5.8 Differential GPS (DGPS)

As has already been stated, the accuracy of GPS fixes can be vastly improved using differential techniques. Experimental differential systems have been in use for some years as part of earlier hyperbolic earth-based navigation systems. DGPS is merely an improvement of those now outdated systems. The principle, as shown in Figure 5.18, is that GPS data from SVs are downloaded to both a mobile station and a fixed station at a precise location. A computer at the fixed site calculates the pseudo-range from GPS SVs and then compares it with the known ranges for that precise geographic location. It then computes a range error figure which is transmitted to mobile stations where it is used to correct the pseudo-range system errors.

The use of DGPS does not eliminate errors introduced by multipath reception or receiver noise.

For maritime use, DGPS differential monitor stations have been established around the coast of some 28 countries. As examples, the US Coast Guard maintains DGPS transmission stations around the continental coastline of the USA (see Figure 5.19 and Table 5.6), and in the UK beacons are operated by Trinity House and the General Lighthouse Authority (see Figure 5.20 and Table 5.7).

Corrective data are transmitted from the beacons on frequencies in the lower medium frequency band and as a result the range over which they can be reliably received is limited to between 100 and 250 km. But DGPS can and does assist in waters where freedom to manoeuvre is restricted.

The US Coast Guard and the International Association of Lighthouse Authorities (IALA) support the International Telecommunications Union (ITU) Recommendation M.823 which allows for DGPS data to be transmitted as supplementary information on the radiobeacon band 283.5–315 kHz (285–325 kHz in some parts of the world). The transmission protocol RTCM SC-104 (developed by the Radio Technical Commission for Maritime Services Special Committee 104) is used to determine the speed and data format of the transmission. DGPS data is phase shift keyed onto the carrier at a rate of 100 or 200 bits per second.

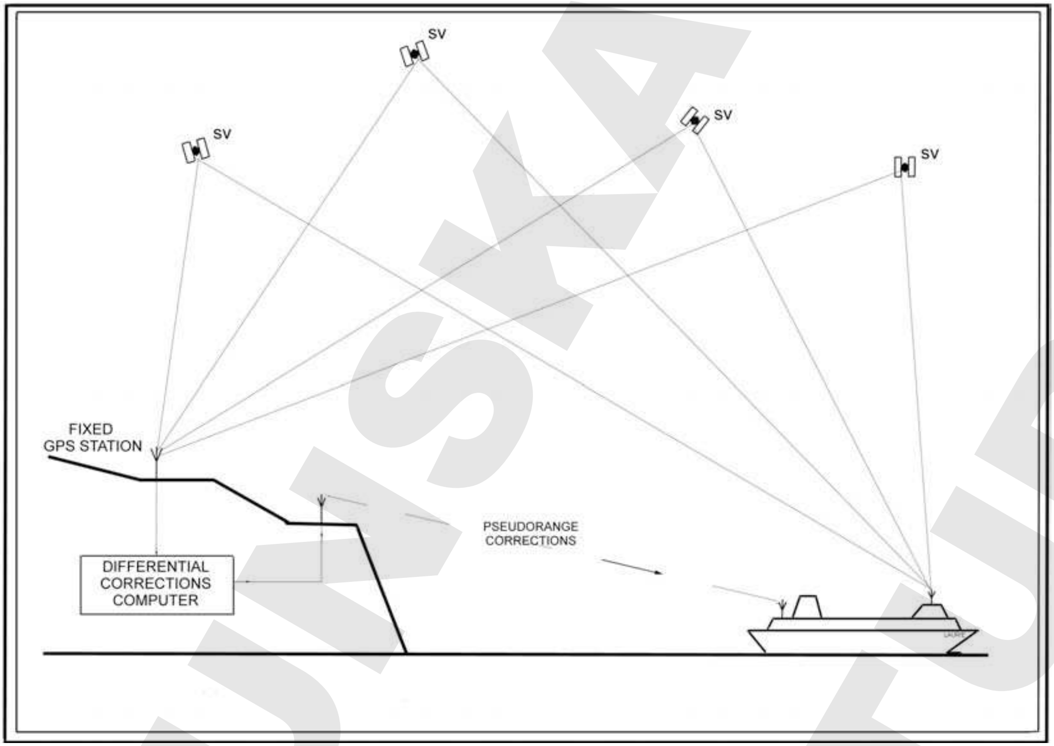


Figure 5.18 Principle of operation of DGPS.

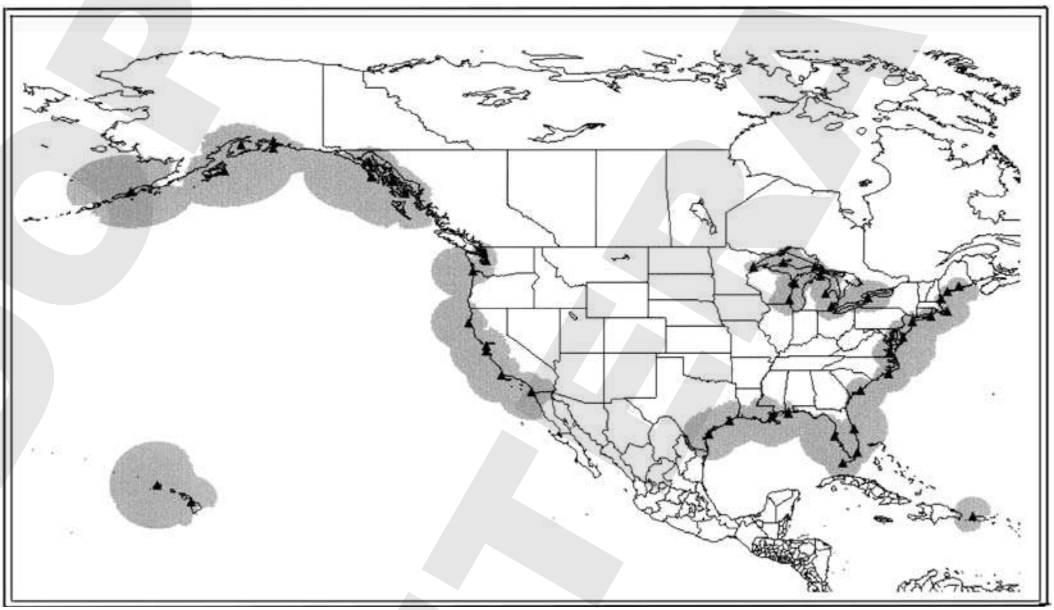


Figure 5.19 Maritime DGPS coverage of the United States. (Reproduced courtesy of the United States Coast Guard.)

