

The Global Positioning System (GPS), an Introduction

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Introduction

This is a basic introduction into the Global Positioning system, or GPS.

Although I work for a company involved in the GPS industry it is not directly my field, and as such I am no expert, however it is my intention to introduce you to the technology involved in GPS, and some possible applications of it as they relate to Search and Rescue.

History

The GPS system, also sometimes historically known as NAVSTAR, was initially developed for the US military back in the 70's. Although paid for and operated by the military the GPS system can offer navigation benefits for civilian use. The first of these satellites, built by Rockwell International was launched into orbit in 1978. In that year four satellites were launched to provide an initial system demonstration of the GPS concept.

Background

The GPS system is made up of a constellation of 24 satellites in 12 hour orbits, orbiting at 10,900 nautical miles, or 20,183 kilometres, altitude. Four satellites in each of six orbital planes in a pattern designed to provide world-wide coverage 24 hours a day. Each satellite has a 12 hour orbital period, and an inclination of 55° to the equatorial plane. The constellation is designed to give visibility of 6 to 11 satellites at 5 degrees or more above the horizon anywhere in the world at any time. These satellites allow for accurate three-dimensional position and velocity information for users anywhere in the world.

Each satellite contains an atomic clock to give precision timing for the signals that it will transmit, which are in turn used by the receiver for accurate determination of time and position.

The GPS system allows for position information accurate to at least $\pm 100\text{m}$, and down to sub-centimetre levels in some instances, this information can obviously be used for many more applications than can be thought of at present. This is a massive undertaking, and the United States government is investing more than \$12 billion to build the system.

The system was designed for use with small antennas and relatively low power at the satellites. To achieve this a code scheme and spread spectrum techniques have been used.

How it works –

Technical Details

Although the satellites, receivers, and some of the maths involved are highly technical the principles behind how GPS works are quite simple. Essentially the system is based on ranging and trilateration, or a three dimensional form of triangulation. Ranging is determined from the distance to the satellite from the time it takes to receive a signal. The time taken is determined from the code of the signal and accurate clocks used on the satellites.

If you know the distance to one satellite then you can determine that your position is anywhere on the surface of a sphere at that distance from the satellite.

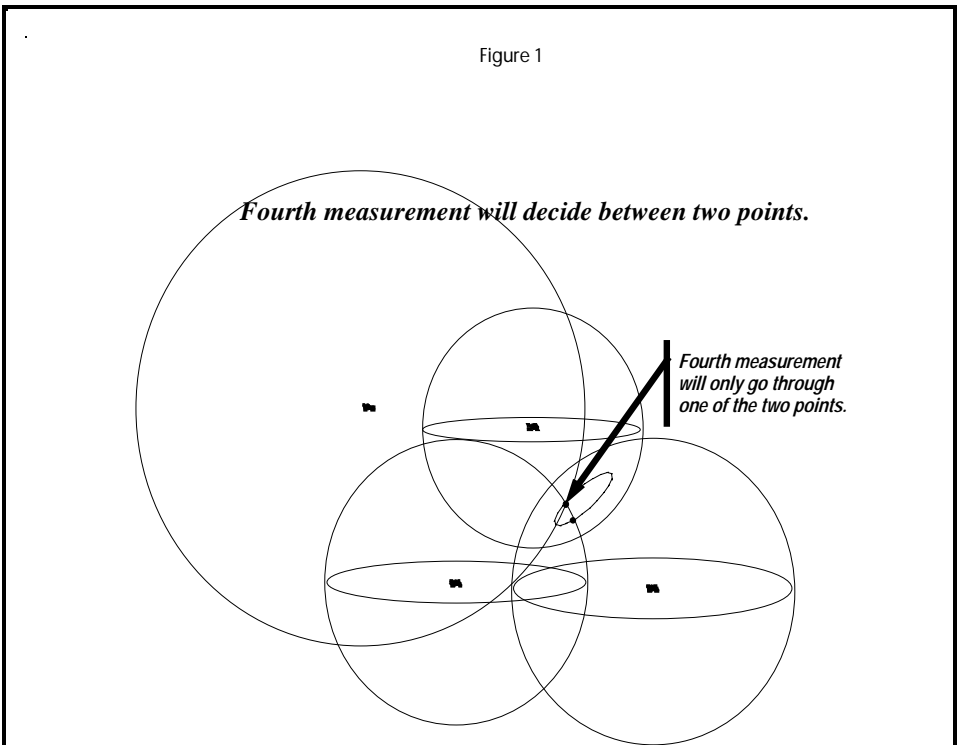
If you know the distance to two satellites then you can determine your position to be anywhere on the intersection of surface of two spheres, which is a circle, thus reducing the possible area. Knowing the distance to three satellites allow you to determine your position to be anywhere the previous circle intersects with a third sphere, and this will be one of two points. It is possible through some mathematics to determine that one of these two points is not on the earth so can be ignored. Thus with distance information from 3 satellites it is possible to determine your position. Due to a number of reasons this position is not absolutely accurate, and having a signal from a fourth satellite allows you to improve the position information. (See Figure 1.)

