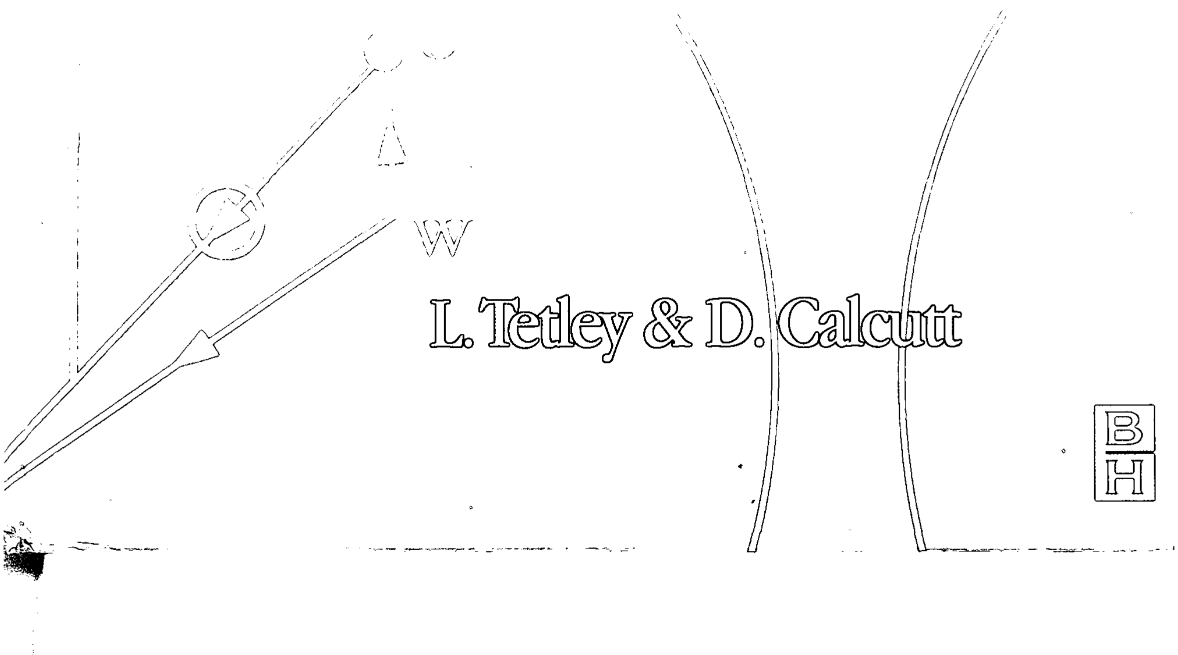
THIRD EDITION

Electronic Navigation Systems



L. Tetley & D. Calcutt

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3rd edition

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Laurie Tetley IEng FIEIE
Principal Lecturer in Navigation and Communication Systems

and

David Calcutt PhD MSc DipEE CEng MIEE
Formerly Senior Lecturer, Department of Electrical and Electronic Engineering, University of Portsmouth

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Contents

Preface

This new edition of *Electronic Navigation Systems* has been extensively rewritten to provide navigators with a detailed manual covering the principles and applications of modern systems.

The past decade has been witness to huge advances in technology and no more so than in maritime navigation and position fixing. As you might expect, spearheading this technological advance has been the computer. It has become as common on board ships as in our normal lives where it now influences virtually everything that we do. A new generation of ship's officer has been trained to use computers, trained to understand how they work and, more importantly, how they can be made to assist in the business of safe and precise navigation. But it would be a serious error to assume that the technology is perfect. All the systems currently used for navigation and position fixing are as near perfect as they can be, but it would be foolhardy to ignore the human link in the electronic chain of action and reaction. In the end, it is a ship's captain who bears the ultimate responsibility and the navigating officer who, with pride, safely brings his ship into port.

Readers will find that this new expanded edition includes many new systems and techniques whereas some older, now obsolete systems have been deleted. The hyperbolic systems, which once formed the backbone of global position fixing, have been decimated by the continuing expansion of the Global Positioning System (GPS).

The hyperbolic systems Decca and Omega have gone, but Loran-C, the one terrestrial network providing extensive coverage, remains as the designated back-up system to the GPS. By Presidential order, on 1 May 2000, Selective Availability, the method by which GPS accuracy was downgraded for civilian users, was set to zero. This significant event means that submetre accuracy position fixing is now available for all users, a factor that will have a major impact on GPS equipment and subsystems over the next decade.

Whilst the GPS is the undisputed king amongst satellite systems, it is by no means the only one. GLONASS, created and maintained by the Russian Federation, also provides users with accurate position fixes and the European Community is actively considering another system to be totally independent of the other two.

Although position fixing by satellite is of paramount importance there are other systems essential to safe navigation. Speed logging, depth sounding, and automatic steering systems are equally as important as they were decades ago and even that most traditional of all systems, the gyrocompass, has been digitized and refined. But essentially, system parameters remain unchanged; it is the collecting, processing and display of data that has been transformed.

Computerization and continuing development of large-scale integration (LSI) technology have been directly responsible for most of the changes. The large-scale manufacture of microchips has enabled the production of low-cost equipment with capabilities that could only have been dreamed about a decade ago. This reduction in size and cost has also brought sophisticated navigation equipment within reach of small-boat owners.

Electronic Navigation Systems has been written to support the training requirements of STCW-95 and consequently the book is an invaluable reference source for maritime navigation students. As with previous editions, each chapter opens with system principles and then continues with their application to modern equipment. Some sections, typically gyrocompass and automatic steering, still contain valid descriptions of analogue equipment but these have been further strengthened with the introduction of new digital technology. Wherever possible we have described the systems and equipment that you, the reader, are likely to meet on board your craft whether it is large or small.

The Global Maritime Distress and Safety System (GMDSS) is a subject which no mariner can ignore and consequently it has been outlined in this book. For extensive details about the principles and applications of this global communications system, see our book *Understanding GMDSS*.

Radar and Automatic Radar Plotting Aids (ARPA) are obviously essential to safe navigation and indeed are now integrated with other navigation systems. They are discussed in depth in the companion volume to this publication, *Electronic Aids to Navigation (RADAR and ARPA)*.

Laurie Tetley and David Calcutt
2000

Acknowledgements

A book of this complexity containing leading edge technology must inevitably owe much to the co-operation of various individuals, equipment manufacturers and organizations. To single out one or more organizations is perhaps invidious. In many cases we have had no personal contact with individuals but despite this they gave freely of their time when information was requested.

We are extremely grateful for the assistance that the following companies and organizations gave during the writing of this book. We are particularly indebted to the organizations that permitted us to reproduce copyright material. Our sincere thanks go to the following.

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The following figures are from the IMO publications on GMDSS and *The Navtex Manual*, and are reproduced with the kind permission of the International Maritime Organization, London: Figure 11.1, page 370; Figure 11.3, page 374; Figure 11.4, page 376; Figure 11.7, page 381; Figure 11.8, page 382; Figure 11.10, page 384; Figure 11.11, page 385.

Chapter 5

Satellite navigation

5.1 Introduction

It is surprising that the space technology that we rely on so heavily today had its origins over 50 years ago when, in the early 1950s, with the shock launching by the USSR of a man-made satellite into low orbit, the United States space programme was born. Although a tiny vehicle by present day standards, the USSR's 'Sputnik' had a radio transmitter on board, the frequency of which exhibited a pronounced Doppler shift when observed from any fixed point on the earth's surface. The Doppler phenomenon was well documented but this was the first time the effect had been produced by and received from a man-made orbiting satellite. Space engineers soon recovered from the initial shock and were quick to see that the effect could be exploited to create a truly accurate global positioning system, free from many of the constraints of the existing earth-bound hyperbolic navigation systems.

The first commercially available system to be developed, the Navy Navigation Satellite System (NNSS), made good use of the Doppler effect and provided the world's shipping with precise position fixing for decades. However, nothing lasts forever. The technology became old and the system was dropped on 31 December 1996 in favour of the vastly superior Global Positioning System (GPS). Although a number of NNSS Nova satellites are still in orbit, the system is no longer used for commercial navigation purposes.

5.2 Basic satellite theory

Whilst it is not essential to understand space technology, it is helpful to consider a few of the basic parameters relating to satellite orbits and the specific terminology used when describing them. A satellite is placed in a pre-determined orbit, either in the nose of an expendable launch vehicle or as part of the payload of a space shuttle flight. Either way, once the 'bird' has been delivered into the correct plane, called the 'inclination', that is the angle formed between the eastern end of the equatorial plane and the satellite orbit, it is subject to Kepler's laws of astrophysics.

Figure 5.1 shows orbits of zero inclination for the equatorial orbit, 45°, and for a polar orbit, 90°. The final desired inclination partly determines the launching site chosen. In practice it is difficult to achieve an inclination which is less than the latitude of the launching site's geographical location. A zero inclination orbit is most effectively produced from a launch pad situated on the equator, but this is not always possible and a compromise is often made. Launch normally takes place in an easterly direction because that way it is possible to save fuel, and thus weight, by using the earth's rotational speed to boost the velocity of the accelerating rocket. For an easterly launch from a site on the equator, the velocity needed to escape the pull of gravity, is 6.89 km s^{-1}, whereas for a westerly launch it is 7.82 km s^{-1}. Launch velocities also vary with latitude and the direction of the flight path.

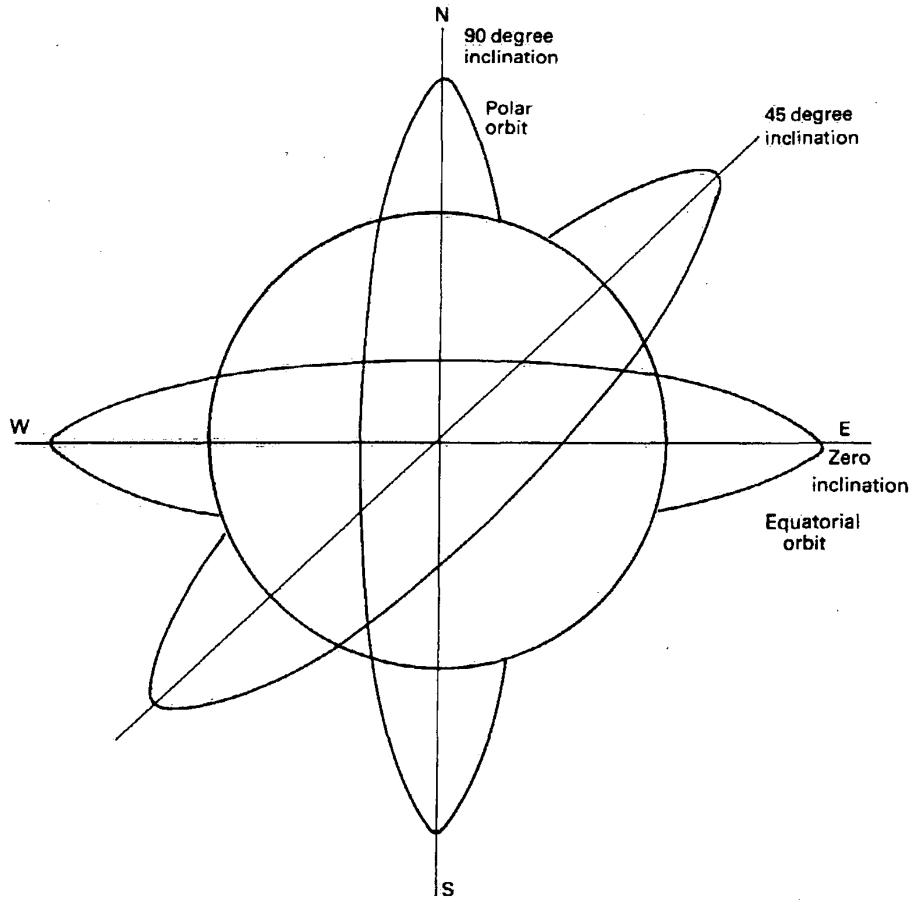


Figure 5.1 Illustration of orbital inclination.

5.2.1 Kepler's Laws

Essentially, an artificial earth-orbiting satellite obeys three laws that were predicted in the late 16th century by Johannes Kepler (1571–1630) who also developed theories to explain the natural orbits of the planets in our solar system. When applied to artificial orbiting satellites, Kepler's laws may be summarized as follows.

- A satellite orbit, with respect to the earth, is an ellipse.
- Vectors drawn from the satellite orbit to the earth describe equal areas in equal times.
- The square of the period of the orbit is equal in ratio to the cube of its mean altitude above the earth's surface.

True to Kepler, artificial earth satellites follow elliptical orbits. In some cases the ellipse eccentricity is large and is a requirement of the first stage of a launch to the higher geostationary orbit, but in most

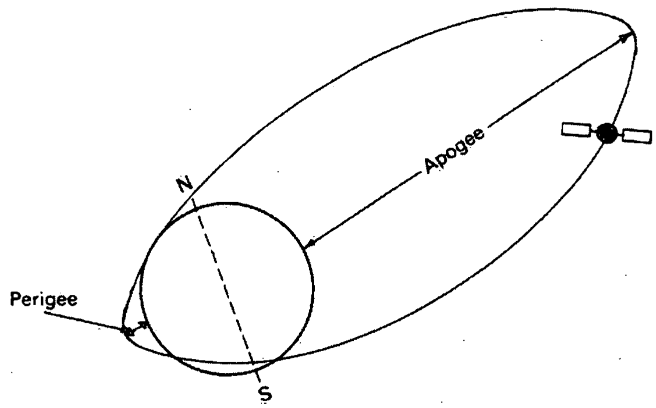


Figure 5.2 Illustration of apogee and perigee.

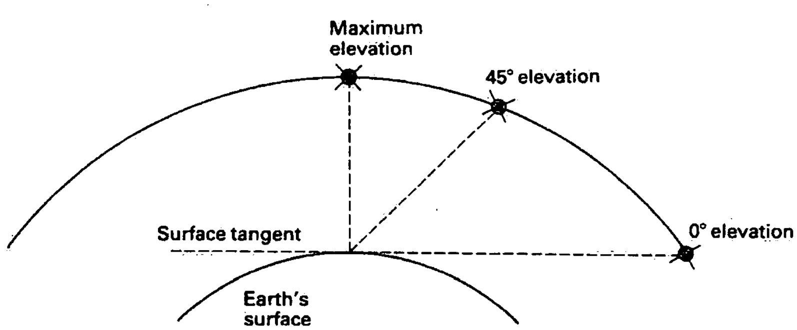


Figure 5.3 Showing the changing angle of elevation during a satellite pass. The angle reaches a maximum at the closest point of approach to the earth bound observer.

cases it is created because the earth is not a perfect sphere. The closest point of approach to the earth of any elliptical orbit is called the 'perigee' and the furthest distance away is the 'apogee', as shown in Figure 5.2. The direction vector to the satellite from a fixed point on the earth is called the 'azimuth' and is quoted in degrees. The angle between the satellite, at any instant, and the earth's surface tangent is the 'elevation' and again is quoted in degrees (see Figure 5.3).

5.2.2 Orbital velocity

A satellite can only remain in orbit if its velocity, for a given altitude, is sufficient to defeat the pull of gravity (9.81 ms^{-1}) and less than that required to escape it. The velocity must be absolutely precise for the orbital altitude chosen. Eventually, drag will slow the satellite causing it to drop into a lower orbit and possibly causing it to re-enter the atmosphere and burn-up. The nominal velocity for a satellite at any altitude can be calculated by using the formula:

$$V = \frac{K}{(r + a)^{1/2}} \text{ kms}^{-1}$$

where V = orbital velocity in kms^{-1},
a = altitude of the satellite above the earth's surface in km,
r = the mean radius of the earth (approximately 6370 km), and
K = 630 (a constant derived from a number of parameters).

The earth is not a perfect sphere and therefore its radius with respect to orbital altitude will vary. However, to derive an approximate figure for velocity, an earth radius figure of 6370 km is close enough. The velocity of a satellite with an altitude of 200 km would be:

$$V = \frac{630}{(6370 + 200)^{1/2}} = 7.77\,kms^{-1}$$

Orbital paths can be transferred to a Mercator projection chart as shown in Figure 5.4. The inclination will be the same in both northern and southern hemispheres and corresponds to latitude. The six orbits shown are for Navstar (GPS) satellites with an orbital inclination of 55°.

5.2.3 Orbital period

The time period for one complete orbit of a satellite can be readily calculated using the simple formula below:

$$P = K\left(\frac{r + a}{r}\right)^{3/2}$$

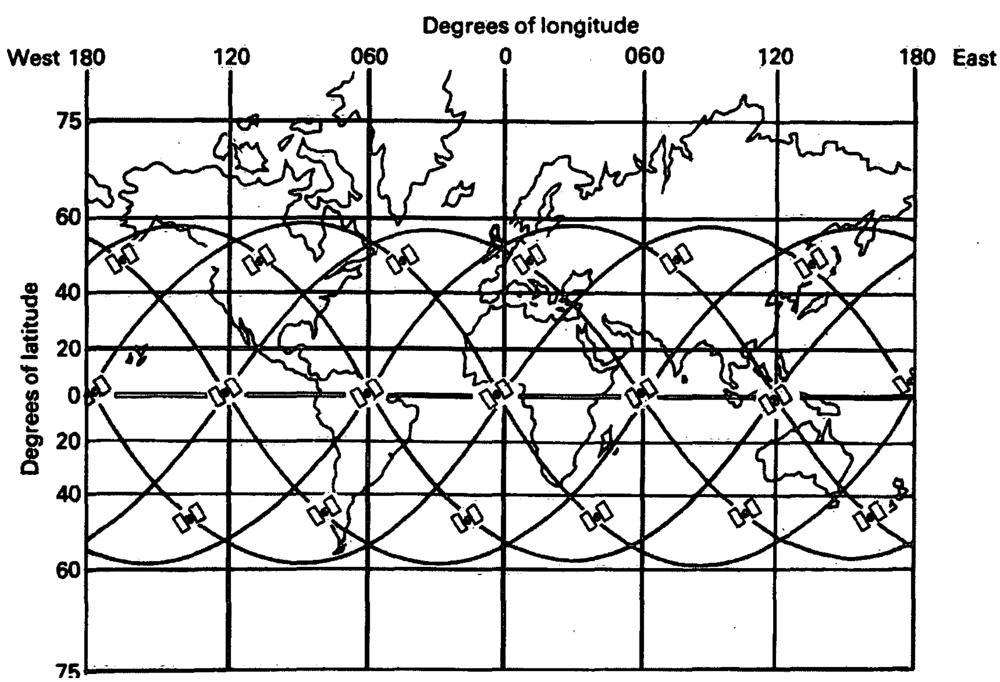


Figure 5.4 Mercator presentation of the orbital inclination paths described by satellite orbits.

where P = the period of one orbit in min,
a = the altitude of the orbit above the earth's surface in km,
r = the mean radius of the earth in km, and
K = 84.49 (a constant derived from a number of parameters).

The orbital period for a satellite at an altitude of 200 km is:

$$P = 84.49\left(\frac{6371 + 200}{6371}\right)^{3/2} = 88.45 \text{ min}$$

5.3 The Global Positioning System (GPS)

In 1973 a combined US Navy and US Air force task-force set out to develop a new global satellite navigation system to replace the ageing Navy Navigation Satellite System (NNSS).

The original test space vehicles (SVs) launched in the new programme were called Navigation Technology Satellites (NTS) and NTS1 went into orbit in 1974 to became the embryo of a system that has grown into the Global Positioning System (GPS). GPS was declared to be fully operational by the US Air Force Space Command (USAFSC) on 27April 1995, and brought about the demise of the NNSS which finally ceased to provide navigation fixes at midnight on 31 December 1996.

The GPS, occasionally called NAVSTAR, shares much commonality with the Russian Global Navigation System (GLONASS), although the two are in no way compatible. The GPS consists of three segments designated Space, Control and User.

5.3.1 The space segment

Satellite constellation calls for 24 operational SVs, four in each of six orbital planes, although more satellites are available to ensure the system remains continuously accessible (see Figure 5.5). SVs orbit the earth in near circular orbits at an altitude of 20 200 km (10 900 nautical miles) and possess an inclination angle of 55°.

Based on standard time, each SV has an approximate orbital period of 12 h, but when quoted in the more correct sidereal time, it is 11 h 58 min. Since the earth is turning beneath the SV orbits, all the satellites will appear over any fixed point on the earth every 23 h 56 min or, 4 min earlier each day. This, totally predictable, time shift is caused because a sidereal day is 4 min shorter than a solar day and all SVs complete two orbits in one day. To maintain further orbital accuracy, SVs are attitude-stabilized to within 1 m by the action of four reaction wheels, and on-board hydrazine thrusters enable precision re-alignment of the craft as required.

This orbital configuration, encompassing 24 SVs, ensures that at least six SVs, with an elevation greater than 9.5°, will be in view of a receiving antenna at any point on the earth's surface at any time. When one considers the problems of rapidly increasing range error caused by the troposphere at low SV elevations, 9.5° has been found to be the minimum elevation from which to receive data when using a simple antenna system.

The original satellites, numbered 1–11 and designated Block I, have ceased operation. Currently, the GPS constellation is based on the next generation of SVs, designated Block II. Block II (numbers 13–21) and block IIA (numbers 22–40) satellites, manufactured by Rockwell International, were launched from Cape Canaveral between February 1989 and November 1997. Each SV holds four atomic clocks, two rubidium and two caesium, and has selective availability (SA) and anti-spoofing (A-S) capabilities, although the US Government has now given an assurance that the system

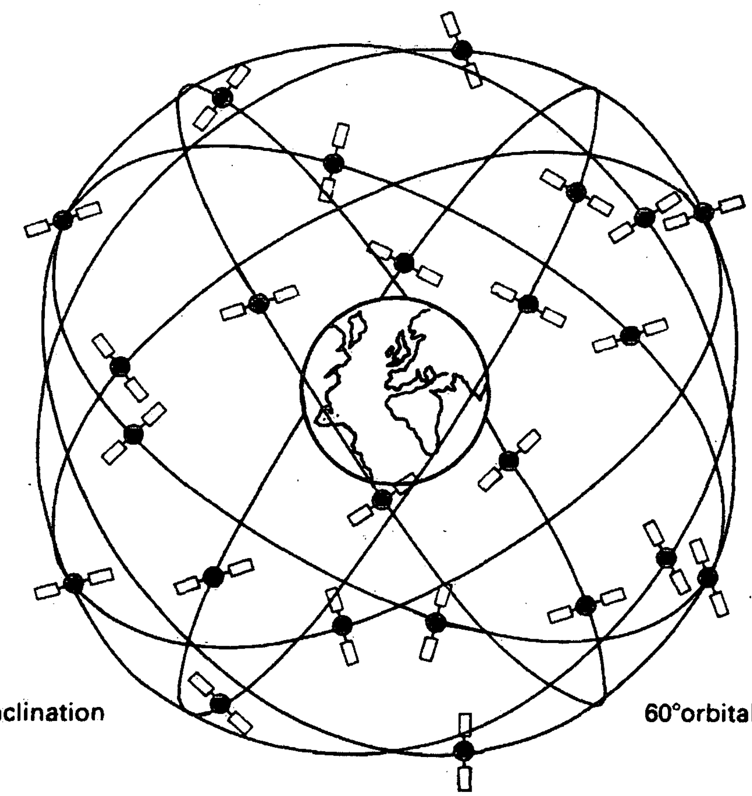


Figure 5.5 GPS satellite coverage. Twenty-four satellites provide global coverage; four in each of six orbital planes.

downgrading functions, SA and A-S, will no longer be implemented in the GPS. Block IIR SVs (numbers 41–62) are replenishment satellites and have been designed for an operational life of 7.8 years.

All SVs transmit a navigation message comprising orbital data, clock timing characteristics, system time and a status message. They also send an extensive almanac giving the orbital and health data for every active SV, to enable a user to locate all SVs once one has been acquired and the data downloaded.

5.3.2 The control segment

The GPS is controlled from Schriever Air Force Base (formerly Falcon AFB) in Colorado. It is from there that the SV telemetry and upload functions are commanded. There are five monitor stations (see Figure 5.6), which are situated in the Hawaii Islands in the Pacific Ocean, on Ascension Island in the Atlantic, on Diego Garcia in the Indian Ocean, on Kwajalein Island, again in the Pacific, and at Colorado Springs on mainland US territory. SV orbital parameters are constantly monitored by one or more of the ground tracking stations, which then pass the measured data on to the Master Control Station (MCS) at Schriever. From these figures the MCS predicts the future orbital and operational

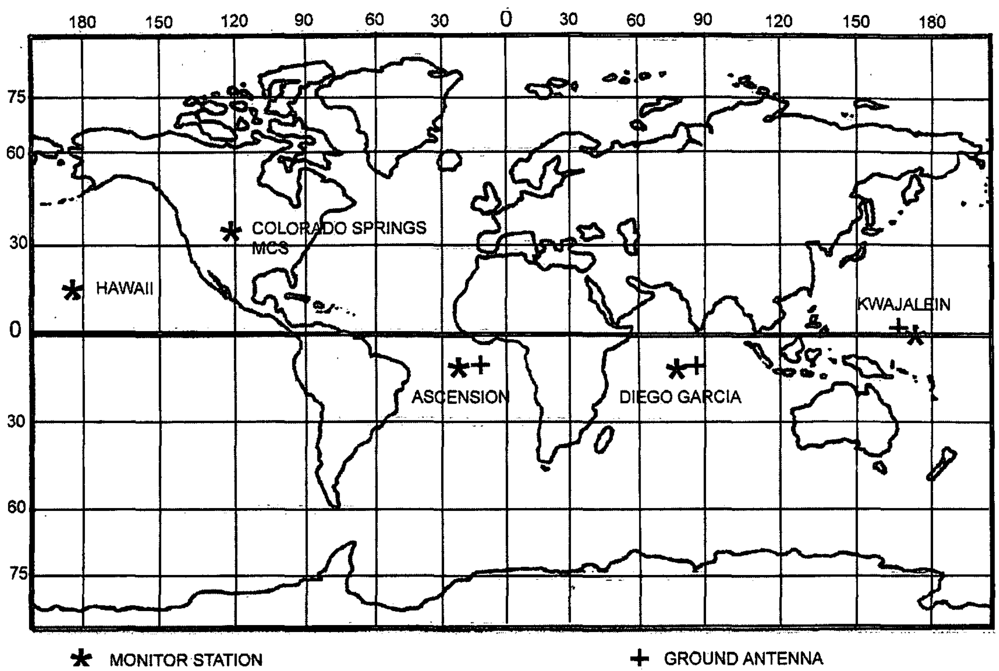


Figure 5.6 GPS control segment stations.

parameters to be fed to the Upload Stations (ULS) on Ascension, Diego Garcia and Kwajalein Islands. All ground station locations have been precisely surveyed with respect to the World Geodetic System 1984 (WGS-84). Data are transmitted to each SV from a ULS, to be held in RAM and sequentially transmitted as a data frame to receiving stations.

Signal parameters

Navigation data are transmitted from the SV on two frequencies in the L band (see Table 5.1). In practice the SV clock is slightly offset to a frequency of 10.229 999 995 45 MHz to allow for the effects of relativity. SV clock accuracy is maintained at better than one part in 10^{12} per day. Dual frequency transmission from the SV ensures that suitably equipped receivers are able to correct for signal delay (range error) caused by the ionosphere. Ionosopheric delays are proportional to $1/f^2$ hence the range error produced will be different on each frequency and can be compensated for in the receiver.

The C/A (Coarse and Acquire) code, see Figure 5.7, is a PRN (pseudo random noise) code stream operating at 1.023 megabits/s and is generated by a 10-bit register. C/A code epoch is achieved every 1 ms (1023 bits) and quadrature phase modulates the L_1 carrier only. This code has been designed to be easily and rapidly acquired by receivers to enable SPS fixing. Each SV transmits a unique C/A code that is matched to the locally generated C/A code in the receiver. A unique PRN is allocated to each SV and is selected from a code series called Gold codes. They are specifically designed to minimize the possibility that a receiver will mistake one code for another and unknowingly access a wrong satellite. Navigation data is modulated onto the L_1 C/A code at a bit rate of 50 Hz.

Table 5.1 SV transmission frequencies

Band	*Derivation (MHz)*	*Frequency (MHz)*	*Wavelength (cm)*	*Code*
L_1	154 × 10.23	1575.42	19	C/A
L_2	120 × 10.23	1227.60	24.5	C/A & P

Both carriers are derived from the SV clock frequency 10.23 MHz

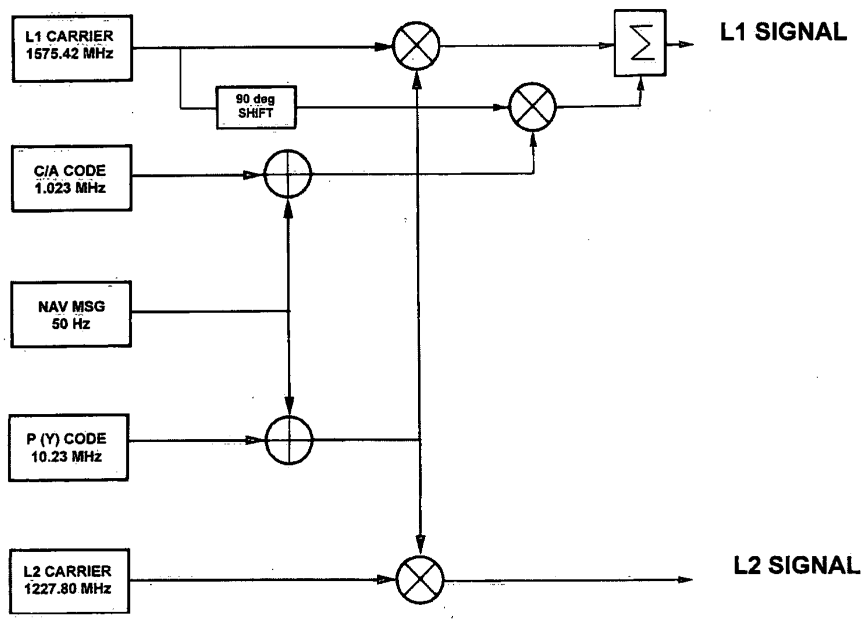


Figure 5.7 Schematic diagram of a SV modulation circuit.

The P (Precise) code, operating at 10.23 MHz, is a PRN code produced as the modulo 2 sum of two 24-bit registers, in the SV, termed X1 and X2. This combination creates a PRN code of 2^{48-1} steps equating to a complete code cycle (before code repetition occurs) of approximately 267 days. Each SV employs a unique and exclusive 7-day long phase segment of this code. At midnight every Saturday, GPS time, the X1 and X2 code generators are reset to their initial state (epoch) to re-initiate the 7-day phase segment at another point along the 267-day PRN code cycle. Without prior knowledge of the code progression, it is not possible to lock into it.

The navigation data message

A 50-Hz navigation message is modulated onto both the P code and C/A codes. One data frame is 1500 bits and takes 30 s to complete at the bit rate of 50 bit s^{-1}. Navigation data are contained in five subframes each of 6 s duration and containing 300 bits. Table 5.2 shows the data format structure.

Table 5.2 Data format structure

Five words 300 bits each with a total of 6 s

	30 bits	*30 bits*	*240 bits*
01	TLM	HOW	Data block 1: Clock correction data. Accuracy and health of the signal.
02	TLM	HOW	Data block 2: Ephemeris data. Precise orbital parameters to enable a receiver to compute the position of an SV.
03	TLM	HOW	Data block 3: Ephemeris. Continued.
04	TLM	HOW	Data block 4: Almanac. Orbital data, low-precision clock data, simple health and configuration status for every SV, user messages, ionosopheric model data and UTC calculations.
05	TLM	HOW	Data block 5. Almanac. Continued.

Subframes 4 and 5 hold low precision data, common to all SVs, and less critical for a satellite to acquire quickly.

As shown in Figure 5.8, each of the five subframes commences with a 14-bit TLM word (telemetry) containing SV status and diagnostic data. This is followed by a 17-bit handover word (HOW). HOW data enables a receiver, which has knowledge of the code encryption, to acquire the P code. Data subframe block 1 contains frequency standard corrective data enabling clock correction to be made in the receiver. Data blocks 2 and 3 hold SV orbit ephemeris data. The two blocks contain such data as orbit eccentricity variations and Keplerian parameters. Message block 4 passes alphanumeric data to the user and is only used when the ULS has a need to pass specific messages. Block 5 is an extensive almanac that includes data on SV health and identity codes.

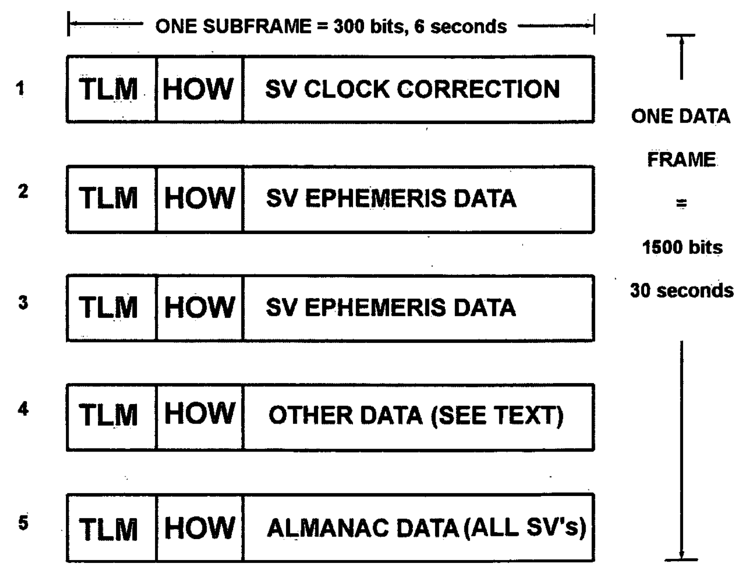


Figure 5.8 Navigation data format.

Table 5.3 Summary of data in a 30-s frame

A	SV orbital parameters
B	SV clock error data
C	Sidereal correction figures
D	Almanac of all operational SVs
E	Polar wander data (Earth axis wander)
F	SV performance status
G	Time of last data inject
H	Data to enable P code acquisition (HOW)
I	Telemetry data (TLM)
J	SV number
K	Specific messages as required (i.e. an indication that an SV is off station)
L	Receiver clock correction data

At the 50-Hz transmission rate, it takes 6 s to download a subframe, 30 s for one data frame (see Table 5.3) and a full 12.5 min to access all 25 frames.

The L_1 signal carrier is BPSK-modulated by both the P and C/A PRN codes and the navigation message. Modulation possesses both in-phase and quadrature components as shown in Figure 5.9.

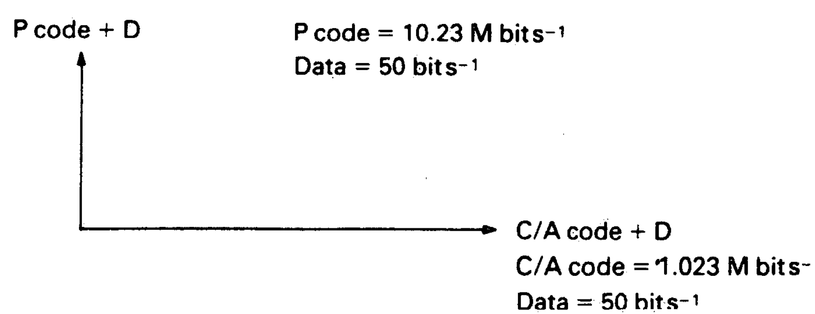


Figure 5.9 Phase relationship between the P and C/A codes.

P code amplitude is –3dB down (half the power level) on the C/A code signal strength, thus the slower C/A code provides a better signal-to-noise ratio at the antenna. This makes the C/A code easier to access. The L_2 carrier is BPSK-modulated by the P code and the navigation message. The use of BPSK modulation causes a symmetrical spread of the code bandwidth around the carrier frequency. The frequency spectrum produced by both P and C/A codes on the L_1 carrier is shown in Figure 5.10. The bandwidth of the C/A code is 2.046 MHz and that of the P code is 20.46 MHz. The C/A code component of the L_1 signal possesses a power of –160 dBW (with respect to 1 watt), the L_1 P code a power of –163 dBW, and the L_2 P code signal has a power level of –166 dBW.

It should be noted that data modulation at 50 bit s^{-1} produces a bandwidth of 100 Hz that is impossible to illustrate on this scale. Signal bandwidth, code matching and data stripping are further explained in the GPS receiver pages later in this chapter.

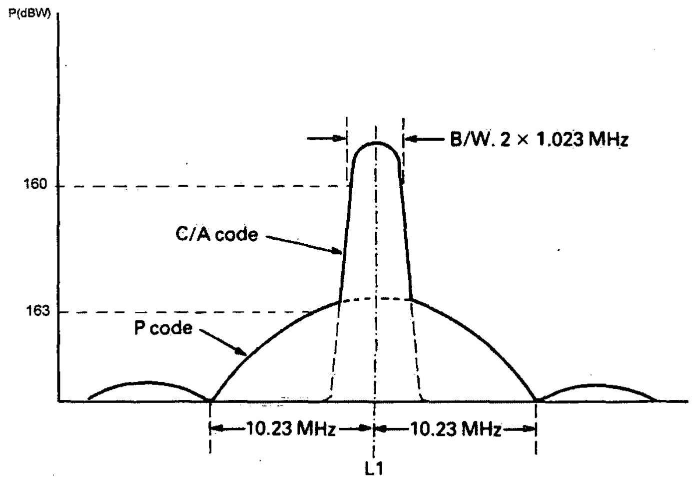


Figure 5.10 Bandwidth power distribution curves for the P and C/A codes.

Frequency stability

SV clock frequency stability is of major importance in any system that relies upon the accurate measurement of range for its operation. Stability is not easy to maintain in an electronic unit that is subjected to constantly varying ambient temperatures. The SV is travelling through a hostile environment where temperatures can vary by as much as 300°C. In addition, at the high altitudes of any SV, there is little protection from the sun's radiation. For these reasons the clock oscillators in SVs are under constant scrutiny

Since the early days of radiocommunication development, oscillator stability has been a major problem and it is one that has been compounded with the need to send clock oscillators into space. Older SVs, such as the Transit and Nova range on which the earlier NNSS sat-nav system was based, used quartz-controlled clock oscillators to give a short-term stability of 10^{-11} with a 24-h change less than 10^{-9}. Timation SVs, the first to provide navigation capability by the calculation of the range between satellite and receiver, carried a quartz clock oscillator with a stability of 1 part in 10^{-11} per day. Timation SVs carried a new frequency standard unit formed by a quartz oscillator locked to an atomic resonance line of rubidium.

The technology used in rubidium and caesium clock oscillators is beyond the scope of this book. However, it should be noted that use of this type of oscillator in NTS1 produced the two transmission signals (UHF and L band) to an accuracy of 1 part in 10^{-12} per day. Caesium/quartz units offer even greater frequency stability and in 1975 the second generation of NTS vehicles was launched into orbit. NTS2 carried a caesium frequency standard unit from which were produced the carrier frequencies (SHF, L_1 and L_2) with an accuracy of 1 part in 10^{-13} per day. These oscillators are still in orbit and still being tested by the armed forces. Caesium clocks, however, require regular updating from the ground and in an effort to further improve and maintain stability for extended periods, clock units using hydrogen maser technology are being considered.

The clock oscillators used in current Navstar SVs are caesium/quartz with rubidium/quartz back-up units.

System time

GPS system time is locked to the Master Clock (MC) at the USNO and further synchronized to UTC from which it will never deviate by more than 1 μs . Actual system time is given by its Composite Clock (CC) or, as it is often called a 'paper' clock, which had its epoch at 0000 UTC on 17 June 1990. Information about the GPS time difference and rate of system time against UTC (USNO) is contained in the navigation message transmitted to all users. Once a satellite has been accessed the user equipment clock is corrected.

5.4 The position fix

The GPS provides two levels of service known as Precise Positioning Service (PPS) and Standard Positioning Service (SPS), the accuracy of which were defined in the 1994 US Federal Radionavigation Plan. The PPS predictable accuracy is given in Table 5.4.

Table 5.4 PPS predictable accuracy

Horizontal accuracy	21 m
Vertical accuracy	27.7 m
Time transfer accuracy	197 ns

Based on a 95% Rayleigh distribution probability

PPS fixes are based on range measurement and the acquiring and integrating of the C/A code and the complex P code transmitted on both the L_1 and L_2 carrier frequencies. The method provides highly accurate positioning, timing and velocity figures for users authorized by the US Government. PPS users were generally the US military, government agencies and approved allied forces, but since 1 May 2000, when selective availability was ended, PPS fix accuracy is available to anyone with suitable equipment.

Selective availability (SA) was the name given to a process employed by the US Department of Defence to deny PPS accuracy to civilian users. SA was applied by offsetting SV clock frequency (dithering), and/or manipulating navigation orbit data (epsilon). To guard against the fake transmission of SV data, a system called anti-spoofing (A-S) was used whereby the P code was encrypted becoming the Y code. By Presidential order, on 1 May 2000, the US Government ceased to apply SA to the GPS and thus there is now little difference between SPS and PPS fix accuracy (see Table 5.5).

Table 5.5 SPS predictable accuracy

	Prior to 1 May 2000	*Subsequent to 1 May 2000*
Horizontal error	100 m	25 m
Vertical error	156 m	30 m
Time transfer error	340 ns	200 ns

Based on a 95% Rayleigh distribution probability
Note: On 1 May 2000, Selective Availablity (S/A) was set to zero and SPS accuracy was thus improved by a factor of almost 10. The figures in column 3 are an approximation.

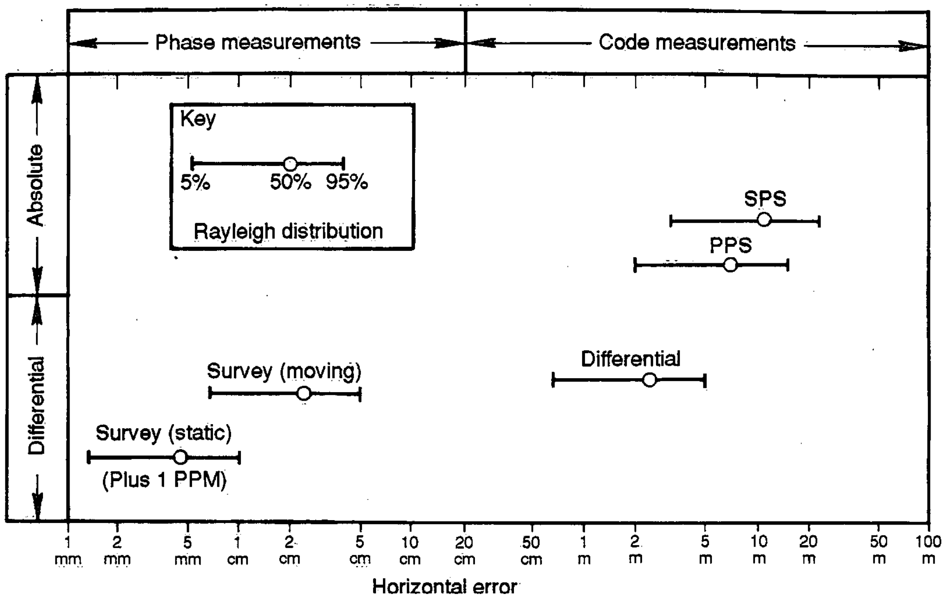


Figure 5.11 Levels of GPS accuracy. (Reproduced courtesy of Magnavox.)