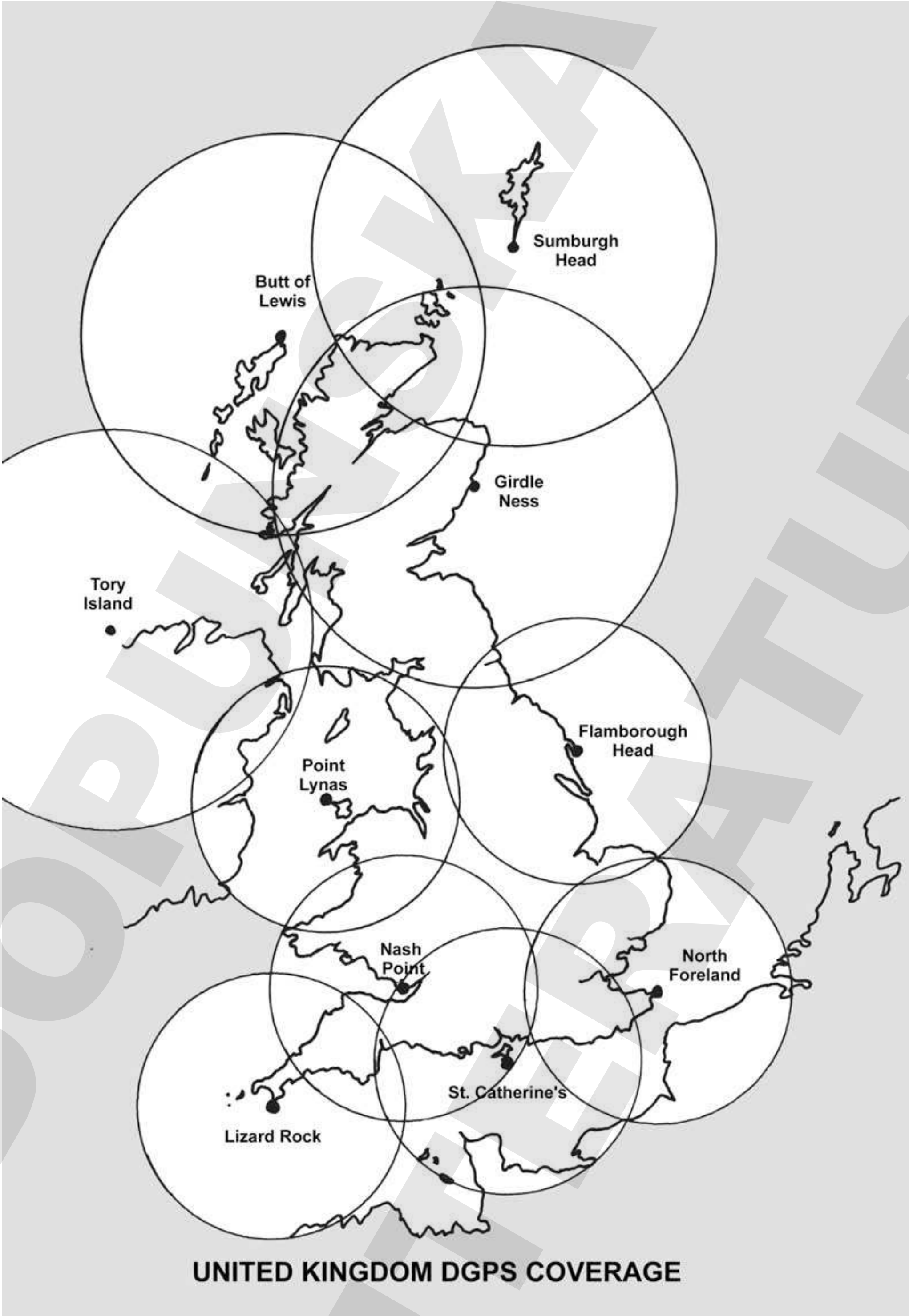


Figure 5.20 DGPS coverage of the UK coastline.

Table 5.6 Florida differential GPS stations data

Station	*Location*	*Frequency (kHz)*	*Nominal range (km)*
Cape Canaveral	28.27 N 80.32 W	289	200
Miami	25.43 N 80.09 W	322	75
Key West	24.34 N 81.39 W	286	75
Egmont Key	27.36 N 82.45 W	312	200

Source: United States Coast Guard.

Table 5.7 UK differential GPS station data

Station	*Location*	*Frequency (kHz)*	*Nominal range (km)*
Sumburgh Head	59.51 N 01.16 W	304.0	275
Butt of Lewis	58.31 N 06.16 W	294.0	275
Girdle Ness	57.08 N 02.03 W	311.0	275
Tory Island	55.16 N 08.15 W	313.5	275
Flamborough Head	54.07 N 00.05 W	302.5	185
Point Lynas	53.25 N 04.17 W	305.0	185
Nash Point	51.24 N 03.33 W	299.0	185
North Foreland	51.23 N 01.27 E	310.5	185
St. Catherine's	50.35 N 01.18 W	293.5	185
Lizard Rock	49.58 N 05.12 W	284.0	185

Source: Trinity House

5.8.2 Wide Area Differential GPS (WDGPS)

WDGPS is a real-time global differential system currently under consideration for future implementation. Using the INMARSAT communications network, differential data will be transmitted to ships throughout the world enabling better fixes to be made. It is still in the discussion stage.

5.9 GPS antenna systems

Arguably the antenna is the most critical part of any radiocommunications system but unfortunately it is the piece of hardware that is most often ignored. Carefully designed and constructed, an antenna sits, open to the elements, on board a vessel's superstructure in a position where routine maintenance can be difficult. GPS antennas are small and rigidly constructed and to ensure that they survive the elements they are protected by a raydome.

In common with the INMARSAT communications antenna, a GPS antenna ideally requires an unobstructed view through 360° from the horizon up to 90° in elevation. Radiated energy from other microwave transmission systems can damage sensitive pre-amplifier circuitry inside the GPS protective dome. It is wise, therefore, to mount the GPS antenna below the INMARSAT raydome and outside the radar transmission beamwidth as shown in Figure 5.21.

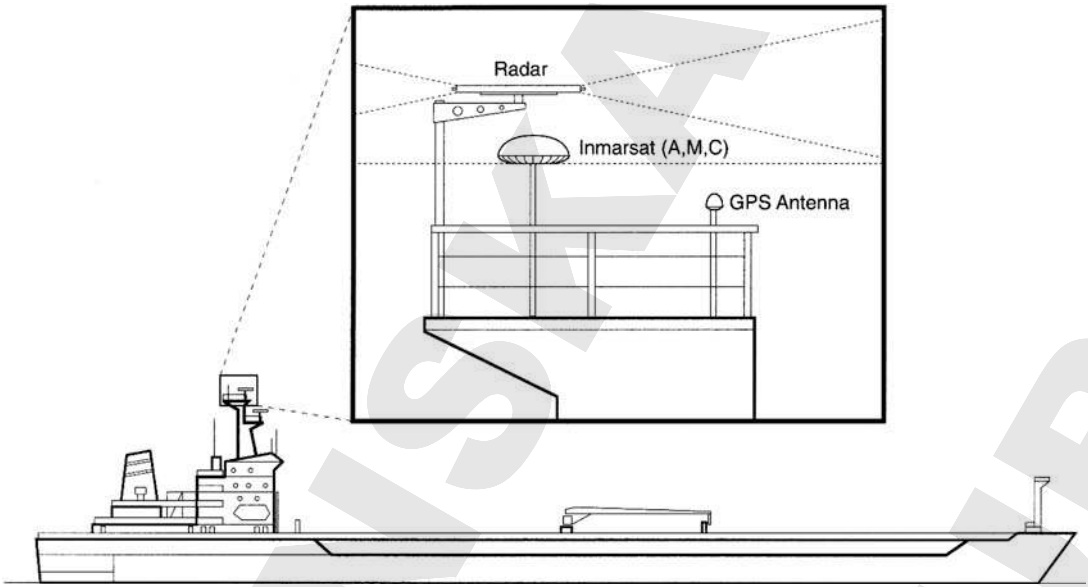


Figure 5.21 A GPS antenna mounted below other microwave system antennas on the superstructure of a merchant vessel. (Reproduced courtesy of Trimble Navigation Ltd.)

Other factors to be considered when siting an antenna are as follows.

- Mounting the antenna on the top of a tall mast will accentuate range errors caused by the vessel's motion especially if DGPS is used. The range error is dependent upon the extent of the vessel's motion and is therefore unpredictable.
- No special ground plane is required, but a large open deck space below the antenna will reduce the error caused by reflected multipath signals.
- Stays, masts and dry sails in the path between the SV signal and the antenna will have little effect of the received signal.
- GPS systems use an active (containing some electronic circuitry) antenna head which can be affected by severe vibration. Mount the antenna away from other antennas, engine housings or exhaust stacks.

5.10 GPS receiver designation

Because GPS is freely available to all users throughout the world, the range of available user equipment is vast. There are thousands of manufacturers producing a bewildering range of fixed and mobile equipment, all of which must comply with GPS standards. GPS receiver architecture varies depending upon how it is to be used. The following list itemizes the most popular GPS receiver systems currently produced. The more commonly found commercial receivers are listed first.

Multiplex (MUX) Receivers

Amongst the cheapest GPS receiver architecture, MUX receivers are commonly found in the commercial sector. A MUX receiver continuously tracks multiple SVs by continuously switching its single channel between them. Time measurements and data streams are held in memory algorithms and ‘topped-up’ when data is made available by the MUX switch rate. Receiver architecture is less complex and consequently cheaper. MUX receivers are only used on slow moving platforms such as merchant vessels.

Sequential Receivers

Receiver architecture is designed to track one SV at a time and calculate the pseudo-range. The data is held in memory until four SVs have been interrogated, when the position–velocity–time (PVT) fix is calculated. These receivers are the least expensive and possess the slowest time-to-first-fix (TTFF) performance.

Single Channel Sequential Receivers

As the title suggests, these receivers use a single channel to sequentially measure the pseudo-ranges from four SVs. Each SV is fully interrogated in sequence and the final fix made from stored data. Any uncorrected movement of the receiver during this process reduces the fix accuracy.

Dual Channel Sequential Receivers

The only advantage of this type of receiver is that, in using two channels, it reduces the time it takes to calculate a fix. They tend to be used on medium velocity platforms, such as aircraft.

