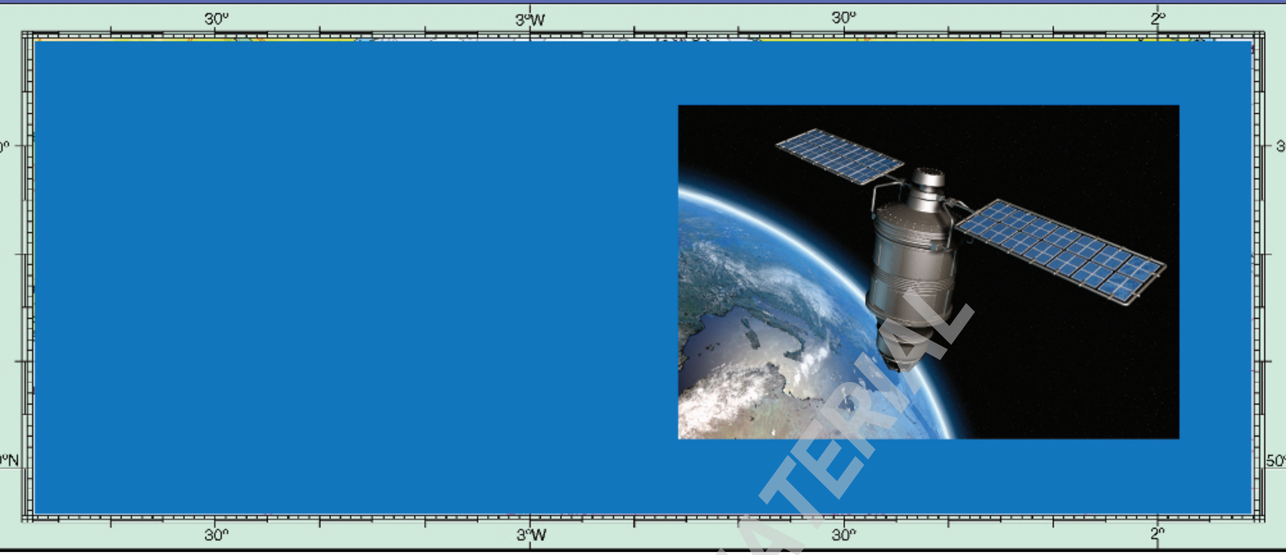
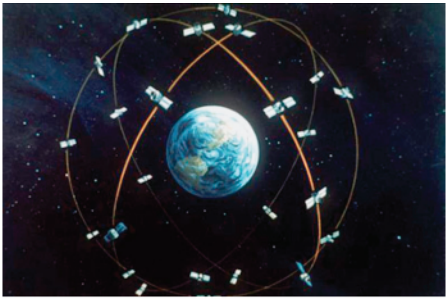


The Global Positioning System

How Your GPS Receiver Tells You Which Satellites It Can See
How GPS Works
Accuracy of the Fix
GPS Blackout
Deliberate Interference
GPS Is Line of Sight
Selective Availability
Differential GPS
Wide Area Augmentation Service
Switch-On Delays
Measurement of Speed
Measurement of Course
Measurement of Heading
Errors in COG and SOG

The original global positioning system (GPS) consists of 24 satellites orbiting the Earth at a distance of around 11 000 miles. Each orbits once every 12 hours in six orbital plains, so there will be between five and eight satellites in view at any time, from any point on the Earth's surface. The drawing here shows only three orbital plains for clarity.


Artwork courtesy of US Dept of Defense

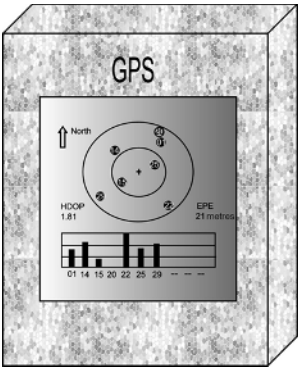
Simplified GPS satellite constellation

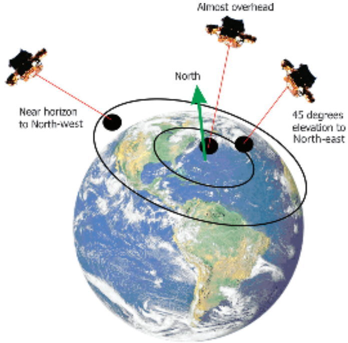
There are a number of spare satellites in orbit in case of failure and each satellite has a life expectancy of about 7 years. New satellites are launched by the US military as required.