There are two signals used by the satellites, one on 1227.6 MHz, the L2 channel, and the other on 1575.42 MHz, the L1 channel. The use of two frequencies is mostly to allow for correction of errors caused by ionospheric delay, propagation time and doppler effect.

There are also two pseudo-random pulsed code signals used. These codes are unique to each satellite, and known to the receiver, the P Code, or Precise or Protected Code, is classified, and only known to military receivers, the C/A Code, or Course Acquisition Code, is public and used in all receivers. The first pseudo-random code, or P code, is for precise measurement of time, and the second code, or C/A code, is for quicker and easier lock, or identification, of the desired signal. The L1 channel is modulated by both the P code and the C/A code, and the L2 channel is modulated by the P code only, hence most commercial receivers only use the L1 channel. Both channels are also modulated by a 50 bps data stream that contains the navigation data. The C/A code has a 480W transmitter, the L1 P Code has a 240W transmitter, and the L2 P Code has a 81W transmitter. These powers and antennas are relatively low and simple due to the use of the pseudo-random code sequences and spread spectrum technology.

To accurately determine the amount of time taken for the signal to reach the receiver is the key to the whole system. This is done by comparing the pseudo- random code signal received against one generated in the receiver.

The timing of the pseudo-random code sequence is timed at the satellite by atomic clock, at the receiver timing is not as accurate, but still pretty accurate. This does introduce a possible error in the measurements, but the use of the fourth satellite signal allows for corrections to be made in the receivers timing. This can be done because the error caused by the receiver clock being out will be constant for all satellite signals. Thus through algebra it is possible to solve an equation based on all four signal positions to determine the correct position.



All satellite signals are based on a single accurate 10.23MHz standard. The L1 frequency is $154 \times 10.23\text{MHz}$, the L2 frequency is $120 \times 10.23\text{MHz}$. The P Code pseudo random sequence is based on 10.23MHz, and the C/A Code is based on a tenth of the standard, or 1.023MHz.

For the receiver to track the satellites rough position in advance of acquiring a signal it keeps an 'almanac' which amongst other things includes a set of keplerian elements for each satellite. To keep the almanac up to date the Department of Defence GPS control stations monitor the positions of the satellites, and can determine any orbital, or "ephemeris", errors and update the data for the almanac through the satellites. This information is transmitted by the satellite as a "data message" which is a part of the 50 bps navigation data stream. Therefore the positions of the satellites are known to a fairly high degree of accuracy, but small errors in this information will cause small errors in the position information.

Satellite status, time synchronisation, propagation delay and clock correction parameters are also included in the navigation data.

There are a number of errors that have not been covered so far. One of these is errors due to changes in the propagation of the signals from the satellites due to changes in the ionosphere. This can be done to some extent by comparison of the propagation time of the signals from the two frequency channels that are used by the satellites. This is only available on the more advanced receivers that support both channels.

Other errors such as atmospheric errors, and multi-path errors are almost impossible to correct by the receiver in real time, however they can be compensated for in post processing of the data for more accurate non-real time measurements, such as for surveying.

There are also errors caused by geometry if the satellites that you are tracking are in particularly bad locations, however this is not usually a problem as there are now usually sufficient satellites in view to select the best available four or more satellites for the best solution.

The biggest error of all in the GPS system is a purposely generated one. As the system is developed for military use it operates in two modes. One mode, called Selective Availability, allows the best accuracy to be only available to military receivers, and the signals for commercial receivers are degraded by a factor of about $\pm 100\text{m}$. For military users, or all users if Selective Availability is turned off, the normal accuracy of GPS would be about $\pm 15\text{m}$.

Differential GPS

The error introduced by the military with Selective Availability can be pretty well eliminated by the use of a system called Differential GPS. This system requires two GPS receivers, one at a known location. A receiver that is capable of generating differential corrections takes its known position from the position that it determines, and the difference is mostly caused by Selective Availability. This difference is then transmitted in some way, eg radio link, to the receiver at the unknown location, and applied to the position that it determines. This process does assume that all other errors will be the same for both receivers which may or may not be completely true. Differential GPS allows for accuracies of about $\pm 5\text{m}$ for commercial users with Selective Availability turned on.