All-in-View Receivers

An All-in-View receiver has the necessary hardware to search the sky and track all the SVs that it finds. Whilst four SVs are needed to give a good PVT fix, it is likely that satellites will be lost before they can be fully interrogated. This type of receiver architecture can track seven or eight SVs continuously so if some SVs drop out of its view the PVT fix should still be good. If satellite data is not lost during tracking, a fix is produced from the data of more that four SVs. In general, the more satellites that provide data for a fix, the better the fix.

Continuous Tracking Receivers

This type of GPS receiver possesses multiple channels to track four SVs simultaneously whilst acquiring new satellites. TTFF figures are the lowest for any receiver architecture and PVT fix accuracy can be maintained on high velocity platforms such as fighter aircraft and missiles. Continuous tracking receivers offer the best performance and versatility but, as you would expect, they are the most expensive.

Differential GPS Receiver

DGPS receivers are now in common use on maritime vessels that require better PVT fix accuracy than can be obtained with a basic receiver. Vessel’s trading in confined waters use DGPS receivers. They are more expensive, but the cost is justified. (See the section on DGPS.)

Time Transfer Receiver

This type of GPS receiver provides an accurate time source. It may be integrated into one of the receiver systems previously described or the time figure may be used in other navigation fix solutions.

5.11 Generic GPS receiver architecture

This section includes the description of a simple receiver and then goes on to consider specific modern systems. Figure 5.22 shows a generic GPS receiver system.

5.11.1 SV selection and acquisition

If the receiver can immediately 'recognize' a SV it will target that satellite and begin a tracking sequence. This is possible if the receiver has already downloaded almanac data from any SV, if not it will enter a 'search' mode and systematically hunt the sky looking for a recognizable PRN code. Once this is received, tracking will be initiated, lock will be achieved and the navigation message can be interrogated. The current almanac will then be cross-examined and the health status of all the other satellites will be determined. The computer then selects the best subset of visible SVs, or, all-in-view. In practice, data from a minimum of four SVs is required to provide a reliable navigation fix, but the greater the number that can be tracked and accessed, the better.

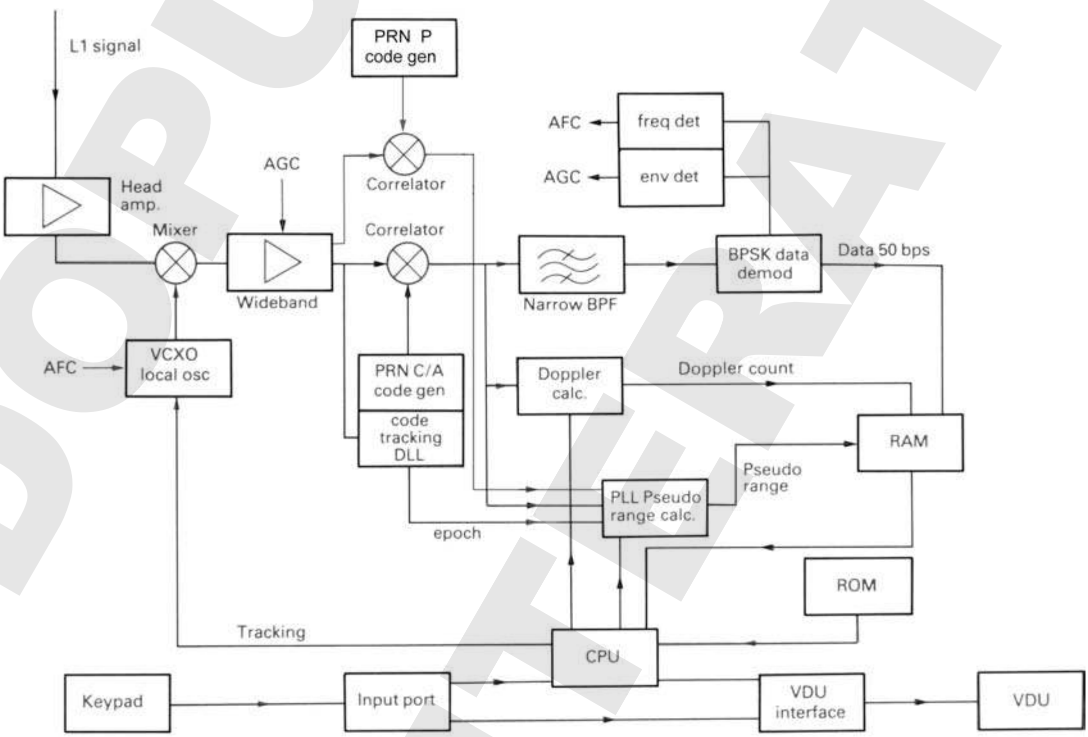


Figure 5.22 A generic GPS receiver system.

Because of limited satellite transmitter power, spread spectrum modulation techniques and ionospheric attenuation, the satellite signal power received at the earth's surface is far less than the receiver's natural or thermal noise level. This minute signal is received by a compact, fixed, above-deck unit using an isotropic antenna with ground plane radial reflectors, a low noise pre-amplifier and filters. Circularly polarized radio waves from the SV, are received by the isotropic antenna whilst the radial reflectors reduce the problem of multipath errors caused by the earth's surface reflected signals. The head unit should be mounted in such a way that the antenna has a clear view of the whole area in azimuth from the zenith to the horizon. Input to the receiver is therefore the amplified SV signal at 1575.42 MHz, plus a slight Doppler frequency shift and possessing a very poor signal-to-noise ratio.

The single signal mixer down-converts the L_1 carrier to an intermediate frequency. Frequency conversion is achieved using a Variable Frequency Local Oscillator (VCXO) under the control of both the Central Processing Unit (CPU) and a signal derived Automatic Frequency Control (AFC). CPU input to the VCXO enables initial SV tracking to be achieved and the tiny direct current AFC, derived from the received signal, maintains this lock. A wideband IF amplifier is used to permit reception of the 20.46 MHz bandwidth P code enabling future modification of the receiver to be made if required. Output from this amplifier is coupled to a correlator along with the locally generated PRN C/A code.

It is essential that the receiver tracks the received signal precisely despite the fact that it is at an amplitude which is hardly above the locally generated noise level. To achieve tracking the received signal is applied to a Delay Lock Loop (DLL) code tracking circuit that is able to synchronize the locally generated PRN code, by means of the EPOCH datum point, with the received code to produce the reconstituted code to the narrow bandpass filter. The DLL is able to shift the local PRN code so that it is early or late (ahead or behind) when compared to the received code. A punctual (Pu) line output to the correlator is active only when the two codes are in synchronism. PRN codes are described in more detail at the end of this chapter.

Output of the correlator is the autocorrelation function of the input and local PRN C/A codes. The bandwidth of the narrow band bandpass filter is 100 Hz so that data is passed only to the BPSK data demodulator where code stripping occurs. The autocorrelated C/A code is also used for both Doppler and pseudo-range measurement. The PLL used for pseudo-range measurement has a clock input from the CPU to enable clock correction and an EPOCH input each millisecond for alignment.

All receiver functions are controlled by a microprocessor interfaced with a keypad and a VDU display. The use of a microprocessor ensures economy of design. In this outline description most of the control lines have been simplified for clarity. The receiver operating sequence is given in Table 5.8.

5.11.2 Autocorrelation of random waveforms

The main function of the correlator in this receiver is to determine the presence of the received PRN code that is severely affected by noise. Correlation is a complex subject and the brief description that follows attempts to simplify the concept. Both the C/A and P codes are 'chain codes' or 'pseudo-random binary sequence' (PRBS) codes that are actually periodic signals. Within each period the code possesses a number of random noise-like qualities and hence is often called a 'pseudo-random noise code' (PRN code). The PRN binary sequence shown assumes that the code has a period of 15 samples, i.e. it repeats every 15 bits. The GPS P code possesses a period of 267 days and the C/A code a period of 1 ms. It is obvious therefore that a PRN code can possess any period.

To establish the autocorrelation function, both the received C/A code and the locally generated C/A code are applied to the correlator. Consider the local code to be shifted three stages ahead or behind (early or late) on the received code by a time period (t) known as parametric time. To obtain the product of the two codes, add each received bit to a locally generated bit shifted in time, as shown in Figure 5.23.