The decision to remove SA from the GPS was taken because it would have minimal impact on national security. Based on threat assessment analysis, it is possible for the US Government to selectively deny GPS signals on a regional basis if national security is threatened.

SPS fixes are based on acquiring and integrating the C/A code data transmitted on the L_1 carrier frequency, measuring ranges and decoding the navigation message. SPS fix accuracy can be extensively improved by using Differential GPS (see Figure 5.11). Data is received, at both a mobile and a ground station, from multiple SVs and, after the computation of correction figures at the fixed station, is retransmitted to the mobile receiver. The process is achieved in real time although because of the relatively short distances travelled by a ship between fixes it is possible to apply corrections to subsequent computations.

The upper part of Figure 5.11 shows the anticipated levels of accuracy of a standard position fix without the aid of differential techniques, whereas the lower half shows fix accuracy for receivers with a differential input. It also demonstrates that the use of phase measurement in addition to code measurement improves the fix still further. All fix lines are shown as Rayleigh distribution data.

GPS position fixes are achieved by the precise measurement of the distance between a number of SVs and a receiver at an instant in time and/or by phase measurement. It is possible for a receiver, with a precise clock and with a knowledge of altitude above the earth reference spheroid, to fix its position in three dimensions by interrogating a minimum of three SVs. But in practice, modern equipment provides for more precise position fixing using the data from four or more SVs. By interrogating multiple SVs it is possible to obtain accurate fixes in three dimensions (XYZ) plus time. All fixes computed by a receiver are known as earth-centred-earth-fixed (ECEF) locations and therefore navigation fixes are often quoted as ECEF XYZ positions.

To measure the precise distance between the transmitter and the receiver requires highly accurate time clocks in both vehicles. The satellite clock is monitored from the ground and is corrected by atomic standard time. During calculations, it is accepted therefore, that this clock, which is used to generate the transmission frequencies, is accurate and the receiver clock may be in error.

For this reason range measurements are termed false or 'pseudo-ranges', and must be corrected in the receiver. The pseudo-range measurement for a receiver with an imprecise clock is given as:

$$PsR = Rt + C\Delta td + C(\Delta tu - \Delta ts)$$

where range figures are in metres and time in seconds, PsR = pseudo-range between satellite and receiver, Rt = true range, C = speed of light (3×10^8 ms^{-1}), Δts = satellite clock error from GPS time, Δtu = receiver clock error from GPS time, and Δtd = propagation delays due to both the ionosphere and the troposphere.

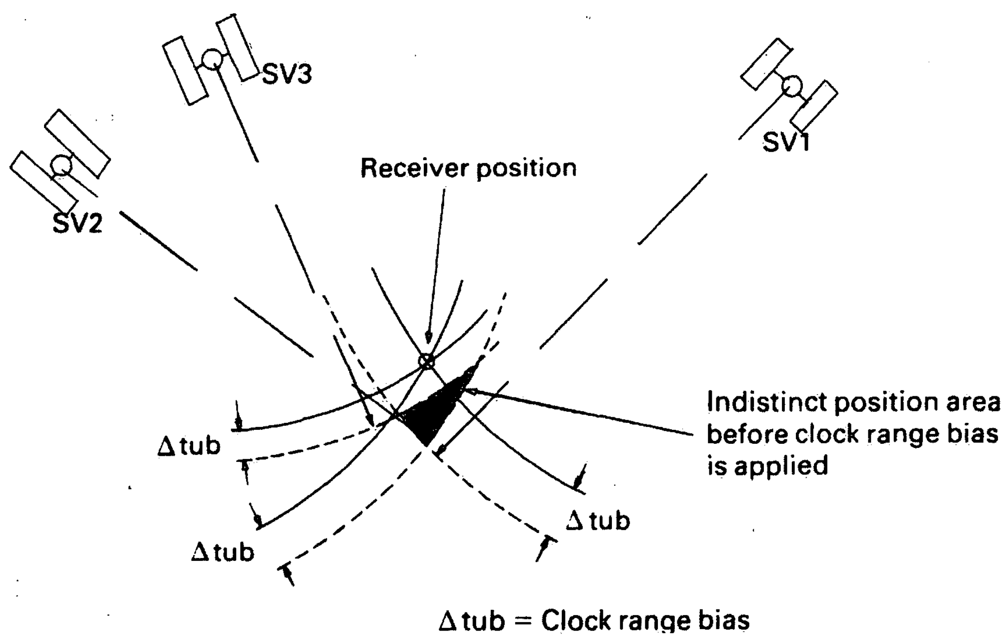


Figure 5.12 Showing the indistinct position fix obtained from three SVs before clock range bias is applied.

The GPS receiver calculates the pseudo-range time taken for the transmission by measuring the phase shift of the P code and comparing it with a locally generated code in the receiver computer. Figure 5.12 illustrates that the pseudo-ranges calculated for three satellites will not converge at a specific point unless the receiver clock error is corrected.

The computed position in XYZ co-ordinates is converted as a function of the receiver algorithm to geodetic latitude, longitude and altitude above the reference ellipsoid. The ship's position is solved with reference to Cartesian co-ordinates as shown in Figure 5.13 with reference to a minimum of three celestial 'fixed' points (the SVs).

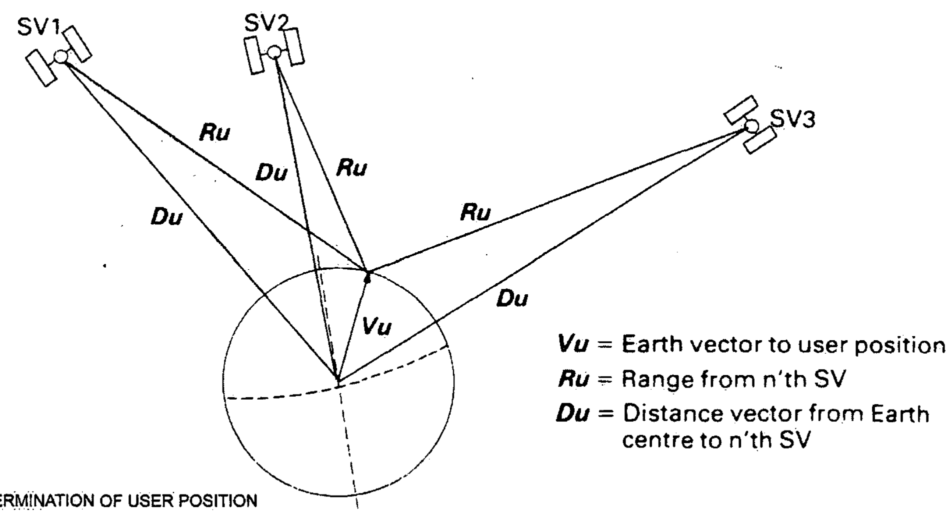


Figure 5.13 Using Cartesian co-ordinates to determine an earth centred position fix.

5.5 Dilution of Precision (DOP)

Dilution of Precision (DOP) is a term used for expressing the mathematical quality of a solution. DOP can exist in one dimension only. Examples are; time DOP (TDOP); horizontal DOP; vertical DOP and geometric DOP, referring to SV geometry. But it is the position dilution of precision, PDOP, that is of most value to a navigator. PDOP in the GPS has an optimum value of unity. If the figure is higher the solution is degraded (diluted). The PDOP will approach unity when a solution is made with a satellite overhead and three other satellites evenly spaced at low elevation angles. Alternatively, if all satellites are in the same plane, PDOP would be near infinity and the navigation fix solution would be unsound. The PDOP figure has a direct bearing on user range error (URE). For example, for a URE of 50 m and a PDOP of unity, the best fix accuracy is 50 m. If the PDOP is 2, the accuracy drops to 100 m. Modern GPS receivers may be programmed to reject a position solution if the PDOP level is high.

The geometry of the satellite orbital cage can seriously affect the accuracy of a position fix. With 24 satellites in six orbits there is a better than average chance that as many as six will be in view of a receiver at any given time. When pseudo-ranges are measured from SVs that are close together in the sky (Figure 5.14(a)), the result is an enlarged area of improbability resulting in a bad GDOP, as shown above. Alternatively if the SVs are well spaced, the improbability area will be smaller. Modern GPS receivers pick the optimum SVs from those available before correcting timing errors.

5.6 Satellite pass predictions

The system is so well documented and controlled that it has become increasingly easy to predict satellite passes at a given location. Trimble Navigation Limited, one of the biggest manufacturers of GPS equipment, operates a world wide web site that will be of interest to students. It is called GPS Mission Planning and is accessed on http://www.trimble.com/cgi/satview.cgi. It is also interactive and

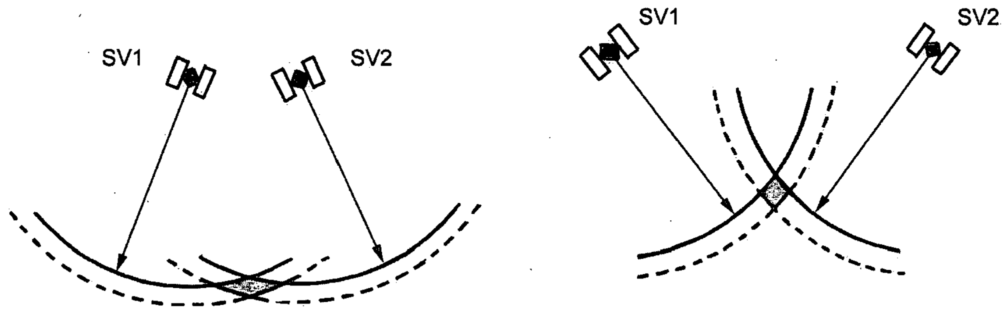


Figure 5.14 Fix accuracy can be improved by selecting appropriate SVs. (a) Two SVs giving a poor GDOP and (b) two SVs providing a much better solution.

provides six different charts of predictions. User parameters for all the plots are input into boxes as shown below. Latitudes south of the equator and longitudes west of the Greenwich Meridian are identified with a minus sign. The time input in GMT is in two figures between 00 and 23.

Using this system it is easy to predict SV passes at a given location and consequently it is simple to select the appropriate SVs to give a good GDOP.

Latitude:	32.43	Date:	00–00–2000
Longitude:	–117.10	Starting hour GMT:	00 hours
Mask:	15.0 degs.	Duration:	4 hours

The six plots are as follows.

- *Azimuth Plot.* Use this plot to locate SVs with optimum azimuth angle for a given location.
- *DOP Plot.* A low DOP indicates a high probability of accuracy, whereas a high DOP shows a low probability. The plot shown in Figure 5.15 is the result of calculations evaluating the geometry of four available SVs that will provide the most accurate fix. The plot has three data lines corresponding to HDOP, VDOP and PDOP predictions.
- *Elevation Plot.* This plot (Figure 5.16) shows the paths of all the satellites in view for a specified time period at a specific location. An SV reaching an elevation of 90° will pass directly overhead.
- *Sky Plot.* This plot (Figure 5.17) is oriented so that the GPS receiver is in the centre of concentric rings spaced at 15° intervals. The outer ring represents the horizon. Using this plot it is easy to see if a SV could suffer signal block from buildings or trees because it is low on the horizon.
- *Total-in-View Plot.* This is a graph showing the total SVs in view over a specified elevation angle. It is particularly useful for checking if sufficient satellites will be in view to make a good fix.
- *Visibility Periods Plot.* Another form of presentation showing the time periods when satellites will be in view above the angle of elevation specified.

5.7 System errors

Errors in any system arise from a number of sources. They can be predictable or not and avoidable or not. The GPS is no exception. If suffers from error-inducing factors which will downgrade its

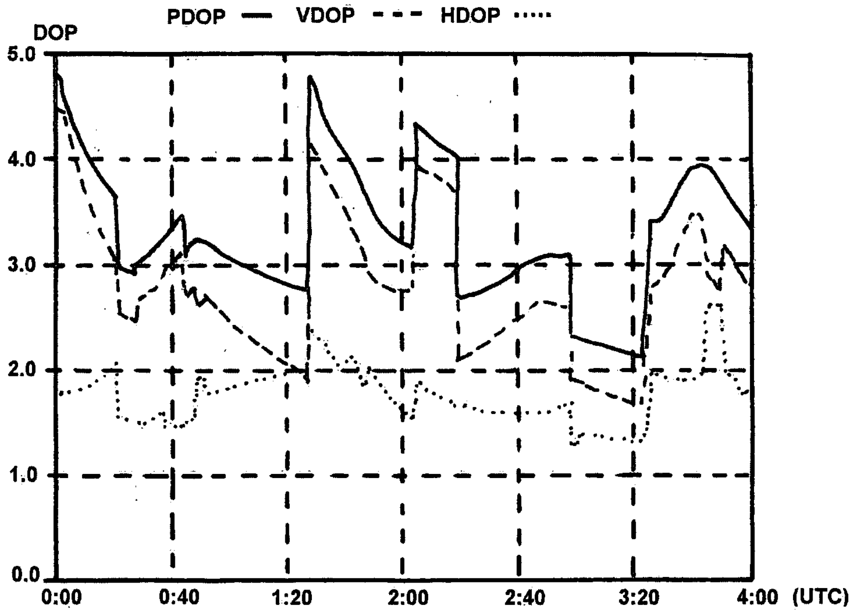


Figure 5.15 Trimble mission planning DOP graph taken over 4 hours. A low DOP indicates a high level of accuracy.

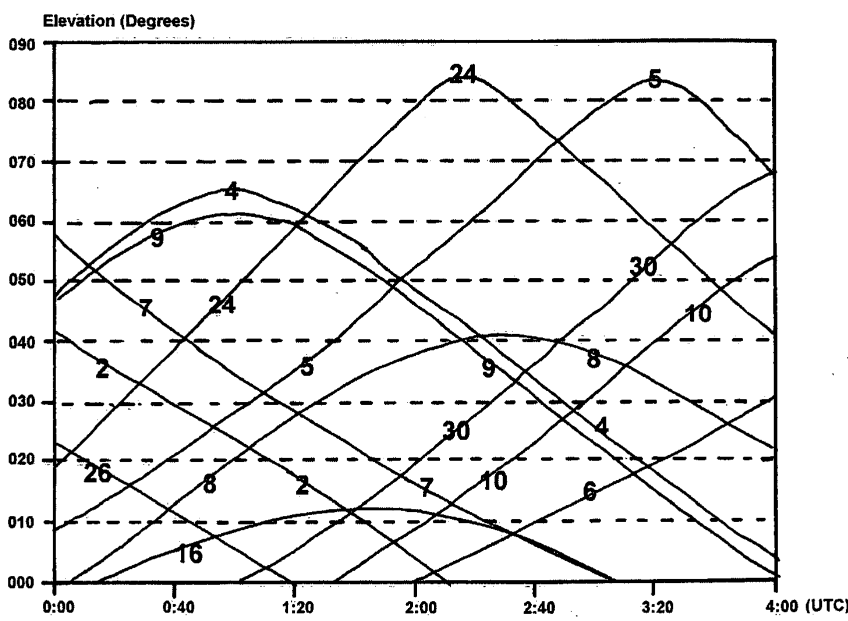


Figure 5.16 Trimble SV elevation plot. A 4-h plot showing all SVs in view.

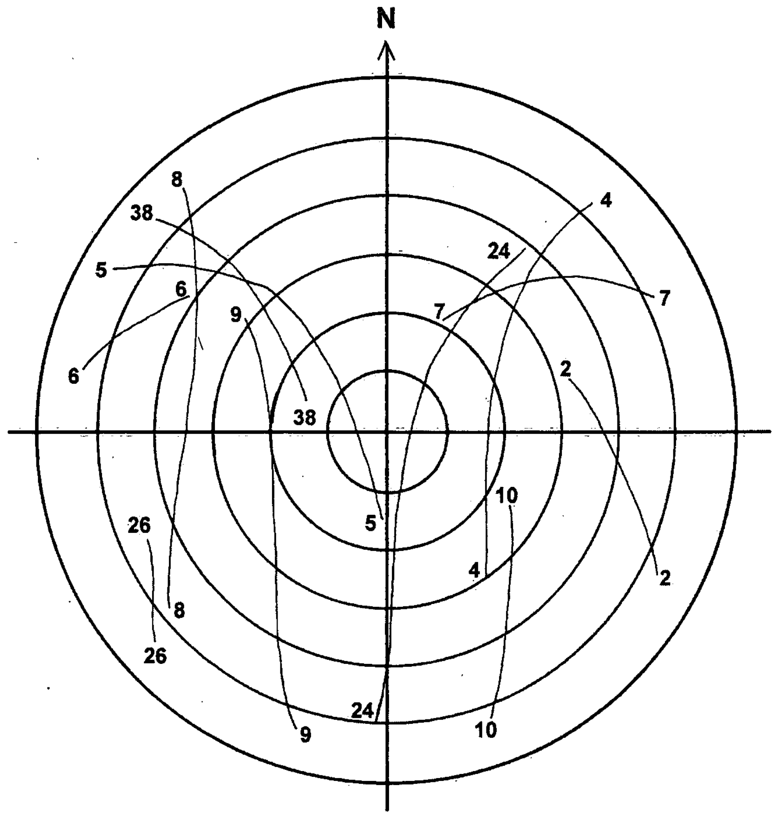


Figure 5.17 Trimble SV sky plot presentation. A GPS receiver is in the centre of concentric circles. The outer ring represents the horizon or zero elevation.

performance as a position fixing system. However, the total error produced by a combination of all error-producing factors is very small. Assuming that the system is free from operator error (corrupt data inputting), the error most likely to downgrade system accuracy is an error in the SV clock, which in turn will cause range measurement error.

GPS accuracy is promulgated in a number of ways as indicated below.

- *Circular Error Probable (CEP).* This represents an accuracy figure achievable 50% of the time in two dimensions only. This is a fix error in latitude and longitude.
- *Spherical Error Probable (SEP).* An accuracy that is achievable 50% of the time in all three dimensions.
- *Root Mean Square Radial Distance error (d_{RMS}).* A circle around the true position containing 95% of the fix calculations.
- *User Equivalent Range Error (UERE).* This is determined by summing the squares of the individual range errors and then taking the square root of the total.

The following errors affect the accuracy of GPS position fixes.

Satellite clock error

It has already been stated that a satellite clock oscillator is a precision instrument, but it is still necessary to re-adjust it from the ground support network. Error introduced by SV clock error is unlikely to exceed 1 m and regular uplinking of clock data reduces it to a minimum. Block IIA and Block IIR satellites, the latest SVs, carry better clock oscillators and will consequently provide higher accuracy fixes.

Ionospheric delay error

As the two transmitted carriers must pass through the ionosphere, a speed reduction caused by refraction of the radio wave occurs. The extent of the delay, and consequently the error introduced into the pseudo-range measurement calculation, is dependent upon the electron density the radio wave encounters along the signal path. Electron density is itself dependent upon three main factors:

- the time of day
- the SV elevation
- the latitude of the receiver.

Fortunately, ionospheric error is inversely proportional to the square of the carrier frequency. GPS SVs transmit on two frequencies so that the delay may be quantified in the receiver, an error correction figure calculated and applied to the final fix solution. After all corrective data has been applied to the solution in a single frequency GPS receiver system, fix error due to the ionosphere is unlikely to exceed 10 m.

Tropospheric delay error

Extending from the earth's surface to an altitude of 70 km, the troposphere also introduces a delay into the pseudo-range calculation. Unfortunately the error is independent of frequency, but it is predictable. GPS receivers hold a software solution in the form of a mathematical model to eliminate the effect of this delay. Figures for relative humidity, pressure and temperature are interfaced with the processor computer to produce corrective data which is then applied to fix calculation. Error from this source is unlikely to exceed 1 m.

Both ionospheric and tropospheric errors are reduced if ranges are measured from SVs showing a high elevation from the receiver. Modern receivers are capable of automatically selecting SVs with the highest elevation or those exceeding pre-set limits.

Multipath error

This results from the reception of the same SV signal from more than one source. A major contributor to this error is the reflected wave from an object close to the receiving antenna. Each receiver position is unique and therefore the error is not consistent. Final fix errors in the region of 1 metre can be produced by this effect. Careful positioning of the antenna will eliminate this error.

Relativity error

A commonly referred error is that produced by the effects of relativity. It is entirely predictable and is effectively cancelled in the GPS but it is briefly described here.

Albert Einstein stated that time is compressed by the mass of the earth. Time on the surface of the globe is compressed by $1.4 \times 10^{-9}\,ms^{-2}$ compared to time in free space. It is evident that as one travels further away from the earth's surface towards free space, the compression of time is of less significance. At the altitude of a GPS SV, time compression is calculated to be $0.4 \times 10^{-9}\,ms^{-2}$. An effective rate range time error of 1 ns therefore exists between the time on board the SV and that in the receiver. At the accepted propagation velocity of radio waves, i.e. $300 \times 10^{6}\,ms^{-1}$, an error of 1 ns corresponds to a range error of 0.3 m. In addition, a second time error is produced by time compression caused as the SV moves at $26.61\,kms^{-1}$ through space. To compensate for all relativity errors, the SV clock oscillator frequency is slightly offset. By the time that the radio wave arrives at the receiving antenna the effects of relativity will have been cancelled and the pseudo-range can be more accurately calculated.

These are by no means the only factors that affect the accuracy of the GPS system but they are often referred to in papers on this subject. A combined position error produced by all the above factors is unlikely to exceed 12 m.

User Range Error (URE)

This is a parameter for the estimated error in range calculation due to unknown factors. These include multipath, unmodelled atmospheric effects, operator error and unpredictable orbital errors. The URE figure is sent from SVs to GPS receivers and may be displayed in metres.

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.

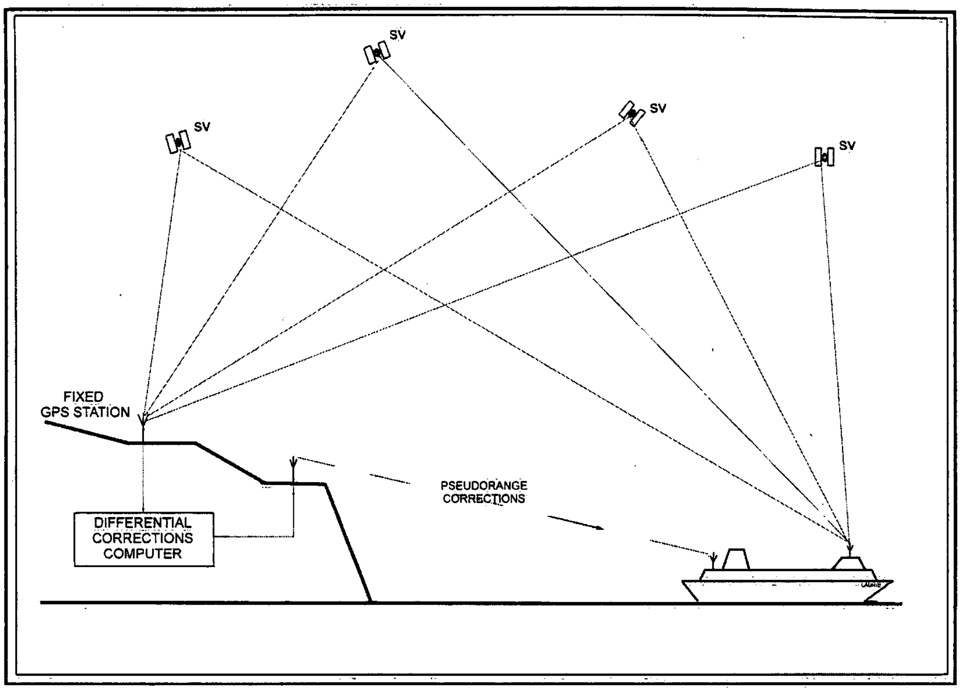


Figure 5.18 Principle of operation of DGPS.

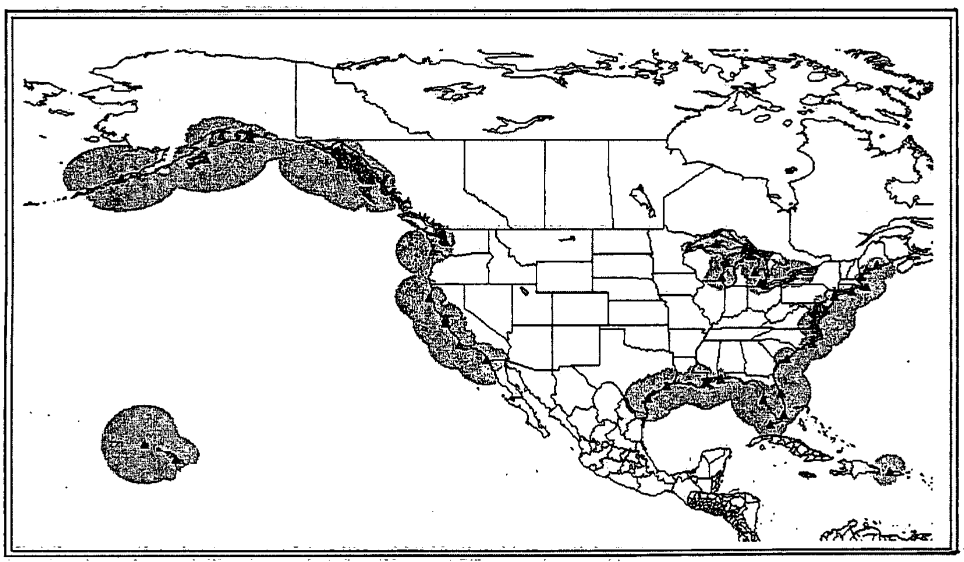


Figure 5.19 Maritime DGPS coverage of the United States. (Reproduced courtesy of the United States Coast Guard.)

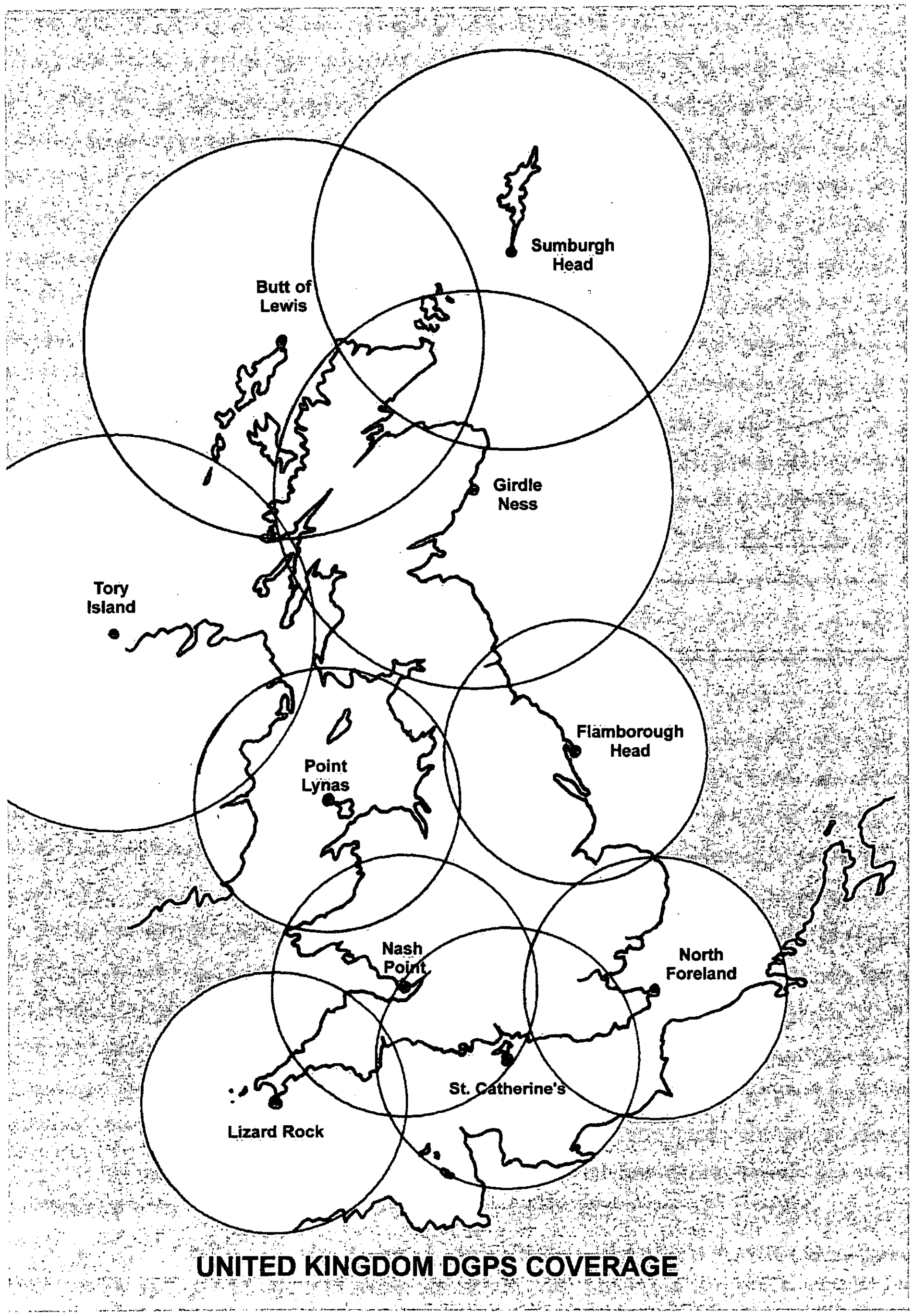


Figure 5.20 DGPS coverage of the UK coastline.

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.

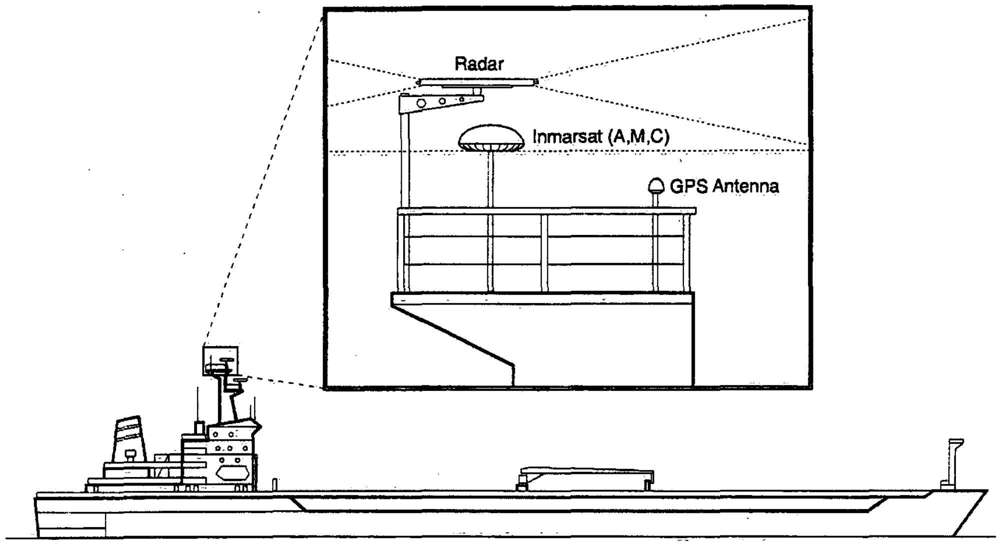


Figure 5.21 A GPS antenna mounted below other microwave system antennas on the superstructure of a merchant vessel. (Reproduced courtesy of Trimble Navigation Ltd.)

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.

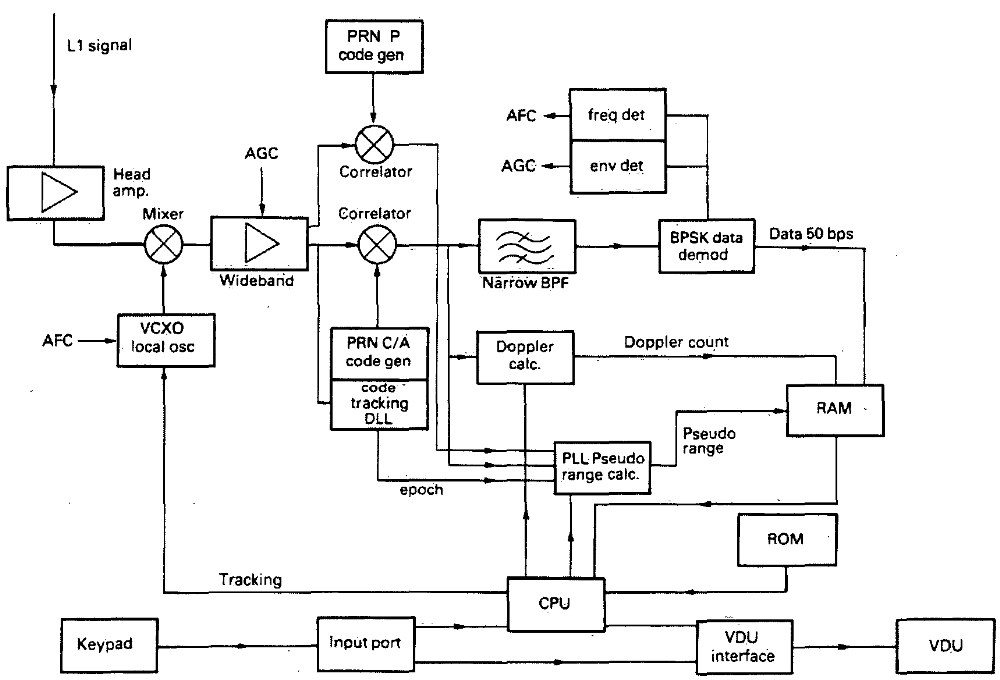


Figure 5.22 A generic GPS receiver system.

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

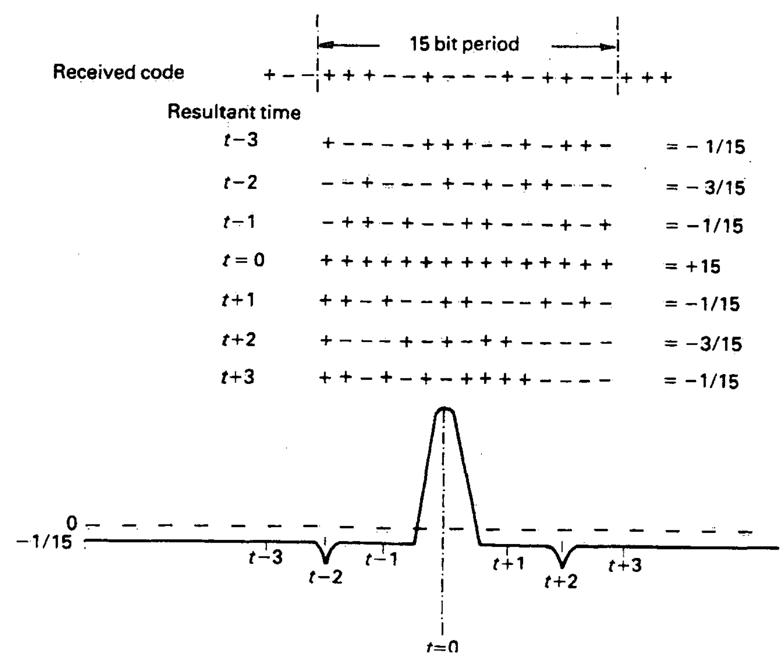


Figure 5.23 Autocorrelation function of a random waveform.

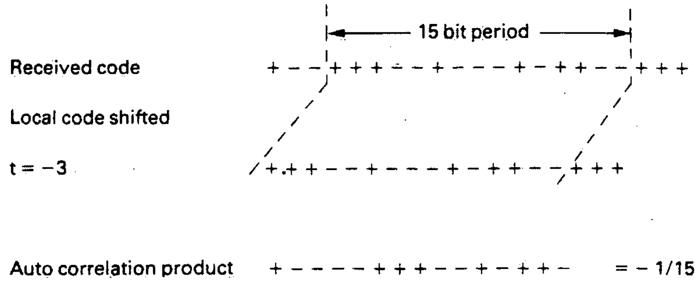


Figure 5.24 The autocorrelation product of a random waveform.

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.

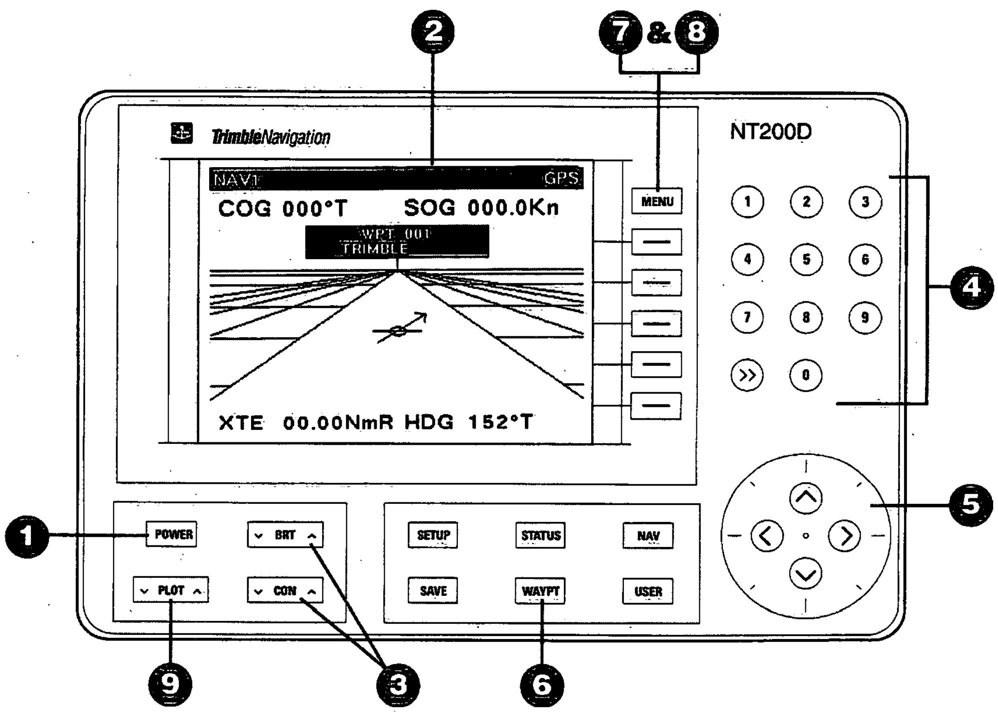


Figure 5.25 The NT200D GPS receiver displaying the NAV1 navigation display. (Reproduced courtesy of Trimble Navigation Ltd.)

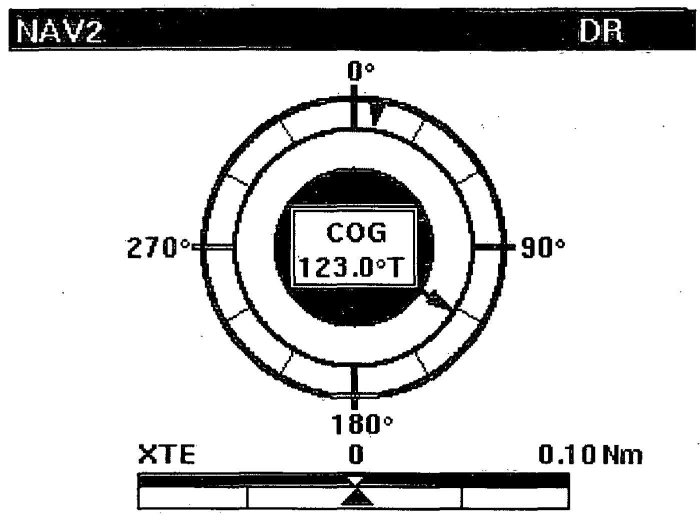


Figure 5.26 NAV 2 display. (Reproduced courtesy of Trimble Navigation Ltd.)

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

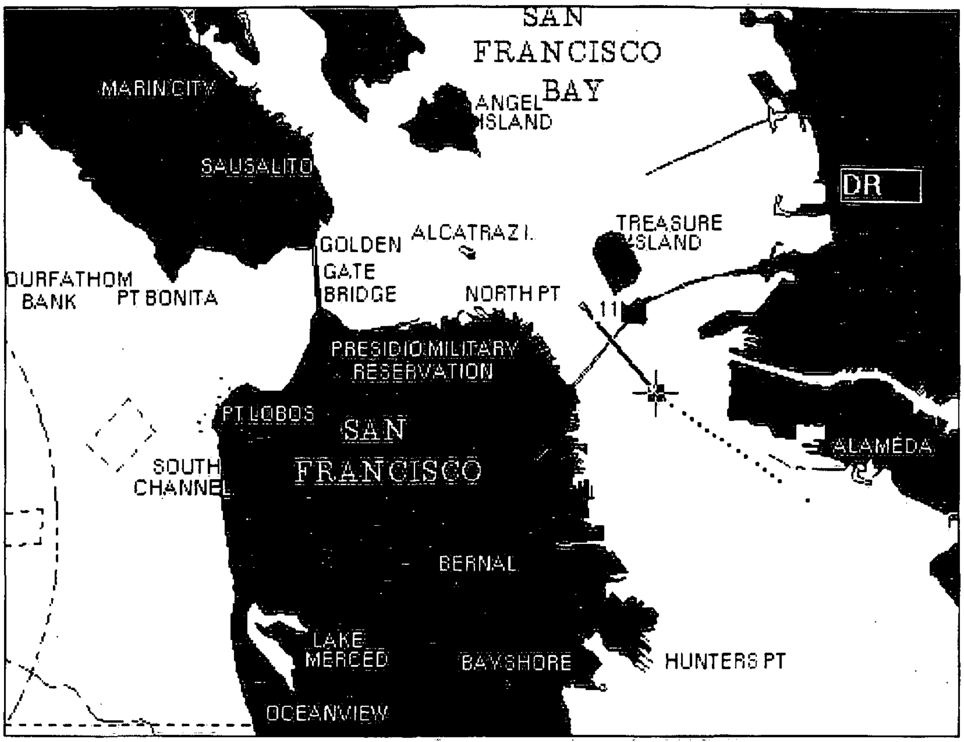


Figure 5.27 Chart display of San Francisco Bay and approaches using data input from a smart card. (Reproduced courtesy of Trimble Navigation Ltd.)

