

## Chapter 3

# Speed measurement

### 3.1 Introduction

Speed measurement has always been of the utmost importance to the navigator. The accuracy of a dead reckoning position plotted after a long passage without star sights being taken, is dependent upon a sound knowledge of the vessel's heading and speed.

To be of value, the speed of any object must be measured relative to some other point. At sea, speed may be measured relative to either the seabed (ground reference speed) or to the water flowing past the hull (water reference speed). Both of these types of speed measurement are possible and both have their place in modern navigation systems.

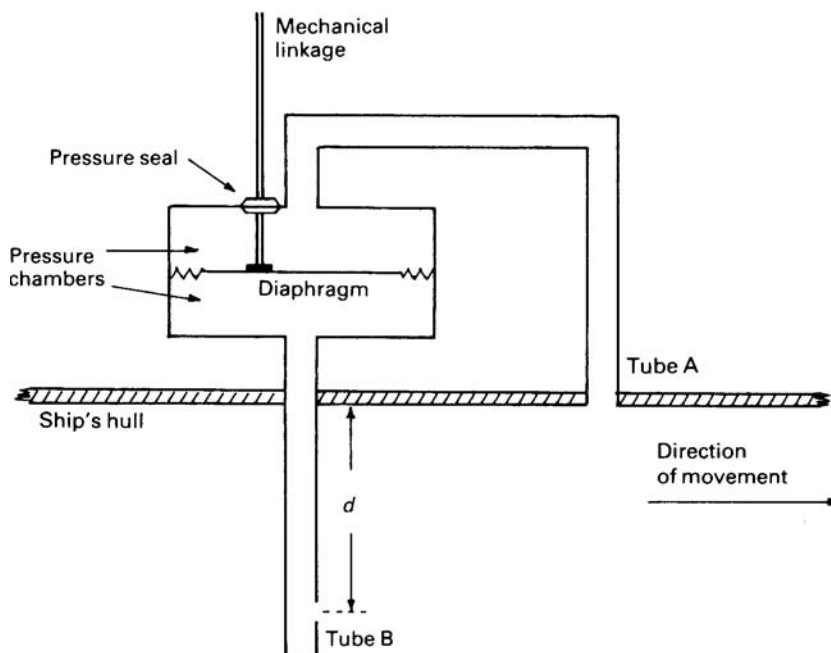
This chapter deals with the methods of speed logging that are in general use on board modern vessels. One of these, the pressure tube log, is old but it still gives a satisfactory performance. Another, the electromagnetic log, is often used on smaller vessels and the popular Doppler speed log is to be found everywhere.

### 3.2 Speed measurement using water pressure

When a tube, with an opening at its base, is vertically submerged in water, a pressure, proportional to the depth to which the tube is submerged, will be developed in the tube. If the tube is held stationary the pressure remains constant and is termed 'static' pressure. If the tube is now moved through the water, whilst keeping the depth to which it is submerged constant, a second pressure called 'dynamic' pressure is developed. The total pressure in the tube, called a Pitot tube, is therefore the sum of both the static and dynamic pressures.

To ensure that the dynamic pressure reading, and thus speed, is accurate, the effect of static pressure must be eliminated. This is achieved by installing a second tube close to the first in such a way that the static pressure produced in it is identical to that created in the Pitot tube but without the pressure increase due to movement through the water (see Figure 3.1).

In a practical installation, tube B, the Pitot tube, extends below the vessel's hull to a depth  $d$ , whereas tube A, the static pressure intake tube, is flush with the hull. With the vessel stationary, the static pressures from tube A to the top of the diaphragm and tube B to its underside almost cancel. The unequal pressures, which cause a small indication of speed to be displayed when the vessel is stationary, are compensated for in the log electromechanical system and the erroneous indication is cancelled. As the vessel moves through the water, in the direction shown, water is forced into tube B producing a combined pressure in the lower half of the chamber equal to both the static and dynamic pressures. The difference in pressure, between upper and lower chambers, now forces the diaphragm upwards thus operating the mechanical linkage. Obviously the greater the speed of the vessel through the water, the more the diaphragm will move and the greater will be the speed indicated.



**Figure 3.1** The pressure tank and tube intakes of a pressure tube speed logging system.

Unfortunately, the dynamic pressure developed in tube B, by the relative movement through the water, is proportional to the square of the vessel's speed. Pitot's Law states that this pressure  $p$  is proportional to the square of the ship's speed  $v$  multiplied by the coefficient  $K$ .

$$p = K \times v^2$$

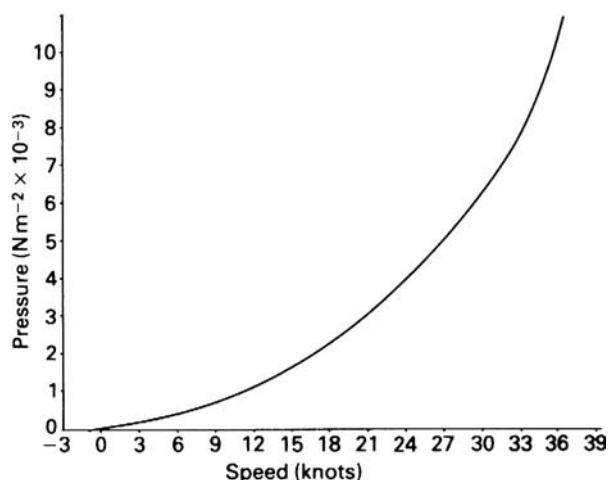
where the constant  $K$  is derived from the vessel's tonnage, shape of hull, speed of the ship, and the length of the protruding part of the Pitot tube (distance  $d$ ).