Table 5.8 Receiver operating sequence

01	Initialize
02	Search for an SV
03	Identify L_1 carrier
04	Acquire L_1 C/A code
05	Track L_1 C/A code
06	Strip data
07	Measure pseudo-range
08	Measure Doppler frequency shift
09	Store data
10	Commence next SV search and repeat steps 03–09
11	Commence next SV search and repeat steps 03–09
12	Commence next SV search and repeat steps 03–09
13	Compute navigation position
14	Output position data to display

The product is achieved by adding bits of data using the terms:

$$(+1) + (+1) = +1$$
$$(-1) + (-1) = +1$$
$$(+1) + (-1) = -1$$
$$(-1) + (+1) = -1$$

The average value of the products thus produced is –1/15. If the local code is now shifted one bit to the right and the products are noted again, the average value of the products is –3/15. When the two

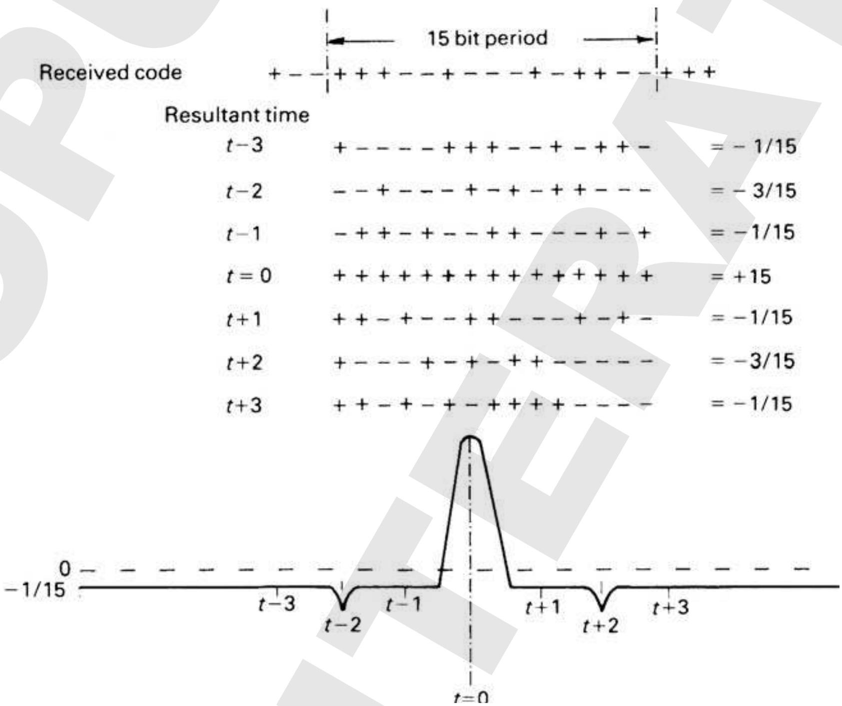


Figure 5.23 Autocorrelation function of a random waveform.

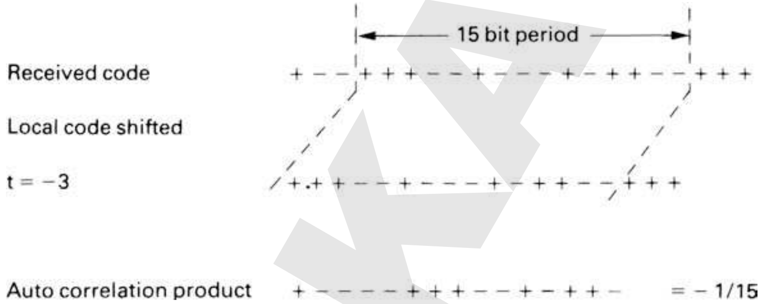


Figure 5.24 The autocorrelation product of a random waveform.

codes are synchronized the product of all bits is +1. Therefore the average value of the products is also +1. This is the only time per code period when all the code products are +1. The peak thus produced is called the autocorrelation function (see Figure 5.24) and enables the received code to be identified, even in the presence of noise which is essentially an amplitude variation.

The PRBS is periodic, therefore the autocorrelation function is periodic and repeats at the rate of the original signal. It is possible to determine the period of the received code by noting the periodicity of the peaks produced in parametric time. Thus the C/A code can be acquired even when it is severely affected by noise. The autocorrelation function peak also indicates the power density spectrum of the received code signal. A signal with a wide bandwidth (the P code) produces a sharper narrower correlation spike, whereas a wide correlation spike indicates a narrow bandwidth signal (C/A code). Obviously the width of the correlation spike is inversely proportional to the bandwidth of the received signal code.

The user equipment just described demonstrates many of the principles of GPS reception. However, equipment manufacturers will have their own ideas about how a GPS receiver should be configured.

5.12 GPS user equipment

The GPS is the undisputed leader in modern position fixing systems and, when interfaced with various shipboard sensors, GPS equipment forms the heart of a precise navigation system offering a host of facilities. Modern equipment is computer controlled, and this fact along with a versatile human interface and display means that the equipment is capable of much more than that produced for earlier position fixing systems.

There is a huge selection of GPS equipment available from a large number of manufacturers. Much of this equipment is designed for the small craft market, more is specifically designed for geodesy and earth mapping, still more is designed for the aeronautical market, and more for trucking operators. In fact it appears that the GPS has found a range of diverse uses in every corner of the globe. This book is written for the maritime navigation sector of this huge market and equipment is described to demonstrate the versatility and flexibility of modern GPS receivers.

Two huge companies that offer a full range of GPS equipment and services are Trimble Navigation Ltd. based in the heart of silicon valley at Sunnyvale, California, and Garmin based at Olathe, Kansas in the USA.

5.12.1 Trimble GPS receiver specifications

At the top of the Trimble's GPS range is the NT300D, a 12-channel parallel GPS receiver, capable of tracking up to 12 satellites simultaneously and also containing a dual-channel differential beacon receiver. The equipment is capable of submetre accuracy derived from carrier-phase filtered L_1 pseudo-range calculations. In addition, vessel velocity is obtainable from differentially corrected Doppler measurements of the L_1 carrier. Position information is displayed on a backlit LCD screen in one of two main navigation modes.

Interfacing with other navigation equipment is via one of the two serial RS-422 data ports using a variety of protocols including NMEA-0183 output and RTCM SC-104 in/out. Speed data output is available at the standard rate of 200 ppnautical mile.

Receiver operation

At switch on, the equipment automatically begins to acquire satellites and calculate range error to produce a position fix. TTFF varies between 30 s and 2–3 min depending upon the status of the GPS almanac, ephemeris data stored in the NT GPS's memory, and the distance travelled while the unit was switched off. During the acquisition process, the equipment operates on dead reckoning and shows this by displaying a DR in the top right corner of the display.

Figure 5.25 shows the user interface of the Trimble Navigation GPS NT200D. The buttons/keypads data input controls have been ergonomically designed to be easily operated and user friendly. A 15 cm (6 inch diagonal), high resolution, 320×240 pixel, backlit, LDC displays navigation data that can be easily read in most lighting conditions. Referring to Figure 5.25, the numbered functions are as follows.

1 Power key
2 Display
3 Brightness and contrast keys. Standard up/down scrolling key for screen viewing parameters.
4 Numeric keypad. Used to enter numeric data as well as controlling chart information layers when in the chart mode of operation.
5 Cursor controls. Arrow keys permitting movement of the cursor on those screens where it is present. When inputting data they are used to move through the programming functions.
6 Function keys. Used to access various functions.
   SETUP: used when customizing the operation of the equipment.
   STATUS: used to display various GPS parameters such as signal strength.
   NAV: toggles between NAV1 and NAV2 displays.
   SAVE: pressing this displays current position and time and gives the user a choice of entering the position as a waypoint or selecting the position as an emergency destination – the 'man overboard' function.
   WAYPT: used to access waypoint and route libraries.
7 Soft keys. So named because the functions they perform changes from screen to screen.
8 Menu key. Toggles the soft key labels on and off.
9 Plot key. Toggles between an electronic chart display and a Mercator grid display.

The NAV 1 screen shown is a graphic depiction of the vessel's relationship to the intended course. The intended course, represented by the central lane in the graphic, is based on the active route and current leg. The next waypoint is shown, by number and name, in the box located above the central lane.

At the top of the page, the screen header displays the current mode of operation. This may be DGPS, GPS, DR or EXT (external). External mode indicates that the equipment is receiving updates from an external device.