The military are not very concerned about this process as they can generally take measures to ensure that the 'oppositions' transmitted corrections do not get to their destination through jamming or similar techniques.

The spread spectrum nature of the GPS signals themselves makes them almost impervious to jamming.

GPS Receivers

The GPS receiver is a sophisticated L Band spread spectrum receiver with digital demodulation systems all controlled by powerful microprocessors.

GPS receivers come in many shapes and forms. The most common receiver in the consumer market is a handheld device, this gives a position to $\pm 100\text{m}$ or thereabouts depending on a few finer points about the receivers design. These can be used for marine, aviation, or terrestrial navigation use. These are readily available from a number of manufacturers for around the \$1,000 - \$2,000 price range.

More sophisticated receivers are available for use for more demanding applications such as accurate navigation, surveying, tracking and the like. These are larger and more expensive, ranging up \$100,000 at the top end.

Single board receivers are becoming available for the OEM, Original Equipment Manufacturer, market, and these are coming down in price and size to an extent that they can be used for some amateur radio related applications. More on this in future articles.

GPS Receiver Operation

The basic operations of a GPS receiver are:

- satellite selection
- signal acquisition
- tracking
- measurement
- data recovery
- corrections

The principle components of a GPS receiver system are:

- antenna
- receiver
- processor
- I/O device

One basic parameter of receiver design is the number of channels that it has. A receiver needs to be able to receive data from at least four satellites at a time to determine an accurate position. To do this it can either receive data simultaneously from four or more satellites, or it can change from one satellite to another. The later approach of sequencing allows a receiver to be a simpler and cheaper design, but does not allow for as accurate or fast a solution of position. Receivers can vary in design from a single channel through to 12 or more channels. Common designs typically have one, three, six, or twelve channels.

Receivers can also be designed to make use of one or both of the two frequencies used by GPS. Although commercial receivers cannot use the P code on the L2 frequency there are some techniques that some manufactures are using to use the second frequency to produce more accurate results than single frequency receivers.

As mentioned above, GPS uses pseudo-random code sequences. These allow the GPS receiver to determine the time taken for a signal to reach the receiver from the satellite, but they are used to make the whole GPS system smaller, lighter and more power efficient. The use of low power transmitters on the satellites and small antennas on the receivers is paramount in the functionality of the system. As such the GPS receiver has to be able to determine signals from the satellites from a very weak signal. The pseudo-random codes and spread spectrum techniques are used to achieve this.



First of all the receiver needs to have a current set of data on where the satellites are. If this data, the almanac, is not available or is too old then the receiver must wait for a while so that it can collect this data from the satellites that it can 'hear'. It does this by stepping through and trying to match the C/A code sequence for each of the satellites in turn.

With a reasonably current almanac, some indication of current position, and some indication of current time, the receiver can start the process of selecting satellites that it would expect to be available. The best four satellites are selected, those that are below the horizon, or soon will be are excluded, and if possible any that form a poor geometrical solution are also excluded, hopefully leaving four satellites in good positions for acquisition of signal to calculate position. This selection process will be reviewed from time to time as the satellites move, or the receiver moves, to ensure that the best set of satellites is in use.

Acquisition of signal from the satellites is attempted by first synchronising on the C/A code. This code is designed for quicker acquisition than the P code, so even for P code receivers this is the first step. In the acquisition process the receiver must allow for doppler shift on the signal. Once the C/A code is synchronised then tracking of the code timing, and in some cases the carrier phase, is started.

While the satellite position data from the almanac is sufficient for the acquisition of signal from the satellite a more accurate set of data is required for the determination of position information. This data, called the ephemeris, is contained in the data stream for each satellite, so this needs to be decoded.

As indicated above the actual data that is transmitted on the satellites is a very low throughput, however it is spread over a wide bandwidth using spread spectrum techniques to improve the overall signal to noise ratio of the system.

The basis of a GPS receiver is the use of correlation techniques to resolve the low signal levels from the noise, correlating the internally generated signal with the received signal, and then synchronising it for timing.

The use of pseudo random codes and Spread Spectrum techniques allows for the scheme of synchronising the clocks of the receiver and the satellite as well as correlation of signals, the ability to have low power from the satellites and small antennas at the receiver, and for all satellites to use the same frequencies

An in-depth discussion of Spread Spectrum techniques is beyond the scope of this article, but see the references for more information.

The data is a 50bps BPSK signal that is demodulated with a conventional demodulator after it has been locked onto from correlation.

Most of the design of a GPS receiver can be achieved using analogue techniques, however modern GPS receivers almost universally use Digital Signal Processing techniques as computation is required for the calculation and presentation of the GPS data anyway.