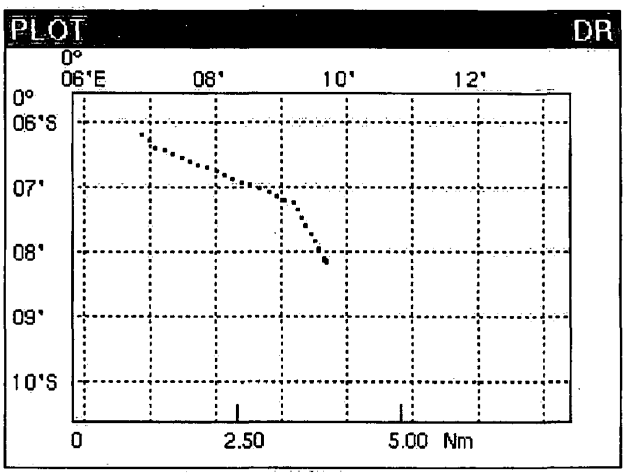
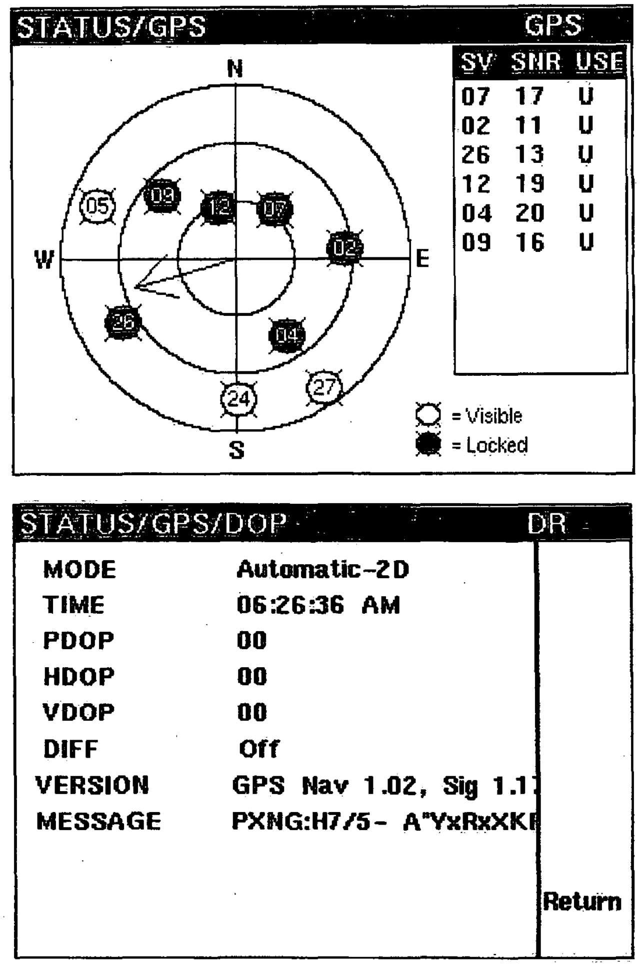


Figure 5.28 The Mercator grid plot screen display of the GPS receiver DR track. The vessel's current position is indicated by a flashing icon in the centre of the screen. (Reproduced courtesy of Trimble Navigation Ltd.)



(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.

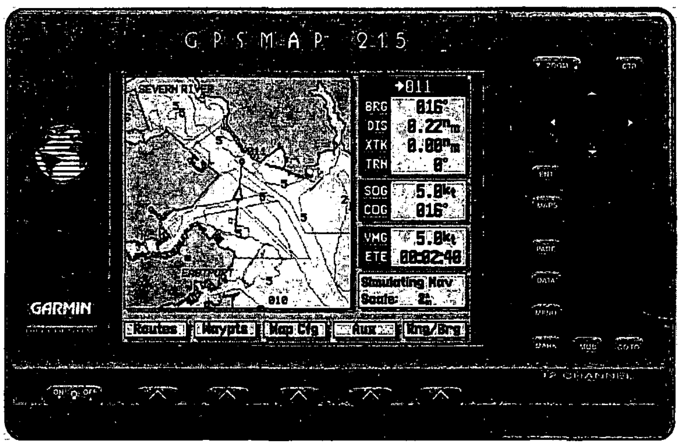


Figure 5.30 Front panel of the Garmin GPSMAP 225 system showing operator controls and a sample navigation map generated in the simulation mode. (Reproduced courtesy of Garmin.)

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.

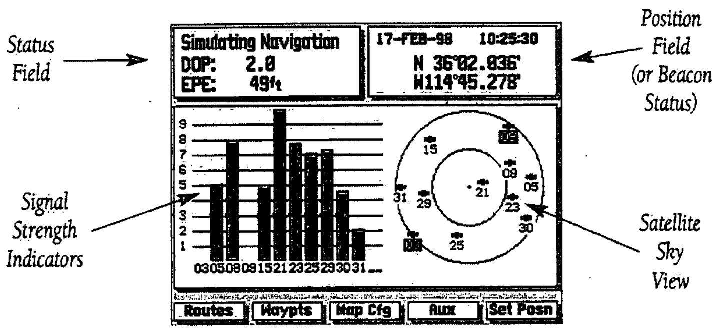


Figure 5.31 The satellite status display of the Garmin GPSMAP 225 system.

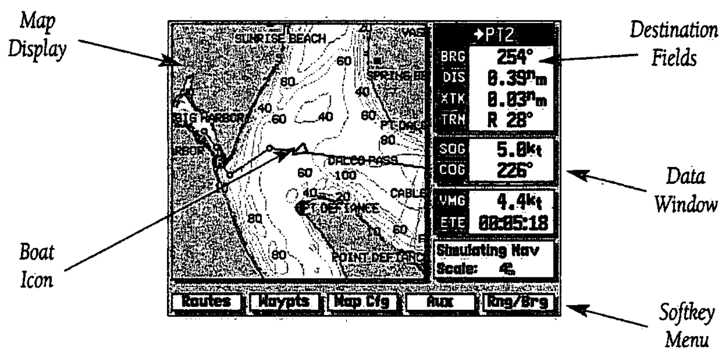


Figure 5.32 The MAP page, the main navigation display of the Garmin GPSMAP 225 system showing own vessel and track.

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),

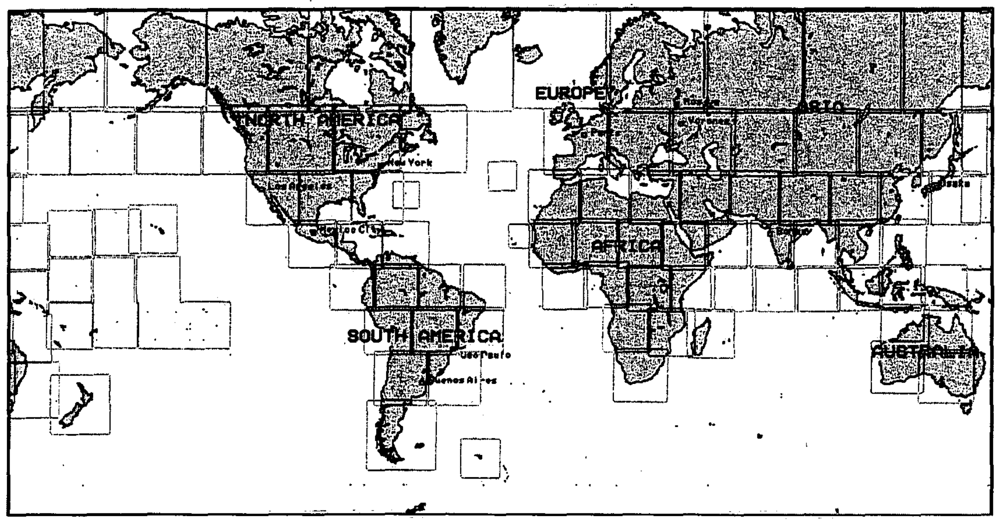


Figure 5.33 Global coverage chart showing the Garmin GPSMAP's built-in database for chart coverage down to 64 nautical miles.

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.

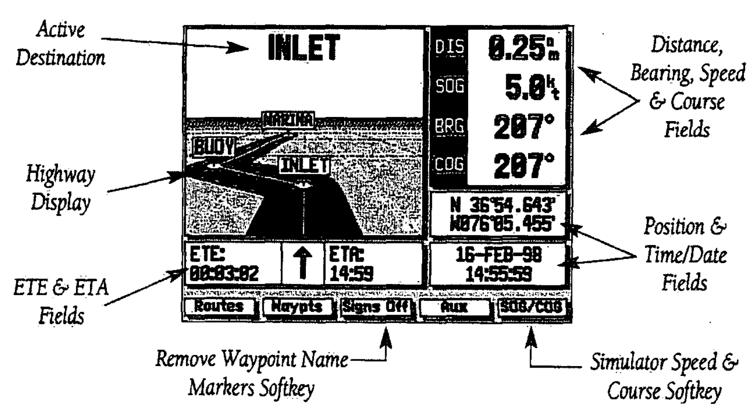


Figure 5.34 A sample Highway page of the Garmin GPSMAP 225 system used when navigating a route to an active waypoint.

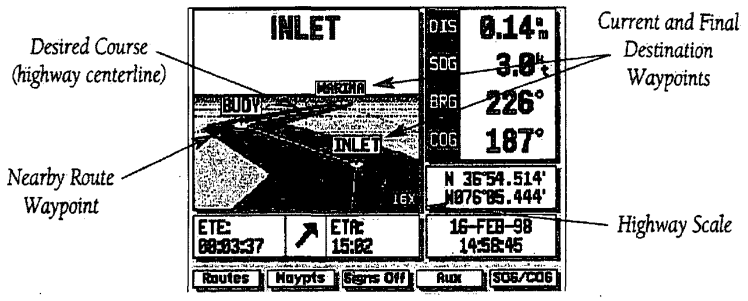


Figure 5.35 A sample Highway page of the Garmin GPSMAP 225 system used when navigating a route to an active waypoint.

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 MHz
L2 = 1242.9375 + 0.4375 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.

5.16 Glossary

Almanac data	Satellite constellation information including location and health status.
Apogee	The furthest point away from the earth reached by a satellite in orbit.
Azimuth	The direction vector drawn to a satellite from a fixed point on earth.
BNM	USCG Broadcast Notice to Navigators.
BPSK	Bi-phase shift keying.
BRG	Bearing.
C/A code	Coarse/Acquire code. A PRN code operating at 1.023 Mbit s^{-1}
CEP	Circular area probable. An accuracy figure achievable for 50% of the time in two dimensions; latitude and longitude.
COG	Course over ground.
CSOC	Consolidated Space Operations Centre.
dB	A unit for measuring power in a communications system.
DTK	Desired track. The compass course between the start and finish waypoints.
DGPS	Differential GPS. A method to improve the accuracy of a GPS fix by the use of corrective data transmitted on medium frequency to coastal shipping.
DMA	US Defence Mapping Agency.
DoD	US Department of Defence.
DOP	Dilution of Precision. A term used for expressing the mathematical quality of a solution.
d_{RMS}	A circle around the true position containing 95% of the fix calculations.
ECEF	Earth-centred-earth-fix. A GPS fix solution is quoted in ECEF co-ordinates.
EPE	Estimated position error.
ETA	Estimated time of arrival.
ETE	Estimated time en route. The time remaining to a destination.
FAA	US Federal Aviation Authority.
GDOP	Geometric dilution of precision. A measure of the quality of a solution.
GLONASS	Global Orbiting Navigation Satellite System. The Russian Federation system.
GMT	Greenwich mean time. Often referred to as Zulu.
GNSS	Global Navigation Satellite System.
GPS	Global Positioning System.
Ground speed	The vessel's velocity referenced to the ocean floor.
HDOP	Horizontal dilution of position. A measure of the quality of a solution in terms of latitude/longitude.
Inclination	The angle formed between the eastern end of the equatorial plane and a satellite orbit. For GPS orbits it is 55°.
Kepler's laws	Satellites in orbit follow an ellipse as defined by Johannes Kepler.
L_1	The GPS primary transmission frequency; 1575.42 MHz.

L_2	The GPS secondary transmission frequency; 1227.6 MHz.
MCS	The GPS Master Control Station situated at Colorado Springs.
NMEA	National Maritime Electronics Association. An organization of manufacturers and distributors responsible for agreeing the standards of interfacing between various electronic shipboard systems.
NOTAM	FAA's Notice to Airmen regarding GPS service interruption.
P code	Precision code. A PRN code operating at 10.23 MHz.
PDOP	Precision dilution of position.
Perigee	The closest point of approach to the earth reached by an orbiting satellite.
PPS	GPS Precise Positioning Service.
PRN	Pseudo-random noise.
RTCM	Radio Technical Commission for Maritime Services.
SEP	An accuracy that is achievable 50% of the time in all dimensions.
SOG	Speed over ground.
SPS	GPS Standard Positioning Service.
SV	Space vehicle – a satellite.
TDOP	Time dilution of precision.
TTFF	Time to first fix. Used to identify how long a GPS receiver takes before a fix is available.
TTSF	Time to subsequent fix.
TRN	Turn.
URE	User range error.
UERE	User equivalent range error. Determined by summing the squares of the individual range errors and then taking the square root of the total.
USCG	United States Coast Guard.
USNS	United States NOTAM Service.
ULS	Satellite uplink station.
UTC	Universal time co-ordinated.
UTM	Universal transverse mercator. A grid co-ordinate system that projects global sections onto a flat surface.
VDOP	Vertical dilution of precision.
VMG	Velocity made good.
WADGPS	Wide area differential GPS. An experimental system for improving the accuracy of GPS fixes globally.
WGS-84	World Geodetic Survey 1984.
XDOP	Cross-track dilution of precision.
XTE	Cross-track error.

5.17 Summary

- The GPS has replaced the Navy Navigation Satellite System (NNSS).
- Satellites, called space vehicles (SVs), follow elliptical orbits conforming to Kepler's laws of astrophysics.
- The GPS, occasionally called NAVSTAR, has three segments: Space, Control and User.
- There are 24 operational SVs, four in each of six orbital planes inclined at 55°.
- SVs orbit the earth at an altitude of 20 200 km and possess an approximate 12-h orbital period.

- SVs transmit two codes to enable receivers to acquire the signal. The Coarse and Acquire (C/A) code is a pseudo-random noise (PRN) code stream operating at 1.023 Mbit s^{-1}. The precise (P) code is also a PRN stream operating at the faster rate of 10.23 MHz.
- The C/A code epochs every 1 ms and has been designed to be easily acquired while the P code has an epoch every 267 days and is difficult to acquire.
- Navigation data is transmitted at 50 bit s^{-1} and is modulated onto both codes.
- The L_1 signal carrier frequency (1575.42 MHz) is modulated with the C/A code, the P code and the navigation message, whilst the L_2 carrier carries only the P code and the navigation message.
- There are two levels of fix available. The Precise Positioning Service (PPS) and the Standard Positioning Service (SPS). Until May 2000 the SPS was downgraded by a factor of 10, but on that date downgrading, called Selective Availability, was removed and now SPS and the PPS fixes have virtually the same accuracy.
- GPS position fixes are achieved by the precise measurement of the distance between a number of SVs and a receiver at an instant in time and/or by phase measurement. It is assumed that the receiver clock is in error and therefore the range measured is called a pseudo-range (false range). The receiver processor corrects the range measurement to produce a precise fix.
- The fix, in XYZ co-ordinates (latitude/longitude and altitude) is converted to earth-centred co-ordinates called ECEF (earth-centred-earth-fix).
- Dilution of precision (DOP) is the term used for expressing the mathematical quality of a fix solution. TDOP, HDOP, VDOP, and PDOP are also used in the GPS.
- System errors may cause an imprecise fix. Fix error and thus GPS accuracy is quoted using one of the figures CEP, SEP, d_{RMS} and UERE.
- Differential GPS (DGPS) is a system whereby SV signals are received at a fixed location, errors are corrected and the new data is transmitted on MF to vessels in the local area.
- GPS uses an active antenna with a ground plane to reduced the effect of reflected signals.
- There is a huge range of GPS equipment available ranging from simple hand-held units to sophisticated dual-channel systems used for survey purposes.
- The Russian Federation's satellite navigation system, GLONASS, is operational but is not compatible with GPS.

5.18 Revision questions

1. What are the basic principles of Kepler's laws of astrophysics?
2. How are the orbital period and the velocity of a space vehicle (SV) related?
3. How many SVs are used in a full GPS constellation and how many are there in each orbital plane?
4. What are the GPS transmission frequencies?
5. Why do Navstar SVs transmit on two frequencies?
6. How long does it take an SV to transmit an entire navigation data message of 25 frames?
7. The GPS uses two codes, the P code and the C/A code, for encryption purposes. Why is this?
8. Why is the P code more difficult for a receiver to lock onto than the C/A code?
9. Why is it essential to maintain SV transmit frequency stability?
10. PPS fixes require the use of more complex receiving equipment. Why is this?
11. What is a pseudo-range measurement?
12. How does the choice of SVs used for a fix affect the PDOP?
13. What is ECEF XYZ?
14. Which of the error-inducing factors is likely to introduce the largest error?

15 How is the figure for UERE derived?
16 The use of DGPS offers improved fix accuracy. Over what range would you expect to receive DGPS data?
17 Why does a GPS antenna need a ground plane?
18 Why is the C/A code generated (or held in memory) in a receiver and applied to the correlator?
19 Autocorrelation is used in the signal processing stages of a GPS receiver. Why is this?
20 The Russian Federation satellite navigation system, GLONASS, offers similar features and accuracy of position fixing to the GPS. Are the two systems compatible?

Chapter 6
Integrated bridge systems

6.1 Introduction

The 20th century saw many milestones in terms of nautical events and much was learnt from such events for the benefit of those seafarers that came afterwards. Starting with events such as the sinking of the Titanic in 1912 with its impact on the Safety of Life at Sea, the use of wireless telegraphy and, continuing throughout the century, the increasing use of electronics and satellites for navigation and communication purposes.

During that time there was a realization for the need to set up international bodies with a view to the harmonization, and the international recognition, of standards for ships involved in international trading. Bodies set up during the 20th century to monitor and influence these trends included the following.

6.1.1 International Maritime Organization (IMO)

Originally set up as the Inter-Governmental Maritime Consultative Committee (IMCO) in 1958, the name was changed in 1982. Its first task was to adopt a new version of the International Convention for the Safety of Life at Sea (SOLAS) and this was completed in 1960. The best known of the responsibilities of the IMO is the adoption of maritime legislation. About 40 conventions and protocols have been adopted by the organization and amended as necessary to keep pace with the changes in world shipping. The IMO has 158 member states and is based in London, England.

6.1.2 The International Standards Organization (ISO)

This is a non-governmental organization established in 1947 with a view to promoting the development of standardization in the world, facilitating the international exchange of goods and services, and developing co-operation in the areas of intellectual, scientific, technological and economic activity. The work of the organization results in international agreements, which are published as International Standards. There are more than 130 countries represented within the organization which is based in Geneva, Switzerland.

6.1.3 The International Electrotechnical Commission (IEC)

Established in 1906, the organization has more than 50 member countries covering 85% of the world's population. Standards established are used in more than 100 countries and there are approximately 200 Technical Committees (TCs) of which TC80 is an important part (see Section 6.3). The IEC collaborates with the ISO in matters of mutual interest and both organizations co-operate on a joint basis with the International Telecommunications Union (ITU). Like the ISO, the IEC is a non-governmental body while the ITU is part of the United Nations organization with governments as its members. The IEC is based in Geneva, Switzerland.

6.2 Design criteria

In the 1960s Planned Ships Bridges were available from at least one manufacturer and fitted on some vessels. This was probably the first attempt to construct a bridge within design concepts that took into consideration the operational requirements of the vessel. Integrated navigation systems and integrated bridge systems have evolved from those days and the concept is now accepted, with a variety of systems available from many different manufacturers.

Certain classification societies have initiated terms of carriage requirements if particular notations are specified for a vessel. A leading influence has been Det Norske Veritas (DNV) of Norway, a member of the International Association of Classification Societies (IACS). The Association was formed in 1968 and claims that 'At the heart of ship safety, classification embodies the technical rules, regulations, standards, guidelines and associated surveys and inspections covering the design, construction and through-life compliance of a ship's structure and essential engineering and electrical systems.' More than 90% of the world's merchant tonnage is classed by the 10 members and two associates of IACS. IACS members include the American Bureau of Shipping (ABS), Germanischer Lloyd and Lloyds Register of Shipping, together with societies from China, France, Italy, Japan, Korea, Norway and Russia. IACS has held consultative status with the IMO since 1969 and is the only non-government organization with observer status able to develop rules. The DNV rules for ships are as follows.

- To reduce the risk of failure in bridge operation, causing collisions, groundings and heavy weather damages and to minimize the consequences to ship and complement, should an accident occur.
- To include relevant requirements and recommendations from the IMO.
- To include relevant international standards within the rules or indicating the points in which they differ.

The various classification societies have adopted different standards although discussions on establishing international performance standards for integrated bridge systems have progressed under the direction of the IEC's Technical Committee 80 (TC80). Progress has been made on type approval and system notation.

The integrated bridge system should be designed and installed as a physical combination of equipment or systems using interconnected controls and displays. Workstations should provide centralized access to all nautical information. The type of operational function carried out from the bridge would include navigation, communications, automation and general ship operation. Manufacturers can provide shipbuilders and potential shipowners with computer-generated drawings of how a particular bridge layout would look when installed. One such diagram produced by Litton Marine Systems is shown in Figure 6.1.

In the absence of any internationally-agreed operating standards, from either the IMO or national authorities, reliance must be placed on industry guidelines and standards which do exist for bridge layout and equipment. These include the ISO standard for 'bridge layout and associated equipment.'

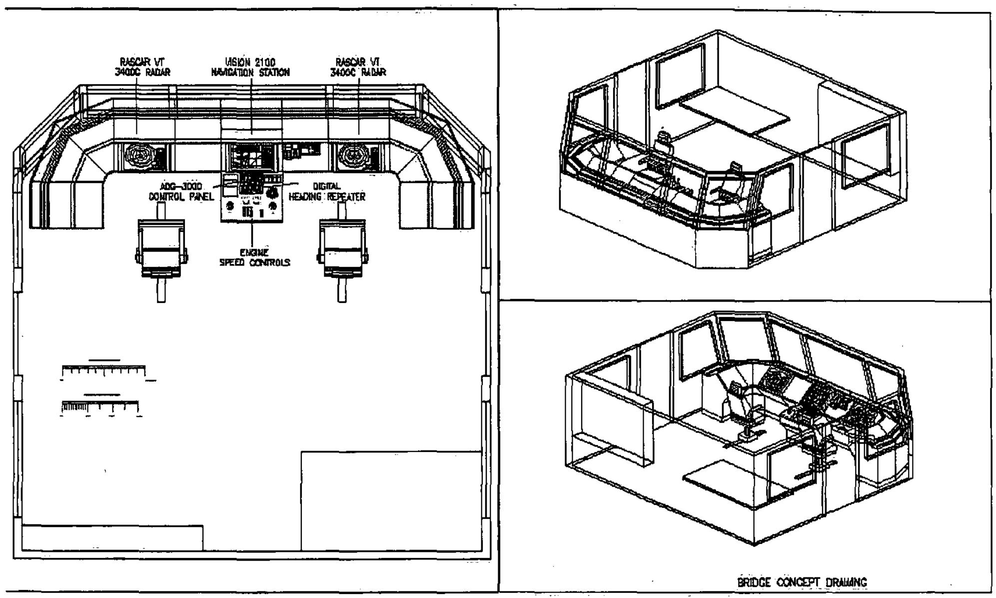


Figure 6.1 Line drawing of an integrated bridge system. (Reproduced courtesy of Litton Marine Systems.)

An IEC definition of an integrated bridge system states that such a system must be capable of carrying out at least two of the following functions:

- navigation planning
- passage execution and manoeuvring
- collision and stranding avoidance
- communications
- machinery control and monitoring
- loading and discharge of cargo
- safety and security
- management.

The integrated bridge system that meets these requirements must provide: redundancy in the event of system failure; the use of standardized equipment interfacing; the centralization of all nautical data and alarms; and the use of suitable displays to allow the monitoring of sensor data. The fact that current trends involve a reduction in manning levels suggests that the few members of a crew on the bridge must be capable of interpreting and responding to the multitude of information and alarms being presented to them. This would involve improvements in training and system documentation for the crews.

The DNV rules specify design criteria for particular workstations namely:

- traffic surveillance/manoeuvring
- navigation

- route planning
- manual steering
- safety operations
- docking operations
- conning operations.

In each case the tasks that have to be performed are specified and the siting of relevant instruments/ equipment required for those tasks is defined. As an example, the workstation for navigation is specified to enable the following tasks to be performed:

- determine and plot the ship's position, course, track and speed;
- effect internal and external communications related to navigation;
- monitor time, course, speed and track, propeller revolutions, pitch indicator and rudder angle.

The following instruments and equipment should be installed within reach:

- navigation radar display and controls
- chart table
- relevant position fixing systems (GPS and Loran-C)
- VHF unit
- whistle control.

Instruments, indicators and displays providing information considered essential for the safe and efficient performance of tasks at the navigation workstation should be easily readable from the workstation. These instruments, indicators and displays should include:

- gyro repeater
- rudder angle indicator
- depth indicator
- clock
- propeller RPM indicator
- pitch indicator (where fitted)
- speed and distance indicator.

Means to be used at intervals for securing safe course and speed in relation to other ships and safety of bridge operation should also be easily accessible from the navigation workstation. Such means include:

- instruments and equipment installed at the workstation for traffic surveillance/manoeuvring
- internal communications equipment
- central navigation alarm panel (if provided)
- wipers and wash controls for the windows within the required field of vision.

DNV specification for one-man bridge systems in an unbounded voyage area, known as DNV-W1, requires an Automatic Navigation and Track-keeping System known as ANTS. The specification requires integration of the following:

- Electronic Chart Display and Information System (ECDIS)
- automatic steering system (including software for calculation/execution of adjustments for the maintenance of pre-planned routes)

- differential GPS (2)
- gyrocompass (2)
- speed over ground (SOG) and speed through water (STW)
- course alteration warnings and acknowledgement
- automatic safety contour checking and alarming during voyage planning and execution
- capacity to create own electronic charts from paper charts for areas not covered by ENCs issued or certified by official sea chart authorities.

In addition to the above functional requirements, ANTS also places great emphasis on suitable technical documentation.

The requirements for ANTS place additional demands on certain aspects of the system. For example, the accuracy of the ship's heading should be a value that has been corrected for any errors typical of the source of the heading input, and at least one of the gyrocompasses should be provided with an automatic system for the correction of errors caused by speed and latitude. The steering system should also keep automatic track-keeping of the ship within the limits set on both sides of the pre-planned track and should provide the capability to steer the ship along a route consisting of straight and curved lines by both automatic and manual input of turn orders. The speed input should have sufficient accuracy to safeguard the quality of position fixing by dead reckoning. The system should be provided with a filtered position from the GPS receiver and when performing turns, the system should be provided with the most accurate real-time position. The quality of the integrated position fixing system should be monitored and a warning should appear if the quality is below an acceptable limit.

The need for integration has meant that there has been a tendency to move away from sourcing equipment from a variety of manufacturers and attempts to integrate disparate pieces of equipment, to single-sourcing a package of equipment from just one manufacturer. Many manufacturers, aware of the requirement, now offer complete systems with all the necessary interfacing requirements guaranteed. The use of standard modules and interfaces, not only for navigation but also for other bridge functions, such as communications, engine monitoring and control, power supply etc., is likely to produce cost savings and reduce the amount of equipment required. Factors such as the reduced number of consoles, reduced installation and interfacing costs, more cost-effective design, installation and testing requirements have to be taken into account.

6.3 Standards

Those organizations involved in the production of world standards are the International Standards Organization (ISO), the International Electrotechnical Commission (IEC), and the International Telecommunications Union (ITU). The first two organizations work closely together and, as they both have their headquarters in Geneva, some facilities have been amalgamated.

The International Maritime Organization (IMO) is responsible for defining the requirements for marine equipment but it does not provide sufficient specification detail for manufacturers to design specified equipment or for national maritime authorities to provide test and approval facilities for the equipment. Thus, the IEC and ISO standards are designed to allow the necessary specification requirements for design, testing and approval.

The IEC has several Technical Committees working in specialized technical areas. The IEC Technical Committee 80 (IEC TC80) covers the area of 'Marine Navigation and Radio communication Equipment and Systems' and was formed in 1980. IEC TC80 responsibility is to concern itself with the development of international technical standards for the navigation and radio communication equipment designated by the IMO for mandatory carriage on vessels covered by the SOLAS (Safety of Life at Sea) Conventions.

IEC TC80 currently has 10 working groups:

- WG1 radar and ARPA
- WG1A Track control
- WG4 Terrestrial position-fixing aids
- WG4A Global Navigation Satellite Systems (GNSS)
- WG5 General requirements
- WG6 Digital interfaces
- WG8 Global Maritime Distress and Safety System (GMDSS)
- WG8A Automatic shipborne Identification Systems (AIS)
- WG10 Integrated navigation systems
- WG11 Voyage data recorders.

Until fairly recently there were two other TC80 working groups: WG7 Electronic chart display and information system (ECDIS) and WG9 Integrated bridge systems for ships. The latter group was responsible for the publication in April 1999 of IEC 61209 'Maritime navigation and radio communication equipment and systems – Integrated bridge systems (IBS) – operational and performance requirements, methods of testing and required test results'. This document covers features such as: data exchange, displayed information, system configuration, human factors, alarms, training facilities, power supplies and failure analysis. This latter point is doubly important as it has implications in other areas such as training facilities.

6.4 Nautical safety

All aspects of bridge operation have evolved because of the requirement for the safety of the ship, crew and, where applicable, the passengers. The safety philosophy is encapsulated within the rules of Det Norske Veritas (DNV) and the following is reproduced from the DNV rules, part 6, chapter 8 with their kind permission.

6.4.1 Safety philosophy

To achieve optimum safety and efficiency in bridge operation the rules address the total bridge system, which is considered to consist of four essential parts.

- The technical system which deduces and presents information as well as enabling the proper setting of course and speed.
- The human operator who is to evaluate available information, decide on the actions to be taken and execute the decisions.
- The man/machine interface which safeguards that the technical system is designed with due regard to human abilities.
- The procedures which shall ensure that the total bridge system performs satisfactorily under different operating conditions.

6.4.2 Scope of rule requirements

These are set out in each section of the Rules for Nautical Safety and reflect the different factors that affect the performance of the total bridge system and are intended to regulate the following areas.

- Design of workplace, based on the analysis of functions to be performed under various operating conditions and the technical aids to be installed.
- Bridge working environment, based on factors affecting the performance of human operators.
- Range of instrumentation, based on information needs and efficient performance of navigational tasks.
- Equipment reliability applicable to all types of bridge equipment, based on common requirements to ensure their suitability under various environmental conditions.
- Specific requirements to different types of bridge equipment, based on the facilities required for the performance of their specific functions.
- Man/machine interface, based on the analysis of human limitations and compliance with ergonomic principles.
- Qualifications, based on the competence required for mastering rational navigational methods and relevant technical systems installed on board the ship.
- Operating procedures, based on the work organization needed to make the bridge system function under different operational situations.
- Information on the ship's manoeuvring characteristics, based on the manoeuvres commonly used in various operational situations.
- Tests and trials for new ships, based on the need to ensure that technical systems perform in accordance with their specifications before being relied upon and used in practical operation.
- Reporting system, from ships in service, on bridge instrument failures, based on the information needed to detect their factual reliability level.
- Survey schemes for ships in service, based on the follow-up and testing required to safeguard that bridge systems maintain their reliability.

6.5 Class notations

The Rules for Nautical Safety are divided into three class notations. Two class notations represent the minimum requirements within bridge design, instrumentation and procedures whereby NAUT-C covers bridge design and W1-OC, in addition, includes instrumentation and bridge procedures. The third class notation, W1, extends the basic requirements for bridge design and instrumentation and additionally requires information on the manoeuvring characteristics of the ship and an operational safety manual for safe watchkeeping and command of the ship.

NAUT-C covers bridge design, comprising the following main areas:

- mandatory and additional workstations
- field of vision from workstations
- location of instruments and equipment.

W1-OC covers bridge design, instrumentation and bridge procedures comprising the following main areas:

- NAUT-C
- range of instrumentation
- instrument and system performance, functionality and reliability
- equipment installation
- monitoring and alarm transfer system
- procedures for single-man watchkeeping.

W1 covers W1-OC and extensions within the following areas of W1-OC:

- design of one-man workstation
- field of vision astern
- range of instrumentation
- instrument performance
- automation level
- qualifications.

Also covered is information on the manoeuvring characteristics of the ship comprising the following main items:

- speed at different settings
- steering ability
- turning ability
- stopping ability.

There is also a requirement for an operational safety manual comprising the following main items:

- bridge organization and responsibilities
- watchkeeping procedures
- system fall-back procedures
- accident and emergency procedures.

6.6 Bridge working environment

Ships requesting class notation NAUT-C, W1-OC or W1 should comply with rules for bridge working environment which specifies vibration levels, noise, lighting, temperature, ventilation, surfaces, colours and the safety of personnel.

6.6.1 Equipment carriage requirements

Ships requesting class notation W1-OC are equipped with the following systems:

- course information systems (two gyrocompasses or one gyro + one TMC)
- steering systems (manual and automatic steering)
- speed measuring system (water speed, > 40 000 tons gross, dual axis)
- depth measuring system (over 250 m length, two transducers)
- radar systems (two radars, at least one X-band)
- traffic surveillance systems (ARPA)
- position fixing systems (Loran-C, GPS)
- watch monitoring and alarm transfer system
- internal communication systems
- nautical safety radio communication systems
- sound reception system (technical device to receive signals).

Additional equipment required for class notation W1 includes:

- steering system with rate of turn indicator
- course information system, which should have two independent gyrocompasses
- speed measuring system, through the water, which should provide information for traffic surveillance system
- Electronic Chart Display and Information System (ECDIS)
- Automatic Navigation and Track-keeping System (ANTS)
- conning information display
- central alarm panel
- wind measuring system.

6.6.2 General bridge equipment requirements

The rules specify the following:

- environmental conditions
- location and installation of equipment
- electrical power supply, alarms, performance confirmation and failure protection
- computer-based systems and software quality.

6.6.3 Specific requirements for different types of bridge equipment

Ships requesting class notation W1-OC shall comply with specific requirements for the following systems:

- course information system (speed and latitude correction)
- steering systems (manual override control and rate of turn display)
- speed measuring system (if bottom track then up to 200 m depth)
- depth measuring system
- radar systems (two floating EBLs, interswitch, ship track monitoring)
- traffic surveillance systems (ARPA with two guard zones)
- position fixing systems (performance standards)
- watch monitoring and alarm transfer system
- internal communication systems
- nautical communication systems
- sound reception system.

Class notation W1 requires in addition the following systems:

- Electronic Chart Display and Information System (ECDIS)
- Automatic Navigation and Track-keeping System (ANTS)
- conning information display
- central alarm panel.

6.6.4 Man/machine interface

Ships requesting class notation W1-OC or W1 must comply with the rules in this section. All instruments must be logically grouped according to their functions within each workstation. Their location and design should give consideration to the physical capabilities of the human operator and comply with accepted ergonomic principles. The amount of information to be presented for conducting the various tasks, as well as the methods of displaying the information needed, should give consideration to the capabilities of the human operator to understand and process the information made available. The rules specify the following:

- instrument location and design
- illumination and individual lighting of instruments
- requirements for the man/machine dialogue of computer-based systems.

6.7 Ship manoeuvring information

Ships requesting class notation W1 must comply with rules for manoeuvring information. Information about the ship's manoeuvring characteristics, enabling the navigator to safely carry out manoeuvring functions, shall be available on the bridge. This section deals with: the manoeuvring information to be provided, and the presentation of the manoeuvring information.

The provision of manoeuvring information should include:

- speed ability
- stopping ability
- turning ability
- course change ability
- low-speed steering abilities
- course stability
- auxiliary manoeuvring device trial
- man-overboard rescue manoeuvre.

The presentation of manoeuvring information should include:

- pilot card
- wheelhouse poster
- manoeuvring booklet.

6.8 Qualifications and operational procedures

Class notation W1-OC specifies responsibilities of shipowner and ship operators, qualifications and bridge procedures. Class notation W1 has extensions to responsibilities, qualifications, bridge procedures, and a special requirement for operational safety standards.

6.8.1 Operational safety manual

This is a requirement for class notation W1 to obey the following guidelines.

1 Organization:
- general
- bridge organization

- responsibilities of shipowners and ship operators
- responsibilities of the master
- responsibilities of the officer in charge of single-man watchkeeping
- qualifications of bridge personnel
- manning
- safety systems – maintenance and training.

2 Daily routines:
- general
- look-out
- changing of the watch
- periodic checks of navigational equipment
- log-books
- communications and reporting.

3 Operation and maintenance of navigational equipment:
- general
- radars/ARPA
- automatic pilot
- gyro and magnetic compasses
- echo sounder
- speed/distance recorder
- electronic position fixing aid
- electronic navigational chart
- automatic navigation and track-keeping system
- hydrographic publications
- emergency navigation light and signal equipment.

4 Departure/arrival procedures:
- general
- preparation for sea
- preparation for arrival in port
- embarkation/disembarkation of pilot
- master/pilot information exchange.

5 Navigational procedures:
- general
- helmsman/automatic pilot
- navigation with pilot embarked
- navigation in narrow waters
- navigation in coastal waters
- navigation in ocean areas
- navigation in restricted visibility
- navigation in adverse weather
- navigation in ice
- anchoring.

6 System fall-back procedures:
- general
- bridge control/telegraph failure
- gyrocompass failure
- steering failure
- auxiliary engine failure
- main engine failure.

6.8.2 Contingency and emergency manual

1 Contingency and emergency organization:
- general
- duties and responsibilities.

2 Accident procedures:
- general
- collision
- grounding
- fire/explosion
- shift of cargo
- loss of buoyancy/stability.

3 Security procedures:
- general
- sabotage threat/sabotage
- hijacking threat/hijacking
- piracy
- local war situation
- criminal act committed on board
- detention/arrest.

4 Emergency procedures:
- general
- emergency notification
- abandon ship preparations
- lifeboat evacuation
- helicopter evacuation
- use of other evacuation equipment.

5 Miscellaneous:
- general
- dead or injured person aboard
- man overboard
- search and rescue actions
- stowaways
- political refugees
- missing or lost person
- documentation and reporting
- press releases.

6.9 Bridge equipment tests

Ships requesting class notation W1-OC or W1 must comply with rules for equipment tests. After installation of equipment, on-board testing shall be performed in order to ascertain that the equipment, as installed, operates satisfactorily.

It should be noted that reliable figures for all aspects of equipment performance/accuracy cannot be established by the on-board testing required for classification. Hence, to ensure that equipment performance is in accordance with specifications, shipowners are advised to choose equipment that is type approved.

A detailed test programme for the on-board testing of equipment should be submitted for approval at the earliest possible stage before sea trials. The following systems are tested according to general requirements for testing of equipment:

- gyrocompass
- automatic steering system
- rudder indicator(s)
- rate-of-turn indicator
- speed log
- echo sounder
- radar system
- ARPA system
- electronic position fixing systems
- watch monitoring and alarm transfer system
- internal communication systems
- nautical communication system
- sound reception system
- computer system(s)
- Electronic Chart Display and Information System (ECDIS)
- Automatic Navigation and Track-keeping System (ANTS)
- conning display.

6.10 Examples of integrated bridge systems

A variety of manufacturers offer a range of integrated bridge systems that can be tailored to fit the requirements of the user. Some of these systems will be described in this section. The systems selected come from leading manufacturers in this field.

6.10.1 Voyager by Furuno Electric Co. Ltd

An automatic navigation system designed by Furuno to meet the requirements for one-man bridge operation and the new ECDIS standards is the Voyager Integrated Bridge System. The system was designed to meet the class notation W1-OC of DNV, Norway. The system is modular which allows it to be set up to meet the requirements of the user and to provide capability for future expansion of the system as necessary. The complete system requirement comes from a single supplier with the claimed benefits of:

- increased safety
- increased cost-effectiveness
- increased navigation efficiency.

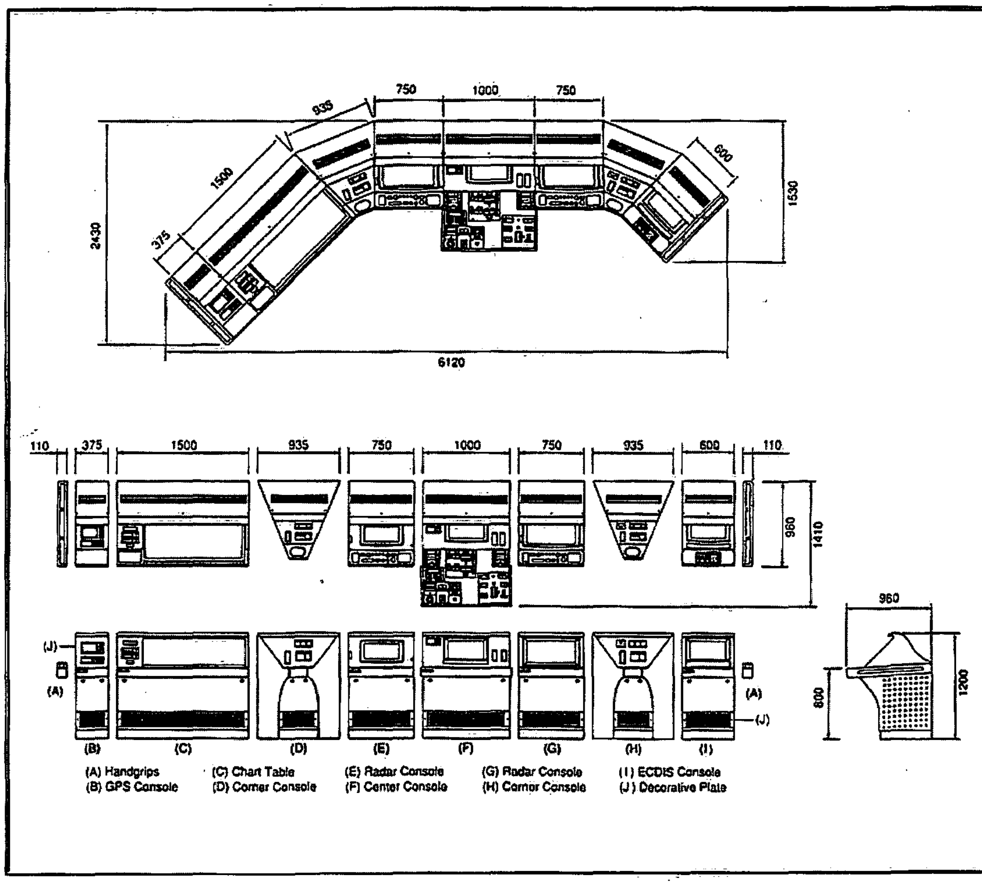


Figure 6.2 Components of the Voyager integrated bridge system. (Reproduced courtesy of Furuno Electric Co. Ltd.)

The modular nature of the system components can be seen from Figure 6.2 which shows a possible bridge layout using the Voyager system. Figure 6.3 shows one module, that of the ARPA/Radar which is module E/G in Figure 6.2.

Main functions of Voyager

There are three main functions of the system:

- electronic chart display and user interface
- position calculation and track steering
- automatic steering of the vessel.

Each of the main functions is performed using an individual processor as indicated in Figure 6.4. This guarantees real time data processing for critical applications such as positioning and steering.

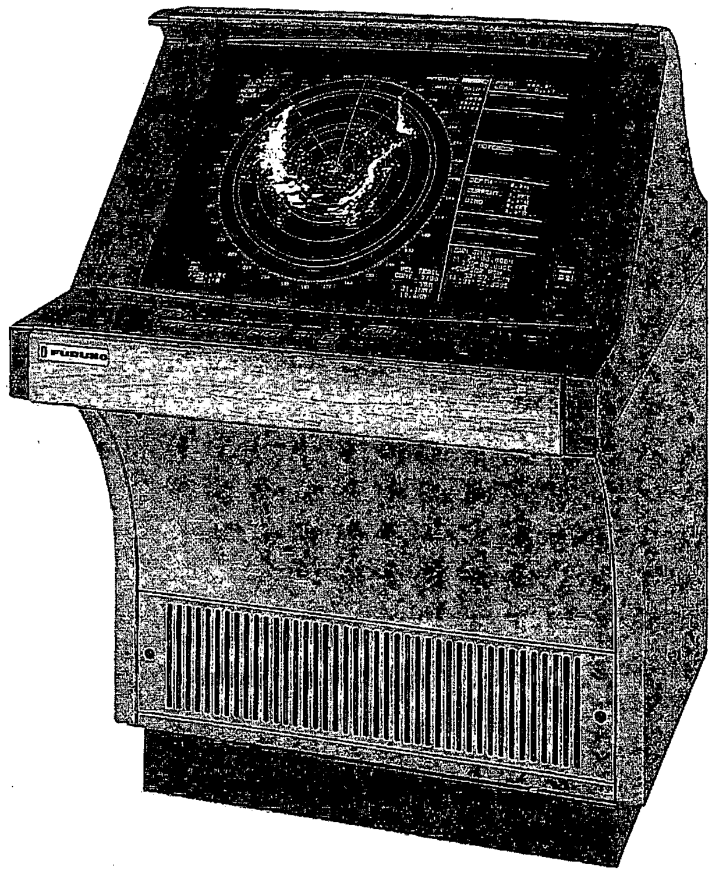


Figure 6.3 Voyager ARPA console. (Reproduced courtesy of Furuno Electric Co. Ltd.)