In the centre of the display is a circular symbol with crossed lines representing the ship's position. An arrow intersecting the screen centre indicates the ship's current heading (course over ground

(COG)) relative to the destination. When this arrow points at the next waypoint (course to waypoint (CTW)), the ship is heading in the correct direction; COG = CTW.

A right or left offset of the ship's symbol signifies the cross-track error (XTE). No error exists when the symbol is shown in the centre of the lane. XTE limits can be set using the main Setup screen. The relative velocity of the ship is indicated by the rate of advance of the horizontal lines located outside the central lane.

Other data fields may be selected for display. In Figure 5.25 the following have been selected: true course over ground (COG), speed over ground (SOG) in knots, XTE in NmR, and the ship's true heading (HDG) in degrees. Other options are CTW, speed (SPD), distance to waypoint (DTW), distance to destination (DTD), velocity made good (VMG), and distance made good (DMG).

An alternative display, NAV 2 in Figure 5.26, shows a graphic representation of a compass displaying the vessel's course COG and the bearing to the next waypoint CTW. The compass card graphic consists of an inner ring with a COG arrow and an outer ring with a CTW indicator arrow. When the two arrows are in alignment, COG = CTW, the vessel is on course. The compass graphic defaults to a north-up presentation but may be changed to a head-up display.

At the bottom of the display a steering indicator, labelled XTE, shows any cross track error in nautical miles. When the two arrowheads are in alignment at the centre of the bar, XTE is zero.

As a further indication of the capabilities of a modern electronic system, the Trimble NT GPS range may be fitted with a Smart Card Reader to read Navionics chart cards.

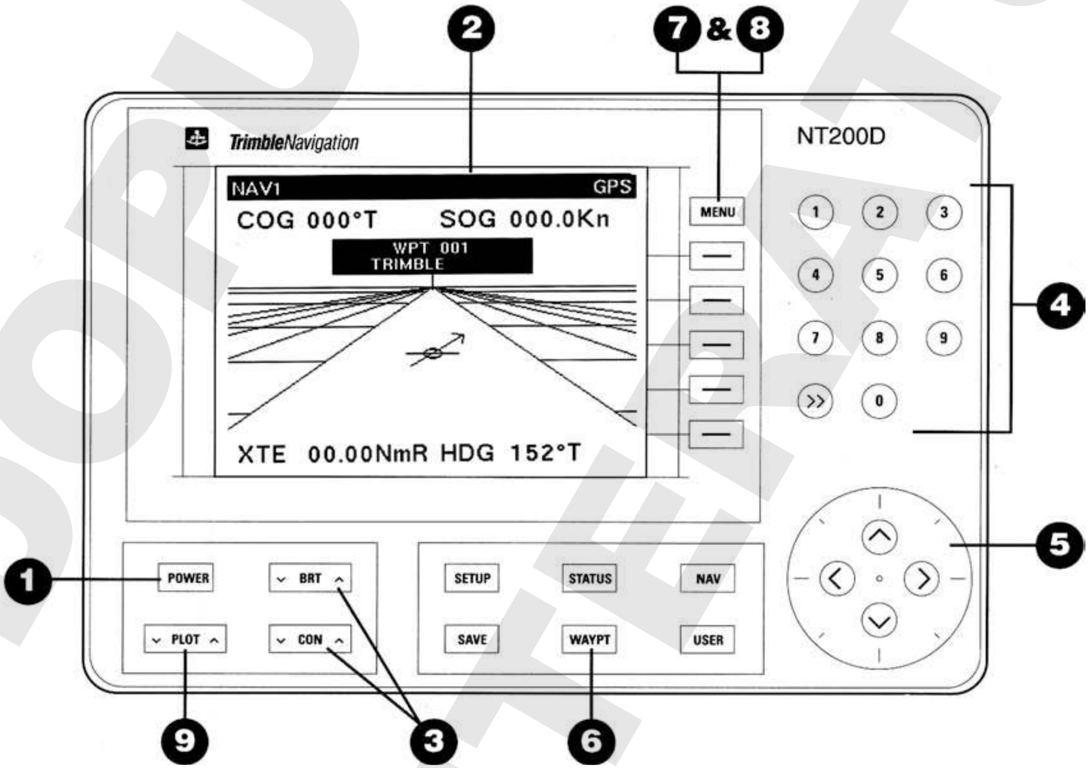


Figure 5.25 The NT200D GPS receiver displaying the NAV1 navigation display. (Reproduced courtesy of Trimble Navigation Ltd.)

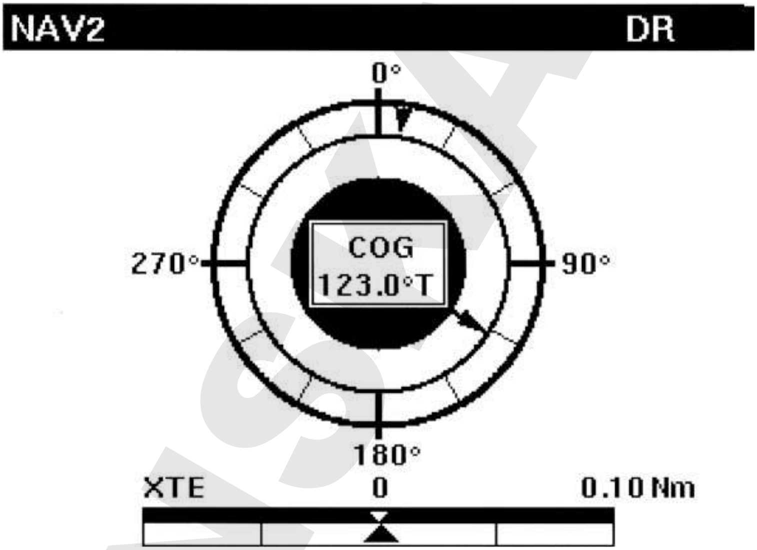


Figure 5.26 NAV 2 display. (Reproduced courtesy of Trimble Navigation Ltd.)

Each Navionics card holds the data necessary to give a screen display in the form of a maritime chart for a specified geographical area. The display then integrates the GPS data with the chart data, producing a recognizable nautical chart and the vessel's course and speed. Figure 5.27 shows a vessel (a flashing icon) with a track (a solid line) taking it under the western part of the Bay Bridge and a residual course (a line of dots) extending back to Alameda.

To avoid cluttering the chart, not all available data is shown on the Bay Area chart in Figure 5.27. Additional key commands are able to bring up the following information: depth contours, XTE lines, COG indicator, names (of cities, ports, bodies of water etc.), track, lighthouses and buoys, waypoints, landfill (for a clearer display of coastlines), maps, and much more. It is also possible to zoom in/out to show greater detail.

Another navigation screen display is the Mercator grid plot (Figure 5.28) showing the vessel's current position, the track history and the waypoints and legs in the active route. There are several scale or zoom levels ranging from 010 to 1000 km plus nautical miles or Mi increments.

Modern equipment is capable of much more than simply calculating and displaying position and track information and the NT200D is no exception. The versatility of its display coupled with adequate computing power and reliable data processing circuitry means that a wealth of other information can be accessed and presented to users. Set-up screens, system health checks, interface information, status displays, waypoint information, routes and more can be selected for display. Two displays in the status directory (Figure 5.29), of interest to students, present information about the satellites in view.

In Figure 5.29(a), the vessel is at the centre of concentric circles with a radial arrow indicating the current COG. The outer ring of the plot represents the horizon (0° elevation) and the inner rings, 30° and 60° elevation, respectively. Satellites in the centre of the plot are directly overhead (90° elevation). A satellite's true position in azimuth is shown relative to the north-up plot or may be determined relative to the vessel's COG.

Blackened icons indicate satellites being tracked by the receiver. Received data from the others falls below the parameters selected for their use. The table on the right shows the number of the SV and

Figure 5.27 Chart display of San Francisco Bay and approaches using data input from a smart card. (Reproduced courtesy of Trimble Navigation Ltd.)