Glossary: A glossary of Terms and abbreviations often used in relation to GPS, or by GPS receivers.

ALT	Altitude	Height above sea level
BRG	Bearing	Direction to a given point
CDI	Course Deviation Indicator	A bar graph indicator of how far you are on or off course
DATUM		A surveying model of the elliptical nature of the earth for a specific geographical area
DGPS		Differential Global Positioning System
DOP	Dilution of Precision	A measure of inaccuracy caused by position of satellites relative to your position. (Also known as GDOP or Geometric Dilution of Precision)
DIS	Distance	Distance to a given point
DNT		Count Down Timer
ETA	Estimated Time of Arrival	
ETE	Estimated Time En-route	
FIX		Some times referred to as current position Some times a reference to the receivers position quality
GPS		Global Positioning System
GS	Ground Speed	Actual Speed over ground
PCF	Position Correction Factor	A correction offset specific to a map or chart
PDOP	Position Dilution of Precision	An indicator of the overall inaccuracy of a position due to a number of factors
POSITION		Present Location as determined by the GPS receiver
PROJECTION		A surveying model to project the curved earth onto a map for a specific geographical area
ROUTE		A series of waypoints linked together in a sequence
SA	Selective Availability	The deliberate error introduced into the GPS signal by the US Military
TRK	Track	The direction that you are travelling in at this instant
TTG	Time to Go	Time remaining at your present speed until you reach a given point
UPT		Count Up Timer
VMG	Velocity Made Good	Your ground speed toward a given point
WPT	Waypoint	A stored position
XTK	Cross Track Error	The distance left or right off of desired line of travel

Some Notes on Using the Eagle Explorer - Dave Saunders and Steve Davis

General Notes

Press EXIT to take you back to the previous menu/screen

To Set the Eagle into NZMG Mode

1. MENU
2. ↓ GPS Setup
3. → GPS Setup Menu
4. ↓ POSITION FORMAT
5. → List of formats
6. ↓ N ZEALAND
7. ENT Saves it
8. EXIT Back to GPS Setup Menu
9. EXIT Back to GPS/Nav/Plot screen

To Set the Eagle into Lat/Long Mode

1. MENU
2. ↓ GPS Setup
3. → GPS Setup Menu
4. ↓ POSITION FORMAT
5. → List of formats
6. ↓ DM or DMS
7. ENT Saves it
8. EXIT Back to GPS Setup Menu
9. EXIT Back to GPS/Nav/Plot screen

To Set the Date/Time

1. PAGES
2. ↓ GRP
3. → **GRP L**
4. MENU
5. ↓ SET LOCAL TIME
6. →
7. ↔↑↓ scroll to enter current time
8. ENTER to save

Pages

These are a range of displays to provide different information.

They are split into 3 function, NAV for Navigation, PLOT for plotting, and GRP for Group (a group of Windows).

To change a display

1. **PAGES**
2. ↓ Select Nav, Plot, or GRP Pages
3. → Select the particular page
4. **EXIT** Exit the Pages Menu

GROUP Pages

GRP A	Simple Navigation Display
GRP B	Navigation Display
GRP C	Simple Navigation Display
GRP D	Navigation Display
GRP E	Simple Navigation Display
GRP F	Navigation Display
* GRP G	General Position and Navigation Display
* GRP H	Position and Navigation Display
GRP I	Navigation and Time Display
GRP J	Time Display
GRP K	Timer Display
GRP L	Clock and Time Display
* GRP M	Battery, Altitude and DGPS Status Display
GRP N	DGP Display
GRP O	GPS Satellite info Display

The most useful Group Pages are marked with an *

Other PAGES include NAV and PLOT.

The NAV Pages give you a Compass like screen to Navigate from.

The PLOT Pages allow you to store and retrieve Plots of courses that you have followed.

Menus

The MENU Key allows you to select a number of the functions and Settings of the GPS Unit.

See the other sections of this guide for specific uses of these Menus.