The system has built-in dual displays to satisfy the requirement for separate ECDIS and conning monitors. The ECDIS monitor provides the main display and user interface for the navigation system, while the conning monitors display the most important navigational sensor data in a graphical form, i.e. gyrocompass, speed log etc.

The navigation system is operated through a control panel that has dedicated function and execute keys for fast, easy operation. The steering functions are performed on their own operation control panel that integrates all functions for automatic steering. A block diagram that shows these control panels and also indicates all inputs to the navigation and track-keeping processor is shown in Figure 6.5. Figure 6.5 also indicates the type of interface connection that exists between a particular sensor and the processor.

Electronic chart display and user interface

For this system the electronic chart functions are designed to meet the performance standards for the ECDIS as laid down by the IMO and the IHO. More details on these requirements can be found in

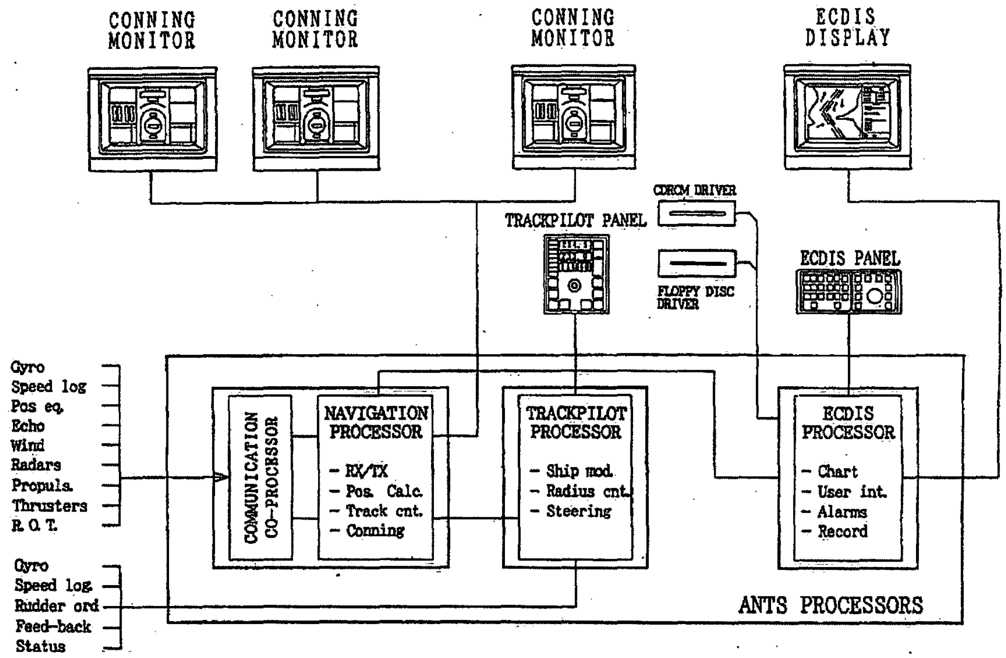


Figure 6.4 Block diagram of the Voyager integrated bridge system. (Reproduced courtesy of Furuno Electric Co. Ltd.)

Chapter 7. ECDIS functions are performed on their own computer unit, housed in the same electronic cabinet, so as to optimize graphical performance and cost, especially when a second chart display is necessary.

The main features of the ECDIS are:

- presentation of an electronic version of a sea chart, based on the latest ENC format using a 21- (or 29-) inch high resolution colour display
- multiple navaid interface for GPS/DGPS, gyrocompass, speed log, echo-sounder etc.
- capable of use with both ENC and ARCS
- route planning and route monitoring
- primary and secondary route planning facilities
- grounding warnings
- user generated navigational safety lines which are overlaid on the radar screen
- user selectable chart layer presentation
- navigational tools such as VRM, EBL, track-ball
- display of ARPA targets
- voyage recording to meet standards
- user generated information note-books
- display of alarms
- MOB and event functions
- dedicated function keys for scale up/down, standard display, TM-reset and other functions which are the most often used functions.

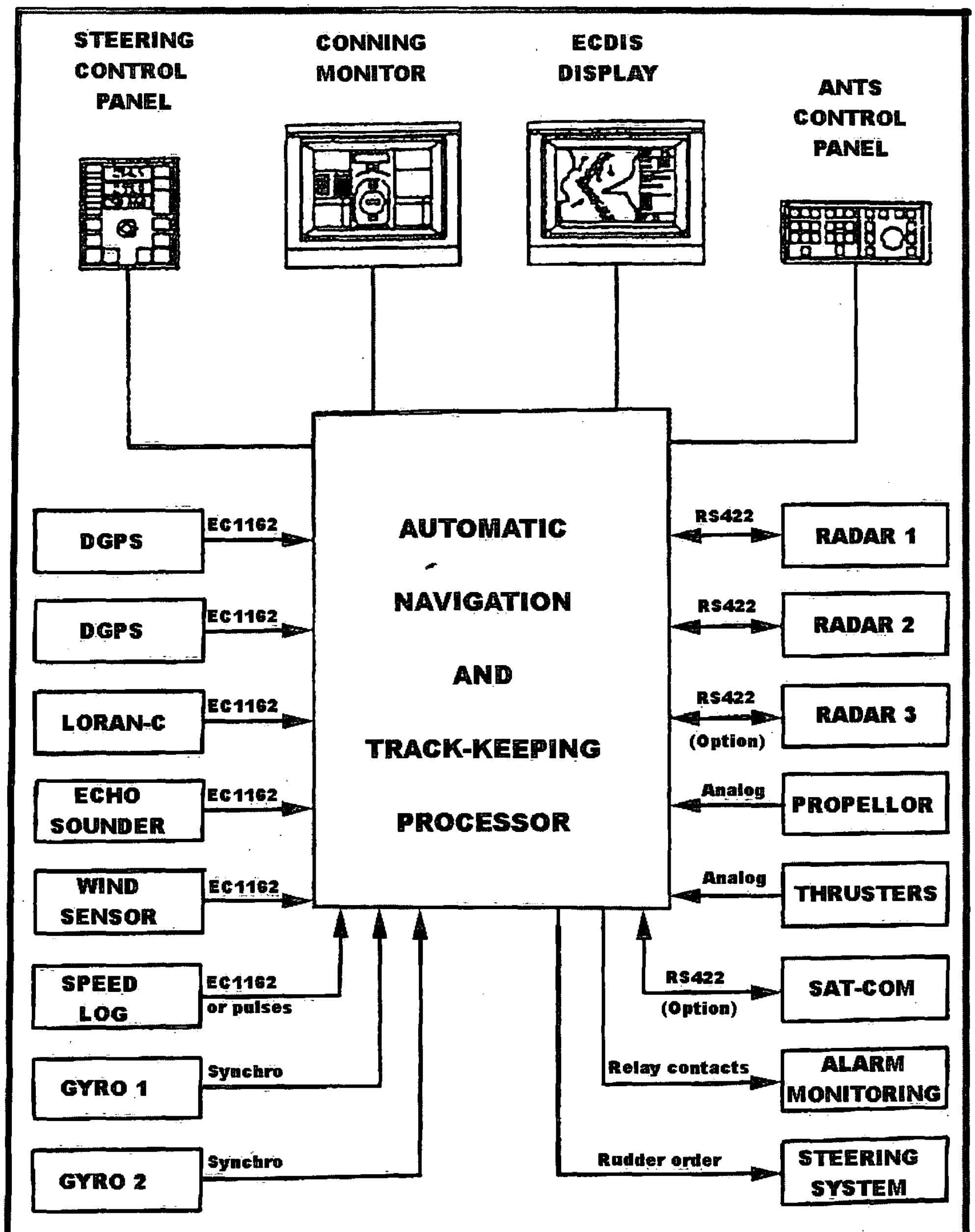


Figure 6.5 Block diagram of Voyager automatic navigation and track-keeping system (ANTS). (Reproduced courtesy of Furuno Electric Co. Ltd.)

The option of fitting a second ECDIS computer and display, to meet the required back-up arrangements in case of an ECDIS failure, is available. If fitted, the second ECDIS computer is linked to the first through a local area network (LAN).

Position calculation and track steering

The ship's position is calculated from the position sensors using the information from the gyrocompass and speed log. The position calculation is based on Kalman filter technology, which is capable of using different types of sensors and in operator-defined configurations.

Because of the need to allow for time-critical operations in position calculation and track steering, a separate processor is used for these functions. The main features of this processor are:

- interface to all external devices
- position calculation based on Kalman filter technology
- position quality calculation and alarm
- off-track calculation and alarm
- waypoint pre-warning and waypoint alarm
- graphical process and display for conning information.

Automatic steering function

The system includes a complete radius/track controlled autopilot for safe and automatic steering of the vessel with the functions and operations meeting the DNV-W1 requirements. The autopilot is fully integrated into the system allowing it to be easily controlled and operated.
The main features of the automatic steering system are:

- speed adaptive operation
- radius controlled turns
- direct gyro and log inputs for accurate and reliable performance
- user selectable steering modes
- gyro mode (rudder limit controlled)
- radius mode (immediate course change)
- programmed radius mode (programmed course change)
- programmed track mode (position referenced course change)
- precision track steering with pre-memorized waypoints
- relaxed track steering with pre-memorized waypoints.

The autopilot system has its own operation control panel for logical, simple to use operation while two separate operation control panels can be installed for special applications.

Interface specifications

The Voyager has a wide and flexible interface structure that allows for the system to be easily set up and configured for use. Both analogue and serial digital interfaces are available. The available interfaces to other systems are:

- gyrocompass: one analogue and one serial (NMEA) or two serial (NMEA)
- rate-of-turn gyro: analogue or serial (NMEA)
- speed log: pulse type or serial (NMEA)

• position receivers:	up to five serial inputs (NMEA)
• echo sounder:	serial input (NMEA)
• wind sensor:	serial input (NMEA)
• rudder angle:	analogue or serial (NMEA)
• propeller RPM/pitch:	analogue or serial (NMEA)
• thrusters:	up to four analogue inputs.

The autopilot interface requirements are:

• gyrocompass:	two 1:1 synchros or high update rate serial inputs (NMEA)
• speed log:	200 p/nautical miles pulses or serial input (NMEA)
• rudder order:	analogue output (0.25 V/degree) or solid-state solenoid outputs
• steering status:	galvanically isolated contacts.

If a direct solenoid type of steering order is required then an optional feedback unit and solenoid drive distribution box is required.

Electrical specifications

The following supplies are required with battery back-up in case of supply failure:

navigation system	24 V d.c. supply (250 W approx.)
alarm supply	24 V d.c. supply (10 W approx.)
display monitors	230 V a.c. or 110 V a.c.

6.10.2 NINAS 9000 by Kelvin Hughes

Kelvin Hughes, the Naval and Marine division of Smiths Industries Aerospace, offer a fully integrated navigation system. Units from the Kelvin Hughes Nucleus Integrated Navigation System (NINAS) are used together with ancillary navigational equipment from specialist manufacturers.

The advantages claimed for the NINAS 9000 system include the following.

- Any number of auxiliary consoles can be added to the basic radar and navigation displays
- The use of modules gives flexibility in the final arrangement adopted by the ship owner and ship operator
- The centre consoles can be adapted to accept equipment from a number of Kelvin Hughes preferred third party suppliers
- The system is based around the proven nucleus2 6000 radar systems which are available with a variety of antennas and transmitters.

A possible bridge layout for a large passenger-carrying vessel is shown in Figure 6.6.

The wheelhouse layout consists of a centre-line steering console, two mid-position (manoeuvring and pilot) and two enclosed bridge wing consoles. The manoeuvring and pilot stations consist of a dedicated radar and a dedicated ECDIS/conning display, both being type approved CRT equipment. The centre-line station has two multifunctional LCD displays, which connect to any of three radar processors, for use as a remote operating station for either of the two ECDIS displays or as a remote operating station for any other function as required. The two stations at each wing bridge perform a similar function to that of the centre-line station.

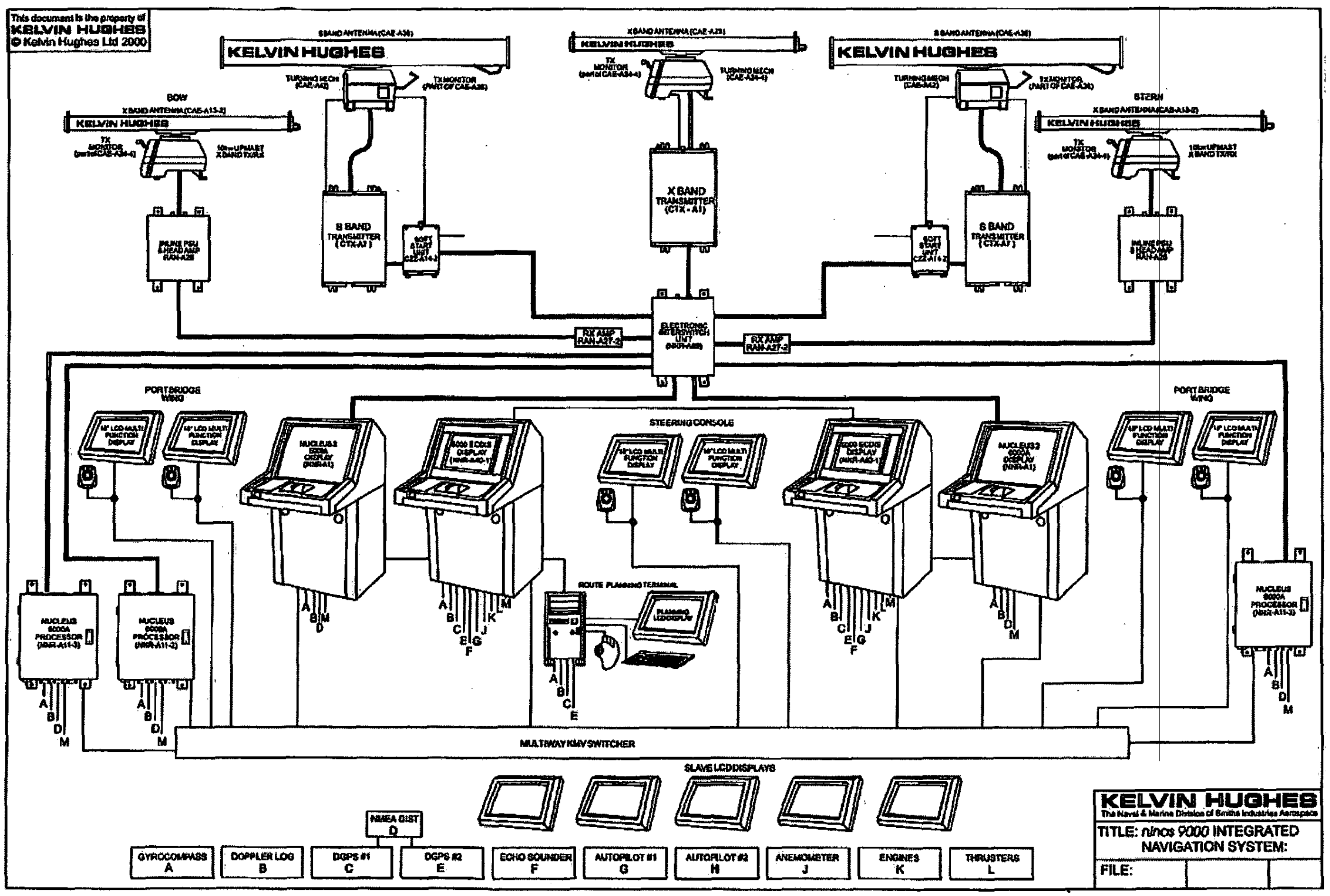


Figure 6.6 NINAS 9000 integrated bridge system. (Reproduced courtesy of Kelvin Hughes.)

Display systems

1 Radar displays

The two radar displays are 26-inch PPI, rasterscan ARPA radar displays with 10 range scales 0.25–96 nautical miles presented in relative motion, true motion and centred display true motion. There is auto tracking capability for up to 50 targets with a choice of manual or auto acquisition of targets using guard zones or footprint acquisition. The display has as standard parallel index lines, a flexible mapping system with a map storage capacity of 64K byte showing, for example, 100 maps of 80 elements.

The display has an interfacing capability of two RS232 bi-directional serial links and four NMEA opto-isolated inputs. The input capabilities are:

- GPS/Loran; waypoints; route; chart 'puck' position
- steering sequence; man overboard position; turning radius data
- serial link data from navigation display.

Output capabilities are tracker ball position and target data to ECDIS. A tracker ball and three buttons control all the radar display functions with external tracker-ball capability from each bridge wing.

2 ECDIS displays

The two ECDIS displays are IEC 1174 type approved 20-inch displays with the following functions.

- Operates with Windows-NT operating software with multi-window display showing S57 ed.3 ENC vector charts and/or ARCS/NOAA (BSB) raster charts. These may be viewed simultaneously or independently in variably sized windows.
- Graphic overlay of ownship symbol, route, waypoints, target vectors and trails on chart.
- Radar interlay of radar target echoes on chart. The interlay technique places the radar information video plane below that of the overlay to avoid obstruction of essential information.
- The ECDIS display can also act as a slave radar display by having its own radar video processing functions that allow independent control of the radar image on the ECDIS.
- North-up, course-up and head-up ENC chart presentation.
- Route safety zone function which provides a three-dimensional guard zone around own ship to monitor ship draft against chart depths and ships air draft against chart clearances to improve safety when on passage or route planning.
- Automatic plotting of time on chart with plot-on-demand function for special events.
- Passage calculator that allows route planning from the ECDIS screen. This allows calculation of distances, ETA, required speed for specific ETA and other navigational computations. This may be carried out locally or at a networked optional route planning workstation.
- Planning may be carried out visually with waypoints being dragged to modify legs and to allow the route to pass around obstacles.
- Uses ENC chart embedded database for interrogation feature, which allows the operator to request pop-up window information for any buoy, light etc. Also menu selection allows ECDIS or traditional chart symbols to be viewed for buoys and lights. There are six ENC colour palettes for optimal viewing in all light conditions.
- Continuous display of own ship heading, speed, position and depth on right side of the screen.
- Automatic Navigation and Tracking System (ANTS) interface to autopilot, allowing automated route sailing and constant radius turns.
- ECDIS display may be controlled either from the local tracker ball and three-button screen control unit (SCU) or from the remote display.

Additional functions within the ECDIS systems include a conning display, featuring the display of real-time vessel's position upon the chart in use, while displaying navigational and dynamic data in side panels. Data displayed includes:

- position
- heading
- speed (dual axis)
- depth
- wind (true and relative)
- route data
- engine RPM
- engines and thrusters.

3 Centre line console multi-function displays
Two 20-inch LCD displays that are capable of operating in the following modes.

- Fully independent radar displays capable of controlling any one of the five main radar transmitters.
- Remote radar displays capable of controlling any one of four main radar transmitters via another display (in the event of failure of the unit's own processor).
- Remote ECDIS/Conning display.

Additional functions that could also be allowed include:

- CCTV
- control and command monitoring
- alarm monitoring.

4 Bridge wing multi-function displays
Two 18-inch LCD displays that are capable of operating in the following modes.

- Fully independent radar displays capable of controlling any one of the five main radar transmitters.
- Remote radar displays capable of controlling any one of four main radar transmitters via another display (in the event of failure of the unit's own processor).
- Remote ECDIS/conning display.

Additional functions that could also be allowed include:

- CCTV
- control and command monitoring
- alarm monitoring.

5 Route planning terminal
A 17-inch LCD display with a dedicated processor designed in the same manner as an IEC 1174 type approved ECDIS display. The route planning terminal is installed as a slave unit to allow off-line route planning at the chart table position. The unit includes dedicated interfaces to log, gyro and GPS to allow it to act as a back-up ECDIS in the event of failure of the main units. Features are as for the type approved ECDIS, with the exception of radar interlay and target data.

Other components of the total system include the following.

- *Radar transmission system.* This comprises a five-way interswitched X and S band system allowing independent control of individual systems and complete interswitching of all radars.
- *Autopilot and steering system.* A system with full ANTS functionality when connected to the ECDIS. The system has inputs for both gyrocompass and magnetic compass heading data. During the normal operating mode the headings from both gyrocompass and magnetic compass are produced in the independent course monitor. In the event of a gyrocompass failure all major receivers of the gyrocompass heading, such as radar, Satcomm, GPS and digital repeaters, can be switched over immediately to the heading from the magnetic compass from the course monitor.
- *Gyrocompass system.* This is a microprocessor-controlled digital system designed as a single unit with control and display unit in the front cover. The control and display unit can be removed from the housing and installed at a position (e.g. a bridge console) remote from the gyrocompass. The gyrocompass has an integrated TMC function, gives a rate-of-turn (ROT) output, has seven independent RS 422 and NMEA 0183 serial outputs and complies with DNV-W1.
- *Magnetic compass.* The system includes aluminium alloy binnacle, magnetic flat glass compass, a fluxgate pick-off with an integrated sine/cosine interface, bypass arrangements, azimuth devices, electronic compasses, and magnetic compass autopilots (TMC). Variation correction, gyro/TMC changeover etc. is incorporated in the gyrocompass monitor/changeover system. System uses gyro repeaters for indication when TMC is selected at the compass monitor.
- *Dual axis Doppler log.* The log is a two-axis system, the data obtained from the speed log is longitudinal and transversal bottom-track speed and depth, and longitudinal water-track speed. The log provides simultaneous W/T and B/T speeds of ±30 knots with 0.1 knot scale and depth. Bottom-track speed and depth are displayed from 3 to 300 m. Data from the log is transmitted to the log processing unit (LPU) which serves as a data concentrator/distributor in the system. The LPU is programmed according to the geometry of the ship and the position of the transducer. With this information the LPU computes transversal speeds of bow and stern. The system comprises two independent log systems each with a dedicated display at the chart table. Log selection for output to other repeaters, integrated bridge system etc. is via a selector switch at this position.
- *Echo sounder.* This unit can be operated as a single or dual frequency unit with up to four transducers. The display offers five basic ranges between 0 and 2000 m. The high resolution LCD display allows continuous observation of bottom recordings and shows all relevant navigation data. The display includes continuous indication of digital depth and range. Bottom alarm can be set at any required depth. The unit can store the last 24 h data together with the position so that a printout can be made if required.
- *DGPS.* The receiver automatically locates the strongest transmitting beacon station and lock on in seconds. In the case of signal loss it automatically switches over to an alternative station ensuring a strong signal at all times. A navtalk NMEA distribution unit is included which is fed with the output from both DGPS receivers and supplies 10 buffered outputs. In the event of failure of the primary DGPS the system automatically switches to the secondary.
- *Loran-C.* The system uses the Furuno LC-90 Mk-II receiver. Full details of this receiver can be found in Chapter 4.
- *Bridge alarm system.* This is a central alarm/dead man system which meets the highest current classification society bridge alarm specification. The system is capable of handling 40 opto-isolated switched inputs. Alarms are managed and displayed in order of priority. It is connected interactively to the integrated navigation system to allow the alarms to be repeated on the ECDIS.

6.10.3 Sperry Marine Voyage Management System – Vision Technology (VMS-VT)

The Sperry VMS-VT system, provided by Litton Marine Services, is a computer-based navigation, planning and monitoring system which typically consists of two or more computer workstations connected by a local area network (LAN). A typical arrangement for a VMS-VT system is shown in Figure 6.7.

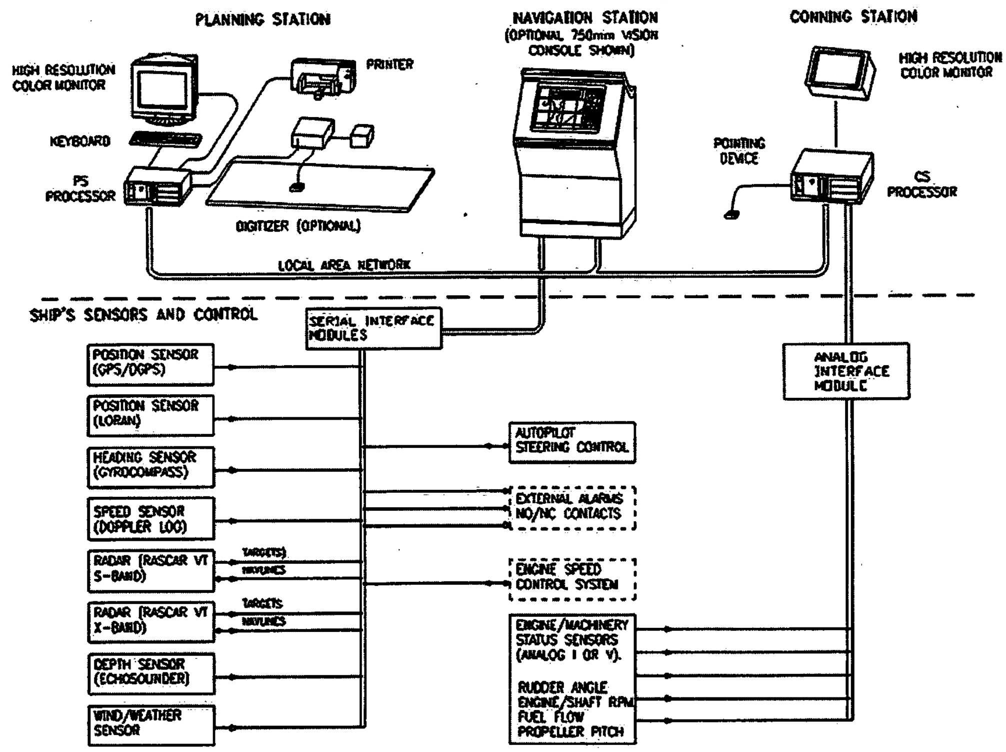


Figure 6.7 Typical arrangement for the Voyage Management System – Vision Technology (VMS-VT). (Reproduced courtesy of Litton Marine Systems.)

Figure 6.7 shows three workstations, providing a navigation station, a planning station and a workstation designated as a conning station. The navigation station is usually located in the conning position. All VMS-VT functions are available at this station except chart digitizing and chart additions.

The planning station is usually located in the chart room and has a high-resolution monitor and printer which can provide hard copies of voyage data. Separating the planning station from the navigation station allows an operator to effect voyage planning or chart editing at the planning station without interfering with conning operations at the navigation station. The display at the navigation station is also available at the planning station so that the ship's position can be monitored at either location. A typical VMS-VT main display is shown in Figure 6.8.

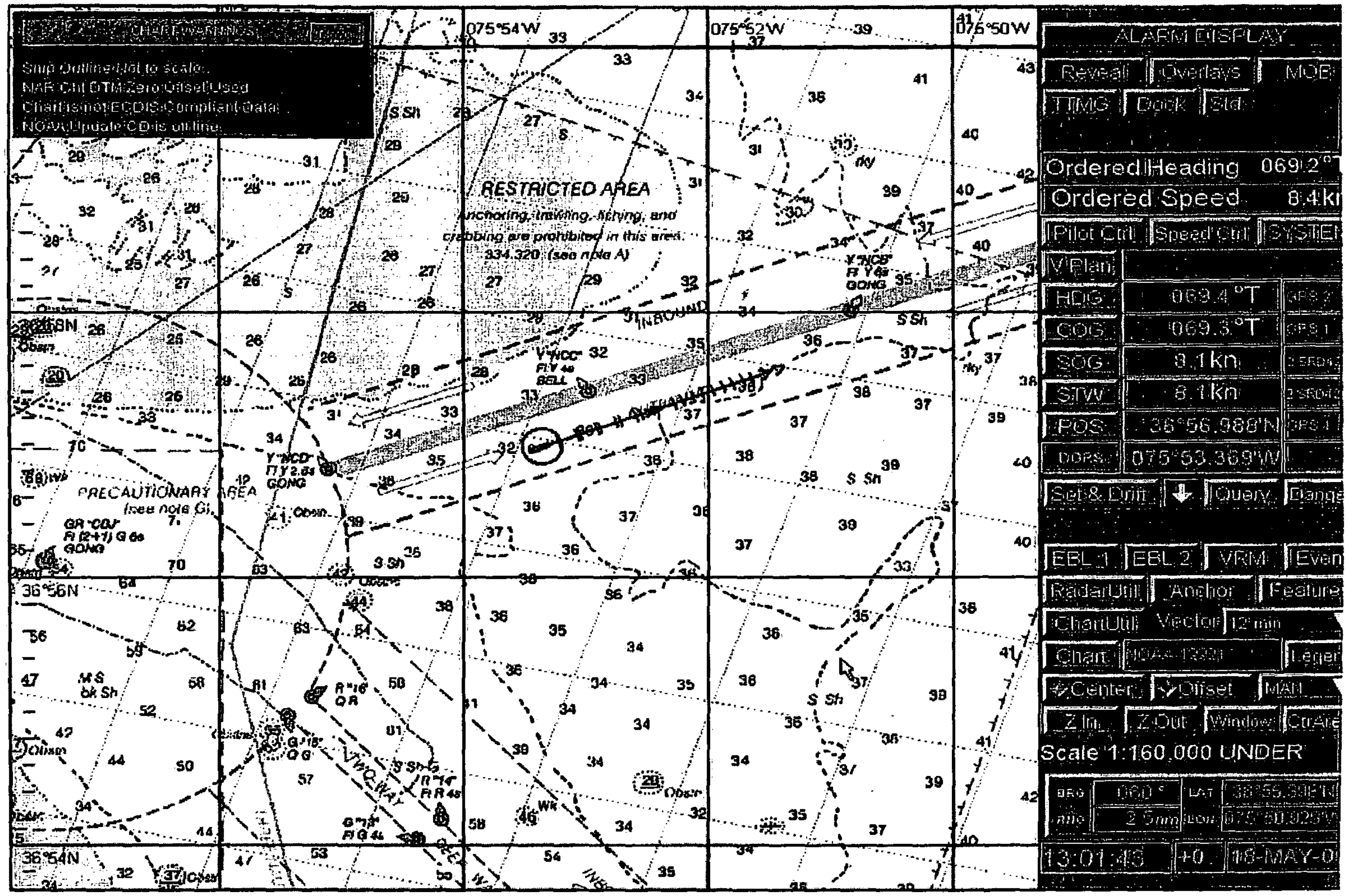


Figure 6.8 VMS-VT main display screen showing own ship's position, heading and speed using an electronic chart. (Reproduced courtesy of Litton Marine Systems.)

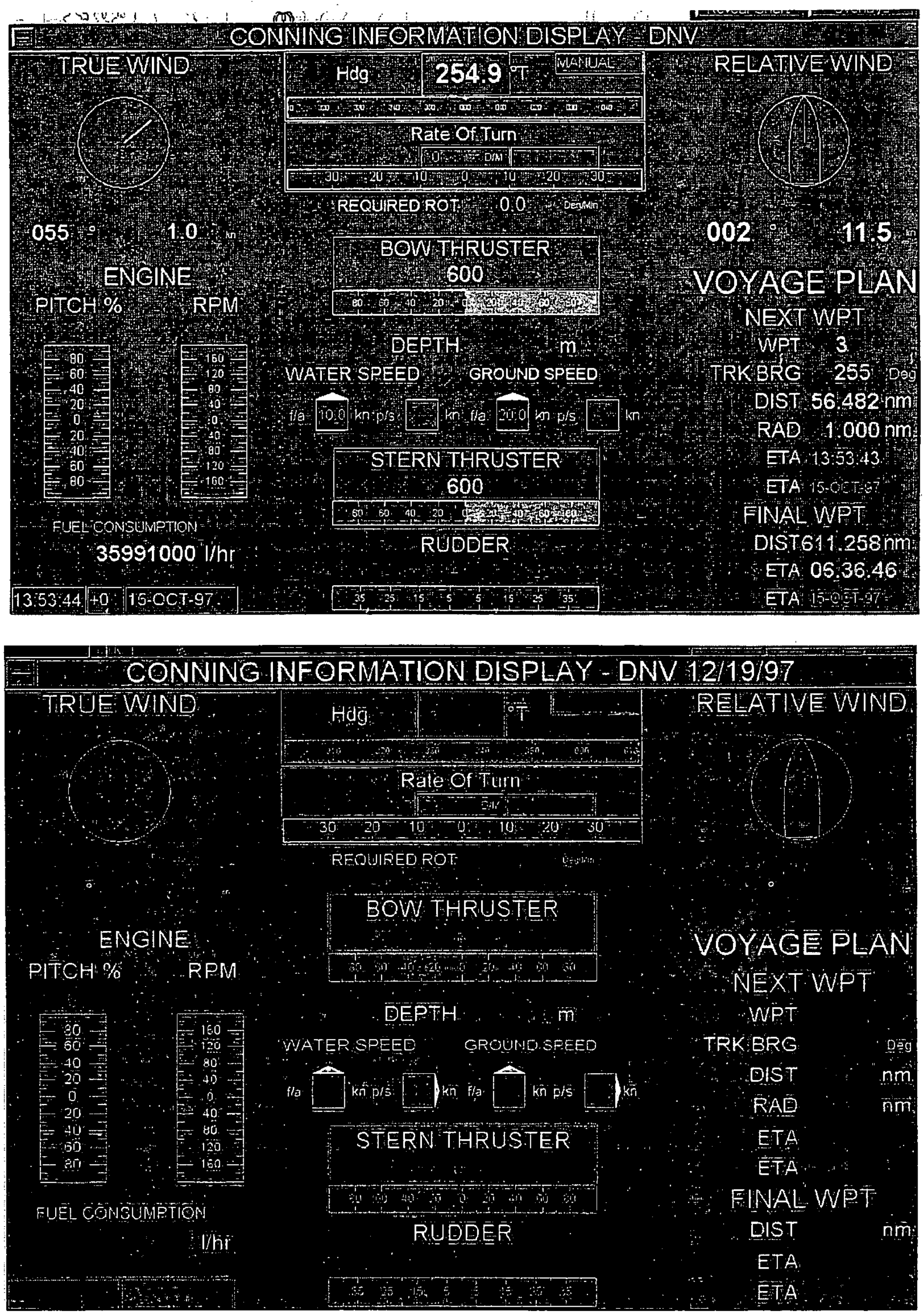


Figure 6.9 Examples of VMS-VT conning information display screens. (Reproduced courtesy of Litton Marine Systems.)

The conning station is usually configured to display a single page of specific navigation data as specified by regulatory group requirements. For this arrangement a pointing device is not provided since the display is non-interactive. At the conning station the screen is known as the conning information display (CID). Where possible the navigational and meteorological digital data is presented on the CID screen graphically to mimic analogue instruments in order to make it easier for an operator to assimilate and manage data quickly. The data presented is updated continuously and has a fixed layout pattern so that particular data is always available at the same location. A similar CID page is often available as a large display overlay screen at the VMS-VT navigation station and planning station (see Figure 6.9).

DNV on the screen displays of Figure 6.9 refers to the classification society Det Norske Veritas, Norway.

An engineering information display, as shown in Figure 6.10, can be provided as a display overlay screen at the VMS-VT navigation station and planning station or as a full-screen display at a dedicated monitor. The system can also be configured to display other pages such as a performance monitor window as shown in Figure 6.11.

As Figures 6.9–6.11 indicate, the main advantage of the VMS-VT system is its flexibility in presenting information that can be displayed in a manner that meets the customer's requirements.

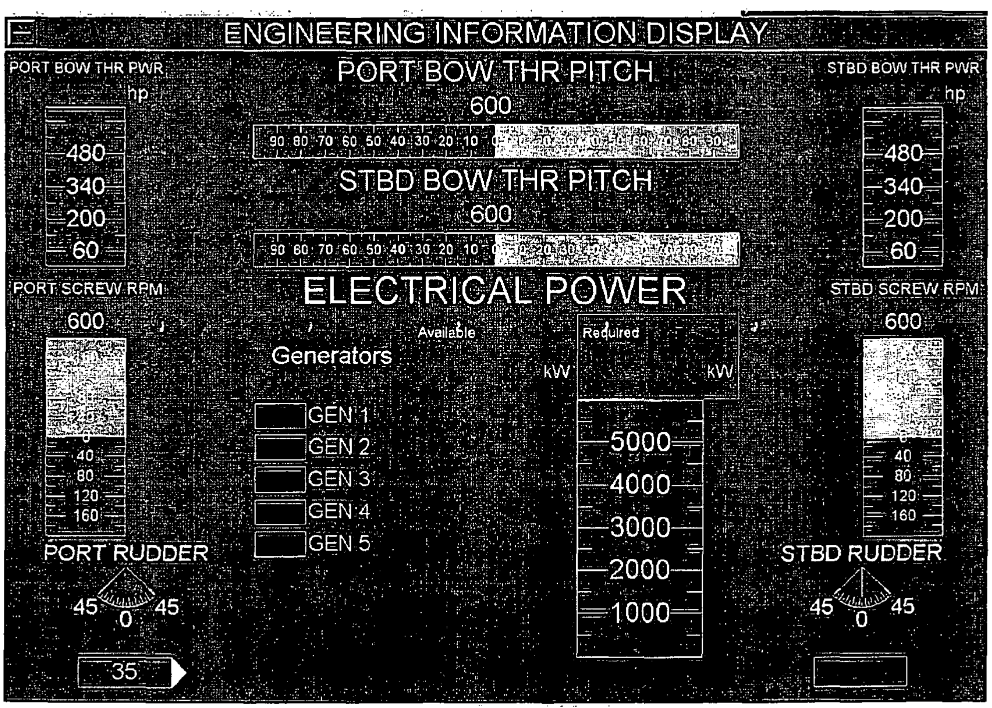


Figure 6.10 Example of VMS-VT engineering information display screen. (Reproduced Courtesy of Litton Marine Systems.)

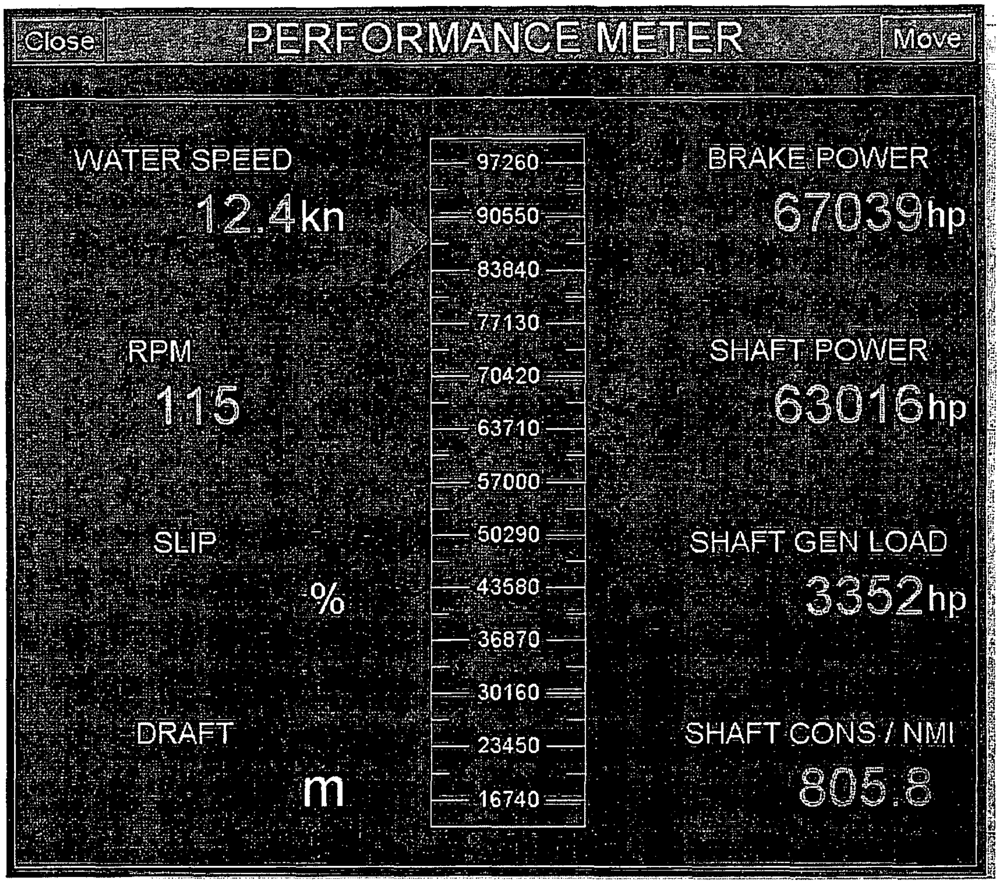


Figure 6.11 Example of VMS-VT performance monitor window. (Reproduced courtesy of Litton Marine Systems.)

Basic VMS-VT functions include:

- integration of data from various sensors
- data sharing on a local area network (LAN)
- display of real-time sensor information
- display of electronic charts with ownship position
- creation of a voyage plan
- execution of a voyage plan
- display of electronic bearing lines (EBLs)
- display of variable range markers (VRMs)
- comprehensive alarm and operator message system
- printing of ship's navigation data.

Optional VMS-VT functions include:

- autopilot control
- speed order control
- display of radar target information
- DNV certified track keeping
- ECDIS S-57 or digital navigational chart (DNC) display
- interface to voyage recorder
- creation and editing of charts using the digitizer or chart additions editor
- providing data to docking displays
- providing precision manoeuvring displays
- man overboard display
- providing data to a conning station
- display of engine room data
- display of meteorological data.

Computers required for essential and important functions are only to be used for purposes relevant to vessel operation and the VMS-VT is normally configured to prevent the operator from installing or running any other application.

A VMS-VT application that includes some of the optional functions mentioned above is shown in Figure 6.12.

Among the displays shown in Figure 6.12 is an ECDIS that uses digital chart data to produce a chart display (see Chapter 7 for more information on ECDIS). The VMS-VT system has the capability to catalogue and display many types of chart formats including commercially available scanned charts produced by official hydrographic offices and/or commercially produced vector charts. Chart formats differ but VMS-VT can be configured at the factory or on the ship to use the chart format specified

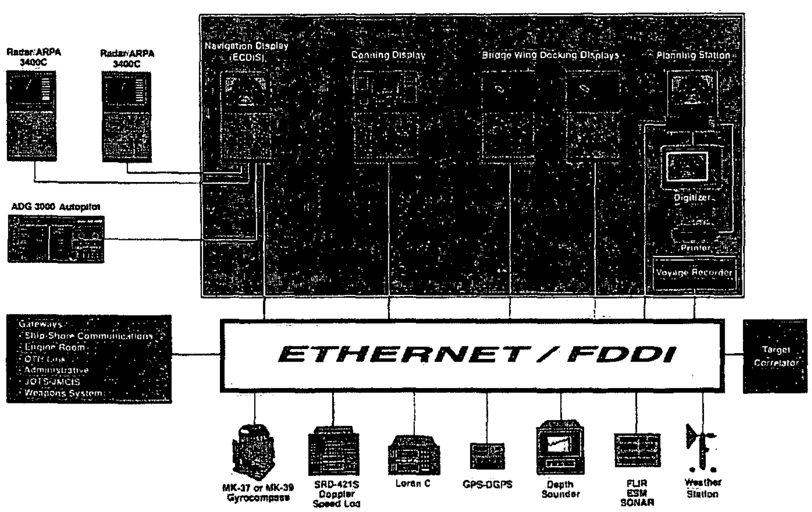


Figure 6.12 Block diagram of the VMS-VT system. (Reproduced courtesy of Litton Marine Systems.)

by the customer. Reference to Chapter 7 will show that an ECDIS must use an electronic navigational chart (ENC) which possesses a single universal data format and they must be 'official' charts in that they are issued on the authority of a government authorized hydrographic office.