As shown in Figure 3.2, the speed indication produced is not linear. It is necessary therefore to eliminate the non-linear characteristics of the system and produce a linear speed indication. This is achieved mechanically, by the use of precisely engineered cones or electronically using CR (capacitive/resistive) time constant circuitry.

### 3.2.1 A pressure tube speed logging system

Figure 3.3 shows a typical installation of the Pitot system on board a vessel with a double bottom. The Pitot tube is encased in a sea-cock arrangement with valve control, to enable the tube to be withdrawn, without shipping water, when the vessel goes alongside. The static pressure opening is controlled by the use of a valve. Both dynamic and static pressures are transferred via air collectors and strainer valves to the pressure chamber. The strainer valves are designed to prevent water oscillations in the interconnecting pipes during operation. Such oscillations would cause the diaphragm to oscillate producing an erratic speed indication.

Figure 3.4 shows the basic speed and distance translating system of a Pitot tube log. The diagram includes two repeating systems for speed and distance data transmission to remote indicators on the



**Figure 3.2** Graph indicating the non-linear increase in pressure due to speed.

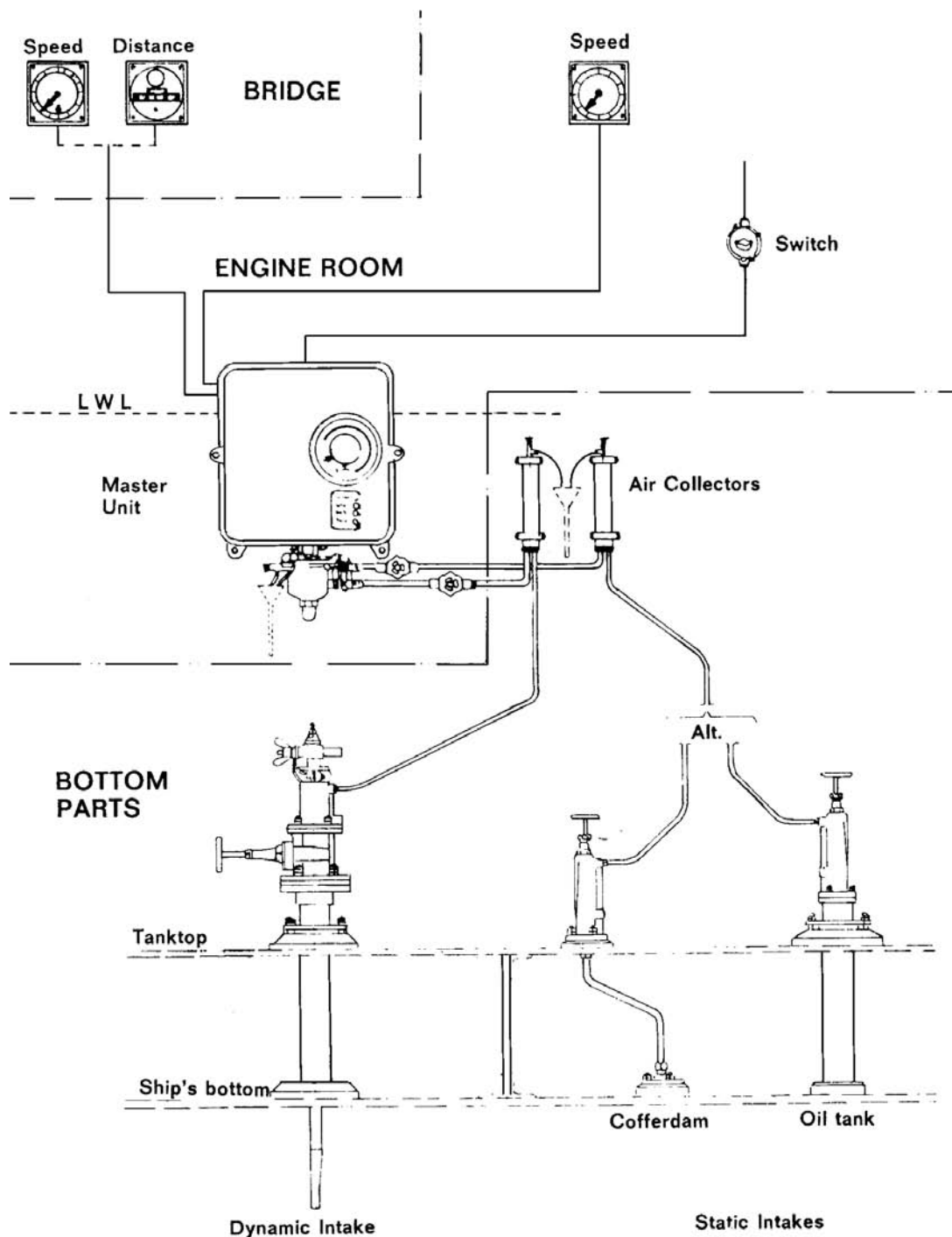
ship's bridge. This system was superseded by the SAL24E which replaced some of the mechanical apparatus with electronics. The original log has been included here because it is still in use on many vessels and is a fine example of a pressure type speed logging system.