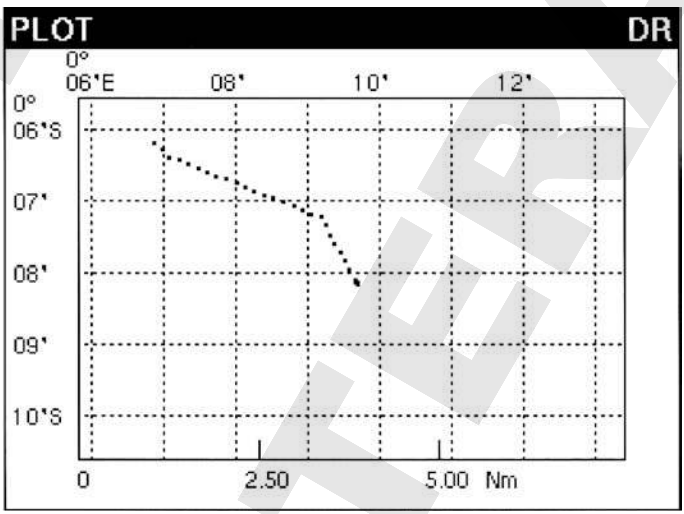
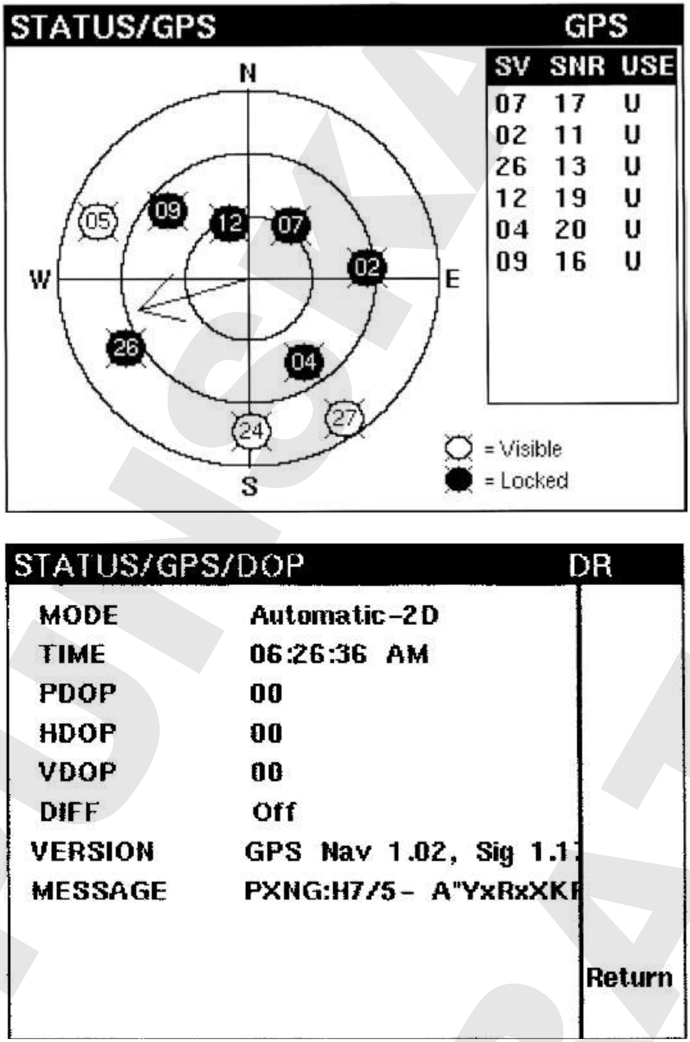


Figure 5.28 The Mercator grid plot screen display of the GPS receiver DR track. The vessel's current position is indicated by a flashing icon in the centre of the screen. (Reproduced courtesy of Trimble Navigation Ltd.)



(a)

(b)

Figure 5.29 Satellite status/GPS display. Darkened icons are the numbered satellites currently being tracked by the receiver. Light icons represent received satellites that fall below the parameters selected for their use. The vessel is in the centre of the display and its course-over-ground is indicated by an arrow. (Reproduced courtesy of Trimble Navigation Ltd.)

the signal-to-noise ratio (SNR) for each satellite tracked. A SNR of 15 is considered good, 10 is acceptable and a SNR below 6 indicates that the satellite should not be relied upon for a position solution. A ‘U’ shows that an SV is being used and a ‘D’ that the equipment is receiving differential correction data for the satellite.

The second Status/GPS display is the dilution of precision screen (Figure 5.29(b)). PDOP, HDOP, and VDOP are numerical values based on the geometry of the satellite constellation used in a position solution. A figure of unity, 1.0, is the best DOP achievable. The most important of these parameters is the PDOP, the position dilution of precision. The lower the PDOP figure, the more precise the solution will be and the better the position fix. In practice a PDOP figure greater than 12 should be used with caution. A PDOP in the range 1–3 is excellent, 4–6 is good, 7–9 acceptable, 10–12 marginal and 12+ should be used with caution.

HDOP represents the accuracy of the latitude and longitude co-ordinates in two- or three-dimensional solutions, and VDOP is the accuracy of the altitude in a three-dimensional solution.

The display also shows the current GPS operating mode, the time of the last GPS fix, the current DGPS operating mode DIFF, the receiver firmware version, and the GPS system message.

For further information about Trimble GPS products see www.trimble.com

5.12.2 Garmin GPS receiver specifications

Amongst a range of GPS equipment designed for the maritime market, Garmin offers a 12-channel GPS receiver (with an optional DGPS receiver) combined with a navigation plotter. This versatile equipment, known as the GPSMAP 225, is representative of the way that system integration is making life easier for the maritime navigator. The GPSMAP 225 effectively presents an electronic charting/navigation system based on a 16-colour active-matrix TFT display that modern navigators will feel comfortable with.

Figure 5.30 shows the front panel of the receiver including the main operator controls and a sample chart showing own ship as a wedge icon. Note that the equipment is operating in a simulation mode.

Figure 5.30 Front panel of the Garmin GPSMAP 225 system showing operator controls and a sample navigation map generated in the simulation mode. (Reproduced courtesy of Garmin.)

Operator controls

ZOOM key	Changes the map display scale to one of 16 settings, or the highway display scale to one of five settings.
CTR key	Eliminates the cursor and centres own vessel on the screen.
ARROW keys	Controls the movements of the cursor and selects screen options and positions.
ENT key	Used to confirm data entry and execute various on-screen function prompts.
MAPS key	Returns the display to the Map page and/or displays the outlines of chart coverage in use.

PAGE key	Scrolls through the main screen pages in sequence.
DATA key	Turns the data window on or off in map mode and toggles the displayed data on other pages.
MENU key	Turns the softkey menu on or off in the map mode.
MARK key	Captures present position for storage as a waypoint.
MOB key	Marks present GPS position and provides a return course with steering guidance.
GOTO key	Enables waypoints or target cursor position as a destination and sets a course from current position.
SOFT keys	Perform route, waypoint and set-up functions. Also enable custom set-ups and many navigation functions from the map display.

Navigation and plotting functions

By using the built-in simulator mode for full route and trip planning, the GPSMAP system is capable of relieving a navigator of some of the more mundane navigation exercises. The system also includes the following specification to assist with the day-to-day navigation of a vessel.

- Over 1900 alphanumeric waypoints with selectable icons and comments.
- Built-in worldwide database usable from 4096 to 64 nautical miles scales.
- 20 reversible routes with up to 50 waypoints each.
- Graphic softkeys for easy operation of the chart display.
- G-chart^{TM} electronic charting for seamless, worldwide coverage (see Figure 5.33).
- On-screen point-to-point distance and bearing calculations.
- 2000 track log points with time, distance or resolution settings.
- Built-in simulator mode for full route and trip planning.
- Conversion of GPS position to Loran-C TD co-ordinates.

Loran-C TD conversion

The GPSMAP unit automatically converts GPS co-ordinates to Loran-C TDs (time delay) for users who have a collection of Loran fixes stored as TDs. When the unit is used in this mode, it simulates the operation of a Loran-C receiver. Position co-ordinates may be displayed as TDs, and all navigation functions may be used as if the unit was actually receiving Loran signals. The expected accuracy is approximately 30 m.

GPSMAP system operation

At power-up, the satellite status page will appear. This gives a visual reference of satellite acquisition and status, with a signal bar graph and satellite sky view in the centre of the screen. In Figure 5.31, satellites 5, 8, 15, 21, 23, 25, 29, 30, and 31 are all currently being tracked, with the corresponding signal strength bars indicating the relative strength of the signals. Satellites 3 and 9 (shown with highlighted numbers) are visible but are not being tracked. The Dilution of Precision (DOP) figure is shown as 2 giving an estimated position error (EPE) of 49 feet.

The outer circle of the satellite sky view represents the horizon (north-up), the inner circle 45° above the horizon, and the centre point at a position directly overhead.

The GPSMAP Map page (see Figure 5.32), the primary navigation page, provides a comprehensive display of electronic cartography, plotting and navigational data. The Map page is divided into three main sectors: chart display, data window and softkey menu.