Available chart formats include: S57 charts; NIMA (National Imagery and Mapping Agency) DNC charts; British Admiralty ARCS raster charts (BA charts); BSB format charts such as those issued by the National Oceanic and Atmospheric Administration (NOAA); and digitized charts. Electronic charts can be retrieved from CD-ROM disks or from the computer hard disk if the required chart has been stored there.

The VMS-VT Planning Station may include a digitizer pad so that staff can create electronic charts. The digitizer can also be used to edit these electronic charts when a published Notice to Mariners updates the corresponding paper chart. The charts are stored as individual files in the VMS-VT workstations. Those charts digitized at the planning station can be copied to floppy disks for back-up storage and for transfer between ships. A standard 1.44M byte floppy disk can hold about 20 detailed charts. The digitizer can also be used to create navlines with a latitude/longitude reference, which can be transferred and displayed on the RASCAR radars.

Sensor data integration and display

A major feature of the VMS-VT system is the ability to receive sensor data from the local area network and from direct hardware interfaces. The primary type of sensor data processed by the system is navigational information, which includes:

- heading
- speed over the ground
- speed through the water
- geographic position
- set and drift
- course over the ground.

The VMS-VT sorts the data by type and provides a separate source window for each type of data. To display the source window for a particular data type requires the operator to select the appropriate button on the main menu. Each source window lists a group of sensors appropriate to the data type. The present data from each sensor is included in the window so that the best source can be selected from the list. As an example the position source window, as shown in Figure 6.13, is displayed by selecting the POS button on the main menu.

The position source window provides a list of all the configured position sensors along with the present data from each sensor. The operator may select the desired source of position data from this list or may open source windows for other types of navigational data in a similar manner.

Radar target data

The VMS-VT system allows access and display of target information from multiple ARPA radars. The Litton Marine Systems RASCAR radar contains a target data logging switch for the target data logging option. If required, all the connecting RASCAR radars can send their target data allowing the operator to choose the source of ARPA target information. Radar data is automatically processed into a single target list so that if two radars have acquired the same target it will be displayed as one target at the VMS-VT. Symbols representing radar targets are displayed on the electronic chart. Each target symbol includes a speed vector, history dots and an identification number (ID).

A typical bridge layout with VMS-VT installed is shown in Figure 6.14.

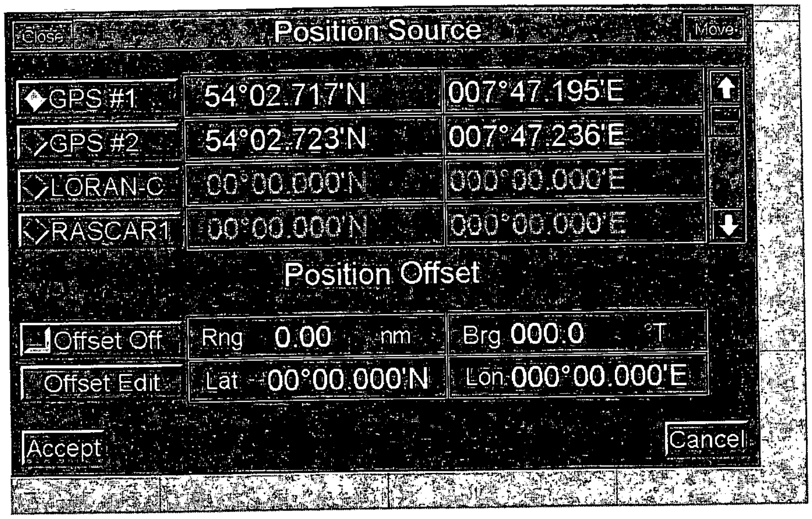


Figure 6.13 Example of VMS-VT position source window. (Reproduced courtesy of Litton Marine Systems.)

Figure 6.14 A typical integrated bridge VMS-VT installation. (Reproduced courtesy of Litton Marine Systems.)

6.11 Glossary

ABS	American Bureau of Shipping.
AIS	Automatic Identification System.
ANTS	Automatic Navigation and Track-keeping System. A system which automatically keeps a ship along a safe pre-planned track.
ARCS	Admiralty Raster Chart Service. The UKHO proprietary Raster Navigational Chart.
ARPA	Automatic Radar Plotting Aid.
Bridge	The area from which the navigation and control of the ship is managed.
Bridge system	The total system required for the performance of bridge functions, including bridge personnel, technical systems, man/machine interface and procedures.
Bridge wing	That part of the bridge on each side of the wheelhouse which extends to the ship's side.
CCTV	Closed Circuit Television. A system that allows monitoring of positions remotely by using cameras and monitor screens.
Coastal waters	Waters that encompass navigation along a coast at a distance less than the equivalence of 30 min of sailing with the relevant ship speed. The other side of the course line allows freedom of course setting in any direction for a distance equivalent to at least 30 min of sailing with the relevant speed.
Conning position	A place on the bridge with a commanding view, which provides the necessary information and equipment for a conning officer (pilot) to carry out his functions.
Conning information display (CID)	A display which clearly presents the state and/or value of all sensor inputs relevant to navigation and manoeuvring as well as all corresponding orders to steering and propulsion systems.
Display	The means by which a device presents visual information to the navigator.
DGPS	Differential Global Positioning System.
DNV	Det Norske Veritas. A member of IACS.
Docking	Manoeuvring the ship alongside a berth and controlling the mooring operations.
EBL	Electronic bearing lines.
ECDIS	Electronic Chart Display and Information System. The performance standard approved by the IMO and defined in publications from the IHO (Special Publications S-52 and S-57) and IEC document 1174.
ENC	Electronic Navigational Chart. Those charts, manufactured for use with ECDIS, which meet the ECDIS performance standards and are issued by or on the authority of government-authorized hydrographic offices.
Ergonomics	Application of the human factors implication in the analysis and design of the workplace and equipment.
ETA	Estimated time of arrival.
GMDSS	Global Maritime Distress and Safety System.
GNSS	Global Navigation Satellite System. The use of GPS for civilian purposes.
GPS	Global Positioning System. A satellite navigation system designed to provide continuous position and velocity data in three dimensions and accurate timing information globally.

Helmsman	The person who steers the ship when it is under way.
IACS	International Association of Classification Societies. Classification embodies the technical rules, regulations, standards, guidelines and associated surveys and inspections covering the design, construction and through-life compliance of a ship's structure and essential engineering and electrical systems.
IEC	International Electrotechnical Commission. The organization which produces world standards in the area of electrical and electronic engineering.
IEC TC80	A technical committee of the IEC that covers the area of Marine Navigation and Radio Communication Equipment and Systems.
IHO	International Hydrographic Organization. A grouping of national hydrographic offices responsible for promoting international standards in the fields of hydrographic surveying and chart production.
IMO	International Maritime Organization. A specialized agency of the United Nations and responsible for promoting maritime safety and navigational efficiency.
ISO	International Standards Organization. A non-governmental organization working to produce international agreements that are published as International Standards.
ITU	International Telecommunications Union.
LAN	Local area network.
LCD	Liquid crystal display. A form of display where the display elements are typically dark coloured alphanumerics on a grey screen. The display is easily read even in bright light conditions.
MOB	Man overboard.
Narrow waters	Waters that do not allow the freedom of course setting to any side of the course line for a distance equivalent to 30 min of sailing with the relevant ship speed.
Navigation	The determination of position and course of a ship and the execution of course alterations.
NMEA	National Marine Electronics Association. An organization comprising manufacturers and distributors. Responsible for agreeing standards for interfacing between various electronic systems on ships. NMEA 0183 version 2.3 is the current standard.
Manoeuvring	The operation of steering systems and propulsion machinery as required to move the ship into predetermined directions, positions or tracks.
Monitoring	The act of constantly checking information from instrument displays and environment in order to detect any irregularities.
Ocean areas	Waters that encompass navigation beyond the outer limits of coastal waters. Ocean areas do not restrict the freedom of course setting in any direction for a distance equivalent to 30 min of sailing with the relevant ship speed.
PPI	Plan position indicator. A type of radar display.
Route planning	Pre-determination of course and speed in relation to the waters to be navigated.
Route monitoring	Continuous surveillance of the ship's position and course in relation to a pre-planned route and the waters.
RPM	Revolutions per minute.

Screen A device used for presenting visual information based on one or more displays.

SOLAS Safety of Life at Sea. The International Convention for the Safety of Life at Sea, Chapter V Safety of Navigation, Regulation 20, Nautical Publications requires that 'All ships shall carry adequate and up-to-date charts, sailing directions, lists of lights, notices to mariners, tide tables and all other nautical publications necessary for the intended voyage.' SOLAS does not apply universally and some vessels, such as ships of war, cargo ships of less than 500 GRT, fishing vessels etc are exempt from the SOLAS requirements.

VRM Variable range markers.

Watchkeeping Duty undertaken by an officer of the watch. The officer of the watch is responsible for the safety of navigation and bridge operations until relieved by another qualified officer.

Waypoint A point entered into a computer and used as a reference point for navigational calculations. Planned voyages would have a series of waypoints indicating legs of the voyage. A modern computer is capable of storing multiple waypoints.

Wheelhouse Enclosed area of the bridge.

Workstation A position at which one or more tasks constituting a particular activity are carried out.

6.12 Summary

- Organizations such as the IMO, ISO and IEC have established international recognition of standards for ships involved in international trading.
- The integrated bridge system should be designed and installed as a physical combination of equipment or systems using interconnected controls and displays.
- Rules from classification societies, such as DNV, specify design criteria for bridge workstations, defining tasks to be performed and the siting of equipment to enable those tasks to be performed.
- The IEC Technical Committee (TC80) has produced a publication IEC 61209 covering operational and performance requirements, methods of testing and required test results for integrated bridge systems.
- To achieve optimum safety and efficiency in bridge operation, the classification society rules address the total bridge system that is considered to consist of four essential parts, namely the technical system, the human operator, the man/machine interface, and the procedures.
- The Rules for Nautical Safety are divided into three class notations: NAUT-C covers bridge design; W1-OC covers bridge design, instrumentation and bridge procedures; and W1 covers W1-OC and extensions within specified areas of W1-OC.
- Equipment carriage requirements are specified for ships according to the requested class notation.
- An operational safety manual is a requirement for class notation W1 and should obey the following guidelines: organization, daily routines, operation and maintenance of navigational equipment, departure/arrival procedures, navigational procedures, and system fall-back procedures.
- Ships requesting class notation W1-OC or W1 must comply with rules for bridge equipment tests. After installation of equipment on-board testing shall be performed in order to ascertain that the equipment, as installed, operates satisfactorily.

- A variety of manufacturers offer a range of integrated bridge systems that can be tailored to fit the requirements of the user.

6.13 Revision questions

1 Describe briefly the design criteria that define an integrated bridge system.
2 Describe briefly the equipment requirements for an automatic navigation and track-keeping system (ANTS).
3 Discuss the DNV rules for design criteria for bridge workstations and comment on the implications of such rules in terms of the tasks that have to be performed and the siting of relevant instruments/equipment required for those tasks.
4 What are the four essential parts that have to be considered to achieve optimum safety and efficiency in bridge operation.
5 Discuss the rule requirements set out in each section of the DNV Rules for Nautical Safety and comment on the different factors that affects the performance of the total bridge system.
6 What do you understand by class notations? Discuss the differences between the class notations NAUT-C, W1-OC and W1.
7 What do you understand by the term 'general bridge equipment requirements'. What are the specific requirements for different types of bridge equipment?
8 Comment briefly on the rules for manoeuvring information. What type of information should be included in the provision of manoeuvring information? What form should the presentation of manoeuvring information take?
9 Describe the requirement for bridge equipment testing. Mention the type of equipment to be tested and discuss the reasons for the requirement for testing.
10 Refer to one of the examples of an integrated bridge system discussed in Section 6.10 and discuss how the system is organized to meet the requirements for such a system as specified in Sections 6.2, 6.3 and 6.4.

Chapter 7
Electronic charts

7.1 Introduction

Ever since man first went to sea there has been a requirement for some form of recognition of the sea-going environment to assist in the safe passage to the required destination. Knowledge of the coastline, safe channels for navigation which avoid wrecks, sandbanks etc., and tidal information all play their part in assisting the navigator. Paper charts giving information about particular areas have been around for centuries and hydrographers from various countries have explored the world's oceans to produce up-to-date charts which are an invaluable aid to the seafarer whether they are aboard commercial vessels plying their trade around the world or leisure craft sailing for pleasure and recreation.

In 1683 an official survey of British waters was initiated by Royal Command, although the surveys that were published some 10 years later were produced at the surveyor's expense. In the 18th century much hydrographic work around the world was done by British hydrographers, although they still had to have their work published at their own expense, gaining recompense only by selling the results of their efforts privately. It was not until 1795 that the office of Hydrographer to the Board of Admiralty was established, the French having established their Hydrographic Office some 75 years earlier. The United Kingdom Hydrographic Office (UKHO), as it is now called, has an enviable reputation as a supplier of high quality charts and provides worldwide coverage with a folio of some 3300 charts. The UKHO is a member of the International Hydrographic Organization (IHO), a body set up to co-ordinate the activities of national hydrographic offices, promote reliable and efficient hydrographic surveys and ensure uniformity of chart documentation.

It was in 1807 that the Office of Coast Survey was set up in the United States for the purpose of surveying the US coast. Various name changes followed over the years, becoming the National Ocean Survey under the newly established National Oceanic and Atmospheric Administration (NOAA) in 1970. In 1982 a further name change produced the National Ocean Service (NOS) which contained an Office of Charting and Geodetic Services which was renamed as the Coast and Geodetic Survey (C&GS) in 1991. C&GS disappeared in a 1994 restructuring but the former subordinate division, the Nautical Charting Division, re-emerged as the present Office of Coast Survey (OCS), responsible for NOAA's mapping and charting programmes. Divisions within the OCS include the Marine Chart Division, which collects the data to enable the production of nautical charts, and the Hydrographic Surveys Division, which is responsible for all areas of hydrographic survey operations.

The OCS produces about 1000 nautical charts and is also a member of the IHO and, together with the National Imagery and Mapping Agency (NIMA) share responsibilities associated with IHO membership. The IHO presently consists of 67 member states. Most of these chart only their own waters but there are three nations that can supply chart folios of the world and two more that have coverage that extends outside their own waters. The IHO is a force for chart standardization throughout the world and this is an important feature of the move towards digital production of chart data.

At the present time most hydrographic offices still operate with the paper chart as the basis of their operations. However, over the past few years electronics has moved into the sphere of charting and now digital chart data is becoming more popular and is likely to be the mainstay product of the hydrographic offices in the years to come. With this new technology the seafarer is provided with a means of viewing a chart using a monitor that can display, in colour, all the information present on a paper chart. The chart information is contained on a memory device such as a CD-ROM and can be stored on a computer hard disk. Suitable navigational software can enable the chart data to be viewed for the purpose of 'safe and efficient navigation'. The electronic chart is one where chart data is provided as a digital charting system and it is capable of displaying both geographical data and text to assist the navigator. An electronic chart may fall into one of two categories.

- Official, which describes those electronic charts which are issued by, or on the authority of, a national hydrographic office. The hydrographic offices are government agencies and are legally liable for the quality of their products regardless of whether those products are paper or digital. Such charts are updated at regular intervals in order to conform to the SOLAS (Safety of Life at Sea) requirement that charts should be 'adequate and up-to-date for the intended voyage'.
- Non-official, which describes those electronic charts which are issued by commercial organizations which may use data owned by a hydrographic authority but are not endorsed by that authority.

An electronic chart may be constructed using either of two types of data, raster or vector.

7.1.1 Raster data

Raster data is produced by scanning a paper chart. This process produces an image that is an exact replica of the paper chart and which comprises a number of lines that are composed of a large number of coloured dots, or pixels. This technique does not recognize individual objects, such as a sounding, which limits its ability to conform to certain international guidelines. However, the use of what is termed a vector overlay, which can display specified user data such as waypoints and system data such as radar overlays etc., can overcome this deficiency. The advantages of raster charts can be summarized as follows.

- User familiarity since they use the same symbols and colours as paper charts.
- They are exact copies of the paper charts with the same reliability and integrity.
- The user cannot inadvertently omit any navigational information from the display.
- Cost of production is less than their vector counterpart.
- Wide availability of official raster charts. ARCS charts, for example, have near worldwide coverage.
- By using vector overlays together with appropriate software, raster charts can be used for all standard navigational tasks normally undertaken using paper charts. They can also emulate some of the functions of an electronic display and information system (ECDIS).

Disadvantages of raster charts can be summarized as follows.

- The user cannot customize the display.
- When using vector overlays the display may appear cluttered.
- They cannot be interrogated without an additional database with a common reference system.

- They cannot, directly, provide indications or alarms to indicate a warning to the user.
- Unless data content is the same, more memory is required to store data compared to a vector chart.

7.1.2 Vector data

Apart from the electronic navigational chart (ENC), which is compiled using raw data, vector data may also be produced by scanning a paper chart. However, the raster image is then vectorized by digitally encoding individual charted objects and their attributes (structured encoding) and storing such data, together with the object's geographical location, in a database. The ENC is the designated chart for the ECDIS system and is discussed in the next section. Chart features may be grouped together and stored in thematic layers that individually categorize each group. For example, the coastline could form one layer while depth contours are found on another layer etc. The system operator can thus optimize the display to show only that data of interest and avoid the display becoming cluttered with unwanted data. The vector chart is intelligent in that it can provide information that allows a warning of impending dangers to be generated.

The process of producing vector charts is time consuming and expensive while verification of chart data is more complicated than its raster counterpart. The advantages of vector charts can be summarized as follows.

- Chart information is in layers which allows selective display of data.
- The display may be customized to suit the user.
- Chart data is seamless.
- It is possible to zoom-in without distorting the displayed data.
- Charted objects may be interrogated to give information to the user.
- Indications and alarms can be given when a hazardous situation, such as crossing a safety contour, occurs.
- Objects may be shown using different symbols to those used on paper or raster charts.
- Chart data may be shared with other equipment such as radar and ARPA.
- Unless data content is the same, less memory is required to store data compared to a raster chart.

Disadvantages of the vector chart can be summarized as follows.

- They are technically far more complex than raster charts.
- They are more costly and take longer to produce.
- Worldwide coverage is unlikely to be achieved for many years, if ever.
- It is more difficult to ensure the quality and integrity of the displayed vector data.
- Training in the use of vector charts is likely to be more time consuming and costly compared to that needed for raster charts.

The vehicle for the delivery of electronic chart data is the Electronic Chart Display and Information System (ECDIS) which is a navigation hardware/software information system using official vector charts. Such a system must conform to the internationally agreed standard adopted by the International Maritime Organization (IMO) as satisfying a vessel's chart-carrying requirements under SOLAS. The ECDIS hardware could be simply a computer with graphics capability or a graphics workstation provided as part of an integrated bridge system. The system has inputs from other sources, namely position sensors such as GPS or loran, course indication from the gyrocompass, speed from the ship's log etc.

The information is transmitted to the ECDIS using National Marine Electronics Association (NMEA) interfacing protocols. Radar information can also be superimposed using either raw data from a raster scan radar or as synthetic ARPA (automatic radar plotting aid) data. The ECDIS software must comprise a user interface and a component that allows charts to be displayed and data read. The chart data component of ECDIS is the electronic navigational chart (ENC) which must comply with ENC production specifications under the IHO's S-57 edition 3 data transfer standard. More details of this system can be found in Section 7.3.

7.2 Electronic chart types

There are many different types of electronic charts available that use different formats, different levels of content and attribution, and may, or may not, be official charts. As described above, all presently available electronic charts are either vector or raster. For the former, the chart may be based on the IHO S-57 format or some other format. Only if the level of content and attribution of the chart conforms to the IHO ENC product specification and is produced by, or on the authority of, a government authorized hydrographic office, can the chart be considered an ENC as defined by the IMO ECDIS performance standards.

Official vector charts issued by the relevant hydrographic offices should conform to the ENC product specification based on the IHO S-57 format. Privately produced vector charts (non-official) may, or may not, conform to the ENC product specification. However, the use of unofficial ENCs will render an ECDIS non-compliant. Finally, it is possible to obtain charts that do not use the IHO S-57 format and do not conform to the ENC product specification.

7.2.1 Privately produced vector charts

These are generally made from scanned hydrographic office paper charts. The image produced is then digitized by tracing lines and features on the chart. This vectorization process stores chart features in 'layers' which can be redrawn automatically at an appropriate size if the chart is zoomed into. Categories of data, such as spot depths, navigation marks etc., can be added/deleted as required. In some systems specific chart items can be interrogated to obtain more information.

The nature of the vector display is such that the chart data is not displayed electronically as it was compiled in its paper chart form. Most systems automatically decide on the information to be displayed, depending on the level of zoom, to avoid the image being cluttered. Thus a new operational regime has to be developed to take account of the implications of:

- adding/deleting layers of data
- zooming and seeing more/less data appear according to the level of zoom
- displaying the chart at a larger scale than the source paper chart.

One of the principal producers of digital format electronic charts is C-MAP of Norway with worldwide coverage of 7500 charts on a CD-ROM. Data is coded in a System Electronic Navigational Chart (SENC) format called CM-93/3 which is compliant with the IHO S-57 format. C-MAP 93/3 displays a -U- (for unofficial) on their privately produced S-57 compliant charts. Details of the use of a SENC in an ECDIS is discussed in Section 7.3.

7.2.2 Official raster chart

There are two official raster chart formats.

- BSB raster charts, which contain all the data found in NOAA paper charts, with updates published weekly. These updates are available via the Internet and are in-sync with the US Coast Guard (USCG), NIMA and Canadian notices. NOAA has 1000 official charts and all have been available in raster form since 1995. These raster charts are produced jointly by NOAA and Maptech Inc. under a co-operative research and development agreement. The growth of computer-based navigation systems, together with GPS and other positioning systems, has meant an increase in the sale of raster charts and today approximately twice as many raster charts are sold compared to paper charts. The raster charts are available in CD-ROM form with each CD-ROM containing about 55 charts together with other relevant navigational facilities.
- UKHO ARCS and Australian Hydrographic Office (AHO) Seafarer both produced in the UKHO's proprietary hydrographic chart raster format (HCRF). ARCS is updated weekly using a CD-ROM with the same information as the weekly Notice to Mariners used to correct paper charts. Seafarer is updated monthly on a similar basis. ARCS has near worldwide coverage with 2700 charts available on CD-ROM.

ARCS/Seafarer charts are produced from the same process used to print paper charts, i.e. a rasterized process is used either to print a paper chart or produce a raster chart. They are accurate representations of the original paper chart with every pixel referenced to a latitude and longitude. Where applicable, horizontal datum shifts are included with each chart to enable the chart, and any information overlaid on it, to be referenced back to WGS-84. Not all available charts have WGS-84 shift information and such charts must be used with caution when a GPS position fix is applied. Chart accuracy is discussed further in Section 7.4.

The UKHO ARCS production system involves the use of a raster base maintenance and on-line compilation system (ABRAHAM) which is used to update, manage and plot navigational chart bases. The ARCS production system is integrated with ABRAHAM as is shown in Figure 7.1.

In its simplest terms ABRAHAM is all processes that are necessary to create and maintain the high-resolution (25 μ/1016 dpi) monochrome raster bases from which paper charts are produced, and ARCS is all processes that turn the ABRAHAM bases into ARCS CD-ROMs including:

- processing bases into lower resolution (200 μ/127 dpi) colour images
- adding header and catalogue information
- quality assurance checks
- encrypting the data
- ending a CD-ROM master to a pressing plant
- checking the stock returned by the pressing plant.

The ARCS CD-ROM production can be subdivided into periodic processing cycles.

- Weekly. Updates for all charts affected by Notice to Mariners are generated, checked and placed on the weekly ARCS update CD-ROM. New charts and new editions published that week are also included on the update CD, as is the text of temporary and preliminary Notices to Mariners.
- Periodic. To prevent the update CD from filling up, accumulated updates are periodically moved onto reissues of the ARCS chart CD-ROMs. This results in the production of a reissued chart CD at the same time as the weekly update CD. Nominally, one chart CD requires to be reissued each

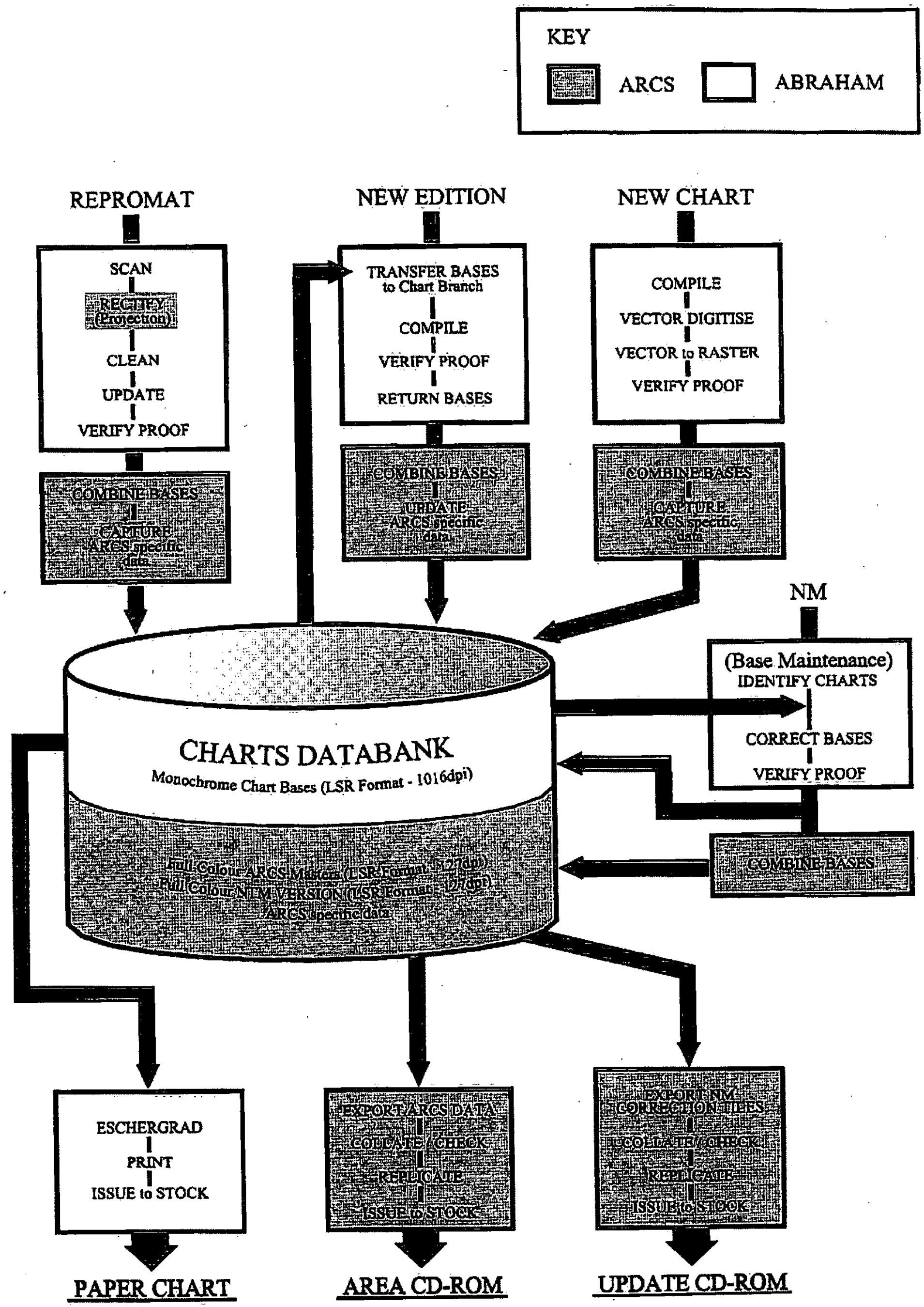
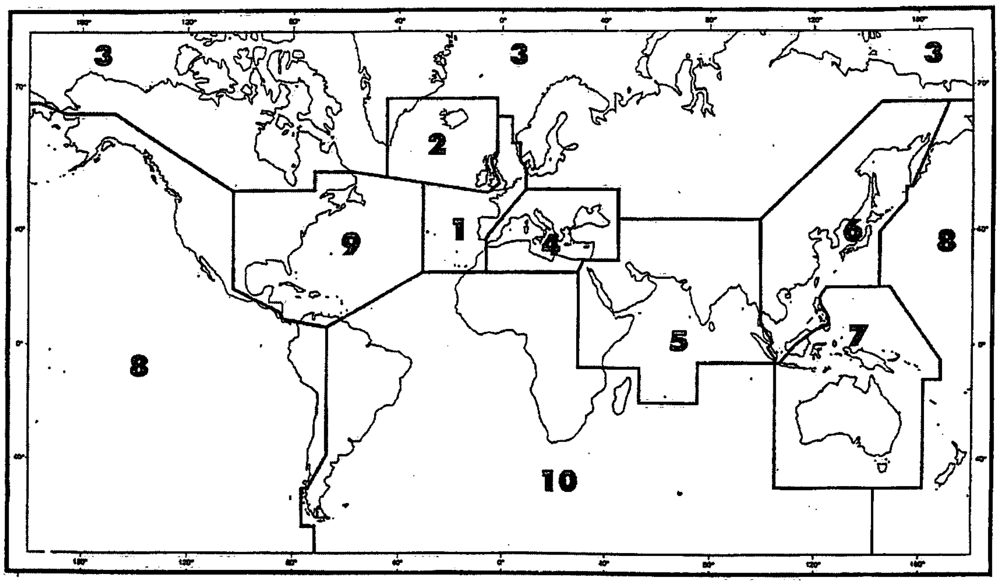


Figure 7.1 ARCS/ABRAHAM production system. (Reproduced with the permission of the Controller of HMSO and the United Kingdom Hydrographic Office.)



RC 1. North Sea and English Channel to Gibraltar
RC 2. British Isles (west coast) and Iceland
RC 3. Northern waters and Baltic Sea
RC 4. Mediterranean and Black Seas
RC 5. Indian Ocean (northern part) and Red Sea
RC 6. Singapore to Japan
RC 7. Australasia, Borneo and Philippines
RC 8. Pacific Ocean
RC 9. North America (east coast) and Caribbean
RC 10. South Atlantic and Indian Ocean (southern part)
RC 11. Ocean Charts (1:3.500.000 and smaller)

Figure 7.2 Regional coverage of ARCS CD-ROMs. (Reproduced with the permission of the Controller of HMSO and the United Kingdom Hydrographic Office.)

month, but the schedule varies according to the number of corrections outstanding and the number of chart CDs in stock.
- Monthly. Cross-checks are carried out against the data held on the Sales Order Processing System and the Chart Information System (CIS).

The UKHO provides a near worldwide coverage with 2700 charts available as ARCS CD-ROMs. The regional coverage of these charts is shown in Figure 7.2.

Table 7.1 gives a comparison between the BSB and ARCS raster types.

7.2.3 Electronic navigational charts (ENC)

These are the designated charts for the ECDIS system and they possess a single universal data format. Such charts use vector data based on the IHO Special Publication S-57, edition 3, IHO Transfer Standard for Digital Hydrographic Data. Some of the major points which identify the unique property of these charts are as follows.

- They are issued by or on the authority of a government-authorized hydrographic office.
- Items on the chart must be attribute-coded and must be able to be interrogated to provide information.

Table 7.1 Comparison between different raster chart types. (Reproduced courtesy of D. Edmonds of PC Maritime, UK)

Feature	*BSB*	*ARCS*
Government authorized	Yes	Yes
Entire catalogue always up to date to latest notice to mariner	Yes	Yes
Update service	Weekly	Weekly
Original scan from:	Stable mylar film originals used for printing paper charts	Stable colour separates used for printing paper charts
Scan resolution	762 dpi	1016 dpi
Chart resolution	256 dpi	127 dpi
Anti-aliasing	Yes	Yes
No of points used to relate the chart images to Lat/Long conversion	10–20, pixel to location conversions are also provided, accuracy depends on the printed chart	Pixel to position conversion is by calculation and is accurate to 1 pixel
Geodetic datum shifts	Yes	Yes
Integrity checks	Byte checksums are included in chart file	32-bit CRC check on original and updated image
Liability	US government accepts liability for errors on NOAA charts	UK government accepts liability on UKHO products

- The data is delivered in cells to provide seamless data for the task in hand. The cell structure changes according to the data set used.
- All chart data is referenced to a global geodetic datum, WGS-84, which is the datum used by GPS.

The data is fully scaleable and it only needs a view area to be defined for an appropriate level of data to be automatically presented to the operator. If it is required to add/delete data then information can be grouped into layers and turned on/off as required. Zooming can allow the chart image to be enlarged to provide greater ease of use. Zooming with a raster chart clearly shows when an image is presented at a scale greater than the compilation scale since the text and navigational symbols would be larger than their normal size rendering the chart unsafe for navigation. Over-scaling with an ENC has the problem that the navigational symbols remain the same size regardless of the scale used and this could cause a potential navigation hazard. The ECDIS is required to display an over-scale warning automatically if it has used zooming to produce an image beyond the compilation scale of the chart.

Individual contour lines can be defined as safety contours with anti-grounding warnings given based on the ship's closeness to them. Alarms will be generated automatically if the ECDIS detects a conflict between the vessel's predicted track and a hydrographic feature within the ENC that represents a potential hazard to the vessel.

The ECDIS can offer different chart information by displaying all ENC content, a subset of the ENC content (known as standard display) or a minimum permitted subset of ENC content (known as display base). The first two categories permit information to be added/deleted while the display base cannot have information deleted since it is stipulated as the minimum required for safe navigation. A System Electronic Navigational Chart (SENC) is that database obtained by the transformation of the ENC data, including any updates and data added by the user, by the ECDIS prior to display. It is the SENC that forms the basis for the display and the user decides what part of the SENC database is required for the display. It is a requirement that the ENC database must remain unaltered so that the SENC database could be reconstructed should it be debased in any way during operations.

The availability of ENCs will depend on key factors that affect the NHOs producing them. These factors include the following.

- Production experience. The rate of production should increase as staff gain more experience in the production of these charts.
- Data quality. Software tools necessary to underpin the quality assurance of the digital database have to be developed to ensure compliance with S57, edition 3 requirements. This will take time.
- Uniformity of data. There is a need for all hydrographic offices to ensure their ENCs are produced with consistency in the interpretation of the standard and to product specification. The use of regional co-ordinating centres is of use in facilitating this.
- Geographical cover. By concentrating on the geographical areas most used by shipping companies it should be possible to deliver the required charts ahead of others.

As an example of the development of ENCs, the UKHO awarded a contract to the Indian company, IIC Technologies, for data capture work in February 2000. This is the first step in the production of ENCs with the data sets produced by IIC to be quality assessed by the UKHO to ensure compliance with the required standards. The UKHO will also concentrate on stitching together the data set cells and matching the edges to produce a seamless ENC database. The contract is an enabling contract of up to four and a half years allowing the UKHO to request data sets in tranches with continuity of production.

The regional co-ordinating centres are an important means of distributing the ENCs to potential customers. The International Hydrographic Organization (IHO) proposed a system for supplying ENCs to be known as Worldwide ENC Database (WEND). Using this concept the world is divided into Regional ENC Co-ordinating Centres (RENCs). At present only one RENC has been set up,

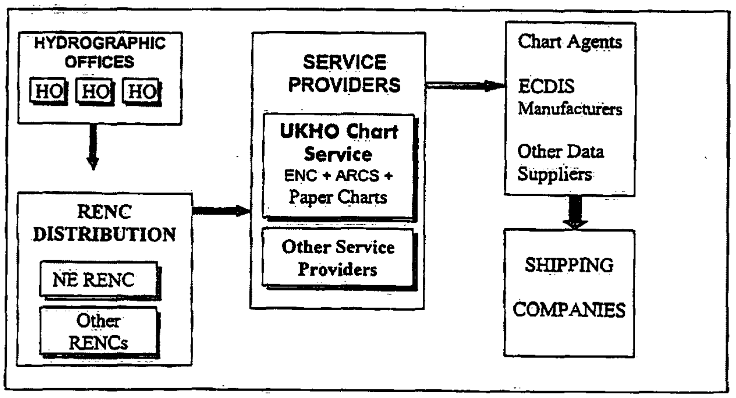


Figure 7.3 RENC distribution system. (Reproduced with the permission of the Controller of HMSO and the UK Hydrographic Office.)

Table 7.2 Equivalence to the paper chart. (Reproduced courtesy of D. Edmonds of PC Maritime, UK)

Privately produced vector charts	*Official raster (RNCs)*	*ENCs*
Generally a copy of the paper chart	An exact replica of paper chart	All data merged into cells
A different image to the original paper chart is presented at all levels of zoom and scale	The same image as the paper chart is always presented. The chart is more equivalent to the paper chart than any vector chart including ENCs	No resemblence to the paper chart
Symbols and colour vary with manufacturer	Symbols and colour are the same as the paper chart equivalent	The IHO publication S–52 defines new colours and symbols for ENCs
Accuracy, reliability and completeness vary with manufacturer	RNCs are as accurate, reliable and complete as the paper version	ENCs should eventually be more accurate and reliable than the paper version
A new operational regime is required	The same operational regime as paper charts is followed. There are some changes, if only because of screen size	A new operational regime is required

Table 7.3 Chart integrity. (Reproduced courtesy of D. Edmonds of PC Maritime, UK)

Privately produced vector charts	*Official raster (RNCs)*	*ENCs*
Produced by private companies	Produced by, or under the authority of government authorised hydrographic offices	Produced by, or under the authority of government authorised hydrographic offices
Unofficial	Official	Official
Generally no responsibility is accepted	Responsibility is accepted for chart data in terms of its completeness and accuracy in comparison with the equivalent paper chart	Responsibility is accepted for chart data in terms of its completeness and accuracy
Is unlikely to become legally equivalent to the paper chart	Is unlikely to become legally equivalent to the paper chart	Is legally equivalent to the paper chart
It may be possible to change original chart data	The chart data is tamper proof	The chart data is tamper proof
Charts can be zoomed (i.e., the display of a single chart is magnified or reduced without restriction. Chart detail varies depending on the level of zoom)	Chart zoom should be limited to a level that does not break up the image. Information displayed on the chart remains unaltered	Charts can be zoomed in or out without restriction. Chart detail varies depending on the level of zoom
Quality control varies with manufacturer	Quality control is government standard	Quality control is government standard

Table 7.4 Chart corrections. (Reproduced courtesy of D. Edmonds of PC Maritime, UK)

Privately produced vector charts	*Official raster (RNCs)*	*ENCs*
Up-to-dateness of charts varies with manufacturer	Charts are up-to-date at the point of sale	Charts will be up-to-date at the point of sale
It is difficult to determine the up-dating policy of manufacturers	Chart data is maintained up-to-date to clearly stated standards	Chart data is maintained to a clearly defined standard
Varies with manufacturer	On demand updates for leisure users	Not applicable
Varies with manufacturer	Subscription updates for commercial users	Subscription updates available
Varies with manufacturer	Automatic integration of chart updates	Automatic integration of chart updates

Table 7.5 Safety. (Reproduced courtesy of D. Edmonds of PC Maritime, UK)

Privately produced vector charts	*Official raster (RNCs)*	*ENCs*
Geodetic datum shift to WGS-84 may not be provided	Chart data includes geodetic datum shift to WGS-84, if known	All data is referenced to WGS-84
Chart data can be removed from the display. Significant navigation information may be inadvertently removed	Chart data cannot be removed from the display. The user cannot inadvertently remove significant navigation information	Chart data can be removed from the display. Significant navigation information may be inadvertently removed

namely the Northern Europe RENC known as PRIMAR. This is a co-operative arrangement between most of the national hydrographic offices in northern and western Europe. To date the hydrographic offices of Denmark, Finland, France, Germany, Netherlands, Norway, Portugal, Poland, Sweden and UK have signed the formal co-operation arrangement and other hydrographic offices have expressed an interest in joining. PRIMAR is operated by the UK Hydrographic Office and the Norwegian Mapping Authority's Electronic Chart Centre.

The ENCs will be sold through a network of distributors and should be able to provide worldwide cover by exchange of data with other RENCs once these are established in other parts of the world. A block diagram showing the RENC concept is shown in Figure 7.3.

Tables 7.2 to 7.5 summarize the features of each chart type in relation to each other.

7.3 Electronic chart systems

7.3.1 Electronic Chart Display and Information System (ECDIS)

There are several types of electronic chart systems available but only one performance standard has been approved by the International Maritime Organization (IMO) in November 1995. The IMO resolution A817(19) states that the ECDIS should 'assist the mariner in route planning and route monitoring and, if required, display additional navigation-related information'. The system approved is known as the Electronic Chart Display and Information System (ECDIS) and applies to vessels governed by Regulation V, Chapter 20 of the 1974 Safety of Life at Sea (SOLAS) convention. It complies with the carriage requirement for charts with an ECDIS system using Electronic Navigational Charts (ENCs). ECDIS is a navigational information system comprising hardware, display software and official vector charts and must conform to the ECDIS performance standards; amongst other aspects these performance standards govern chart data structure, minimum display requirements and minimum equipment specifications. Chart data used in an ECDIS must conform to the Electronic Navigational Chart (ENC) S-57, edition 3.0 specification and the performance standard for this was agreed by the International Hydrographic Organization (IHO) in February 1996. Any ENC must be issued on the authority of a government-authorized hydrographic office.

Back-up arrangements for ECDIS were agreed by the IMO in November 1996, becoming Appendix .6 to the Performance Standards and allowing ECDIS to be legally equivalent to the charts required under regulation V/20 of the 1974 SOLAS convention. It is an IMO requirement that the National Hydrographic Offices (NHOs) of Member Governments issue, or authorize the issue of, the ENCs, together with an updating service, and that ECDIS manufacturers should produce their systems in accordance with the Performance Standards. Other notable milestones leading to the ECDIS specification include the following.

- IHO Special Publication S-52 which specifies chart content and display of ECDIS. This includes appendices specifying the issue, updating and display of ENC, colour and symbol specification. The IHO Special Publication S-52 was produced in December 1996.
- IEC International Standard 61174. In this publication the International Electrotechnical Commission describes methods of testing, and the required test results, for an ECDIS to comply with IMO requirements. The standard was officially published in August 1998 and is to be used as the basic requirement for type approval and certification of an ECDIS which complies with the IMO requirements.

Some ECDIS definitions are summarized below.