Fears about the American monopoly of accurate position fixing amongst non-USA countries have lead to the establishment of GLONASS (a Russian system) and the pending establishment of GALLILEO (a European system). They work in a similar manner and new versions of GPS receiver may be able to operate with any system.

How Your GPS Receiver Tells You Which Satellites It Can See

On startup, a GPS receiver starts looking for satellites and will display a page showing you its sky view all around the horizon. The outer ring is the horizon, the inner ring is at an elevation of 45 degrees and the centre represents the position in the sky vertically overhead (the zenith). The predicted positions of satellites are shown as empty circles which become coloured when a satisfactory satellite signal is received. The serial number of the satellite is shown in the circle. Alongside the diagrams are vertical bars representing the signal strength (in fact the signal-to-noise ratio or quality of the signal) and again each bar is numbered. In this way, you can see the number of satellites and the quality of the signals being received in order to form an idea of how good a fix you are likely to get. There's often a number giving an indication of the fix accuracy, more of which later.

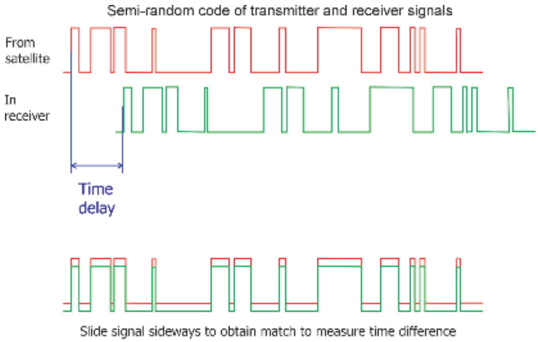




GPS satellite positions

How GPS Works

Timing



Measuring the time taken for the GPS signal to reach the GPS receiver

In order to find its position on the Earth's surface, a GPS receiver needs to find its distances from at least four satellites. Theoretically, it needs only three, but the clock on the receiver is not accurate enough to allow this.

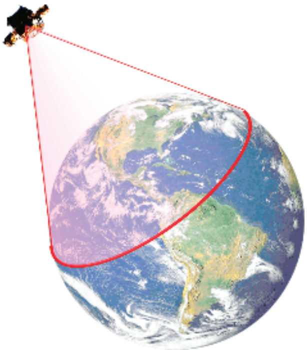
Distance is measured by measuring the time taken for the GPS signal to travel from the satellite to the receiver. As the time taken is only 0.06 second for a satellite immediately overhead, an error of one thousandth of a second would give an error of 200 miles! Each satellite has an onboard 'Atomic Clock', which is super accurate, but for each receiver to be similarly equipped, GPS would not be a practical proposition.

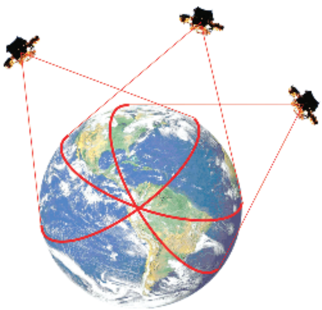
Satellites transmit a semi-random signal, which the receiver matches with its own semi-random signal. The distance the receiver has to move its own signal to get a match is a measure of the time difference and a range can then be calculated. It's a bit like matching continually repeated barcodes in reality. This is accurate enough to get a first guess at the distance.

Fixing Position with GPS

If the distance to the satellite is calculated by the receiver, it can be plotted as a *position line*, where any place on the Earth's surface is the same distance from the satellite. The receiver must lie somewhere on that position line.

If the distances from two more satellites are calculated and plotted, the receiver must lie on all three lines. Normally, this can occur at only one point on the Earth's surface and so that must indicate the position of the receiver.





Cocked hat

Because of small inaccuracies in the receiver's clock, there will be an error in its position. The position lines will not intersect at the same point and will form what is known as a *cocked hat.*

Pseudo Range

A clever trick within the receiver converts the ranges into *pseudo* ranges, which allows them to be shuffled around within certain limits.

The range from a fourth or even more satellites is calculated and added to the *fix*.

The extra position line(s) allows the timing error to be determined and this results in a good fix, where all the position lines intersect at only one point.