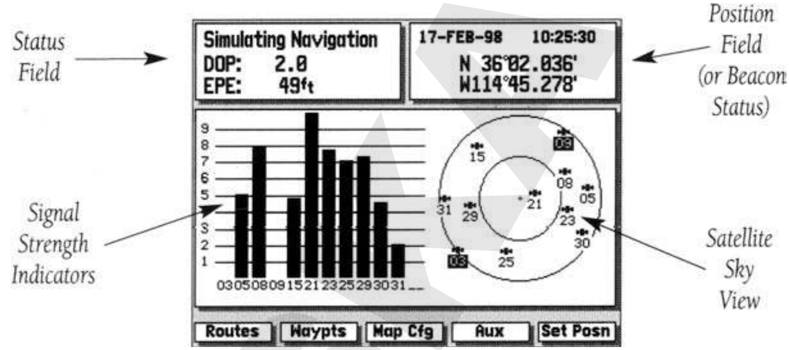


Figure 5.31 The satellite status display of the Garmin GPSMAP 225 system.

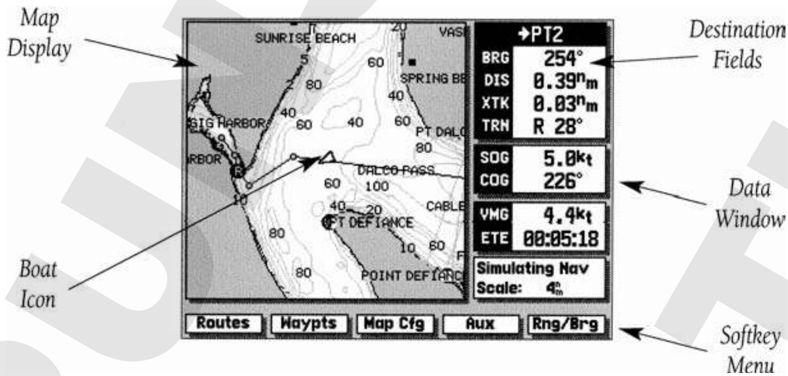


Figure 5.32 The MAP page, the main navigation display of the Garmin GPSMAP 225 system showing own vessel and track.

The chart display shows the user's vessel on an electronically generated chart, complete with geographical names, navaids, depth contours and a host of other chart features. A wedge icon represents the vessel's position, with its track plot shown as a solid yellow line. Routes and waypoints that have been created are also displayed. An on-screen cursor permits panning and scrolling to other map areas showing distance and bearing to a selected positions and waypoints as required. The GPSMAP system, using Garmin G-chart™ data cartridges, has a worldwide database to 64 nautical miles and a global coverage as shown in Figure 5.33.

The Map page also displays a wealth of navigation data in digital form. The destination fields show the bearing (BRG), in this case 254°, and the distance (DIS) 0.39 nautical miles to a destination waypoint or to the cursor. Cross-track error (XTE, 0.03 nautical miles) and turn (TRN, R 28°) information for an active destination is also displayed. The XTE value is the distance the vessel is off a desired course (left or right), whilst TRN represents the direction (left or right) in degrees between the vessel's course-over-ground (COG) and the bearing to the destination. The present speed-over-ground (SOG) is 5.0 knots and course-over-ground (COG) is 226°. This information and the terms used are illustrated in Figure 5.32.

Below this is the arrival and status field. The velocity-made-good (VMG), in this case 4.4 knots, is the speed of the vessel on a destination along a desired track, and the estimated time en route (ETE),

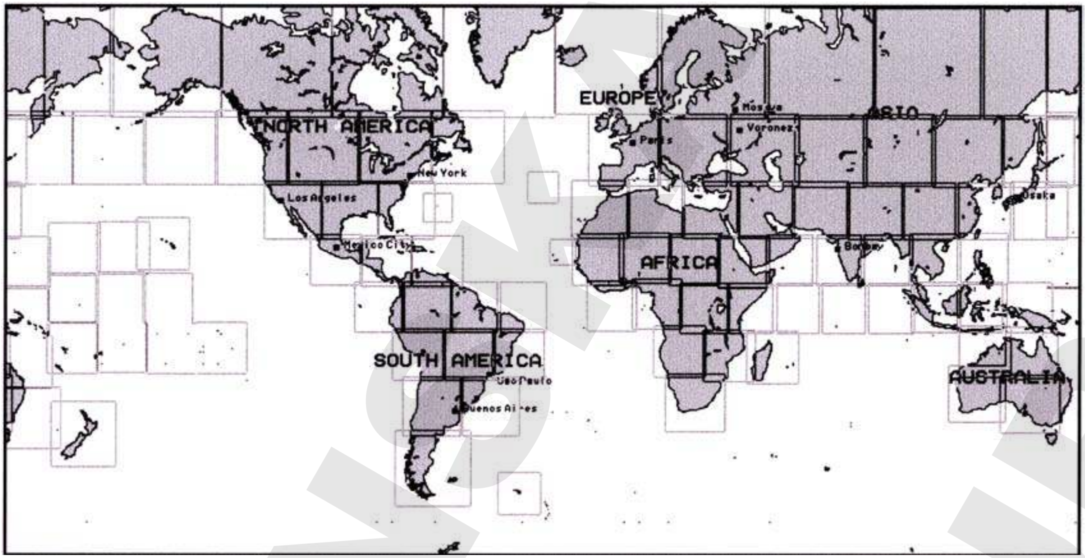


Figure 5.33 Global coverage chart showing the Garmin GPSMAP's built-in database for chart coverage down to 64 nautical miles.

00:05:18, is the estimated time remaining on the voyage leg. The status field indicates the operating mode, in this case simulating navigation, and the scale shows the map display depth, 4 nautical miles.

The GPSMAP's built-in worldwide database includes chart coverage down to 64 nautical miles (120 km) for the areas shown in Figure 5.33.

Switching to the GPSMAP Highway page (see Figure 5.34) provides a large character display of navigation data and graphic steering guidance to an active waypoint via a planned highway. The active destination point is displayed at the top of the screen with the ETE and ETA based on the present speed and course shown at the bottom.

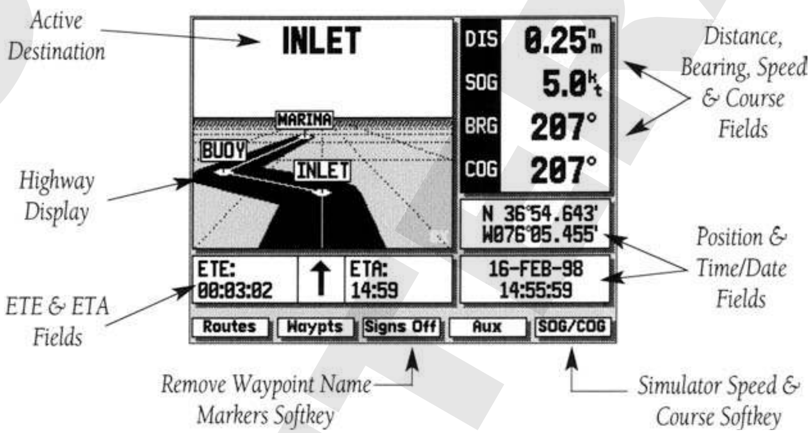


Figure 5.34 A sample Highway page of the Garmin GPSMAP 225 system used when navigating a route to an active waypoint.

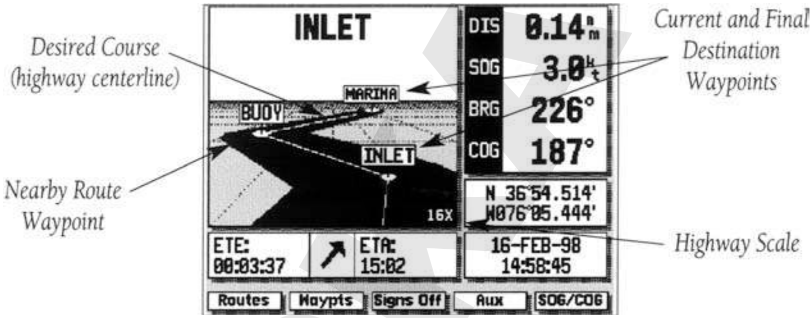


Figure 5.35 A sample Highway page of the Garmin GPSMAP 225 system used when navigating a route to an active waypoint.