### *Description of operation*

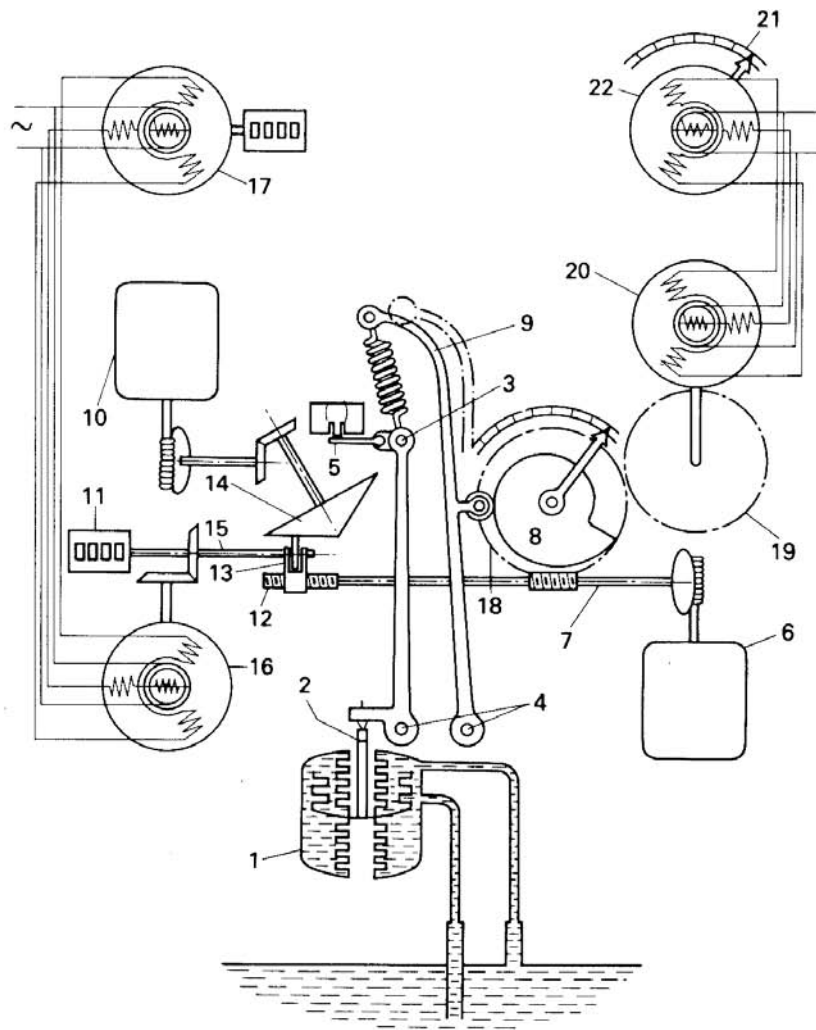
An increase in the vessel's speed will cause an increase in the dynamic pressure beneath the diaphragm in the pressure chamber (1). This causes the diaphragm to move upwards, pushing the pressure rod (2) and moving the lever (3) to the right on pivot (4). The upper end of the lever (3) moves the electric start contact (5) to the right to connect power to a reversible motor (6). The motor now turns causing the main shaft (7) to move a spiral cam (8) clockwise. This action tilts the lever (9), also pivoted on (4), to the left. The deflection stretches the main spring, producing a downward pressure on the diaphragm, via lever (3), causing it to cease rising at an intermediate position. This is achieved when equilibrium has been established between the dynamic pressure, acting on the lower side of the diaphragm, and the counter pressure from the spring on the upper side. At this point the motor (6) stops and thus holds the spiral cam (8) in a fixed position indicating speed.

This method of pressure compensation provides accurate indications of speed independent of alterations of the diaphragm caused by ageing. The shape of the spiral cam (8) has been carefully calculated to produce a linear indication of speed from the non-linear characteristics of the system. Also attached to the spiral cam is a second gearing mechanism (19) that transfers the movement of the speed indicator to the three-phase speed transmission system (20). An identical servo-receiver (22) is fitted in the remote speed repeater unit fitted on the ship's bridge and thus remote speed indication has been achieved.