Pseudo range

Fourth satellite

Good fix

Accuracy of the Fix

With range being calculated using the time taken for the signal to travel between the satellite and the receiver, any variation in the speed of the signal and the actual path followed will lead to errors.

Errors due to these effects will normally amount to no more than ±15 metres for 95% of the time, being made up from the following:

- ionospheric effects, ±10 metres;
- ephemeris errors, ±2.5 metres;
- satellite clock errors, ±2 metres;
- multipath distortion, ±1 metre;
- tropospheric effects, ±0.5 metre;
- numerical errors, ±1 metre or less.

Range rings at 25 metres spacing

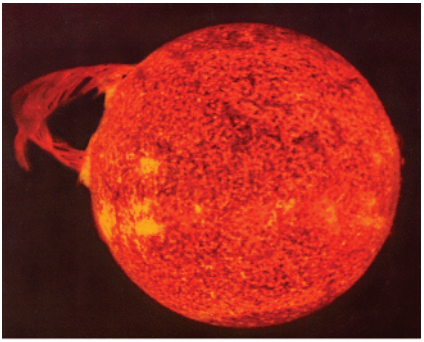
Normal GPS errors

With my boat moored in the marina, normal GPS errors were plotted as shown over an 8 hour period. Although most were contained within the 25 metre diameter circle, one was almost 100 metres in error. This is perfectly normal GPS performance.

GPS Blackout

Solar flares can cause a complete GPS signal blackout on the sunlit side of the Earth's surface. In 2006 flares on the 5th and 6th of December caused profound and severe effects to GPS receivers causing a large number of them to stop tracking satellites. Professor Dale Gary of the New Jersey Institute of Technology said 'This solar radio burst occurred during a solar minimum, yet produced as much as 10 times more radio noise than the previous record … at its peak, the burst produced 20000 times more radio emission than the entire rest of the Sun. This was enough to swamp GPS receivers over the entire sunlit side of the Earth'.

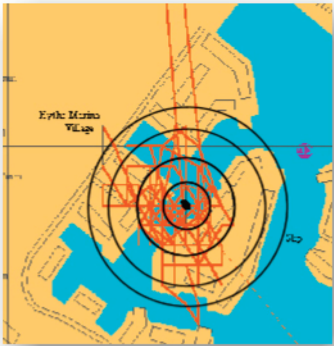
The Solar flare cycle covers a period of 11 years.



Solar flares can cause significant GPS errors even disablement of satellites

Deliberate Interference

The strength of the radio signals carrying the GPS data is very low and can easily be interfered with. Enemies can deliberately try to disrupt signals in a relatively small local area and military agencies regularly deliberately interfere with the signals to judge the results. These tests are promulgated in advance.



Range rings at 25 metres spacing

GPS errors with 'selective availability'

GPS Is Line of Sight

A GPS receiver must be able to 'see' a satellite in order to receive its signal. If buildings, cliffs or trees obstruct that line of site, the signal from that satellite will not be received and the accuracy of the fix may be degraded. It's possible that the signal may be received as it bounces off another surface so it will take longer time to arrive and will give an inaccurate range. Again this can degrade the fix accuracy.

The signal can penetrate some solid surfaces, such as glass, GRP and canvas, and it is sometimes possible for a receiver antenna mounted inside the boat to work satisfactorily.

Selective Availability

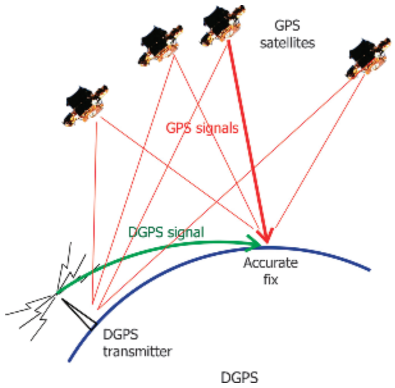
Originally, civilian users had their signals deliberately degraded by the US military inducing a randomly varying error, known as *selective availability*, ensuring that accuracy was no better than 100 metres for 95% of the time. This selective availability has been switched off, but the US military may reintroduce it, without warning, at any time. This must always be considered a possibility. On the accompanying chart, the error that disappears northward off the chart was over 800 metres.