- **Electronic Chart Display and Information System (ECDIS)** means a navigation system which, with adequate back-up arrangements, can be accepted as complying with the up-to-date chart required by regulation V/20 of the 1974 SOLAS Convention, by displaying selected information from a System Electronic Navigational Chart (SENC) with positional information from navigational sensors to assist the mariner in route planning, route monitoring and displaying additional navigational-related information if required.
- **Electronic Navigational Chart (ENC)** is the database, standardized as to content, structure and format, issued for use with ECDIS on the authority of government-authorized hydrographic offices.
- **System Electronic Navigational Chart (SENC)** is a database resulting from the transformation of the ENC by ECDIS for appropriate use, updates to the ENC by appropriate means, and other data added by the mariner.
- **Standard Display** means the SENC information that should be shown when a chart is first displayed on an ECDIS. The level of information provided for route planning and route monitoring may be modified by the mariner.
- **Display Base** means the level of SENC information which cannot be removed from the display, consisting of information which is required at all times in all geographical areas and all circumstances..

The basic ECDIS requirements can be summarized as follows.

- **ENC data.** This is to be supplied by government-authorized hydrographic offices and updated regularly in accordance with IHO standards.
- **Colours/Symbols.** These must conform to the specification outlined in IHO Special Publication S-52. Symbol size and appearance are specified and the mariner should be able to select colour schemes for displaying daylight, twilight and night-time conditions.
- **Own Ship's Position.** The ECDIS should show own ship's position on the display. Such a position is the result of positional input data received from suitable sensors and should be continuously updated on the display.
- **Change Scale.** The use of zoom-in and zoom-out should allow information to be displayed using different scales. ECDIS must display a warning if the information shown is at a scale larger than that contained in the ENC or if own ship's position is produced by an ENC at a larger scale than that shown by the display.
- **Display Mode.** The mariner should be able to select a 'north-up' or 'course-up' mode. Also the display should be able to provide true motion, where own ship symbol moves across the display, or relative motion where own ship remains stationary and the chart moves relative to the ship.
- **Safety Depth/Contour.** The mariner can select safety depth, whereby all soundings less than or equal to the safety depth are highlighted, or safety contour whereby the contour is highlighted over other depth contours.
- **Other Navigational Information.** Radar or ARPA data may be added to the display.

As emphasized earlier, one of the key requirements for ECDIS is to assist the user to plan a route and monitor the route while under way. This and other functions are listed below.

- **Route Planning.** The mariner should be able to undertake the planning of a suitable route, including the provision of waypoints which should be capable of being amended as required. It should be possible for the mariner to specify a limit of deviation from the planned route at which activation of an automatic off-track alarm occurs.
- **Route Monitoring.** ECDIS should show own ship's position when the display covers the area involved. The user should be able to 'look-ahead' while in this mode but be able to restore own ship's position using a 'single operator action'. The data displayed should include continuous indication of ship's position, course and speed and any other information, such as time-to-go, past track history etc., considered necessary by the user. Indication/alarms should feature using parameters set by the mariner.
- **Indication/Alarm.** ECDIS is required to give information about the condition of the system or a component of the system; an alarm should be provided when a condition requires urgent attention. An indication could be visual whereas an alarm could be visual but must also be audible. Indications should include, among others, information overscale, different reference system, route planned over a safety contour etc. Alarms should include, among others, system malfunction, deviation from route, crossing safety contour etc.
- **Record of Voyage.** ECDIS must be capable of recording the track of an entire voyage with timings not exceeding 4-hourly intervals. Also ECDIS should keep a record of the previous 12 h of a voyage; such a record should be recorded in such a way that the data cannot be altered in any way. Also during the previous 12 h of a voyage ECDIS must be capable of reproducing navigational data and verifying the database used. Information such as own ship's past track, time, position, speed and heading and a record of official ENC data used, to include source, edition, date, cell and update history, should be recorded at 1-min intervals.

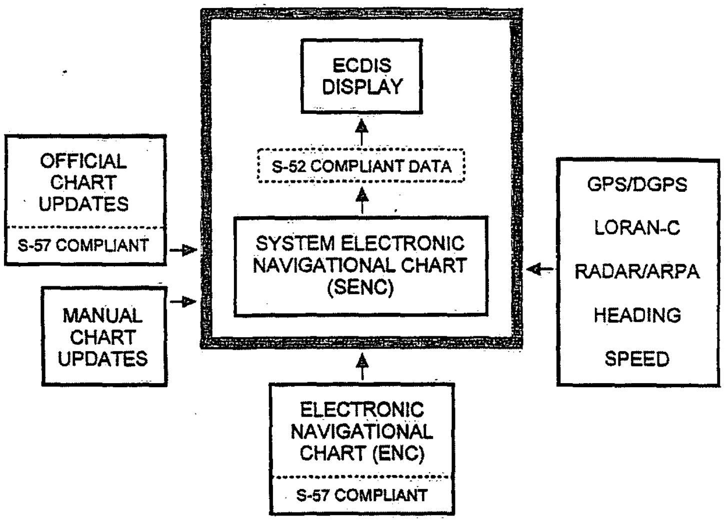


Figure 7.4 Block diagram of an ECDIS. (Reproduced courtesy of Warsash Maritime Centre.)

- **Back-up Arrangements.** This is required in case of an ECDIS failure. The back-up system should display in graphical (chart) form the relevant information of the hydrographic and geographic environment necessary for safe navigation. Such a system should provide for route planning and monitoring. If the back-up system is electronic in form it should be capable of displaying at least the information equivalent to the standard display as defined by the performance standard.

A block diagram of an ECDIS is shown in Figure 7.4.

The production of ENCs is proceeding but it is a lengthy and costly business and it is likely that widespread coverage will not be available for some time and certain regions may never be covered at all. Because of the delay likely in implementing ECDIS, hydrographic offices around the world have proposed an alternative official chart solution that uses the raster chart and is known as the Raster Chart Display System (RCDS).

7.3.2 Raster Chart Display System (RCDS)

This is a system capable of displaying official raster charts that meets the minimum standards required by an appendix to the ECDIS Performance Standard. The raster nautical chart (RNC) is a digital facsimile of the official paper chart and provides a geographically precise, distortion-free image of the paper chart.

The IHO proposed a raster chart standard that 'should form a part of the ECDIS performance standards where it would logically fit'. This was approved by the IMO's Maritime Safety Committee in December 1998 as a new appendix to the existing ECDIS Performance Standard, entitled 'RCDS Mode of Operation'. It is now permissible for ECDIS to operate in RCDS mode using official RNCs when ENCs are not available. The use of ECDIS in RCDS mode can only be considered providing there is a back-up folio of appropriate up-to-date paper charts as determined by national administrations.

Raster charts for these systems have been developed in recent years by major hydrographic offices and include the British Admiralty Raster Chart Service (ARCS) and the NOAA's BSB raster chart. The United States started raster scanning in 1991 and evaluated a prototype of the scheme in 1992. NOAA began converting its charts to raster format in 1993 and completed the task in 1994. The United Kingdom Hydrographic Office (UKHO) started the raster scanning of its Admiralty charts in 1994 and shipboard trials of ARCS began in 1995; the service becoming commercial in 1996. Other nations have also developed their own RCDS charts.

Raster charts are offered as an interim measure while awaiting the arrival of the ENCs and are designed to offer a performance specification that closely follows that of the ENCs and includes important requirements such as:

- continuous chart plotting and chart updating
- at minimum, the same display quality as the hydrographic office paper chart
- extensive checking, alarms and indicators relating to the integrity and status of the system
- route planning and voyage monitoring.

The IMO has drawn mariners' attention to the fact that the RCDS mode of operation lacks some of the functionality of ECDIS. Some of the limitations of RCDS mode compared to ECDIS mode include the following.

- The raster navigational chart (RNC) data will not itself trigger automatic alarms although some alarms can be generated by the RCDS from information inserted by the user.
- Chart features cannot be altered or removed to suit operational requirements. This could affect the superimposition of radar/ARPA.
- It may not be possible to interrogate RNC features to gain additional information about charted objects.
- An RNC should be displayed at the scale of the paper chart and RCDS capability could be degraded by excessive use of the zoom facility.
- In confined waters the accuracy of the chart data may be less than that of the position fixing system in use. ECDIS provides an indication in the ENC that permits determination of the quality of the data.

7.3.3 Dual fuel systems

Because of the adoption by the IMO of the amendments to the performance standards for ECDIS to include the use of RCDS, an ECDIS is now able to operate in two modes:

- ECDIS mode when ENC data is used
- RCDS mode when ENC data is unavailable.

Thus the dual fuel system is one that is either an ECDIS or RCDS depending on the type of chart data in use. At the present there are only few ENCs so the ability to use ECDIS is restricted. RNCs are plentiful and can provide two vital functions:

- provide official electronic chart coverage for areas not covered by ENCs
- provide link coverage between the ENCs that are available.

7.3.4 Electronic chart systems (ECS)

Where a system does not conform to either ECDIS or RCDS performance standards it is classified as an ECS system. There are no official performance standards for this system. The IMO had been considering the production of advisory guidelines but at the 1998 meeting of the IMO Navigation Safety Subcommittee it was decided that guidelines for ECS were not necessary and the matter will not be pursued further. As a general rule, a system is an ECS if:

- it uses data which is not issued under the authority of a government-authorized hydrographic office
- vector chart data is not in S-57 format
- the system does not meet the standards of either ECDIS or RCDS performance standards.

An ECS may not be used as a substitute for official paper charts, and ships fitted with an ECS are legally required to carry suitable up-to-date official paper charts. Examples of ECS include radar systems incorporating video maps, stand-alone video plotters and all systems while using commercial raster charts and vector charts systems.

7.4 Chart accuracy

Any chart is only as good as the original survey data allows and the accuracy with which that data is recorded on the chart by the cartographer. A navigational chart is referenced to two data: horizontal, for latitude and longitude; and vertical, for depth and height.

Since the beginning of mapmaking, local maps were based on the earth's shape in that area and, since the earth is not a perfect sphere, the shape does vary from location to location. Figure 7.5 shows a representation of a vertical slice through the earth. The diagram shows an uneven surface to the

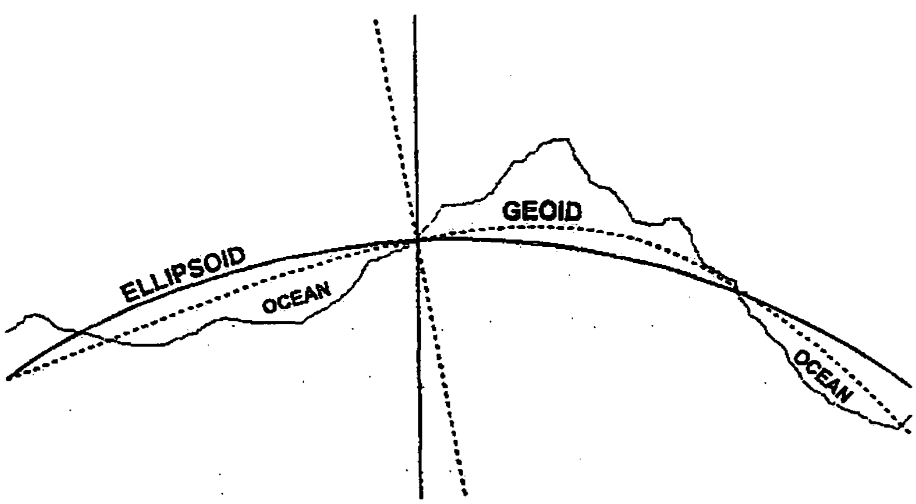


Figure 7.5 View of the earth's surface showing the geoid and ellipsoid. (Reproduced courtesy of Warsash Maritime Centre.)

earth, a dotted line representing a geoid and a solid line representing an ellipsoid. The geoid represents a surface with equal gravity values and where the direction of gravity is always perpendicular to the ground surface. For mapping purposes it is necessary to use a geodetic datum which is a specifically orientated reference ellipsoid. The surface of a geoid is irregular while that of an ellipsoid is regular.

Many different ellipsoids have been used to represent the best fit to the geoid in a particular area. The use of an ellipsoid for positional calculations must first be referenced to the geoid and that relationship defines what is known as a datum. The accuracy of a particular datum may be fine for the local area for which it was intended but the accuracy may suffer as the deviation from that area increases. There are scores of different data such as Ordnance Survey Great Britain 1936 (OSGB36), the European Datum 1950 (ED50), the Australian Geodetic System 1984, North American Datum 1983 (NAD83), etc. Charts drawn for a particular area therefore may contain datum information that is localized.

The use of satellite systems has involved the use of a global datum and GPS uses the World Geodetic System 1984 (WGS-84) which uses a model of the complete earth. The ellipsoid for this system is centred on the Earth's centre of mass and, over the earth as a whole, is a better fit to the geoid than other ellipsoids, although the local datum may give a better fit within their own small area. Ideally all charts should be referenced to WGS-84 but this is not expected to occur for many years to come. Reasons for the delay include:

- the time necessary to replace current charts with new versions using WGS-84
- lack of data necessary to calculate datum shifts and, in some cases, the datum used for the chart is either unknown or poorly defined.

As far as the UKHO is concerned, about 20% of its charts are referenced to the WGS-84 datum, a further 40% use datum when the shift is known, while some 40% use unknown datum. When the shift to WGS-84 is known the UKHO charts have a 'Satellite Derived Positions' note that provides shift values in minutes of latitude and longitude which allows GPS-determined positions, referenced to WGS-84, to be correctly adjusted before they are plotted on the chart. Currently about 40% of the UKHO charts contain shift values.

Electronic chart systems using raster chart displays can use the datum shift values indicated in the 'Satellite Derived Positions' note on the chart to convert the WGS-84 co-ordinates to the local datum. The shift values are mean values for the area covered by the chart but the shift variation across the chart is within manual plotting tolerance at the scale of the chart and can be ignored. However, the quoted shift values on an adjacent chart could well be different.

For electronic chart systems using vector charts it is a requirement that the charts are referenced directly to WGS-84. Since so few official paper charts are referenced directly to WGS-84 it follows that vector chart producers must use a mathematical model to shift the data on certain charts to WGS-84. Users of the system should always check to see whether the official paper chart is referenced directly to WGS-84. If the official chart has a 'Satellite Derived Positions' note giving datum shift values then it could safely be assumed that errors introduced by the conversion to WGS-84 will be small at the scale of the official chart. If WGS-84 shift values do not appear on the paper chart it would suggest that the existing data is insufficient to establish accurate datum shifts and GPS-derived positions cannot be used with confidence.

With ECDIS and the use of ENCs, all references are to WGS-84 so there should be no problem with datum shifts. However, as discussed earlier, there could be a problem of geodetic datum shifts using paper charts, RNCs and privately produced vector charts if positional information is received based on one datum and such data is plotted on a chart which is based on another datum. Figure 7.6

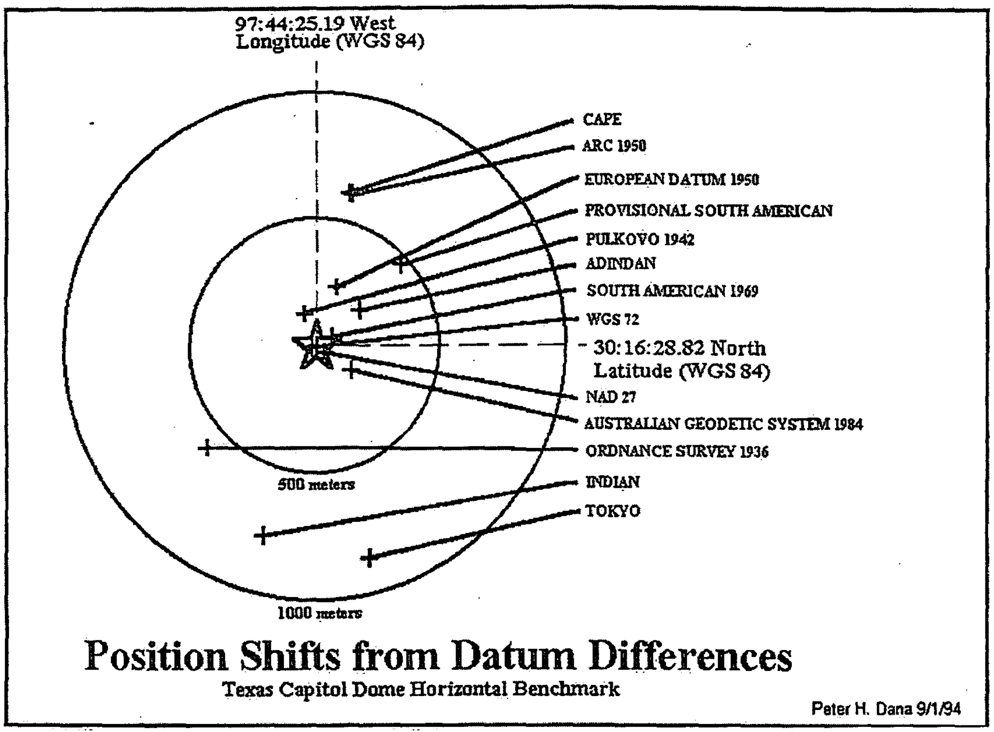


Figure 7.6 World geodetic datums. (Reproduced courtesy of PC Maritime.)

illustrates the variation in latitude and longitude positions that could be derived for the same real location depending on the datum used.

Consider another example of datum differences in the English Channel. The Admiralty charts covering the English coastline are in OSGB36 whereas the Admiralty charts covering the French coastline are in ED50. The OSGB36 datum is used for charts covering the coastline of England, Wales and Scotland while the ED50 was developed for military mapping in Central Europe. UKHO charts covering both sides of the channel tend to be in OSGB36. Thus if an operator working in the channel plotted a position on an OSGB36 chart and then moved to a European 1950 chart without allowing for a datum shift, there will be a positional error as indicated in Figure 7.7.

In some regions of the world the difference between WGS-84 and the local datum can be quite large and this is illustrated in Figure 7.8.

The solution to the problem is obviously to obtain positional information in WGS-84 and to apply the published shift every time a change of paper chart is made. It must be remembered that GPS accuracy has tolerance values and any inaccuracy derived from GPS may be exacerbated by plotting charts of different datum. Most GPSs have built-in datum transformations so that the system can output positions in a local datum but this has certain disadvantages.

- Because there are no standards applicable to the transformation formulae, two different GPSs may use different formulae and give different results. The solutions produced are averaged over a wide

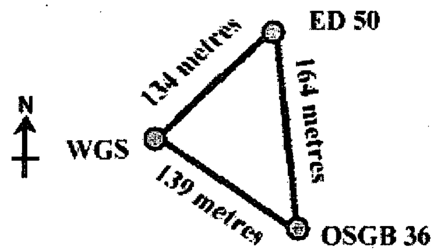


Figure 7.7 An example of datum shift in the English Channel. (Reproduced courtesy of PC Maritime.)

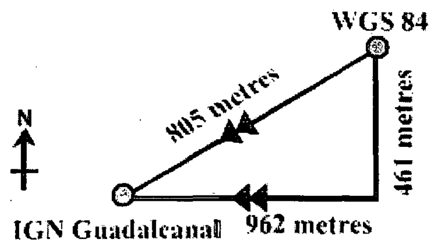


Figure 7.8 An example of datum shift in the Pacific. (Reproduced courtesy of PC Maritime.)

area and any transformation error may range from, say 25 m to much more at the fringes of the area covered by the datum.
- It is difficult to ensure the GPS is switched to the correct datum every time a chart is changed.
- GPS positions may be fed simultaneously to other equipment, such as ARPA, autopilot etc., which expect to receive data in WGS-84 co-ordinates.
- Some GPSs apply the data transformation to all waypoint positions held in memory when a datum other than WGS-84 is selected for the display of positions.

It may be better to maintain the output of GPS in WGS-84. As stated earlier, for the UKHO paper charts, a shift from WGS-84 to the local datum is printed on the chart. Any figure printed on the chart indicates that the original survey has been referenced to WGS-84 and the published shifts can be used with confidence. If the chart contains no shift data then no referencing to WGS-84 has been made and any plotted positions made must be treated with caution because of possible shift errors.

An advantage of modern charts and the use of software is that the management of datum shifts can be automated. A system such as ARCS has the shift data included and thus an RCDS can keep track of the data of positions of all types, including vessel position and track, waypoints and any other overlaid points on the chart, and adjust them all to the local geodetic datum as required.

7.5 Updating electronic charts

As mentioned on page 228 with reference to the UKHO's ARCS system, updates for all charts affected by Notice to Mariners (up to about 200 a week) are generated, checked and placed on a weekly ARCS Update CD-ROM which includes temporary and preliminary notices. This provides error-free automatic corrections and provides cumulative updates with only the latest update CD-ROM required. The CD-ROMs are sent to chart agents who then send them to shipping companies as required.

NOAA provides continuous updating to all 1000 charts using information from the USCG, NIMA and the Canadian Hydrographic Service, and Maptech makes the necessary raster chart updates. Maptech uses modern technology to update only those parts of a chart identified as needing correction. This so-called 'patch' technique compares the existing chart file and its corrected counterpart on a pixel-by-pixel basis. A difference file is produced which can be manipulated so that it registers exactly with the existing raster file to which it applies. A raster chart can therefore be updated by displaying it, using the relevant CD-ROM, and using the patch file to alter the pixels on the old chart as necessary to incorporate the corrections.

The updating service became available on subscription in January 2000. Customers receive a weekly e-mail that contains a hot link to the update computer server. Clicking on the hot link begins the transmission of the update patches to the computer; the updates in the transmission are cumulative updates for all charts on a CD-ROM. Downloading takes from a few seconds to up to 5 min depending on the modem speed. Once the file reception is completed the charts may be corrected and stored on the computer's hard drive. It is anticipated that dynamic updating should soon be available. With this technique the charts and patches are kept separate and the patch is applied to the chart in real time allowing the user to see the changes produced by the patch.

Dynamic patching is the preferred method under the international standards for ECDIS where it is a requirement that mariners should not change the original data files. It is expected that in future single chart updates may be made available rather than a complete CD's worth and that the procedure will be extended to ENCs when they become available.

7.6 Automatic Identification System (AIS)

Automatic Identification System (AIS) is a shipborne transponder system capable of broadcasting continuously, using the VHF marine band, information about the ship. Such information could include:

- ship identification data, i.e. ship name, call sign, length, breadth, draught etc.
- type of cargo carried and whether it was hazardous in nature
- course and manoeuvring data
- position to GPS accuracy limits.

Such broadcast information would be capable of reception by other AIS-equipped ships and by shore sites such as Vessel Traffic System (VTS) stations within broadcast range. Data received by a ship or shore station could be relayed to an ECS and AIS targets could be displayed, with GPS or DGPS accuracy, with a velocity vector indicating speed and heading. By 'clicking' on a target, other information such as ship identification data etc. could be displayed. A typical AIS scenario is illustrated in Figure 7.9.

An AIS transponder system requires a GPS or DGPS receiver, a VHF transmitter, two VHF TDMA receivers, a VHF DSC receiver and a standard marine electronic communications connection to the ship's display system. Position and timing information is derived from the GNSS (GPS) receiver. Information, such as ship's heading, course and speed over ground, is normally broadcast using AIS but other information such as destination, ETA etc. could also be promulgated if available.

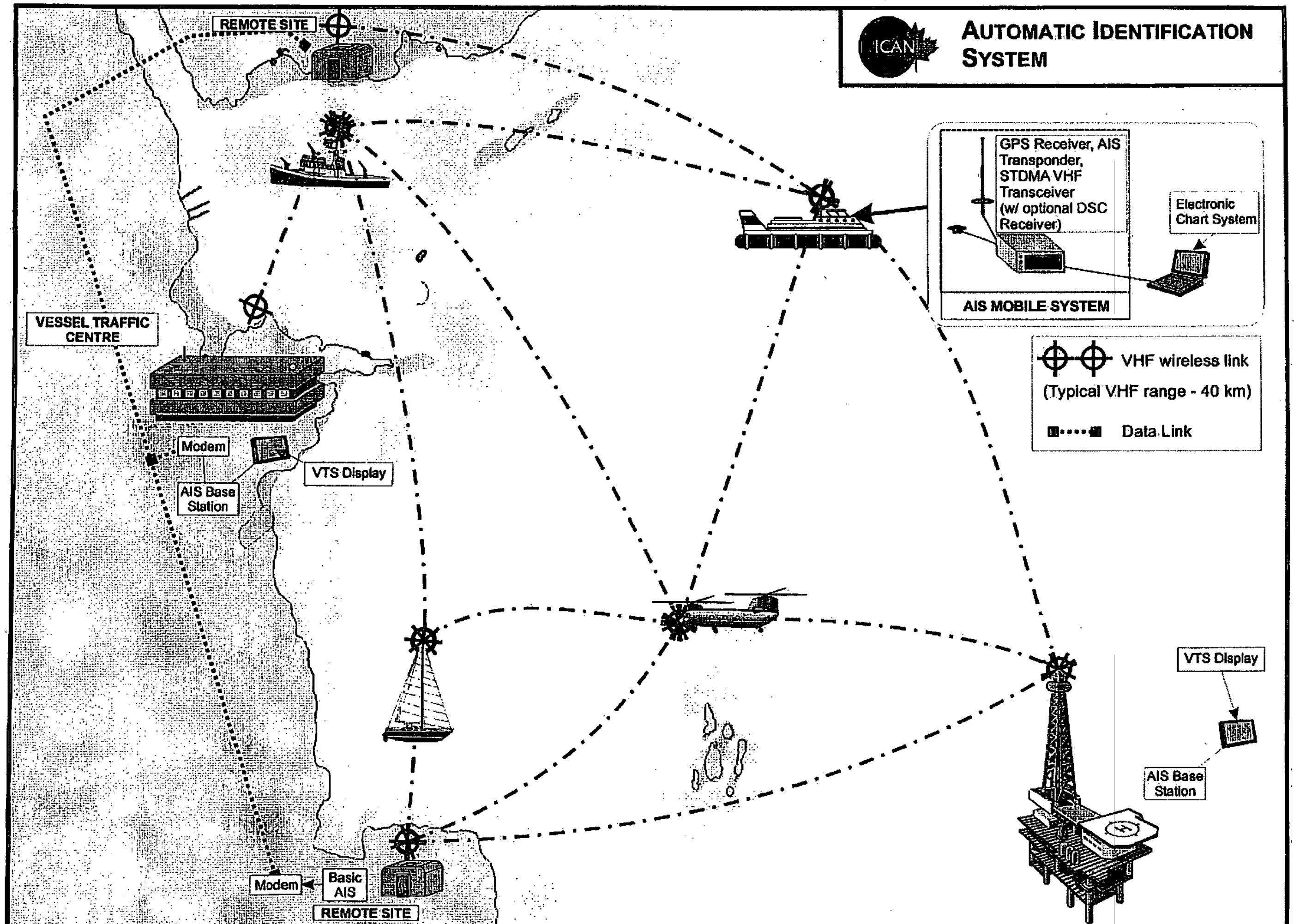


Figure 7.9 Automatic Identification System (AIS). (Reproduced courtesy of ICAN.)

The AIS transponder transmits using 9.6 kbyte GMSK (Gaussian minimum shift keying) FM modulation over 25 kHz or 12.5 kHz channels using HDLC packet protocols. The channel bandwidth of 25 kHz is for use on the high seas and the 12.5/25 kHz channel bandwidth used as defined by the appropriate authority in coastal waters. There are two radio channels available for transmission/reception that minimize RF interference, provide increased capacity and allow channels to be shifted without loss of communication from other ships. The ITU has allocated frequencies with AIS channel 1 using 161.975 MHz (ch87B) and AIS channel 2 using 161.025 MHz (ch88B).

Each transponder self-allocates time slots for its position reports and such reports occur at time intervals that correspond to the traffic situation. This method of communication is known as self-organizing time division multiple access (SOTDMA). The SOTDMA broadcast mode allows the system to be overloaded by up to 500% while still providing nearly 100% communication capacity for ships within 10 nautical miles of each other in ship-to-ship mode. If system overload tends to occur, then targets at the longer ranges will tend to drop out of the system leaving only closer range targets, which are the ones of greater interest to the navigator. There are 2250 time slots established every 60 s for each AIS channel; this gives a time slot duration of 26.67 ms and as each slot has 256 bits the data transmission rate is 9600 bit s^{-1}.

AIS stations continuously synchronize with other stations to obviate any slot transmission overlap. Slot selection by an AIS station is randomized within a defined interval and triggered with a random timeout of between 0 and 8 frames. When a station changes its slot assignment the new location and associated timeout is pre-announced, thus allowing new stations to be received.

Although the AIS concept has been around for many years and trials have taken place at many geographical locations, there is still much work to be done to produce an internationally-agreed standard. Some of the detail of what has been achieved to date is listed below.

IMO Resolution MSC.74(69). Annex 3, Recommendation on Performance Standards for a Universal Shipborne Automatic Identification System (AIS)

The 43rd session of the IMO Navigation Subcommittee, which met in July 1997, completed a draft performance standard on shipborne automatic identification systems (transponders). This performance standard describes the operational requirements for the device but does not define the telecommunications protocol the device must use. The 69th session of the IMO Maritime Safety Committee formally adopted the standard without change in May 1998.

A report from the Subcommittee on Safety of Navigation on its 45th session included the following items.

1 All ships of 300 gross tonnage and upwards (engaged on international voyages), cargo ships of 500 gross tonnage and upwards (not engaged on international voyages), and passenger ships, irrespective of size, shall be fitted with AIS, as follows:
- 1.1 ships constructed on or after 1 July 2002;
- 1.2 ships engaged on international voyages constructed before 1 July 2002;
- 1.2.1 in the case of passenger ships irrespective of size and tankers of all sizes, not later than 1 July 2003;
- 1.2.2 in the case of ships, other than passenger ships and tankers, of 50000 gross tonnage and upwards, not later than 1 July 2004;
- 1.2.3 in the case of ships, other than passenger ships and tankers, of 10000 gross tonnage and upwards but less than 50000 gross tonnage, not later than 1 July 2005;
- 1.2.4 in the case of ships, other than passenger ships and tankers, of 3000 gross tonnage and upwards but less than 10000 gross tonnage, not later than 1 July 2006;

1.2.5 in the case of ships, other than passenger ships and tankers, of 300 gross tonnage and upwards but less than 3000 gross tonnage, not later than 1 July 2007; and

1.3 ships not engaged on international voyages constructed before 1 July 2002, not later than 1 July 2008.

2 The Administration may exempt ships from the application of the requirements of this paragraph when such ships will be taken permanently out of service within two years after the implementation date specified in paragraph 1.

3 AIS shall:

3.1 provide automatically to appropriately equipped shore stations, other ships and aircraft information, including the ship's identity, type, position, course, speed, navigational status and other safety-related information;

3.2 receive automatically such information from similarly fitted ships;

3.3 monitor and track ships; and

3.4 exchange data with shore-based facilities, the requirements of this paragraph shall not be applied to cases where international agreements, rules or standards provide for the protection of navigational information. AIS shall be operated taking into account the guidelines adopted by the Organization.

ITU-R Recommendation M.1371, Technical Characteristics for a Universal Shipborne Automatic Identification System Using Time Division Multiple Access in the Maritime Mobile Band

The International Telecommunications Union Sector for Radiocommunication (ITU-R) met in March 1998 to define the technology and telecommunications protocol for this device. The draft recommendation completed by Working Party 8B was approved by Study Group 8, which met in July 1998. The recommendation was formally adopted in November 1998 and the publication is now available for a fee (see website www.itu.org). The International Association of Lighthouse Authorities (IALA) has been the main organization co-ordinating the development of the Universal AIS Transponder and a revision of this standard is being prepared by IALA for submission to the ITU-R Working Party 8B in October 2000. If adopted it will become ITU-R Recommendation M.1371–1.

IEC Standard 61993–2 on AIS

In July 1998, the International Electrotechnical Commission TC80/WG8-U.AIS started work on the performance, technical, operational and testing standard for the Universal AIS Transponder. The working group is expected to meet regularly and complete its work during the year 2000 with an expected publication date for the standard of December 2001. This standard will supersede IEC Standard 61993–1 on digital selective calling AIS transponders. This new standard will define testing and interfacing requirements for AIS systems. Commercially-produced systems should meet all the three standards described above.

ICAN have developed an AIS module which is an add-on to their 'Aldebaran' Electronic Charting System. The module has been developed for use with Saab TransponderTechs AIS hardware for which ICAN is the exclusive Canadian agent. The AIS module enables ICAN's ECS to display broadcast AIS information on screen in InfoPanels and as overlays. A typical screen display with this feature is shown in Figure 7.10.

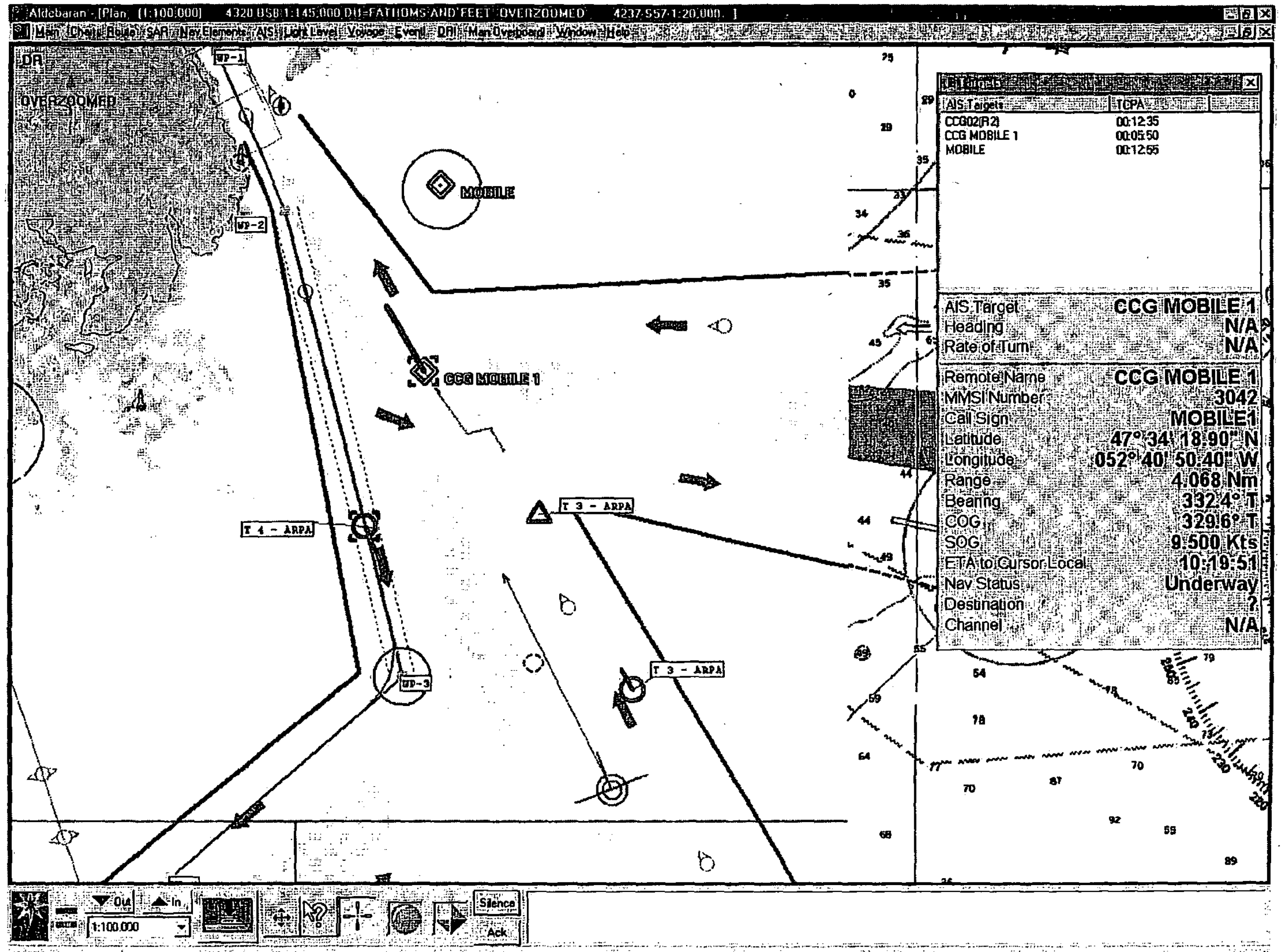


Figure 7.10 Display showing AIS target information. (Reproduced courtesy of ICAN.)

Features of the ICAN AIS module are as follows.

1 AIS Target Monitoring
- Unlimited on-screen AIS targets.
- AIS Tracking InfoBox sorted based on TCPA and RCPA.
- Targets can be individually centred on screen.
- Single target activation.
- Messages can be addressed or sent via broadcast as binary or ASCII data on specific channels.
- Automatic (scheduled) and manual data transmissions.
- Binary transmissions include: man overboard, ARPA, markers and points of interest (SAR, waypoints, routes and zones).
- Displayed AIS transponder channels.
- On screen CPA display.
- Alarms and indications based on configurable CPA properties.

2 Long Range AIS Monitoring
- Microsoft's MAPI (Mail Application Programming Interface) based mail set-up.
- Office and remote monitoring through Inmarsat terminal or service provider.
- Filtered sender information.
- Multiple e-mail address transmissions (single Inmarsat message).
- Configurable gateway formats.

3 AIS Module Configuration
- Remote target properties (shape, labels).
- Name, call sign, ship type, MMSI, IMO no., draught, trip, destination and ETA to destination.
- Own ship transponder transmission information (Nav sensor, antenna location, UTC date time and channel designation).
- Distinguishable transponder characteristics (R2 vs R3 labelling).
- ECS back-up positioning device (transponder GPS).
- Transponder GNSS status.
- Closest point of approach (time and range based).
- Channel polygons.

4 Data logging and Distribution
- Unfiltered logging of serial inputs, including AIS transponder information.
- File-based distribution of logged data.
- TCP/IP distribution of serial inputs.
- Playback of recorded data.

5 ICAN ECS Environment
- Seamless display of charts of S-57, NTX, BSB and MRE formats (other formats in development include ARCS and CM-93).
- Point-of-interest feature allows constant update of range/bearing to any point, marker or waypoint (station keeping).
- Ability to add other software modules including high resolution radar overlay, useful for coastline mapping (scanner up to 120 rpm, 8-bit radar image, raw radar data recording capable).

Information on this AIS module and other useful products offered by ICAN are available on their website www.ican.nf.net.

7.7 Navmaster Electronic Navigation System

There are a multitude of suppliers of software suitable for implementing an electronic navigation system, requiring only the hardware and suitable electronic charts to produce an ECDIS or an ECDIS in RCDS mode. The 'Navmaster Professional' from PC Maritime of Plymouth, UK is used as a basis for showing how the software can assist the navigator in passage planning, position logging and navigation management, providing as it does a continuous display of vessel positions received from GPS and plotted on official electronic charts. The minimum system requirements for Navmaster are: a computer operating with a Pentium 133, or better, processor; Windows 95/98/NT/2000; 10-Mbyte hard drive for minimum installation; CD-ROM and floppy-disk drives; 32-Mbyte RAM; and a monitor with 800 × 600 resolution with 256 colours or more. Input/output requirements are one serial and one parallel port. The software is supplied on a CD-ROM. The system uses electronic chart data, which is the copyright of various national hydrographic offices; chart data is protected by a security key that allows access to the charts only via a user PIN number.

Once the software has been loaded into the computer then starting with Navmaster the display will be similar to the one shown in Figure 7.11.

The toolbars and side panels can be moved around the screen, hidden and displayed as required. The main window contains the following.

Title bar

The title bar displays the program control icon, the activation or active image title and the standard minimize/maximize/restore/close buttons.

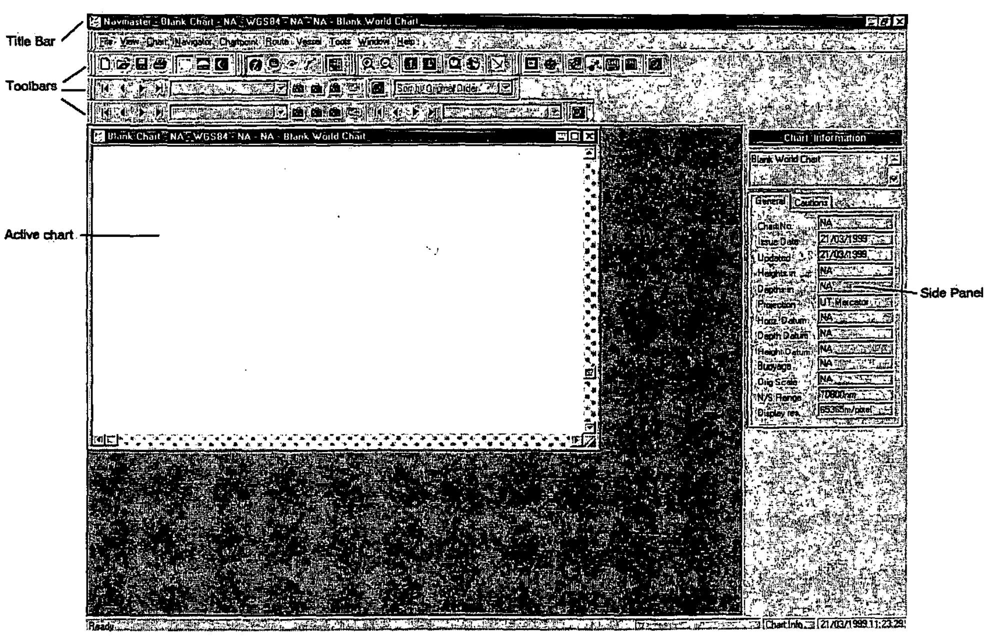


Figure 7.11 The Navmaster start-up window. (Reproduced courtesy of PC Maritime.)

Figure 7.12 Navmaster menu bar headings. (Reproduced courtesy of PC Maritime.)

Menu bar

The menu bar displays the menu headings as shown in Figure 7.12. These are as follows.

- File. Contains standard menu commands for file management, printing and workspace, opening charts, and opening and saving chartpoint and route databases.
- Edit. Provides standard menu commands.
- View. Provides menu commands to select modes of operation, turn on or off the toolbars, side panel and status bar.
- Chart. Provides menu commands to change the chart display, install chart permits and updates, set the location of charts and updates and set chart-related options.
- Navigator. Provides menu commands to: turn position plotting on or off and set DR parameters; turn position logging on or off and make log entries; upload routes and waypoints to GPS; access diagnostic windows for equipment interfacing; open the Autoscroll monitor window; set position and navigation-related options.
- Target. Provides menu commands to Activate/Deactivate ARPA and Tender tracking and set related options.
- Chartpoint. Provides menu commands related to chartpoints.
- Route. Provides menu commands related to routes.
- Vessel. Provides menu commands to enter vessel information for use when calculating plans.
- Tools. Provides menu commands to display tidal atlas and activate the Range and Bearing tool, customize toolbars and set workspace and tidal atlas options.
- Window. Provides menu commands to manipulate windows.
- Help. Provides Help and information on obtaining technical support.

Toolbars

The toolbars provide buttons that access some of the frequently used commands in the menus. If a command is unavailable, its button appears greyed-out. Toolbars and their button functions are shown in Figure 7.13.

Side panels

These panels represent each of the main functions of the Navmaster system, i.e. monitoring position, storing chartpoints and creating and calculating routes. Switching between functions is achieved by pressing a button on the display toolbar or by selecting an item in the View menu.

1 Monitor mode. In this mode it is possible to monitor and plot the vessel's passage. The screen consists of three main areas: the chart area, the side panel and the toolbars. The chart area provides a view of the current chart, which may be manipulated as required. A typical side panel in monitor mode is shown in Figure 7.14.