Distance recording is achieved by using a constant speed motor (10) which drives the distance counter (11), via friction gearing. The constant speed motor has been used in order that a distance indication may be produced that is independent of the non-linear characteristic of the system. The motor is started by contact (5) as previously described. The main shaft (7), whose angle of rotation is directly proportional to the speed of the ship, is fitted with a screw spindle (12). The rotation of the shaft causes a lateral displacement of the friction wheel (13). At zero speed, the friction wheel rests against the apex of the distance cone (14), whilst at maximum speed the wheel has been displaced



**Figure 3.3** A shipboard installation. (Reproduced courtesy of SAL Jungner Marine.)



- |                           |                               |
|---------------------------|-------------------------------|
| 1. pressure chamber       | 12. screw spindle             |
| 2. pressure rod           | 13. friction wheel            |
| 3. lever                  | 14. distance cone             |
| 4. pivot                  | 15. distance shaft            |
| 5. electric start contact | 16. servo transmission system |
| 6. reversible motor       | 17. servo transmission system |
| 7. main shaft             | 18. gear wheels               |
| 8. spiral cam             | 19. gear wheels               |
| 9. lever                  | 20. speed servo transmitter   |
| 10. constant speed motor  | 21. remote speed indicator    |
| 11. distance counter      | 22. servo receiver            |

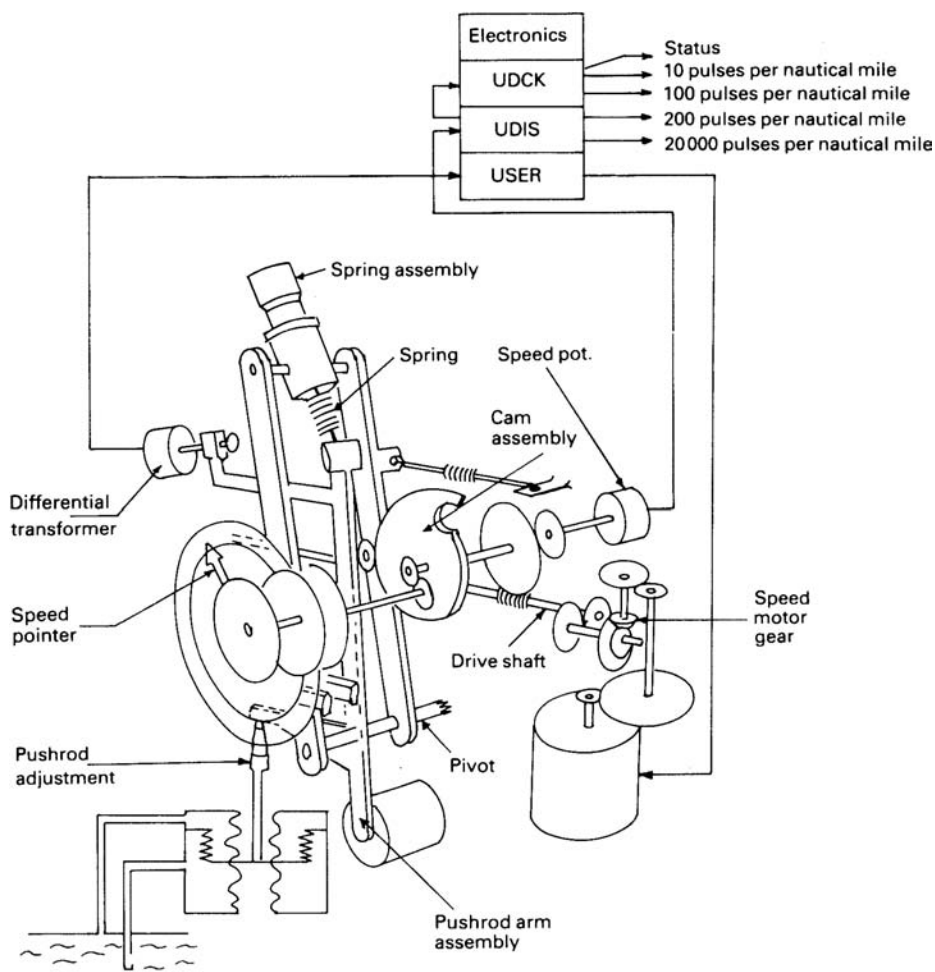
**Figure 3.4** The mechanical speed translating system of the SAL 24 pressure tube log. (Reproduced courtesy of SAL Jungner Marine.)

along the cone to the rim. The distance indicator (11) is driven from the constant speed motor (10) via the cone. The nearer to the rim of the cone the friction wheel rides, the greater will be the distance indication. Revolutions of the distance shaft (15) are transmitted to the remote distance indicator via the servo transmission system (16 and 17).

### *Operation of the SAL 24E*

The SAL 24E utilizes the same system of tubes, pressure tank and diaphragm to convert pressure variations due to speed, to electrical pulses suitable to drive the electronic circuits that replace much of the mechanical arrangement of the SAL 24 log. The distance integration mechanism with servo, cone and counter has been fully replaced with electronic circuitry.

As previously described, when the vessel moves forwards, the dynamic pressure acting on the underside of the diaphragm causes it to move upwards forcing the pushrod upwards. As shown in Figure 3.5, this causes the pushrod arm assembly to move to the right on the pivot, increasing the



**Figure 3.5** Pressure/mechanical assembly of the SAL 24E electronic pressure speed log.  
(Reproduced courtesy of SAL Jungner Marine.)