Errors that occur from a corrupt satellite signal will be incorporated into the fix by a GPS receiver and can lead to very large errors, measured in miles, and will continue until the satellite is switched off by the monitoring team, which could take up to one and a half hours.

Differential GPS

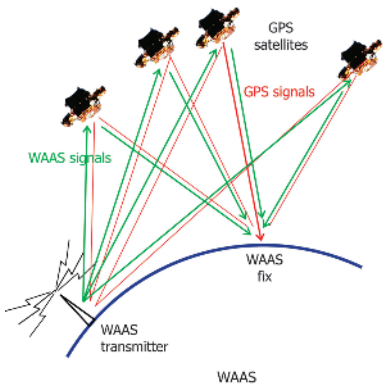
A GPS receiver fixed in one place will know exactly where it is. Any position derived from the received GPS signals can be compared with its known position and any error deduced. If this error was transmitted to the nearby GPS receivers, they could take account of this error in deducing their own position to give a much more accurate result, with a 95% probability error of 3 metres. This is known as *differential GPS* (DGPS).

To take advantage of this, the GPS receiver needs both a separate DGPS receiver and to be within range of a DGPS station, usually about 200 miles. This is commonly used for survey GPS and was beginning to be common for leisure users until selective availability was switched off, when its need for normal leisure use disappeared because of the inherent 15-metre accuracy.



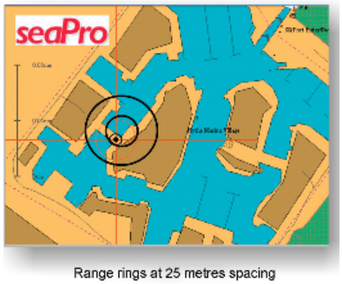
Wide Area Augmentation Service

Wide Area Augmentation Service (WAAS) uses a network of ground stations to monitor the GPS position accuracy. The error corrections are sent to two master stations, which in turn send error correction information to the constellation of satellites. The continuously varying error correction information is broadcast by the satellites and is then available to all WAAS compatible GPS receivers. The 95% error is then reduced to 7.5 metres. Manufacturers usually optimistically claim a 3-metre accuracy. Integrity monitoring is part of this system, so anomalous



signals from under-performing satellites are automatically discarded.

WAAS is available only in the United States of America, but European Geostationary Navigation Overlay Service (EGNOS) and the Japanese Multi-Functional Satellite Augmentation System (MSAS) provide the same service in areas covered by these. A WAAS compatible receiver will operate with EGNOS and MSAS.



Range rings at 25 metres spacing
WAAS GPS errors

The Modern GPS Receiver

Modern GPS receivers normally have 12 or more channels which can receive data from 12 different satellites simultaneously. Satellites are moving fairly rapidly along their paths and the ability of the receiver to 'lock' onto a large number of satellites means that they are always using the best data available. It also means that their 'startup' times are very quick.

The oldest receivers have very few channels, so they have to divide their time between using data from only one or a few satellites and searching for new ones. They are inherently slow.

A modern GPS receiver

Switch-On Delays

Cold Start

When a new GPS receiver is first switched on, it has no idea of the time, date, where it is or where the satellites are. As the information about the whereabouts of the satellites is transmitted only every 12.5 minutes, it will be some time before the GPS can compute its first fix. This is known as a *cold start.*

Hot Start

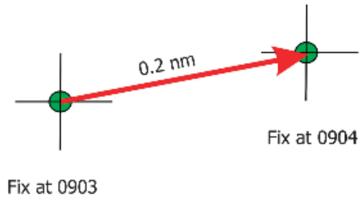
When the GPS is switched in the same geographical position as when it was switched off, it knows where to expect the satellites to be, the date and the time, so modern 12 channel receivers can compute their first fix very quickly.

Warm Start

If the GPS receiver has been moved since it was last switched off, it will take longer time than a hot start but much less than a cold start.

Measurement of Speed

There is nothing inherent in the GPS signals that measure speed. However, the receiver does have a lot of built-in information that it can use to present useful information. Once the GPS receiver has worked out its position, it can use its knowledge of the shape and size of the Earth to determine the distance between any two points, so that once it is in motion it can work out the distance between two fixes, and taking the time taken to travel this distance it can deduce its speed. This speed is the *speed over the ground* (SOG), not to be confused with the speed through the water.