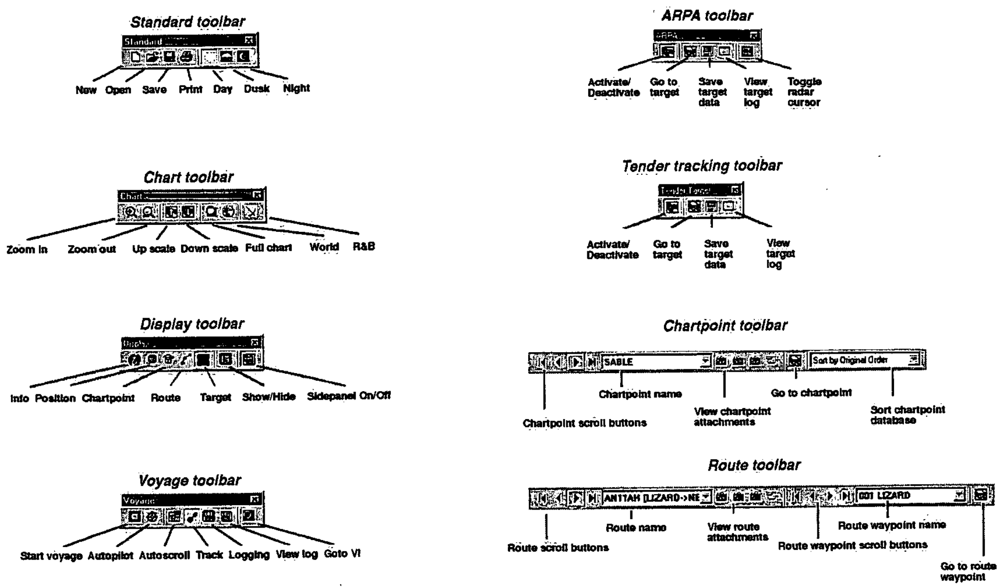


Figure 7.13 Toolbars used in the Navmaster display. (Reproduced courtesy of PC Maritime.)

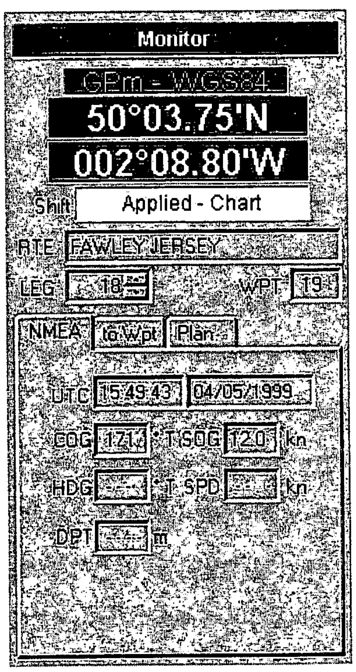


Figure 7.14 Navmaster monitor mode side panel. (Reproduced courtesy of PC Maritime.)

The panel repeats the position obtained from the GPS, provides information on any datum shift that has been applied, and displays the current route name and active leg. Three tabs provide further information:

NMEA	repeats information from electronic instruments;
to Wpt	provides calculated information from current position to the next waypoint in the route;
Plan	repeats information for the leg from the passage plan if one has been calculated.

The Autocheck box activates/deactivates automatic leg advance.

2 Chartpoint mode. In this mode it is possible to add, delete, edit or save chartpoints. A chartpoint is the latitude and longitude of a geographical position stored in a database; a chartpoint on a chart is shown as a blue circle. Each chartpoint has database fields which allow the user to add other information which may be of assistance. Any number of chartpoint databases can be created and each database can contain any number of chartpoints. To enter chartpoint mode, the chartpoint button on the display toolbar (see Figure 7.13) is pressed and, provided side panel display is activated, the chartpoint side panel will be displayed (see Figure 7.15). The panel provides information about the current chartpoint. Each field within the panel can be edited.

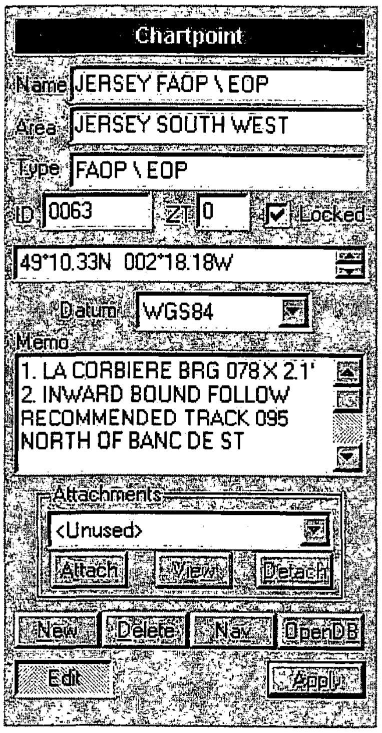


Figure 7.15 Navmaster chartpoint mode side panel. (Reproduced courtesy of PC Maritime.)

Navmaster stores chartpoints in WGS-84 co-ordinates where possible and, provided a selected chartpoint is on the currently selected chart, it is possible to view and edit the chartpoint to match the local chart datum. A chartpoint can simply be used as a marker on a chart or, if used to indicate points on a route, they are known as waypoints.

3 Route mode. This mode enables the user to create new routes, edit existing routes and copy or reverse routes. A route is a sequence of waypoints built up from previously stored chartpoints or created by clicking on a chart. The route is drawn on the chart for evaluation and possible amendment. Routes are stored in databases and there can be many routes stored.

Route mode can be accessed by pressing the route button on the display toolbar (see Figure 7.13). The route side panel will be displayed, provided the side panel is switched on. Routes may be created, and edited, using waypoints from a chartpoint database or by drawing the route directly on the screen chart, or by a combination of both methods. Whatever route method is used, each waypoint in the route is inserted into the box on the route side panel and a line will connect the route waypoints on the chart. This line can be adjusted depending on whether the user adds, deletes or moves waypoints using the route side panel.

Routes are stored in a route database and any number of route databases can be created, containing any number of routes. A typical side panel in route mode is shown in Figure 7.16.

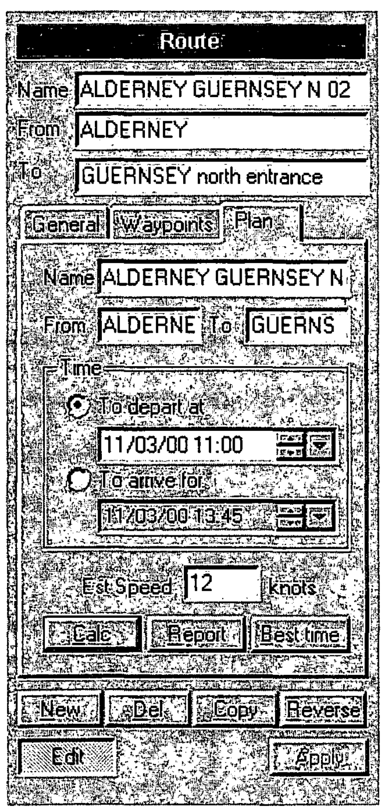


Figure 7.16 Navmaster route mode side panel. (Reproduced courtesy of PC Maritime.)

Three tabs provide further information:

General	enables the user to enter and display a textual note relating to the route;
Waypoints	lists the waypoints in the route and provides a means to select waypoints for amendment or deletion or to locate a new waypoint;
Plan	gives the ability to calculate a passage plan based on the route which the user can print or view on the screen.

Other side panels, which are available but not illustrated, are Target Tracking, which provides information on ARPA and Tender targets, and Information which gives information on the selected chart.

7.7.1 Installing charts

Navmaster supports the UKHO ARCS and the Australian Hydrographic Office Seafarer charts and will support ENC charts by the end of 2000. To install these charts the user needs:

- the floppy disk containing a licence file and chart permit file
- one (or more) chart CD-ROM
- one update CD-ROM with the latest chart corrections.

Each chart CD-ROM contains all the charts available for a particular region. A chart permit is a code that unlocks a specific chart. Charts can be installed from the chart permit disk or by entering the chart permit number manually. The user PIN number must be entered before a chart can be loaded or installed. When Navmaster loads a chart it also applies any chart updates at that time. A chart can be displayed without its update but a warning will be displayed indicating the fact that corrections are missing.

The ARCS or Seafarer chart is supplied as two, independent images namely a low-resolution (LR) image and a high-resolution (HR) image. The LR image provides an overview of the chart while the HR image is the one recommended for navigation and is updated with Notice to Mariner corrections. Navmaster provides further zooming in and out of the LR and HR images to give five levels of display for each chart.

The chart can be manipulated so that it is centred on a selected cursor position and the chart can be panned by using the scroll bars at the sides of the chart window.

Table 7.6 The five levels of display for each chart

Resolution	*Zoom level*	*Warning*
Low resolution	Zoom out (LR-out)	Underscale
	Normal (LR)	Underscale
High resolution	Zoom out (HR-out)	Underscale
	Normal (HR)	None
	Zoom in (HR-in)	Overscale

7.7.2 Using Navmaster

When using Navmaster the recommended sequence to follow is:

- create chartpoints
- create a route
- calculate a plan
- monitor by plotting track, viewing data in the Navigation Monitor panel and comparing progress with the plan.

Navmaster is a multi-window application. Charts, the log, waypoint lists etc. all have their own window and windows can be tiled, cascaded or kept in the background as required. Turning on Autoscroll opens a dedicated window which displays the vessel's position in the centre of a chart. For safety reasons the Autoscroll window cannot be minimized so that the user is fully aware of the vessel's position. However, the window can be resized to allow more room for other charts, or it can be covered by a maximized window.

If the Autoscroll window is closed then Autoscroll is turned off. The remaining windows give complete flexibility to organize the charts to suit the task in hand. For example, new chart windows could be opened to:

- look ahead by displaying the vessel's position on a smaller scale chart than the Autoscroll chart
- view charts for other segments of the route
- view the approaches or harbour charts for intended destination
- plan new routes or chartpoints.

While the above is going on it is still possible to view a continuously updating vessel position on the largest scale chart available.

The maximum number of chart windows that can be opened is limited to three plus the Autoscroll window. The number can be increased but the default value of three is chosen to prevent users inadvertently opening too many windows.

The Chart Information panel in Navmaster displays information on the selected chart and indicates the following.

- Chart Description. The Hydrographic Office description of the chart.
- Chart No. The Hydrographic Office chart number.
- Orig Scale. The scale of the paper version of the chart.
- Edition Date. The date the chart was first issued.
- Updated. The date of the last update.
- Heights In. The units of height used.
- Depths In. The units of depth used.
- Projection. The type of projection used in the production of the chart.
- Horiz Datum. The geodetic datum of the chart. EG OSGB36 – The Ordnance Survey of Great Britain (1936) datum.
- Depth Datum. The datum to which depths are referred.
- Height Datum. The datum to which heights are referred.
- Buoyage. The buoyage system in use on the chart.
- N/S Range. The vertical distance in nautical miles of the portion of the chart currently displayed in the chart window.
- Display Resolution. The number of metres represented by each pixel on the computer display, which will alter depending on the zoom level of the chart.

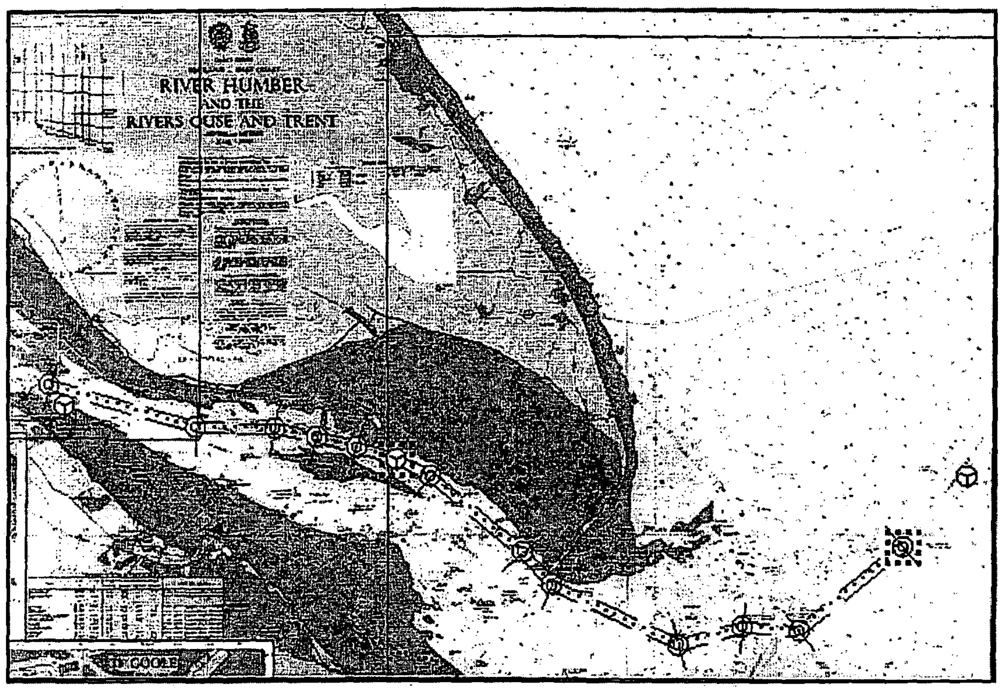


Figure 7.17 ARCS chart 109, River Humber and the Rivers Ouse and Trent OSGB36. (Reproduced courtesy of PC Maritime.)

Passage plans

Having created a route, the user can enter estimated speed, desired departure/arrival times and calculate for each leg of the route:

- course to steer, allowing for variation, deviation and tidal stream (if required)
- distance
- estimated time.

The user can view the plan on screen, change variables as required and then print a copy of the plan. As an example of a chart overlaid with a route Figure 7.17 shows ARCS chart 109, with a route approaching the Humber River, illustrating waypoints entered for the planned route.

Route monitoring options can be chosen so that it is possible to:

- automatically increment route legs as the vessel passes through waypoints so that Navmaster calculations on range and bearing to the next waypoint are relevant, and up-to-date information is sent to the Autopilot
- monitor the vessel's progress against the planned route.

Other options include the following.

- Automatic leg advance. Choosing this option allows the route legs to increment automatically as the vessel passes through the waypoint detection parameters set by the user.

- Waypoint detection. Choosing this option and setting a radius for the route leg to increment to the next leg when vessel position enters the circle. On entry a warning is given. The position and time of entry, and waypoint name are recorded in the log. See Figure 7.18.
- Passing perpendicular. Choosing this option allows the route leg to increment to the next leg when vessel position crosses a line drawn at right angles to the current leg. On passing, a warning is given. Position, time of entry and waypoint name are entered in a log. See Figure 7.18.
- Limits of deviation. Choosing this option allows a deviation limit to be set. If the vessel position exceeds this limit a warning message is displayed and remains until the vessel returns inside the

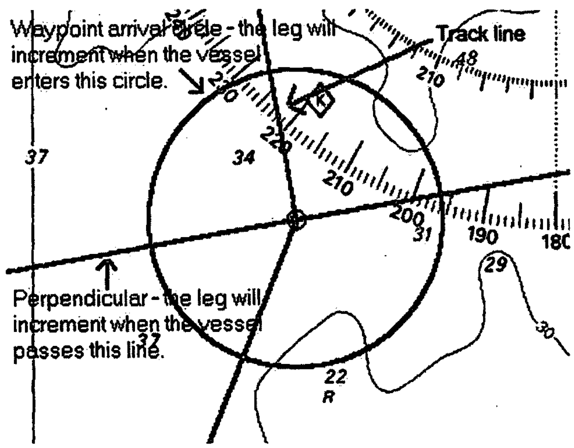


Figure 7.18 Use of waypoint arrival circle and passing perpendicular. (Reproduced courtesy of PC Maritime.)

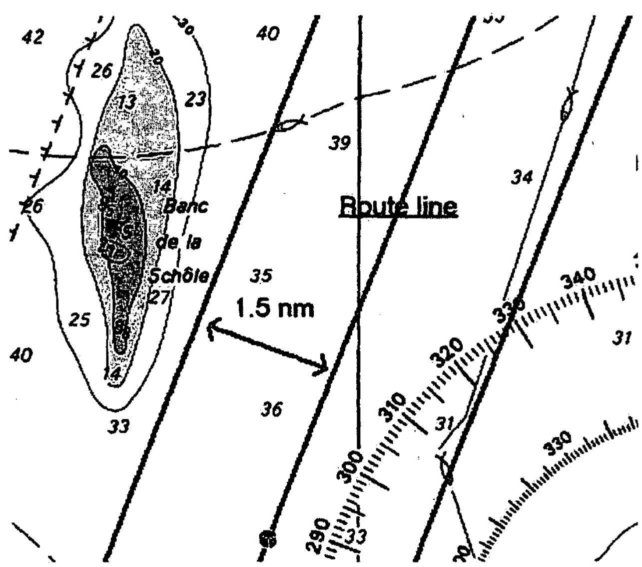


Figure 7.19 Use of limits of deviation. (Reproduced courtesy of PC Maritime.)

Your Company Name

Your company logo

Passage Plan Report

FROM : SPURN APPROACHES
TO : IMMINGHAM

Vessel	:		Options : Tides	[Off]
Estimated speed	: 5.0 knots		Variation	[Off]
Passage distance	: 18.0 nm		Deviation	[Off]
Passage time	: 000:03:35		Calculated	: 11:52:13 / 6/24/00
Route name	: HARBOUR ENTRY		Viewed	: 12:16:52P 24/06/2000

Rte Wpt No	Datum	Time	Elap Time (ddd:hh:mm)	Name	Position	Crse (°T)	Leg (nm)	Accum (nm)	To Go (nm)
1	WGS84	11:52:13 6/24/00	000:00:00	SPURN HEAD APPROACHES	53°34.80'N 000°17.70'E	231	2.51	0.00	18.0
2	WGS84	12:22:20 6/24/00	000:00:30	SPURN LIGHTSHIP	53°33.22'N 000°14.43'E	274	1.05	2.51	15.4
3	WGS84	12:34:57 6/24/00	000:00:43	SE CHEQUER	53°33.29'N 000°12.67'E	254	1.26	3.56	14.4
4	WGS84	12:50:02 6/24/00	000:00:58	NO 3 CHEQUER	53°32.95'N 000°10.64'E	295	2.64	4.82	13.1
5	WGS84	1:21:40 6/24/00	000:01:29	SUNK CHANNEL	53°34.06'N 000°06.63'E	319	0.83	7.46	10.5
6	WGS84	1:31:36 6/24/00	000:01:39	HAWKE	53°34.68'N 000°05.71'E	309	2.25	8.29	9.67
7	WGS84	1:58:38 6/24/00	000:02:06	HAWKE S4	53°36.11'N 000°02.79'E	296	0.74	10.5	7.42
8	WGS84	2:07:27 6/24/00	000:02:15	HAWKE S5	53°36.43'N 000°01.68'E	287	0.78	11.3	6.68
9	WGS84	2:16:48 6/24/00	000:02:25	SUNK S6	53°36.66'N 000°00.43'E	285	0.75	12.1	5.90
10	WGS84	2:25:50 6/24/00	000:02:34	SUNK S7	53°36.86'N 000°00.79'W	281	0.82	12.8	5.15
11	WGS84	2:35:38 6/24/00	000:02:43	SUNK S8	53°37.01'N 000°02.14'W	272	1.47	13.6	4.33
12	WGS84	2:53:17 6/24/00	000:03:01	SUNK SPIT	53°37.05'N 000°04.61'W	286	2.86	15.1	2.86
13	WGS84	3:27:35 6/24/00	000:03:35	IMMINGHAM OIL TERMINAL	53°37.85'N 000°09.22'W	000	0.00	18.0	0.00

Pre-departure check list
Navmaster Raster Chart Display System

1: Navmaster system on ☐
2: Correct chart displayed ☐
3: Folio mode and Autoscroll on ☐
4: This route displayed on chart ☐
5: Position logging on ☐
6: Logging on ☐

On completion of pre-departure checks this form is to be signed by the responsible officer and handed to the master.

Port..............................   Signed..............................
Date..............................

Figure 7.20 Passage plan for a route into Immingham on the River Humber. (Reproduced courtesy of P.C Maritime.)

limit. When the vessel exceeds the limit a log entry is made, with time and position. A further log entry is made when the vessel returns inside the limit. See Figure 7.19.

Creating a passage plan

A passage plan can be created as follows.

1 Prepare the route.
2 Select the plan tab on the Route panel (a typical Route side panel is shown in Figure 7.16).
3 Enter departure/arrival time and estimated speed.
4 Set any options required.
5 Click on Calc.
6 Click on Report to see the plan.

A typical passage plan report for the route of Figure 7.17 is shown in Figure 7.20.

Because Navmaster calculates routes almost instantly it is a simple matter to change parameters such as vessel speed, date and options.

The above has been extracted, with permission, from the Navmaster User Guide and only gives a very limited overview of the facilities available with the system. More detail can be obtained from the manufacturers PC Maritime, Brunswick House, Brunswick Road, Plymouth PL4 0NP, UK. E-mail: marketing@pcmaritime.co.uk and website: www.pcmaritime.co.uk.

7.8 Glossary

AHO	Australian Hydrographic Office.
AIS	Automatic Identification System, see Transponder.
ARCS	Admiralty Raster Chart Service. The UKHO proprietary RNC.
ARPA	Automatic Radar Plotting Aid.
Chart cell	The smallest unit for geographical data. Each cell has a unique address in memory and may possess different data volume and size characteristics.
Chart symbol	A graphical representation of an object or characteristic.
CIS	Chart Information System.
'Course-up' display	A display where the heading of own ship is upwards on the screen and the chart moves relative to own ship.
CPA	Closest Point of Approach.
Database	A set of stored data used for a particular application which can be assessed as required.
Datum	See Geodetic datum.
DGPS	Differential Global Positioning System.
ECDIS	Electronic Chart Display and Information System. The performance standard approved by the IMO and defined in publications from the IHO (Special Publications S-52 and S-57) and IEC document 1174.
ECS	Electronic Chart System. A system that, unlike ECDIS, has no obligation to conform to the ECDIS performance standards.
Ellipsoid	A regular geometric shape which closely approximates to the shape of a geoid, having a specific mathematical expression, and can be used for geodetic, mapping and charting purposes.

ENC Electronic Navigational Chart. Charts, manufactured for use with ECDIS, which meet the ECDIS performance standards and are issued by or on the authority of government-authorized hydrographic offices.

ETA Estimated time of arrival.

Geodetic datum A specifically orientated reference ellipsoid requiring typically eight parameters to define it. Two parameters relate to the dimensions of the ellipsoid, three parameters specify its centre with respect to the Earth's centre of mass while the remainder specify ellipsoid orientation with respect to the average spin axis of the Earth and Greenwich reference meridian. Provides a horizontal datum.

Geoid An undulating but smooth representation of equal values of the Earth's gravitational field coinciding most closely with mean sea level. The geoid is the primary reference surface for heights.

GMSK Gaussian Minimum Shift Keying.

GNSS Global Navigation Satellite System. The use of GPS for civilian purposes.

GPS Global Positioning System. A satellite navigation system designed to provide continuous position and velocity data in three dimensions and accurate timing information globally.

Hardware The physical part of a computer system that provides the processing capability; includes peripheral devices and cabling.

HCRF Hydrographic Chart Raster Format. Developed by the UKHO and used by them for the Admiralty Raster Chart Service (ARCS) and by the AHO for its Seafarer Chart Service. Other HOs are expected to adopt the format.

HDLC High-Level Data Link Control, specified by ISO/IEC 3309, 5th edition 1993.

IEC International Electrotechnical Commission. The organization which produces world standards in the area of electrical and electronic engineering.

IHO International Hydrographic Organization. A grouping of national hydrographic offices responsible for promoting international standards in the fields of hydrographic surveying and chart production.

IMO International Maritime Organization. A specialized agency of the United Nations and responsible for promoting maritime safety and navigational efficiency.

ITU-R International Telecommunications Union Sector for Radiocommunication.

MMSI Maritime Mobile Service Identities. An international system of automatic identification for all ships.

NHO National Hydrographic Office.

NIMA National Imagery and Mapping Agency.

NMEA National Marine Electronics Association. An organization comprising manufacturers and distributors. Responsible for agreeing standards for interfacing between various electronic systems on ships. NMEA 0183 version 2.3 is the current standard.

NOAA National Oceanic and Atmospheric Administration.

'North-up' display A display configuration where north is always in the up direction. This corresponds to the orientation of nautical charts and is the normal display for an ECDIS.

Notice to Mariners A notice issued by hydrographic offices, on a periodic or occasional basis, relating to matters that affect nautical charts, sailing directions, light lists and other nautical publications.

NOS	National Ocean Service.
OCS	Office of Coast Survey.
Own ship	Used to define the vessel on which the electronic chart system is operating.
Performance standard	Used to define the minimum performance requirements for a system to meet the requirements of the SOLAS Convention.
Pixel	An abbreviation for picture element. It is the smallest element that can be resolved by electronic raster devices such as a scanner, display and plotter.
PRIMAR	A series of regional distribution centres (RENCs) will be set up for the distribution of ENCs, and PRIMAR is the first of these centres.
RCDS	Raster Chart Display System. A navigation system which can be accepted as complying with the paper version of the up-to-date chart requirements of regulation V/20 of the SOLAS Convention, by displaying RNCs with position information from navigation sensors to assist the mariner in route planning and route monitoring, and if required display additional navigation related material.
RCPA	Range to closest point of approach.
RENC	Regional ENC Co-ordinating Centre.
RNC	Raster navigational chart. A facsimile of a paper chart. Both the paper chart and the RNC are originated by, or distributed on the authority of, a government authorized-hydrographic office.
Route monitoring	A function required of an ECDIS whereby own ship present position can be displayed on the chart and viewed relative to the chart data.
Route planning	A function required of an ECDIS whereby the mariner can study the intended route on a display and select an intended track, marking it with waypoints and other navigational data.
S-52	IHO Special Publication S-52. Specification for chart content and display aspects of ECDIS.
S-57	IHO Special Publication S-57. IHO transfer standard for digital hydrographic data, edition 3. It describes the data model and format to be used for ENCs.
Safety contour	The contour selected by the mariner, using the SENC data, to determine soundings which, relative to own ship's draught, provide safe water channels. The ECDIS can use the information to generate anti-grounding alarms.
Safety depth	The depth, selected by the mariner, which defines own ship's draught plus under-keel clearance which can be used by the ECDIS to indicate soundings on the display which may be equal or less than the defined value.
SENC	System Electronic Navigational Chart. This is the database produced by chart suppliers which meets the requirements of the IHO Special Publication S-57.
Software	This includes all the programs that can be used on a computer. Software can be subdivided into the operational software required for the computer to function and the application software developed for specific user applications.
SOLAS	Safety of Life at Sea. The International Convention for the Safety of Life at Sea Chapter V Safety of Navigation, Regulation 20, Nautical Publications requires that 'All ships shall carry adequate and up-to-date charts, sailing directions, lists of lights, notices to mariners, tide tables and all other nautical publications necessary for the intended voyage'. SOLAS does not apply universally and some vessels, such as ships of war, cargo ships of less than 500 GRT, fishing vessels etc are exempt from the SOLAS requirements.

SOTDMA Self-organizing time division multiple access. Used by mobile stations operating in autonomous and continuous mode. The protocol offers an access algorithm that quickly resolves conflicts without intervention from controlling stations.

Standard display The SENC information that should be displayed when a chart is first accessed by the ECDIS. The level of data contained can be customized to suit the mariner.

TCPA Time to closest point of approach.

TDMA Time division multiple access.

Transponder (AIS) A shipborne transmit/receive system which broadcasts continuously, on VHF frequencies, details about ship's identity, ship characteristics, type of cargo, destination, course and speed. The ECDIS can be used to display AIS targets together with their speed and course vectors.

UKHO United Kingdom Hydrographic Office.

USCG US Coast Guard.

UTC Co-ordinated universal time. Developed to meet the requirements of scientists to provide a precise scale of time interval and navigators surveyors and others requiring a time scale directly related to the earth's rotation.

VTS Vessel Traffic System. A system for managing shipping traffic in congested areas such as ports and inland waterways.

Waypoint A point entered into a computer and used as a reference point for navigational calculations. Planned voyages would have a series of waypoints indicating legs of the voyage. A modern computer is capable of storing multiple waypoints.

WEND Worldwide ENC database. A model, developed by the IHO, to act as a distribution network to supply ENCs to ECDIS compliant ships.

WGS-84 World Geodetic System 1984. A global datum system for horizontal datum used as a standard in ECDIS.

Zoom A method of changing the scale of the displayed chart information on the screen. Zoom-in or zoom-out facilities are usually provided at the touch of a button.

7.9 Summary

- An electronic chart is one where chart data is provided as a digital charting system capable of displaying both geographical data and text.
- An electronic chart is 'official' if it is issued by or on the authority of a national hydrographic office. All other charts are 'non-official'.
- An electronic chart may use raster data or vector data.
- Delivery of electronic chart data is via an Electronic Chart Display and Information System (ECDIS) which is a navigational information system, comprising hardware, software and official vector charts and must conform to ECDIS Performance Standards.
- Chart types available include privately produced vector, official raster and Electronic Navigational Chart (ENC). The ENC is the designated chart system for ECDIS.
- A Raster Chart Display System (RCDS) is one that displays official raster navigational charts (RNCs).

- A dual fuel system is one that operates as an ECDIS or RCDS mode according to the type of chart data in use.
- Chart accuracy may depend on local datum that may differ from that used by satellite systems which use a global datum, e.g. WGS-84. Corrections may be necessary before a position is plotted on a chart.
- Electronic charts are updated regularly to ensure conformity with the SOLAS requirement that charts should be 'adequate and up-to-date for the intended voyage'.
- Automatic Identification System (AIS) is a shipborne transponder system that broadcasts information about a ship fitted with the system. The data generated may be used by other AIS-fitted ships and/or shore stations and such data may be passed to an electronic charting system where AIS-fitted ships could appear as 'targets' on the electronic chart. Such targets could be interrogated to generate information such as ship's speed, heading and other data.
- For any ECDIS system to operate, suitable software must be available to enable the function of an ECDIS system to meet performance standards as laid down by the regulatory bodies. A particular system examined is the Navmaster Electronic Navigation System of PC Maritime.

7.10 Revision questions

1. What do you understand by the term 'electronic chart'? What is the definition of an 'official' electronic chart?
2. Explain briefly the difference between a chart produced using raster data and one produced using vector data. Give advantages/disadvantages associated with each type of chart.
3. Explain briefly what defines an electronic navigational chart (ENC) used with ECDIS. What are the advantages of an ENC in terms of chart information that can be displayed?
4. Describe what you understand by the term Electronic Chart Display and Information System (ECDIS). What are the basic requirements of an ECDIS?
5. Describe what you understand by the term Raster Chart Display System (RCDS) and state briefly how a RCDS could be used in a dual fuel system.
6. Explain why there may be a difference between local datum used for a particular chart and the global datum used in ECDIS. How would a position, determined from a GPS or DGPS input, be affected if plotted on a chart based on a different datum?
7. Describe briefly the concept of an Automatic Identification System (AIS). Explain the advantages to be gained by fitting ships and specific shore stations with AIS.
8. The Navmaster Electronic Navigation System (Section 7.7) uses on-screen side panels that represent main functions of the system. Describe briefly the function of the following side panels:
   (a) monitor mode
   (b) chartpoint mode
   (c) route mode.
9. Using the Navmaster Electronic Navigation System (Section 7.7) describe how charts may be installed in the system. What information is displayed in the chart information panel for a selected chart?
10. Using the Navmaster Electronic Navigation System (Section 7.7) as a basis, describe the recommended sequence to be followed for route planning and monitoring. Define what is meant by a chartpoint and describe how chartpoints could be used in route planning.

Appendices

A1

Computer functions

Introduction

The function of a computer is to perform operations on data (usually arithmetic or logical) according to a set of specified instructions. The specified set of instructions is a computer program and is known as software. The physical aspects of the computer system, such as the circuitry, monitor, keyboard, printer, cabling etc., is known as the hardware. Computers can be categorized according to the functions for which they are designed.

- Supercomputer. Mainly used for research and capable of 'number crunching' on a massive scale with extremely rapid calculations.
- Mainframe. Mainly used in large commercial concerns such as banking and large automated plants where large amounts of data have to be processed on a daily basis.
- Minicomputer. Smaller version of the mainframe and suited to smaller scale businesses and research establishments.
- Microcomputer/Workstation. Less complex than the others, although still powerful, they tend to be operated by a single user. Workstations tend to be a dedicated version of the microcomputer and could well operate faster and contain more memory.

This appendix will concentrate on the last of the computer types since it is the one most likely to be used on board ship.

The heart of a computer is its central processing unit (CPU) which, for a microcomputer, is a microprocessor. More detail on the microprocessor is included later. It is sufficient for the moment to say that it is a circuit available as a single integrated circuit (IC) 'chip' which, when connected with other IC chips, can produce the microcomputer. A basic system is discussed below.

Basic system

Essentially, the microcomputer consists of three elements as shown in Figure A1.1.

In addition to the three hardware elements, there are three sets of connections, known as buses, that interconnect the chips. Details of each bus and its function are as follows.

- **Data bus.** Provides a path for the data which is to be processed. The data is usually in 'words' which can be anything from 4 bits to 32 bits in length. A 'bit' is a contraction of 'binary digit' and can have the value of 1 or 0; thus a combination of 1s and 0s in a word can represent specific data. It can be shown that for a 4-bit word there are 2^4 or 16 possible combinations ranging from 0000 to 1111. Obviously with 8, 16 or 32-bit words the number of combinations will be increased. A

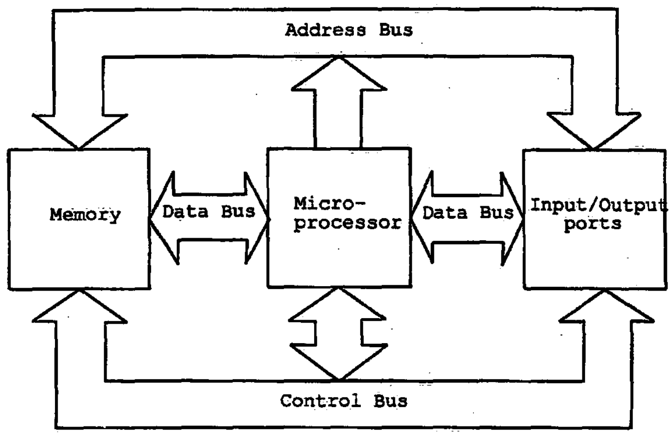


Figure A1.1 A basic microcomputer system.

group of 8 bits is known as a byte while 4 bits is a nibble. Thus two nibbles make a byte. A group of 16 bits is said to be made up of 2 bytes, etc.

- **Address bus.** The memory device will consist of a number of memory cells which can be uniquely identified by an address. The memory cells can contain data or program instructions and each cell could contain several bits.

  As shown in the basic system diagram of Figure A1.1 the input/output (I/O) chip is also accessed via the address bus. This arrangement is known as memory-mapped I/O. An alternative arrangement allows the microprocessor to be connected to the I/O with a dedicated bus structure giving what is known as dedicated or port addressed I/O.

  The size of the address bus can vary; for an 8-bit system the address bus would be typically 16 bits wide giving 2^{16} or about 64 000 (64 kbyte) address locations. For a 16-bit system the address bus is typically 20 bits wide giving 1 Mbyte (one million) addressable locations. When an address is accessed by the microprocessor, all other address locations are disabled so that the microprocessor communicates with only one address location at a time.
- **Control bus.** This bus carries the signals required to synchronize the operations of the system. For example, if the microprocessor needs to read data from (or write data into) a memory location, the control bus carries the necessary signal. The signal in this case is the Read/Write (R/$\overline{W}$) signal, which is sent from the microprocessor to allow the necessary data movement to be carried out. The microprocessor would send a logic 1 via the control bus if a read operation were to be performed from the memory location whose address was currently on the address bus. For a write operation the signal would be a logic 0, as indicated by the bar over the letter W, i.e., $\overline{W}$, indicates an operation carried out with a signal that is active low.

  Some I/O elements can send signals to the microprocessor via the control bus; such signals include interrupts, where the system is designed to respond to an external event, and Reset, where the system could be reset to a specified start condition.

  The most important signal carried by the control bus is the system clock which, operating at frequencies up to 1 GHz, provides the necessary synchronization for the system to operate. The clock is crystal controlled and, although not shown on the system diagram above, is an integral part of the microprocessor block.

Microprocessor

As stated earlier this is a device responsible for executing arithmetic and logical operations and for controlling the timing and sequence of operations. A basic block diagram is shown in Figure A1.2.

The ALU is the arithmetic and logic unit while the control unit undertakes the timing and sequence functions. Additionally there are registers which can hold data while data manipulation takes place. Registers also assist in the role of program execution. A register is simply a store which can contain a set of logic states, i.e. logic 1 and logic 0.

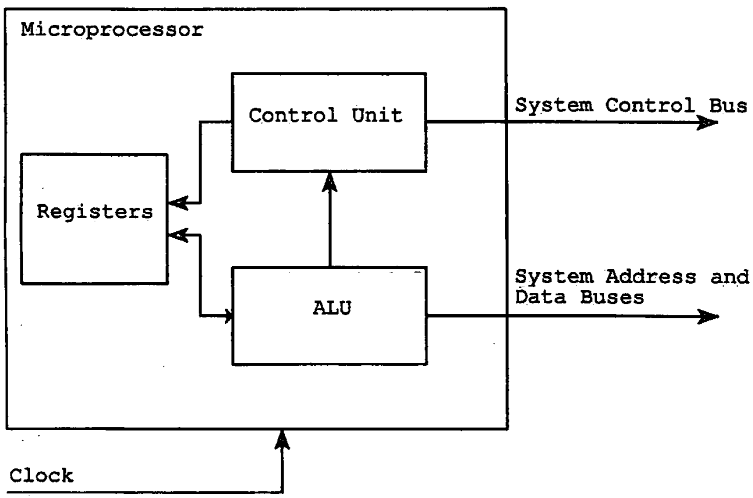


Figure A1.2 Block diagram of a microprocessor.

The ALU performs arithmetic manipulations, such as binary addition, subtraction and, possibly, multiplication and division. Also the logical functions such as AND, OR, NOT and Exclusive-OR can be implemented. The ALU consists of gates which are organized to receive binary inputs and provide binary outputs according to the instruction code in force, i.e. for the addition process the gates are arranged as an adder while for the AND process the gates are arranged as an AND gate etc.

The control unit provides the essential timing of operations within the system including the process of 'fetch and execute' whereby an instruction is fetched from memory and caused to be executed. This is known as the instruction cycle.

The register group contains the data that the processor needs while performing the task of executing a program. Information held by the registers includes the program counter (PC) which allows the processor to keep track of its position within the program. Other registers include the accumulator and the stack pointer. There are many types of microprocessor available, and the registers and the names given to them may vary from device to device.

Memory devices

Memory is necessary to store the program instruction codes, the data used in computation and the results of the computation. The memory devices can consist of one or more ICs which can be interconnected to provide the necessary unique location addresses required by the system. Devices fall into two basic categories: random access memory (RAM), perhaps better described as read/write memory, and read only memory (ROM).

For RAM there is a matrix assembly of flip-flops each forming a memory cell and, for this type of memory, it is possible to determine the contents of any cell by a read operation or to change the contents of a cell by a write operation. The read operation is non-destructive since reading will not alter the contents of a cell. However RAM is volatile since removing the power supply from the memory will destroy the contents; restoring the power supply will allow the cells to once again have particular values (logic 1s and logic 0s) that will not be the same as before the removal of the power.

RAM can be static (SRAM) or dynamic (DRAM); in the latter case use is made of stored charge on a capacitor and since such charge can leak away in time, the cells need to be constantly refreshed to maintain the state of charge. ROM also has a matrix array of cells but is non-volatile in that the contents, written by the manufacturer or the customer, will not vary and can be read to give the value of its contents.

In the normal way ROM cannot be written into since its purpose is to provide a pre-determined fixed value for its contents. However, some ROMs are capable of having their contents altered. By a process known as field programming, users may purchase a ROM containing all 1s, or all 0s, in each cell, and by an electrical process cause certain cells to change value to obtain the required contents. Such a memory is a programmable read only memory (PROM). A PROM once programmed has its memory fixed for good. An erasable PROM, or EPROM, can have its contents removed, by using electrical means or UV light, and new contents put in place.

Typically RAM is available in units of 8, 16, 32, 64 and 128 Mbyte and combinations can be used to produce the desired system memory capacity. Secondary, or auxiliary, memory storage devices are available in the form of magnetic tape and disks which are non-volatile. Hard disk drives are available in excess of 30 Gbyte capacity while floppy disk drives exist in 3.5- and 5.25-inch format. Programs are available on floppy disks and CD-ROMs which can be loaded into computer systems for storage on the hard disk if desired. CD-ROMs are also available as memory storage devices that can be written to once (CD-R) or written to, erased and rewritten to (CD-RW).

Memory organization

A complete computer system needs both RAM and ROM. A memory map will show how the memory locations are divided between the different types of memory. For a system operating with 8 bits of data and a 16-bit address bus, the memory map would extend from location 0000 to location FFFF. This representation of the memory location is known as hexadecimal and provides a simple way of identifying a location without the need to specify all 16 digits of the actual address. There are 16 total variations represented by 4 bits (i.e. $2^4 = 16$), but only 0 (0000) to 9 (1001) can be represented by decimal numbers and the remaining six combinations (1010) to (1111) are represented by alphabetic figures A to F, respectively. Thus 16 bits can be represented by four hexadecimal alphanumeric figures. Thus the first memory location is 0000 0000 0000 0000, represented in hexadecimal form by 0000, while the last is 1111 1111 1111 1111, represented by FFFF. A typical memory map for an 8-bit system is shown in Figure A1.3.

The operating system sits at the top of memory. This system ensures that the facilities of the machine are co-ordinated and also contains information regarding the start address for routines which are executed at reset or external interrupt.

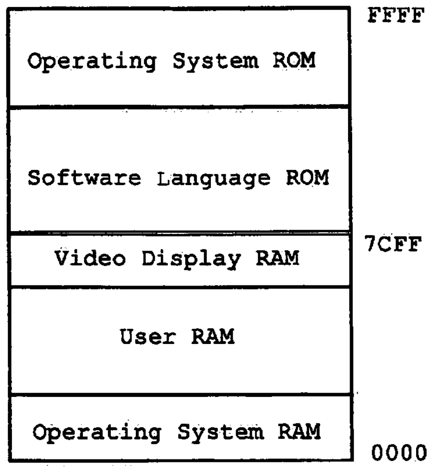


Figure A1.3 Memory map for a system with a 16-bit address bus.

The visual display unit (VDU) screen supported by the system can have any screen location identified by a particular memory address in RAM. The size of the video RAM depends on the system used and its graphics resolution requirements. The operating system also requires some RAM which should not be used by the system user.

Larger systems with 16 data bits and 20 address lines would have 1 Mbyte of addressable memory with a typical memory map as shown in Figure A1.4.

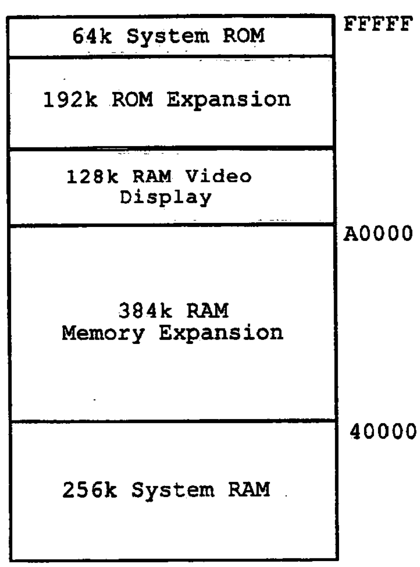


Figure A1.4 Memory map for a system with a 20-bit address bus.