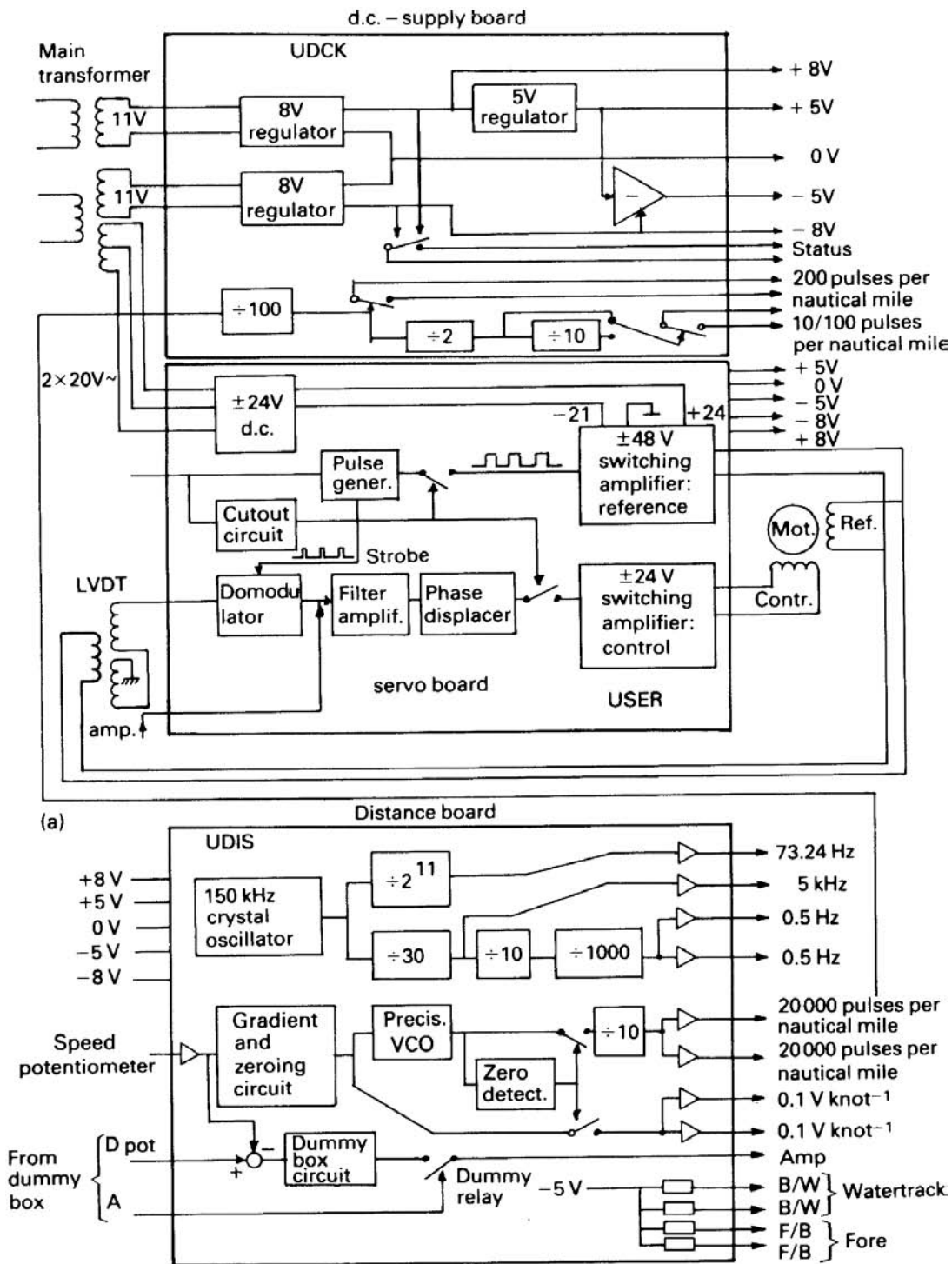


Figure 3.6 The electronics unit. (Reproduced courtesy of SAL Jungner Marine.)

tension on the spring assembly and producing an output from the differential transformer. This output is applied to the USER board, shown in Figure 3.6, where it is processed to provide the drive for the speed servo-control winding via a  $\pm 24$  V switching amplifier. The servo now turns and rotates the cam assembly via gearing and the drive shaft. An increase in speed is now shown on the speed pointer. As the cam rotates it forces the balance arm to the left and tightens the spring until the pushrod arm and the diaphragm bellows are balanced. The cam is carefully designed so that the spring force is proportional to the square of the rotation angle and thus the non-linearity of the pressure system is counteracted. The speed potentiometer turns together with the speed pointer to provide an input to the UDIS board. This input produces a variety of outputs enabling the system to be interfaced with other electronic equipment.

The accuracy of the Pitot type speed log when correctly installed and calibrated is typically better than 0.75% of the range in use.

### 3.3 Speed measurement using electromagnetic induction

Electromagnetic speed logs continue to be popular for measuring the movement of a vessel through water. This type of log uses Michael Faraday's well-documented principle of measuring the flow of a fluid past a sensor by means of electromagnetic induction.

The operation relies upon the principle that any conductor which is moved across a magnetic field will have induced into it a small electromotive force (e.m.f.). Alternatively, the e.m.f. will also be induced if the conductor remains stationary and the magnetic field is moved with respect to it. Assuming that the magnetic field remains constant, the amplitude of the induced e.m.f. will be directly proportional to the speed of movement.