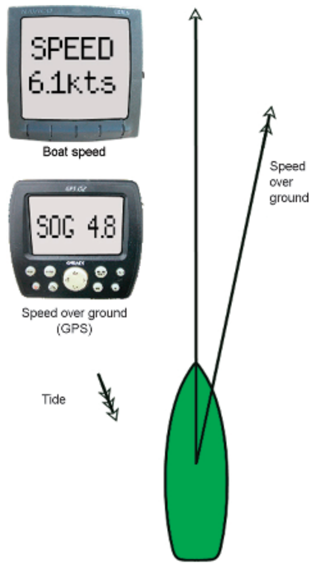


Distance travelled in 1 minute = 0.2 nautical miles

Speed over ground (SOG) = 12 knots

SOG Is Not Boat Speed

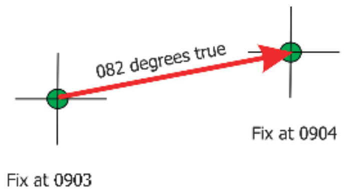
Boat speed is the speed of the boat through the water and is displayed on the water speed display. Wind, waves and tide will cause the speed over the ground to differ from the water speed.



Effect of tide on speed

Measurement of Course

The GPS signal contains no information on the direction in which the boat is moving. Because the GPS receiver knows the shape of the Earth, it can determine the direction that it has travelled from one fix to another. This *course over the ground* (COG) is exactly what it says and may not be the same as the course steered by the boat.



Because the GPS receiver knows the shape of the Earth, it can calculate the bearing of the second fix from the first. It is thus capable of calculating the course over the ground (COG)

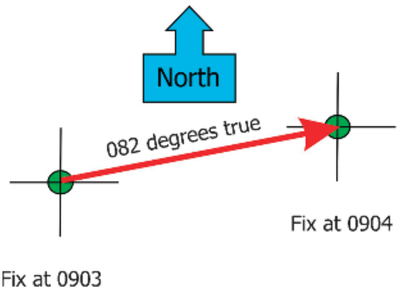
COG Is Not Heading

The heading is the direction that the boat is pointing and is displayed on the compass. The wind, waves and tide can push the boat sideways over the ground, and it's this movement over the 'ground' that is displayed as COG. Only in calm conditions with no tide running will the heading and COG be the same.

The effect of tide on heading

Measurement of Heading

GPS can't measure the boat's heading and can measure only the COG. Once the GPS receiver is moving, because it can determine COG, it knows the direction of true north. We will find, later in this book, that some instruments, such as radar and chartplotters, can make use of heading information to allow the display to be aligned with north to give a *north up* display. Although GPS can provide this information, there are two disadvantages: The information is available only once the boat is in motion and the alignment is based on COG rather than which way the boat is pointing.



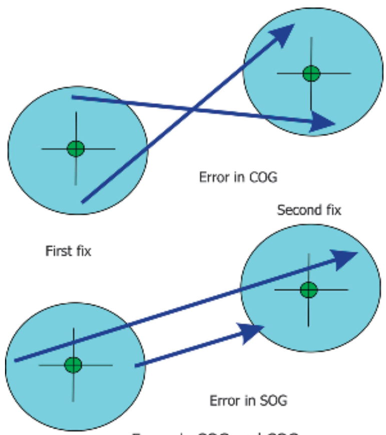
Once the GPS receiver is moving it can determine the direction of North

Errors in COG and SOG

Any random errors in the fixes used to calculate COG and SOG will produce errors in speed and course displayed on the GPS.

The rate at which the GPS position is updated is very rapid, but to minimise the effect of random errors, COG and SOG are averaged over about 5 seconds, by default, although the user may alter this time. The longer the time interval, the steadier the reading, but the slower the response to a real alteration of heading or speed.

If the error between two fixes were 15 metres, one to port and the next to starboard, the error in COG over a 5-second period at 6-knots speed could be greater than 45 degrees. Similarly, with similar errors, but in the direction of movement, the SOG displayed could be in error by 6 knots! With selective availability switched off, the normal



Errors in SOG and COG

situation, random errors are likely to be very small, and COG and SOG are generally stable and accurate. With the default setting for the ‘averaging time’, watch the COG and SOG at a constant speed and heading to get an idea of how they respond in normal conditions.

If selective availability is switched on by the US military, the accuracy of COG and SOG will deteriorate significantly.