The distance and bearing to the destination waypoint, along the present SOG and COG, are shown along the right-hand side. The SOG and COG fields may be changed to display the velocity-made-good and the turn value (VMG and TRN). The position field shows the present GPS position and the date/time field displays the current date and time as calculated from GPS satellites.

The Highway page's graphic display occupies the majority of the screen (see Figure 5.35). It provides visual guidance to the destination waypoint and keeps the vessel on the intended course line. The vessel's course is represented by a centre line down the middle of the graphic highway. As the vessel progresses towards its destination, the highway perspective changes to indicate progress and which direction should be steered to remain on course. When navigating a route, the highway display shows each route waypoint in sequence. Nearby waypoints not in the steered route also will be displayed.

This brief description demonstrates that GPS receivers have moved away from the simple positional display in latitude and longitude. In future the use of more powerful computers and further integration will no doubt see GPS as merely a small but valuable input to a huge electronic charting system (for further details see Chapter 7).

Interface details

The following interface formats are supported by the GPSMAP system for connection to up to three NMEA devices.

NMEA 0180
NMEA 0182
NMEA 0183 version 1.5

Approved sentences-
GPBWC, GPGLL, GPRMB, GPRMC, GPXTE, GPVTG, and GPWPL

Proprietary sentences-
PGRMM (map datum), PGRMZ (altitude) and PSLIB (beacon receiver control input)

NMEA 0183 version 2.0

Approved sentences-
GPGGA, GPGSA, GPGSV, GPRMB, GPRMC, GPRTE and GPWPL

Proprietary sentences-
PGRME (estimated error), PGRMM (map datum), PGRMZ (altitude) and PSLIB (beacon receiver control input)

For further information and explanation about the NMEA format see Appendix 3. For further information about Garmin GPS products see www.garmin.com

5.13 GPS on the web

GPS enjoys massive coverage on the world wide web and there are simply far too many sites to list here. However, some of the better sites are worth a visit and are listed below.

http://www.navcen.uscg.mil
An essential site for all navigators. United States Coast Guard site with numerous pages of data on GPS, Loran-C and US coastal navigation notices.

ftp://tycho.usno.navy.mil/pub/gps
Massive amounts of detail about GPS time transfer, current constellation status and health.

http//:www.spatial.maine.edu/~leick/alpha.htm
GPS and GLONASS alphabetical index link site to dozens of other relevant sites.

http://www.apparent-wind.com/gps.html
Another index site with useful links to other GPS and maritime sites.

http://www.trimble.com
GPS tutorials, fact sheets, satellite plots etc. from one of the biggest GPS equipment manufacturers. One of the best sites on the net.

http://www.trinityhouse.co.uk/dgps.htm
Details of the differential GPS beacons, parameters and availability around the UK coast.

http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html
Extensive high-tech education notes on the GPS system from the University of Texas. Intended for use by university students.

http://www.igeb.gov
Interagency GPS Executive Board site. Includes the latest news about the GPS.

http://www.ngs.noaa.gov
National Oceanic and Atmospheric Administration (NOAA) and the National Geodetic Survey Site. Lots of detailed statistics about GPS health and status.

http://www.notams.faa.gov
The FAA's site holding Notices to Airmen (NOTAMs) listed interruptions in the GPS service. Coastal area NOTAMs are of use to mariners.

http://www.garmin.com
A huge informative site belonging to a major manufacturer of GPS equipment, holding a wealth of information about a huge range of equipment.

GPS continues to be updated and improved. It has been announced that two new civilian signals designed to carry data to enhance the civilian and commercial service will be added to the GPS. Furthermore, 18 additional satellites are to be used to support the system.

5.14 Global Orbiting Navigation Satellite System (GLONASS)

The Russian Federation's GLONASS was developed in parallel with GPS to serve the same primary function, that is, as a weapons navigation and guidance system. And like GPS, GLONASS has been released for international position fixing use, albeit in a downgraded form.

GLONASS is owned and operated by a Military Special Forces team at the Russian Ministry of Defence. SV time synchronization, frequency standards and receiver technology development are controlled from The Russian Institute of Navigation and Time in St. Petersburg. The system possesses similar architecture to the GPS and is equally capable of highly accurate position fixing.

5.14.1 Space segment

Work on the system began in the early 1970s and the first satellites were launched into orbit in 1982. Since then a full constellation has been established and GLONASS became fully operational in early 1996.

The space segment is based on 24 SVs, eight in each of three, almost circular orbital planes spaced at 120° intervals and inclined at 64.8° and at an altitude of 25 440 km. Each SV completes one earth orbit in 11 h 25 min and of course two orbits in 22 h 50 min in real time. Taking into account the length of a sidereal day, the westerly shift of each orbit brings all SVs back to an earth epoch point every 8 days, and the entire cycle repeats naturally.

All GLONASS SVs transmit on two frequencies to allow for correction of ionospheric signal delay, but unlike the GPS system, each SV uses different frequencies. Phase modulated onto the two carrier frequencies are a Coarse/Acquisition (C/A), a Precise code (P) and navigation data frames.

5.14.2 Ground segment

All ground control stations are located in former Soviet Union territory. The Ground Control and Operations Centre and Time Standard Centre are in Moscow. SV telemetry and tracking stations are located in Eniseisk, Komsomolsk-na-Amure, St. Petersburg and Ternopol.

5.14.3 Signal parameters

Initially all SVs were designed to transmit on different carrier frequencies, but in 1992, following the World Administrative Radio Conference (WARC-92) frequencies were grouped. Then in 1998 they were again changed. Currently, the L_1 transmission frequency band is 1598.0625–1609.3125 MHz and the L_2 band 7/9ths below this between 1242.9375 and 1251.6875 MHz (see Table 5.9).

Both L_1 and L_2 carriers are BPSK-modulated at 50 bauds with the navigation message. L_1 also carriers a PRN Coarse/Acquisition (C/A) code and L_2 both a Precision (P) code and the C/A code. The P code has a clock rate of 5.11 MHz and the C/A code is 0.511 MHz.

As in the GPS, the GLONASS navigation message contains timing, SV position and tracking data. All SVs transmit the same message (see Table 5.10).

5.14.4 Position fixing

GLONASS navigation fixes are obtained in precisely the same way as those for GPS. Pseudo-range calculations are made and then corrected in the receiver to obtain the user location in three dimensions. Precise timing is also available.

Table 5.9 SV carrier frequency designation

Channel no.	*L1 carrier (MHz)*	*L2 carrier (MHz)*
–7	1598.0625	1242.9375
–6	1598.6250	1243.3750
–5	1599.1875	1243.8125
–4	1599.7500	1244.2500
↓		
+13	1609.3125	1251.6875

Expression for channel increment:

$$L1 = 1598.0625 + 0.5625\,\text{MHz}$$
$$L2 = 1242.9375 + 0.4375\,\text{MHz}$$

Note: The ratio of L2/L1 channels is 7/9.

Table 5.10 GPS – GLONASS system comparison

Parameter	*GPS*	*GLONASS*
Orbital		
Altitude:	20 180 km	19 130 km
Period:	11 h 58 min	11 h 15 min 40 s
Inclination:	55°	64.8°
Planes:	6	3
Number of SVs	24	24
Carrier frequency		
L1:	1575.420 MHz	1598.6250–1609.3125 MHz
L2:	1227.600 MHz	1242.9375–1251.6875 MHz
Code clock rate		
C/A:	1.023 Mbit s^{-1}	0.511 Mbit s^{-1}
P:	10.23 Mbit s^{-1}	5.11 Mbit s^{-1}
Time reference	UTC	UTC
Navigation message		
Rate:	50 bit s^{-1} (baud)	50 bit s^{-1} (baud)
Modulation:	BPSK NRZ	BPSK Manchester
Frame duration:	12 min 30 s	2 min 30 s
Subframe:	6 s	30 s
Almanac content	Timing and orbital parameters	Timing and orbital parameters

5.14.5 User equipment

Because of the initial secrecy surrounding the system and the scarcity of detailed parameters, it is to be expected that there is little user equipment available. In the past, western manufacturers have had little incentive to invest heavily in the development of receivers when the GPS has been freely available. However, this situation could well change in the future.

5.15 Project Galileo

At the time of writing, the European Commission has produced a working paper for a European-based Global Navigation Satellite Service (GNSS) called the Galileo. It is to be designed to be totally independent of both GPS and GLONASS and thus will end the reliance of countries within the European Commission on systems beyond their control. It remains to be seen if the finance and indeed the impetus to create the system will be forthcoming.