In a practical installation, a constant e.m.f. is developed in a conductor (seawater flowing past the sensor) and a minute current, proportional to the relative velocity, is induced in a collector. The magnetic field created in the seawater is produced by a solenoid which may extend into the water or be fitted flush with the hull. As the vessel moves, the seawater (the conductor) flowing through the magnetic field has a small e.m.f. induced into it. This minute e.m.f., the amplitude of which is dependent upon the rate of cutting the magnetic lines of force, is detected by two small electrodes set into the outer casing of the sensor.

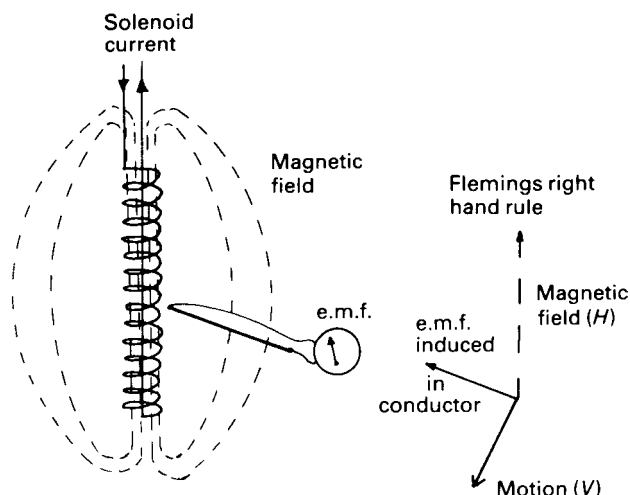
Figure 3.7 shows a solenoid generating a magnetic field and a conductor connected in the form of a loop able to move at right angles to the field. If the conductor is moved in the direction shown, a tiny current will be induced in the wire and a small e.m.f. is produced across it. In the case of an electromagnetic speed log, the conductor is seawater passing through the magnetic field. Fleming's right-hand rule shows that the generated e.m.f. is at right angles to the magnetic field ( $H$ ). Induced current flowing in the conductor produces an indication of the e.m.f. on the meter. If we assume that the energizing current for the solenoid is d.c. the induced e.m.f. is  $\beta lv$ , where  $\beta$  = the induced magnetic field,  $l$  = the length of the conductor, and  $v$  = the velocity of the conductor.

$\beta$  is approximately equal to  $H$ , the magnetic field strength. Therefore,  $\text{e.m.f.} = Hlv$  assuming no circuit losses.

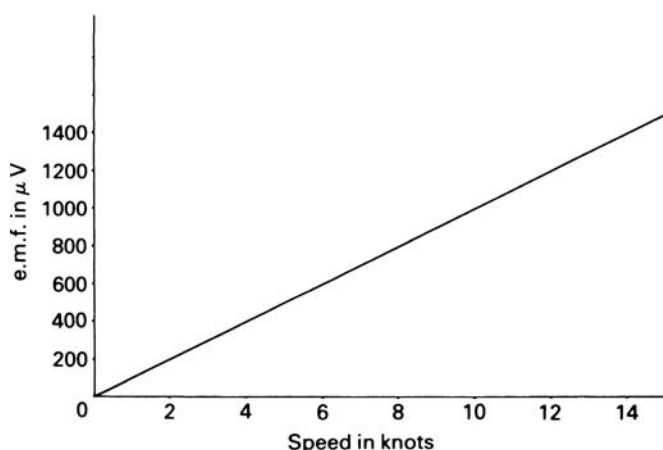
To reduce the effects of electrolysis and make amplification of the induced e.m.f. simpler, a.c. is used to generate the magnetic field. The magnetic field strength  $H$  now becomes  $Hm\sin\omega t$  and the induced e.m.f. is:  $Hmlv\sin\omega t$ . If the strength of the magnetic field and the length of the conductor both remain constant then,  $\text{e.m.f.} \propto \text{velocity}$ .

Figure 3.8 illustrates that the changes of e.m.f., brought about by changes in velocity, produce a linear graph and thus a linear indication of the vessel's speed. The e.m.f. thus produced is very small





**Figure 3.7** Effect of moving a conductor through a magnetic field.



**Figure 3.8** Relationship between the vessel's speed and the output from the sensors.

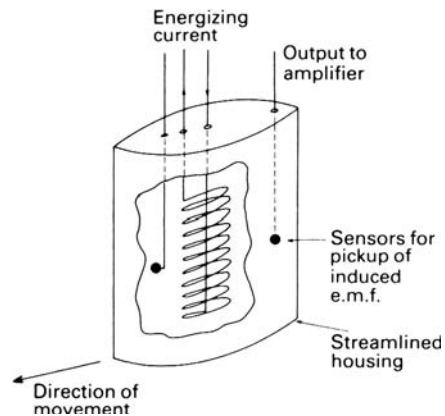
but, if required, may be made larger by increasing the energizing current, or the number of turns of wire on the solenoid.

The following points should be noted.