Input/output (I/O)

The system will need an interface with the 'outside world'. The I/O interface allows the connection of input data via, say, a keyboard and sensors which can transpose information such as movement, pressure, temperature etc., into electrical signals. For output data there could be, say, a monitor to display instructions/data and outputs that can feed external devices, such as relays, solenoids, LEDs etc.

As mentioned earlier it is possible to 'memory map' the I/O interface so that data read from the interface comes directly from the external device while data transferred to the interface is data fed directly to the external device. The I/O interfaces are usually referred to as I/O ports. Most microcomputer systems have ICs which perform the function of I/O ports and some are programmable which means that the operating mode may be changed to suit the particular system requirements.

If the microcomputer is used to monitor and control an external quantity (such as pressure, temperature, displacement etc.) The signals produced by the transducer are likely to be analogue in form. Such a signal would need translating into a digital signal using an analogue-to-digital converter (ADC) before the input can be fed to the input port of the microcomputer. Once the computer has evaluated the received data, it is likely to send a control signal back to the transducer to maintain or amend the quantity being measured. The control signal is digital in form and must be translated into analogue form using a digital-to-analogue converter (DAC) before being applied to the transducer. A possible arrangement is shown in Figure A1.5.

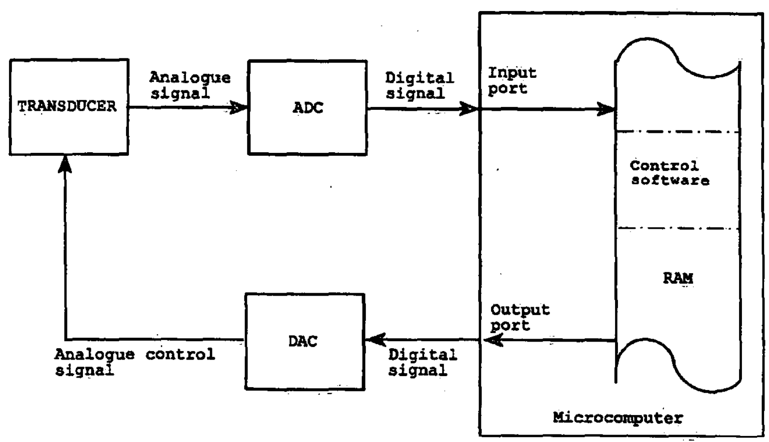


Figure A1.5 Control of an external transducer parameter by a microcomputer.

The ports may be serial, for moving data a bit at a time, or parallel, where data is moved in a block, with the rate of transfer determined by the system clock.

Local Area Networks (LANs)

It is often required to interconnect microcomputers/workstations to form a network which, if distances involved are small, is known as a Local Area Network or LAN. A LAN is typically used to share data and peripherals and to allow communication between stations. It is possible, for instance, to use several outlets to display data, for example ECDIS chart information, to areas other than just a single station.

Interrupts

A microcomputer system may be operated in such a way that the processor is able to respond to a servicing request from an external device as required. Such requests are usually asynchronous in that they are transmitted in an arbitrary manner without being synchronized by an external clock. Two techniques are polling and interrupt.

- Polling is a technique whereby the external devices are interrogated in turn on a priority basis to determine which device made the servicing request. The servicing request will cause the processor to stop its normal program and move to a polling subroutine. After the servicing is carried out the return from subroutine will restore the processor to the task it was engaged in prior to the servicing request being made.
- Interrupt is a technique that causes an interrupt signal to be sent to the processor itself. Such a signal causes the processor to suspend its current operations and transfer to a servicing routine for the device requesting the interrupt. The routine is similar to a subroutine except that it is initiated by hardware instead of software.

Software

The computer will operate according to a program that contains a set of sequential instructions. The categories of programming are:

1 machine code
2 assembly language
3 high-level language.

1 and 2 above provide what is known as 'low-level' programming while 3 provides 'high-level' programming. Machine code is in the form of a set of logic 1s and 0s on which the processor operates. Assembly language uses mnemonics which represent the required machine code, with the required transition from assembly language into machine code being performed by an assembler. A computer operator controlling the processor via a keyboard will use a high-level language to produce what is known as source code which is translated into machine code by instructions stored in ROM.

A similar translation process is necessary for changing the machine code results of programming back to a form which can be understood by the operator. The translation process with a high-level language is undertaken by a compiler or interpreter. The difference in level between assembly and high-level languages is that:

- in assembly language, each symbolic code instruction is related to one machine code instruction
- in high-level language, the compiler can deal with complex symbolic instructions each of which would convert to several machine code instructions.

The language BASIC (beginner's all-purpose symbolic instruction code) is an interpreted high-level language. The source code consists of line-numbered instructions and during program execution each line is converted into machine code prior to execution. No complete machine code translation of the complete source code is produced and program execution is slow but has the advantage that it is easily changed.

Languages such as ADA, C, FORTRAN and PASCAL are compiled with the source code first produced using an editor according to the language rules. The compiler then translates the source programme into machine code form which is termed the object code. The main advantage of compiled high-level languages is that of transportability of the codes between microcomputers that use the same family of microprocessors.

A2

Glossary of microprocessor and digital terms

This appendix is not intended to be a complete listing of terms relating to microprocessor and digital systems. The aim is to give a brief outline description of those terms found in the various chapters so that each section can be understood without the need to refer to specialist texts. Should the reader wish to go further than this then obviously textbooks dealing with these topics can be used.

Using the glossary

Many terms are referred to by an abbreviated form, or acronym, and where applicable the definition appears under this heading. The heading under the full version of the term will direct the reader to the acronym version.

Certain terms are included more than once, although under different headings, with cross-references to link the headings. Cross-references are only used when it is felt necessary, for easier understanding, to expand a particular definition.

ADC Analogue-to-digital converter. A device that samples an analogue signal and converts the observed analogue level to digital form. The digital form is made up from several binary digits, or *bits*.

Active A signal may be described as active high or active low to indicate which of the two logical levels (logic 1 or logic 0) causes the digital circuit to be enabled.

Address A coded instruction that specifies the location in memory of stored data.

Algorithm A set of rules laid out in a logical sequence to define a method of solving a particular problem.

Alphanumeric A system where the required information is in a combination of alphabetic characters and numbers.

Analogue A system where the signal can be considered to vary continuously with time. A digital system on the other hand may be considered to consist of a finite number of discrete levels. The number of levels may only be two as in the case of a binary system.

Analogue-to-digital converter See ADC

AND gate For a description of a *gate* see under that heading. An AND gate is an electronic circuit of two or more inputs which will only generate an output at logic 1 if all the inputs are at logic 1. All other combinations of input signals will give a logic 0 output. The performance of an AND gate may be defined in terms of a truth table which lists the output level for all possible input combinations. The truth table for a two input AND gate is:

A	B	F
0	0	0
0	1	0
1	0	0
1	1	1

where A and B are the inputs and F is the output.

ASCII American Standard Code for Information Interchange. This is a common code which gives a 7-bit word to define letters, numbers and control characters.

Basic Beginner's all-purpose symbolic instruction code. This is a high-level language that enables the computer user to program the system using an easily understood set of instructions. Within the computer memory there is a 'translator' which converts the BASIC language into the binary signals, or machine code, which the machine understands.

BCD Binary Coded Decimal. A system of representing the numbers 0 to 9 inclusive by a binary equivalent. The relationship is as shown:

Decimal number	Binary coded value
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001

Binary A system of numbers using a base 2, whereas the decimal system uses base 10. The binary system only requires two symbols, i.e. 1 and 0.

Bit Contraction of binary digit. A single bit may be a logic 1 or logic 0 and is usually represented by the presence or absence, respectively, of a voltage level.

Buffer An electronic circuit connected between other circuit elements to prevent interactions between those elements. The buffer may also provide extra drive capability. A buffer may be used also as a temporary storage device to hold data that may be required at a later time while the computer is engaged on other tasks.

Bus A collection of conductors used to transmit binary information in parallel around the system. For microprocessor applications there would be an Address bus used by the central processing unit (CPU) to identify storage locations and a Data bus used for the transmission of data around the system.

Byte A collection of 8 bits. In a microprocessor system using 8-bit data buses and a 16-bit address bus, then the data can be contained in one byte while the address needs two bytes to define it.

Character The letters A–Z, numbers 0–9 and other special symbols used by a computer or microprocessor system and coded for use by the system.

Character generator The electronic circuitry required in order to prepare a character for display purposes. Such generators possess memory where the binary-coded characters can be stored.

Chip select An input to an integrated circuit which, when active, allows the integrated circuit to be operative. If the input is not active then the integrated circuit is inactive. This control signal is sometimes called a 'chip enable' input.

Clock A periodic timing signal used to control a system.

Code A set of rules allocated to groups of bits. The combination of the bits in a group gives a unique meaning based on following the rules.

Coincidence gate An electronic circuit used to indicate, by means of a certain output level, when two inputs are identical. When the inputs are binary in form then all bits of one input should be coincident with the corresponding bits of the other input before the required output level is generated. An Exclusive-NOR gate could be used for this purpose.

Command A signal, or group of signals, used to begin or end an operation.

Computer In the case of a digital computer the basic system consists of a central processing unit (CPU), memory, input and output units and a control unit. The computer is able to perform such tasks as: manipulate data, perform arithmetic and logical operations on data and store data.

Computer language A set of conventions, rules and representations used to communicate with the computer system. The language may be low-level, such as assembler (uses mnemonics), or high-level, using user-orientated language like BASIC.

Converter See under the headings of analogue-to-digital converter (ADC) or digital-to-analogue converter (DAC).

Counter A circuit used to count the number of pulses received. The counter may be arranged to start from zero and count from there in increments of one (up-counter) or to start from the counter maximum capacity and decrement from that value one pulse at a time (down-counter).

CPU Central processing unit. Part of a computer system which contains the main storage (registers), arithmetic and logic unit (ALU) and control circuitry. Sometimes referred to simply as the processor.

Data Information or signals, usually in binary form.

D-type flip-flops An electronic circuit which on receipt of a clock pulse will give an output logic level the same as that present at the input terminal prior to the arrival of the clock pulse. It is widely used as a data latching buffer element.

Decoder An electronic circuit which has several parallel inputs and the ability to recognize one or more of the possible input combinations and output a signal when these combinations are received. All signal levels are binary.

Dedicated A dedicated system is one designed to perform a specific operation, i.e. a dedicated microprocessor system is programmed to perform only one specific task.

Demultiplexer A device used to direct a time-shared input signal to several outputs in order to separate the channels.

Digital Information in discrete or quantized form, i.e. not continuous as in the case of an analogue signal.

DAC Digital-to-analogue converter. An electronic device for converting discrete signal levels into continuous form.

Disable A control signal that prevents a circuit or device from receiving or sending information.

Display A means of presenting information required by a user in visual form. Includes the use of CRT (cathode ray tube), LED (light emitting diode), liquid crystal, gas discharge and filament devices.

Driver An electronic circuit that provides the input for another circuit or device.

Enable A control signal that allows a circuit or device to receive or transmit information.

Encoder This is the inverse process of decoding. An encoder has several inputs but only one is in the logic 1 state. A binary code output is generated depending on which of the inputs has the logic 1 level.

EPROM Erasable and programmable read-only memory. A memory circuit with stored data which can be read at random. The data are capable of being erased and the chip reprogrammed with new data.

Exclusive-OR gate A circuit with two inputs and an output which can be at logic level 1 when either of the two inputs is at logic 1 and logic 0 if neither or both the inputs are at logic level 1.

Filament display A 7-segment filament wired element whereby an alphanumeric character may be displayed when certain of the filaments are caused to be lit.

Flag A flip-flop that can be set or reset to inform of an event that has occurred or a condition that exists within a system.

Flip-flop An electronic circuit having two stable states that can be used to store one bit. The circuit uses two gates, the output from each being cross-coupled as an input to the other. The output from one gate is usually referred to as the Q output while the output from the other gate, being the complement of the first output, is called $\overline{Q}$.

Gate This is a circuit with two or more inputs and an output which allows a logic level 1 to exist at the output, or not, as the case may be, when certain defined criteria are met.

Hard copy Printed or graphical output produced on paper by a computer system thus allowing a record to be kept.

Input/output ports These circuits allow external circuits to be connected to the computer internal bus system.

Integrated circuit (IC) A small 'chip' of silicon processed to form several elements directly interconnected to perform a given unique function.

Interface A common boundary between systems to allow them to interact.

Interrupt A computer input that temporarily suspends the main program and transfers control to a separate interrupt routine. Interrupt inputs to the microprocessor systems discussed in the main text are usually referred to by acronyms such as $\overline{\text{IRQ}}$ (interrupt request) and $\overline{\text{INT}}$.

Interrupt masking A technique that allows the computer to specify if an interrupt will be accepted. $\overline{\text{IRQ}}$ and $\overline{\text{INT}}$ are maskable interrupt inputs whereas NMI (non-maskable interrupt) is not.

Keypad (or Keyboard) A unit which forms part of an input device. This may have a full QWERTY type key layout or be a simplified arrangement to suit the needs of the system.

Language See computer language.

Latch A temporary storage element, usually a flip-flop.

Logic Electronic circuits which control the flow of information through the system according to certain rules. These circuits are known as gates since the 'gates' are opened and closed by the sequence of events at the inputs.

Logic level Using binary notation the levels may be logic 1 or logic 0. According to the rules mentioned in the definition of logic, level 1 is taken to mean a logical statement is 'true' while level 0 means the logical statement is 'false'.

Magnetic tape A flexible, standard width, magnetic powder coated tape which can be used to store, and retrieve, binary-based data.

Mask bit With reference to an interrupt request, an internal flip-flop in the MPU can be set to disable an interrupt (interrupt masked) or reset to allow the interrupt to be accepted.

Memory In a digital system, it is that part of the system where information is stored.

Microprocessor See MPU.

Monostable An electronic circuit which has only one stable state. The circuit is normally in the stable state and is triggered into the unstable state where it remains for a period of time determined by a CR time constant value of external components. After this period of time the circuit returns to the stable state.

MPU An IC that can be programmed with stored instructions to perform a wide variety of functions, consisting of at least a controller, some registers and an ALU (arithmetic and logic unit). Thus the MPU contains the basic parts of a simple CPU.

Multiplexing A method of selecting one of several inputs and placing its value on a time-shared output.

NOT gate An inverter. A circuit whose output is high if the input is low and vice versa.

Octal latch An integrated circuit package that offers eight separate flip-flop (or latch) circuits.

OR gate For a description of a *gate* see under that heading. An OR gate is an electronic circuit of two or more inputs which will generate an output at logic 1 if any one or all of the inputs are at logic 1. Only when all inputs are at logic 0 will the output be at logic 0. The performance of an OR gate may be defined in terms of a truth table which lists the output level for all possible input combinations. The truth table for a two-input OR gate is:

A	B	F
0	0	0
0	1	1
1	0	1
1	1	1

where A and B are the inputs and F is the output.

Port Terminals (input and output) which allows access to or from a system.

Printer The output peripheral of a computer system which allows a hard copy to be obtained.

Program A sequence of instructions logically ordered to perform a particular task.

PROM Programmable Read Only Memory. This is the type of memory used to hold microprocessing instructions. It is a form of ROM that can be programmed by the supplier and not the user.

Pulses Those signals used to energize a circuit digitally. There is a transition in signal level between discrete values and each level is maintained for a period of time.

Quad gate An integrated circuit package which offers four separate gate circuits of a particular type.

RAM Random Access Memory. A memory that can be read from and written into.

Readout A presentation of input information from a computer. It can be displayed on a screen, stored on tape or disk or be a hard copy when it is usually referred to as a printout.

Read/Write Can refer to the type of memory element (RAM is sometimes referred to as read/write memory) or to the signal input line to a RAM chip, the logic level on which determines whether the memory is read or overwritten.

Register A group of memory cells used to store groups of binary data in a microprocessor.

Reset This could be an input to a flip-flop to bring the Q output to a logic 0 state or that facility which allows a microprocessor to be returned to a pre-determined state. Where the point of return is situated in memory depends on the system.

ROM A memory element containing information which cannot be altered under computer operation. The data can only be read by the computer.

Self-test In some equipment this is a facility by which when power is first applied the system is checked by running through a special software routine. If a faulty area is found some indication is made to the user.

Sensor A device, possibly a transducer, which converts physical data into electrical signal form. If digital in form the electrical signal can be processed by the computer directly while if analogue in form, it requires analogue-to-digital conversion (ADC) before being applied to the computer.

Seven-segment display That form of display element comprising seven segments where each segment can be individually energized. The element is thus able to display a variety of alphanumeric characters depending on which segments are energized.

Shift register A register in which the stored data can be shifted, a bit at a time, to the left or right.

Signal An electrical variation, either continuously variable or variable between discrete levels, which can be interpreted as information.

Software A program which can be loaded into a computer system and resides in RAM. Such programs can be loaded and changed at will.

Storage A term used to describe any device capable of storing data. Memory elements are storage devices.

Subroutine Part of a master program which can be entered frequently from the master program. Used to save programming space where a part of a program is repetitive.

Tape The media, either paper or magnetic, used to store binary coded data for a computer system.

Test The routine for establishing that a device or system is responding as it was designed to do.

VDU Visual display unit. An input/output peripheral, which has a keyboard for data input and a monitor screen for viewing both the input data and any outputted data. The system usually includes buffer storage facilities so that data may be loaded off-line. Often used to communicate directly with the computer in real time.

A3
Serial data communication

With a wide variety of electronic devices available to perform specific functions there is a need to interconnect the devices so that efficient error-free communication can occur. This appendix will look at the RS-232, RS-422, and RS-485 standards as well as the NMEA 0183 interfacing protocol since they are the ones that are most often used in the marine environment.

Serial communication

Data in digital form has voltage levels that define a logic 1 and logic 0 level; a binary digit, often abbreviated to the term 'bit', will be either 1 or 0. A byte of data is made up of 8 bits while two bytes would comprise 16 bits, etc. If we assume that data comprises a single byte then the data may be sent through a parallel port of a device where all 8 bits would be transmitted simultaneously. The data is transmitted quickly but the required cable is bulky because eight separate wires are required, one for each bit. If a serial port is used then each bit of the data is sent in turn over a single wire. The time taken to transmit the data is eight times longer than the time taken using a parallel port but fewer wires are needed. In fact full duplex (simultaneous transmission in both directions) is possible with just three wires, one for sending, one for reception and a common signal ground. RS-232 is a good example of a full duplex arrangement.

Half duplex devices can transmit data in both directions but not at the same time, i.e. one device transmits while a second device receives; at some other time the direction of transmission can be reversed. RS-485 is an example of a half duplex arrangement while RS-422 can operate in either full duplex or half duplex as required. Simplex transmission (i.e. in one direction only), where one device always transmits and the connected device always receives, would require just two wires.

Serial data can be transmitted in two ways.

- Synchronous. In this arrangement the interconnected devices initially synchronize with each other and continually send characters to keep synchronization even when data is not being transmitted.
- Asynchronous. In this arrangement the sending and receiving devices are not synchronized and each byte of data sent must be identified by a start bit inserted before the data and a stop bit at the end of the data. The extra bits involved means that this type of transmission is slower than the synchronous form although it does not need to transmit idle characters to maintain synchronization.

When transmitting a data byte it is possible to insert an extra bit, known as a parity bit, alongside the data. The logic value of the parity bit can be changed so that the number of data bits sent can be identified as an even or odd number. As an example if even parity is used and the data byte is, say, 00101100 then the parity bit sent would be 1; if the data byte is, say, 01100110 then the parity bit sent would be 0. The converse would be true if odd parity were chosen. The use of a parity bit allows a degree of error-check on received data. Suppose a data byte 00001100 is received together with a parity bit 1, it follows that, using even parity, one of the data bits received is incorrect although it is not specific as to which one. Also if two data bits are incorrect the parity bit would not show any error at all.

Data transmission rates are quoted in bauds, a unit named after the Frenchman Jean Baudot who is credited with devising an original 5-bit code for alphabetical characters in the latter part of the 19th century. The baud rate defines the number of times per second that a line changes state. The baud rate may be the same as the bit rate (i.e., number of bit s^{-1} transmitted) but there may be circumstances where bit rate and baud rate are not the same.

RS-232 Serial Interface

The original Recommended Standard-232C was approved in 1969 by the Electronic Industries Association (EIA) for interconnecting serial devices. In 1987 the EIA produced a new version of the standard which became the EIA-232D. By 1991 the EIA had joined forces with the Telecommunications Industry Association (TIA) and the standard became known as the EIA/TIA-232E. However, the increasing length of the title was too much for most users and the standard is still commonly known as the RS-232C or as simply the RS-232.

The RS-232 standard specifies the physical interface, together with associated electrical signalling, between serial transmitting/receiving Data Communication Equipment (DCE) and Data Terminal Equipment (DTE). A computer, for example, is a DTE device, as are printers and terminal equipment, while other, remote, devices such as a modem are DCE devices. A typical arrangement is shown in Figure A3.1.

The type of signal is known as single-ended unbalanced because each signal line has a voltage level that is set with respect to signal ground. RS-232 drivers (transmitters) are specified with an output voltage more negative than –5 V for a logic 1 level and more positive than +5 V for a logic 0 level. The defined maximum output voltage of a driver stage on open-circuit is ± 25 V. The RS-232 receivers will interpret a voltage level more negative than –3 V as logic 1 while a voltage level more positive than +3 V is a logic 0. This permits a noise immunity of 2 V for the transmission. If a parallel port is used then a Universal Asynchronous Receiver Transmitter (UART) must be placed between the transmitter (and/or receiver) and the RS-232 interface.

The maximum transmission rate for the standard is defined as 20 kbaud with a cable length not exceeding 15 m; the cable length can be increased for lower baud rates and if shielded cable is used.

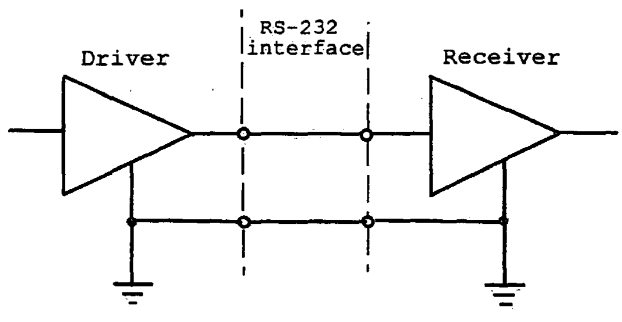


Figure A3.1 Driver and receiver circuit connected via an RS-232 interface.

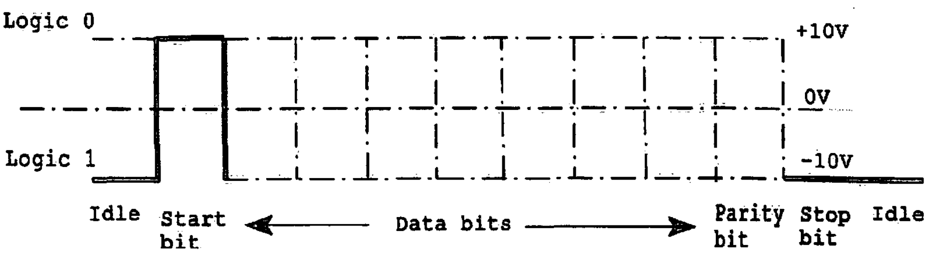


Figure A3.2 Typical arrangement for the transmission of an ASCII character using the RS-232 standard.

Voltage levels could be in the range ±5 to ±15 V for the loaded driver stage. If a voltage level of ±10 V is assumed and with the data transmitted as an 8-bit group consisting of 7 data bits and a parity bit, the arrangement would be as shown in Figure A3.2. The 8-bit group is framed by a start bit at logic 0 and a stop bit at logic 1. If the group represents an ASCII character then the use of 7 bits can only allow ASCII values up to 127.

The RS-232 standard supports two types of connectors, a 25-pin D-type connector (DB-25) and a 9-pin D-type connector (DB-9). The pin assignments for a DB-25 connector is shown in Table A3.1

Table A3.1 DB-25 pin assignment

Pin	*Signal*	*Source*	*Key*
1	-	-	Frame ground
2	TD	DTE	Transmitted data
3	RD	DCE	Received data
4	RTS	DTE	Request to send
5	CTS	DCE	Clear to send
6	DSR	DCE	Data set ready
7	SG	-	Signal ground
8	DCD	DCE	Data carrier signal
9	-	-	Positive voltage
10	-	-	Negative voltage
11	-	-	Unassigned
12	SDCD	DCE	Secondary DCD
13	SCTS	DCE	Secondary CTS
14	STD	DTE	Secondary TD
15	TC	DCE	Transmit clock
16	SRD	DCE	Secondary RD
17	RC	DCE	Receive clock
18	-	-	Unassigned
19	SRTS	DTE	Secondary RTS
20	DTR	DTE	Data terminal ready
21	SQ	DCE	Signal quality detector
22	RI	DCE	Ring indicator
23	DRS	DTE/DCE	Data rate selector
24	SCTE	DTE	Clock transmit external
25	-	-	Busy

Table A3.2 DB-9 pin assignment

Pin	*Signal*	*Key*
1	DCD	Data carrier detect
2	RD	Received data
3	TD	Transmitted data
4	DTR	Data terminal ready
5	SG	Signal ground
6	DSR	Data set ready
7	RTS	Request to send
8	CTS	Clear to send
9	RI	Ring indicator

Typically in many applications only nine of the DB-25 pins are important and the DB-9 connector reflects this as shown in Table A3.2.

Considering the DB-25 connector, signals are carried as single voltages referred to a common earth point SG (pin 7). The TD (pin 2) connection allows data to be transmitted from a DTE device to a DCE device; the line is kept in a mark state by the DTE device when it is idle. The RD (pin 3) connection is the one where data is received by a DTE device; the line is kept in a mark state by the DCE device when idle.

Pins 4 and 5 are the RTS and CTS connections, respectively, and provide handshaking signals. The DTE device puts the RTS line in a mark state when ready to receive data from the DCE; if unable to receive data the DTE puts the line in a space state. For CTS the DCE device puts the line in a mark state to inform the DTE device it is ready to receive data; a space on the line indicates the DCE is unable to receive data.

The DSR/DTR connections (pins 6/20, respectively) are used to provide an indication that the devices are connected and turned on. DCD (pin 8) is used to indicate that the carrier for the transmit data is on. The DCD and RI (pin 22) are only used in connections to a modem. The state of the RI line is toggled by the modem when an incoming call rings the user's telephone.

If the RS-232 link is used to connect devices operating with transistor–transistor logic (TTL) levels then interface integrated circuits (ICs) must be used to convert the TTL logic levels to the RS-232 standard and vice versa.

RS-422

The use of RS-232 is universal and popular but it does have its limitations. The use of a single line to carry the signal does make it susceptible to noise. Screening the cable can mitigate external noise but will do nothing to stop internal noise. An improved standard introduced by the EIA is the RS-422, which uses a balanced line interface. A pair of lines (Line A and Line B) are used to carry each signal and data is encoded/decoded as a differential voltage between the two lines. See Figure A3.3.

Voltage levels at the driver stage output are typically between 2 and 6 V across the A and B terminals while at the input to the receiver stage the voltage levels are in the range 0.2–6V. The lower threshold voltage is to allow for signal attenuation on the line.

Logically, a '1' ('Mark' or 'off' state) is a voltage on line A which is negative with respect to line B, while a '0' ('Space' or 'on' state) is a voltage on line A which is positive with respect to line B. Using RS-422, up to 10 receivers may be connected to one driver stage.

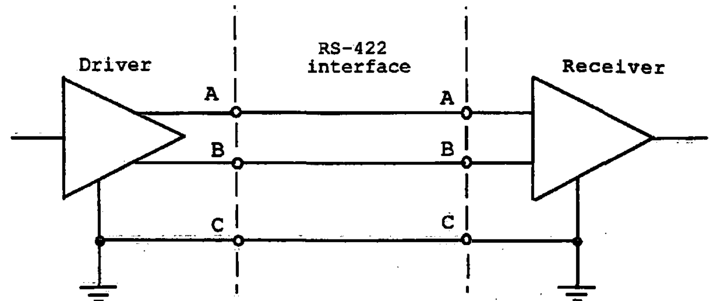


Figure A3.3 Driver and receiver circuit connected via an RS-422 interface.

Because the voltage is differential, the interface is less likely to be affected by differences in ground voltage between transmitter and receiver. Also if the lines are twisted together the effect of external noise will be the same in each line and hence eliminated. This is known as common-mode rejection. Common-mode signals are defined as the average value of the sum of the voltages on the A and B lines. RS-422 can withstand a common mode voltage of ±7 V.

The use of RS-422 allows higher data rates to be transmitted over longer distances. A maximum length of 1300 m is recommended at 100 kbaud, while for distances up to 13 m it can deliver signals at 10 Mbaud.

RS-485

This is also a balanced arrangement similar in detail to RS-422. The RS-485 standard allows up to 32 devices to communicate at half duplex on a single pair of wires, with devices up to 1300 m apart at 120 kbaud, in what is known as a multidrop network. Figure A3.4 shows the arrangement.

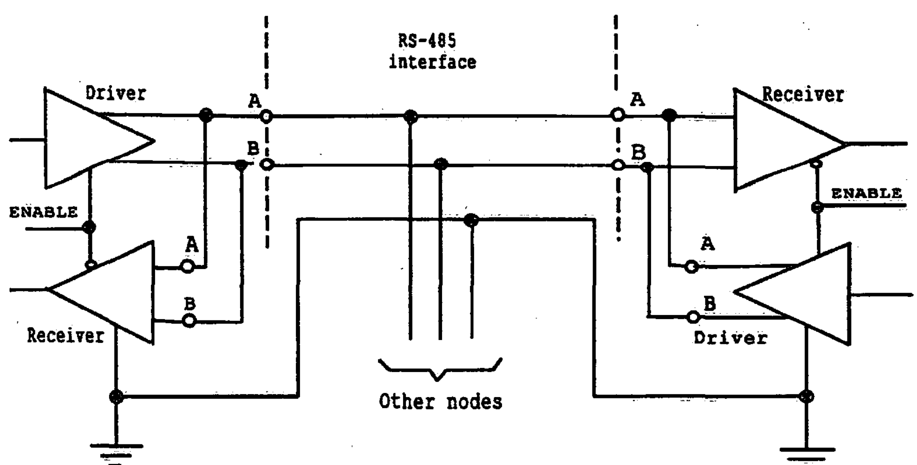


Figure A3.4 Typical arrangement for an RS-485 two-wire multidrop network.

It can be seen from Figure A3.4 that each device has an 'enable' input. Since only one driver stage can be connected to the line at any time, an 'on' signal on the enable input will connect that driver to the line while all other drivers have an 'off' signal on their enable line. This puts their outputs to the line in a high impedance state, effectively disconnecting them from the line. At the same time the associated receivers will have an on signal on their enable line allowing them to be connected to the line and receive a transmission from the connected drive stage. This change in signalling on the enable line can be achieved using hardware or software techniques. The range of common mode voltage levels that the system can tolerate is increased to +12 V to –7 V. Since the driver can be disconnected from the line it must be able to withstand this common mode voltage level while in the high impedance state.

An alternative wiring arrangement allows full duplex operation by having one 'master' port with the driver connected to each of the 'slave' receivers using one twisted pair. In turn each slave driver is connected to the master receiver using a second twisted pair.

All the above descriptions are of the hardware requirements for particular RS connections. There is also a software requirement that has not been discussed because such a requirement depends on the particular application.

NMEA interfacing protocols

The National Marine Electronics Association (NMEA) has established standards to be employed by the manufacturers of marine electronic equipment to ensure compatibility when different equipment is fitted together on a ship. The NMEA Standard 0180 was published in late 1980, NMEA 0182 in early 1982, followed by NMEA 0183 which has had several revisions, the latest of which is version 2.30, issued in March 1998. There are differences in transmission parameters between the various NMEA standards which means that NMEA 0183 is not directly compatible with its predecessors.

NMEA 0180 and 0182 standards are concerned with connections between Loran-C receiver and an autopilot using a simple or complex data format. The former consists of a single data byte transmitted at intervals of between 0.8 and 5 s at 1200 baud using a parity bit and bit 7 always set to zero. The complex data format uses a block of data of 37 bytes of ASCII characters transmitted at intervals of 2–8 s with bit 7 always set to one.

NMEA 0183

This NMEA standard specifies the signal parameters, data communication protocol and timing together with sentence formats for serial data bus transmission rates of 4800 baud. The serial data communication between equipments is unidirectional with one 'talker' and possibly many 'listeners'. The data uses ASCII format and typically a message might contain between 11 and 79 characters in length and require transmission at a rate no greater than once every second.

The arrangement for interconnecting the 'talker' to the many 'listeners' requires just two wires (classified as signal lines 'A' and 'B') and a shield. The 'A' line of the talker should be connected in parallel to the 'A' lines of every listener, and similarly each listener 'B' line is connected in parallel to the talker 'B' line. The listener shield connections should be made to the talker chassis but not to each other.

The talker signal is required to be similar in form to that shown in Figure A3.2 but there are eight data bits and no parity bit. The talker device must have its drive capability defined in order to establish the possible number of listener devices it can drive. Each listener device should contain an optoisolator and protective circuit which limits current, reverse bias and power dissipation at the point of optical coupling.

The standard defines the logic 1 state in the range −15 V to +0.5 V while the logic 0 state is in the range +4–15 V, while sourcing is not more than 15 mA. The receiver circuit should have a minimum differential input voltage of 2.0 V and should not draw more than 2.0 mA from the line under those conditions. The voltage conditions on the data bus should be in accordance with the RS-422 specification.

As described for Figure A3.2, the data bits use the 7-bit ASCII format and for this standard the data bits d0–d6 will contain the ASCII code, while data bit d7 is always set to 0. The ASCII character set consists of all printable ASCII characters in the range 20h–7Eh except for those characters reserved for specific formatting purposes. The individual characters define units of measure, indicate the type of data field, type of sentence etc. A sentence always starts with the character '$' followed by an address field, a number of data fields, a checksum, and finishes with carriage return/line feed.

A field consists of a string of valid characters located between two appropriate delimiter characters. An address field is the first field in a sentence and follows the $ delimiter. The types of address field include the following.

- Approved address field. This consists of five digits and upper-case letter characters. The first two characters are the talker identifier. The following three characters are used to define the format and type of data.
- Query address field. This consists of five characters and is used to request transmission of a specific sentence on a separate bus from an identified talker. The first two characters represent the talker identifier of the device requesting data , the next two characters represent the talker identifier of the device being addressed, while the final character is the query character Q.
- Propriety address field. This consists of the character 'P' followed by a three-character manufacturer's mnemonic code, used to identify the talker issuing a propriety sentence.

Other fields include the following.

- Data fields. These are contained within the field delimiters ','. Data field may be alpha, numeric, alphanumeric, variable or fixed length or constant, with a value determined by a specific sentence definition.
- Null fields. This is a field where no characters are transmitted and is used where the value is unavailable or unreliable.
- Checksum field. This will always be sent and is the last field in a sentence and follows the checksum delimiter character '*'. The checksum is the 8-bit Exclusive-OR (XOR) of all characters in the sentence including the '$' and '*' delimiters. The hexadecimal value of the most significant and least significant 4 bits of the result is converted to two ASCII characters (0–9, A–F(upper case)) for transmission with the most significant character transmitted first.

Sentences may have a maximum number of 82 characters which consists of the maximum 79 characters between the starting delimiter '$' and the terminating <CR><LF>. The minimum number of fields in a sentence is one. The first field shall be the address field, which identifies the talker and the sentence formatter, which specifies the number of data fields in the sentence, the type of data within them and the order in which they are sent. The maximum number of fields in a sentence is limited only by the maximum length of 82 characters. Null fields may be present in a sentence and should always be used if data for that field is unavailable. A talker sentence contains the following elements in the order shown:

$aaccc,df1,df2,df3*hh<CR><LF>

where

$	is the start of the sentence,
aa	are alphanumeric characters which identify the talker,
ccc	are alphanumeric characters identifying the sentence formatter which gives the data type and string format of following fields
,	is the field delimiter which is present at the start of all fields except the address and checksum fields. The field delimiter will still be present even if a null field is transmitted,
df1/2/3	represent the data fields which contain all data to be transmitted. The data field sequence is fixed and is identified by the 'ccc' characters in the address field. Data fields may be of variable length,
*	is the checksum delimiter which follows the last data field. The two characters following represent the hex value of the checksum,
hh	is the checksum field,
<CR><LF>	is the end of the sentence.

An example of a talker sentence is given for a rudder order output message:

$AGROR,uxx.x*hh<CR><LF>

where:

AG	is a general autopilot,
ROR	is autopilot rudder order,
u	is sign, negative for left order, omitted for right or zero order,
xx.x	is automatic rudder order up to 45.0°, empty if unavailable. The field here is for a variable number and the use of a decimal point gives a value to one decimal place,
hh	is ASCII hex 8-bit XOR of characters after $ through to the letter before '*',
<CR><LF>	is the end of sentence marker.

Hence, if sentence reads:

$AGROR,-10.2*hh

it indicates an automatic rudder order of 10.2° left.

A 'query' sentence is used when a listener device requests information from a talker. As an example a query message could be transmitted to a GPS receiver to request 'distance to waypoint' data to be sent. The general form of a query sentence is:

$aaaaQ,ccc*hh<CR><LF>

where the first two characters after the '$' start symbol represent the talker identifier of the request. The next two characters represent the talker identifier of the device from which data is requested. 'Q' identifies that the message is a query and 'ccc' contains the approved sentence formatter for data being requested. An example could be:

$CCGPQ,GGA*hh

where the computer (CC) is requesting the GPS receiver (GP) to send data using the mnemonic GGA which represents global positioning system fix data. Such data would then be transmitted at 1 s intervals.

A 'proprietary' sentence may be used by a manufacturer to transfer data which, although using the sentence structure of the standard, does not come within the scope of approved sentences. The general form of the proprietary sentence is:

$Paaa,df1,df2*hh<CR><LF>

where 'P' indicates a proprietary message and 'aaa' is the manufacturers code, i.e. FUR for Furuno, SMI for Sperry Marine Inc. etc. 'df1,df2' represents manufacturer's data fields that must still conform to the valid character set of the standard.

Details of characters used for data content, talker identifier mnemonics, approved sentence formatters for data fields, field types and manufacturer's mnemonic code identifiers are too numerous to list here. Some of the detail can be found in those chapters relating to equipment where the NMEA standard is used. Also manufacturer's manuals should contain references where applicable.

NMEA 2000

The NMEA has established a working group to develop a new standard for data communication between shipborne electronic equipment. The working group will liaise with the International Standards Organization (ISO), the International Electrotechnical Commission (IEC) and the International Maritime Organization (IMO) to develop a new standard, NMEA 2000, to meet the needs of ships in the 21st century.

NMEA 2000 is expected to be a bi-directional, multi-transmitter, multi-receiver serial data network with the ability to share commands, status and other data with compatible equipment over a single channel link. The capacity of the new system is expected to be much greater than the current NMEA 0183 standard and testing has already begun with a few manufacturers participating in trials. It is anticipated that NMEA 2000 should be available by the middle of 2001.

A4

The United States Coast Guard Navigation Center (NAVCEN)

NAVCEN provides quality navigation services that promote safe transportation, support the commerce of the United States and directly benefit worldwide international trade. As a centre of excellence, NAVCEN is proud to be at the forefront of US transportation and navigation initiatives, leading the nation and the international maritime communities into the 21st century.

Radionavigation and information services

NAVCEN controls and manages Coast Guard radionavigation systems from two sites: Alexandria, Virginia, and Petaluma, California. NAVCEN provides worldwide users with reliable navigation signals, timely operational status, general navigation and other information.

GPS

NAVCEN gives access to a massive amount of information on GPS. The NAVCEN website lists the following GPS data files.

- Press releases
- Status messages
- Active Nanus
- YUMA Almanacs
- SEM Almanacs

DGPS

NAVCEN operates the DGPS service, consisting of two control centres and more than 50 remote broadcast sites. The DGPS service broadcasts correction signals on marine radiobeacon frequencies to improve the accuracy and integrity of the GPS (see Chapter 5).

LORAN-C

Atlantic and Pacific LORAN-C user notifications and system health information is listed on the NAVCEN site (see Chapter 4].

Other services

Other files of interest to navigators on the NAVCEN site are:

- RNAV radio frequency spectrum issues
- local Notices to Mariners
- maritime telecommunications
- Federal Radio navigation plan.

Contact

The easiest way to contact NAVCEN is via the web. The primary site is http://www.navcen.uscg.mil. If you do not have access to the net, NAVCEN's mailing address is: The Commanding Officer, USCG NAVCEN, 7323 Telegraph Road, Alexandria VA22315.

Below is a full list of services and contact numbers.

Table A.4.1

Service	*Availability*	*Info type*	*Contact no.*
NIS watchstander	24 hours a day	User inquires	Phone (703) 313–5900 Fax (703) 313–5920
Internet	24 hours a day	Status Fore/Hist/ Outrages/NGS Data/ Omega/FRP and Misc.info	http://www.navcen.uscg.mil ftp://ftppp. navcen.uscg.mil
Internet Mirror Site	24 hours a day	Status GPS/DGPS Outrages/	http://www.nis-mirror.com
NIS Voice Tape Recording	24 hours a day	Status forecasts historic	(703) 313–5907–GPS
WWV	Minutes 14 & 15	Status forecasts	2.5, 5, 10,15, and 20 MHz
WWVH	Minutes 43 & 44	Status forecasts	2.5, 5, 10, and 15 MHz
USCG MIB	When broadcast	Status forecasts	VHF Radio marine band
NIMA Broadcast Warnings	When broadcast received	Status forecasts	
NIMA Weekly Notice to Mariners	Published & mailed weekly	Status forecast outrages	(301) 227–3126
NAVTEX Data Broadcast	All Stations Broadcast 6 times daily at alternating times	Status forecast outrages	518 kHz

Index

Maritime electronic navigation systems have evolved to the extent that computers and satellite systems dominate. A sound basis for the understanding of modern navigation systems is provided, to bring students and professionals up-to-date with the latest developments in technology, so that ship's officers can assist in safe and precise navigation. *Electronic Navigation Systems*, the updated version of Tetley and Calcutt's previous work, *Electronic Aids to Navigation*, is the book to do this.

Developed with close scrutiny from the US Merchant Marine Academy and maritime navigation centres in the UK, new chapters are included which reflect the developing technology of the 21st Century and how it will affect ship navigation in the future.

- Thoroughly revised and updated to conform to stricter training requirements mandated by the STCW-95 amendments.
- Expanded section on the GPS system.
- Updated and expanded section on integrated bridge systems.
- New chapters on the application of electronic chart systems, including AIS and ECDIS.
- Revision questions at the end of each chapter.
- Fully updated glossary.

Laurie Tetley spent many years serving in the Merchant Navy, and taught electronic navigation and communication systems at the Southampton Institute of Higher Education. *David Calcutt* has held a commission in the Royal Navy, and has spent time as a Technical Civil Servant and as Senior Lecturer at the University of Portsmouth.

Related titles from Butterworth-Heinemann:

Understanding GMDSS ∘ Tetley and Calcutt ∘ 0 3406 1042 5
GMDSS for Navigators ∘ Seaton and Smith ∘ 0 7506 2177 X
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