Waypoints

To Save your Present Position as a Waypoint

1. **WPT**
2. **WPT**

To Edit/Enter a Waypoint

1. **WPT**
2. **↑** WPT #
3. **↔** WPT ←#→ scroll to a vacant wpt
4. **↓** OPTIONS
5. **→** NAME EDIT (default)
6. **→** “Edit Name” screen
7. **↔↑↓** scroll to enter details
8. **ENT** to save
9. **↓** POSITION EDIT
10. **→** “position” screen
11. **↔↑↓** scroll to enter or edit full 14 figure grid reference
12. **ENT** to save
13. **EXIT** back to options

To View Waypoint Details

1. **WPT**
2. **↑** WPT#
3. **↔** WPT ←#→ scroll to a desired wpt
4. **EXIT**

To Navigate to a Waypoint

1. **WPT**
2. **↑** WPT#
3. **↔** WPT ←#→ scroll to a desired wpt
4. **↓** GO TO
5. **ENT** Selects this Waypoint for Navigation

To Cancel Navigation

The Explorer continues to navigate to the last set Waypoint until you stop it. To Cancel Navigation

1. **MENU**
2. **↓** CANCEL NAV
3. **→** Stops navigation

Routes

To Connect Waypoints to create a route

1. **MENU**
2. PLAN/EDIT ROUTES (default)
3. ↔ “Routes” Screen (Scroll until “-EMPTY-” appears)
4. ↓ EDIT ROUTE
5. → “Edit Route” Screen (lists wpts in route)
6. → Menu appears
7. ADD WPT (default)
8. → WPT ←#→
9. ↔ scroll to a desired wpt
10. ↓ ADD WPT
11. → returns to EDIT ROUTE screen (list of wpts)
12. ↓ to add another wpt
13. Repeat steps 6. – 12 as often as required
14. **EXIT** Back to ROUTES Screen
15. ↓ EDIT NAME (To edit name of rout if required)
16. → NAME ROUTE Screen
17. ↔↑↓ scroll to enter details
18. **ENT** to save name
19. **EXIT** to Menu
20. **EXIT** back to GPS/Nav/Plot screens

To View Route Details

1. **MENU**
2. PLAN/EDIT ROUTES (default)
3. ↔ “Routes” Screen Scroll to desired Route
4. ↓ EDIT ROUTE
5. → “Edit Route” Screen (lists wpts in route)
6. ↑↓ Scroll through wpts
7. → Edit Route Menu, if you required details of the wpt
8. ↓ DETAIL
9. → Shows wpt details
10. **EXIT** Back to wpt list
11. Repeat 6. – 10. as required
12. **EXIT** Back to GPS/Nav/Plot screens

To Follow a Route

1. MENU
2. → PLAN/EDIT ROUTES (default)
3. ↔ “Routes” Screen Scroll to desired Route #
4. ↓ START ROUTE
5. → START RTE ←AUTO→ (starts nav to closest wpt)
6. ↔ select start wpt if required
7. ENT Starts navigation along the route

Run A Route in Reverse (Default is always forward)

1. MENU
2. → PLAN/EDIT ROUTES (default)
3. ↓ RUN ←FORWARD→
4. → RUN ←REVERSE→
5. ↑ START ROUTE
6. Then continue with Follow Route from 5. above

GPS Workshop GPSARienteering Course

This is a simple, and hopefully fun, course to allow you to try out using the GPS skills just learnt about.

It is for fun, and for you to practice and learn, it is not a competition or a race, so do not worry if you do not find all the points.

If you get lost, you can't the GPS will always tell you where you are, you can always navigate back to the Starting Point which is given.

Remember that the accuracy of GPS is $\pm 100\text{m}$, so you may have to look around for the required feature. All points should be recognisable, and are

- ◆ Power Poles, with signs on them
- ◆ Road or Street Signs
- ◆ Other prominent structures, eg Bridge, Building

You may need to cross the road to get to the feature, but you do not need to get your feet wet crossing the river. The clues will help a little. The whole course is within a 1.1km radius of the starting point, and **should** take no more than an hour or so to complete.

Good Luck, and have fun.

Steve

Here is the information, which you can load into the GPS before departing.

Your Starting Point is

2483158 East
5743579 North

The Course/Quiz is over the page

1. 2483310 E
5743524 N
Q What do you do with this
2. 2483240 E
5743284 N
Q What is on the signs
4. 2482870 E
5743302 N
Q What is on the signs
5. 2482984 E
5743502 N
Q What is this structure used for
6. 2482838 E
5743251 N
Q What is written on this road sign
7. 2482768 E
5743028 N
Q Some people call this a sleeping policeman,
what do you call it, and what number is associated with it.
8. 2482534 E
5742722 N
Q What is this structure used for
9. 2482629 E
5742801 N
Q What is on the signs
10. 2482944 E
5742847 N
Q What is the name and nature of this business
11. 2483015 E
5742830 N
Q What is this used for
12. 2483414 E
5742846 N
Q What is this road sign
13. 2483369 E
5743212 N
Q What is on these signs
14. 2483325 E
5743600 N
Q Describe what is in the river beside you
15. 2483211 E
5743586 N
Q What is on the signs
16. Starting point
You should be back where you started