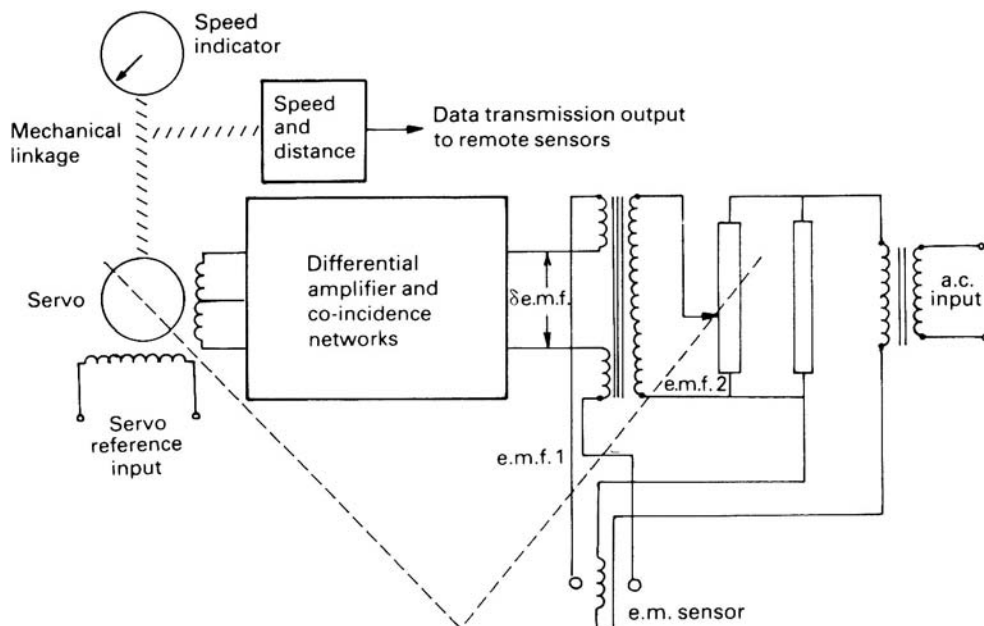
- The a.c. supply to the solenoid produces inductive pick-up between the coil and the wires that carry the signal. This in turn produces a 'zero' error that must be compensated for by 'backing off' the zero setting of the indicator on calibration.
- The induced e.m.f. is very small (for reasonable amplitudes of energizing current), typically  $100 \mu V$  per knot.
- The induced e.m.f. and hence the speed indication will vary with the conductivity of the water.
- The device measures the speed of the water flowing past the hull of the ship. This flow can vary due to the non-linearity of a hull design.

- Ocean currents may introduce errors.
- Pitching and rolling will affect the relationship between the water speed and the hull. Error due to this effect may be compensated for by reducing the sensitivity of the receiver. This is achieved using a CR timing circuit with a long time constant to damp out the oscillatory effect.
- Accuracy is typically 0.1% of the range in use, in a fore and aft direction, and approximately 2% thwartships.

Figure 3.9 shows a typical sensor cutaway revealing the solenoid and the pick-up electrodes. A speed translating system is illustrated in Figure 3.10.



**Figure 3.9** Constructional details of an electromagnetic log sensor.



**Figure 3.10** An e.m. speed log translating system.

### *Description of the speed translating system*

The small signal speed voltage from the sensor, e.m.f.1, is applied to a differential transformer where it is compared to a reference voltage, e.m.f.2, produced from a potentiometer across the input a.c. supply. The potential difference produced across the reference resistor provides the energizing current for the solenoid in the sensor.

If the signal voltage e.m.f.1. differs from the reference voltage e.m.f.2. an error signal voltage  $\delta$  e.m.f. is produced. This error voltage is applied to the speed signal amplifier where it is amplified to produce sufficient power to drive the servo motor. The servo will in turn produce a speed reading, via a mechanical linkage, on the indicator. Also coupled to the servo shaft is the slider of the speed potentiometer that turns in the direction to reduce the error voltage  $\delta$  e.m.f. When this error voltage drops to zero the servo ceases to turn. The speed indicator is stationary until the next error voltage  $\delta$  e.m.f. is produced. Each time an error voltage is created the servo turns to cancel the error and thus balances the system.

### **3.3.1 A practical electromagnetic speed logging system**

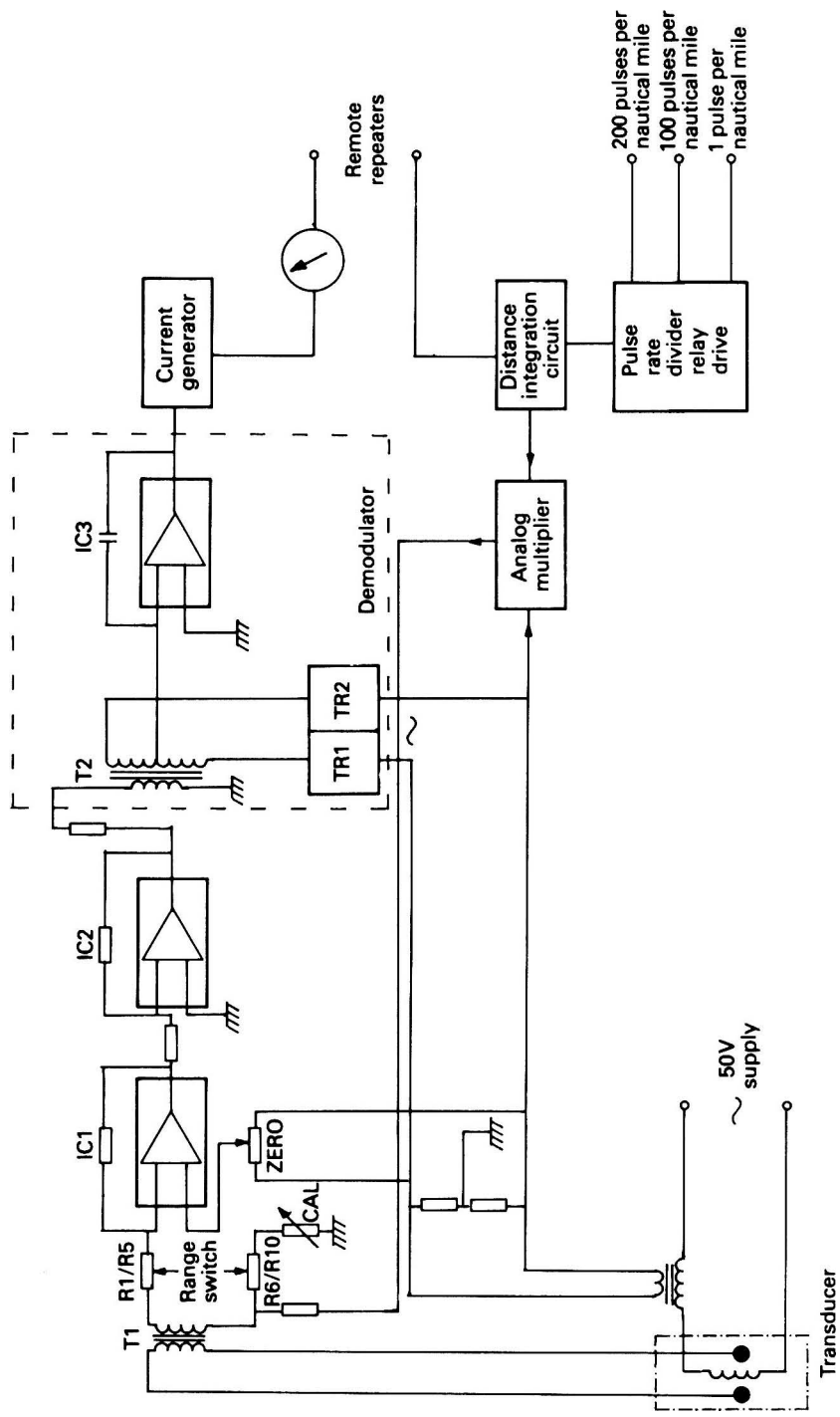
The potential developed across the transducer electrodes is proportional to magnetic field strength (and consequently the energizing current) and the flow velocity in the volume of water influenced by the field. The magnetic field strength is in no way stabilized against any changes in the ship's main voltage, temperature, etc, but by effectively comparing the energizing current with the voltage at the electrodes, their ratio provides a measure of the ship's speed.

The input transformer T1 (shown in Figure 3.11) possesses a very high inductance and a step-down ratio of 5:1. This results in an input impedance, as seen by the pick-up electrodes, approaching 20 M $\Omega$  which when compared with the impedance presented by salt water can be considered an open circuit. Hence changes in salinity have no effect on the measured voltage and the resulting speed indication. A switched resistor chain (R1/R5) sets the gain of the overall amplifier in conjunction with resistor chain (R6/R10) which controls the amplitude of the feedback signal.

The output of IC1 is coupled, via IC2, which because of capacitive feedback (not shown), ensures that the circuit has a zero phase shift from T1 through T2, to the demodulator. Demodulation is carried out by TR1/TR2 that are switched in turn from an a.c. reference voltage derived from a toroidal transformer monitoring the energizing current of the transducer. By driving TR1/TR2 synchronously, the phase relationship of the voltage detected by the electrodes determines the polarity of the demodulated signal. 0° and 180° phasing produce a positive or negative component; 90° and 270° produce no output and hence a complete rejection of such phase-quadrature signals. The demodulated signal is applied to the Miller Integrator IC3 which in turn drives the current generator. Speed repeaters are current-driven from this source.

### *Operation of the loop*

With no vessel movement, there will be a zero signal at the input to IC1 and consequently there will be no signal at the multiplier chip input. No feedback signal is developed at the input to IC1. As the vessel moves ahead, the small signal applied to IC1 is processed in the electronic unit to produce a current flow through the speed repeaters and the multiplier. There now exists an output from the multiplier, proportional to the speed repeater current and the reference voltage produced by the toroidal transformer monitoring the transducer energizing current. The a.c. from the multiplier is fed back to IC1 in series with, and 180° out of phase with, the small signal secondary of T1. This a.c. signal rises slowly and eventually, with the time constant of the demodulator, is equal to the signal p.d.



**Figure 3.11** Simplified diagram of an e.m. log. (Reproduced courtesy of Thomas Walker and Son Ltd.)

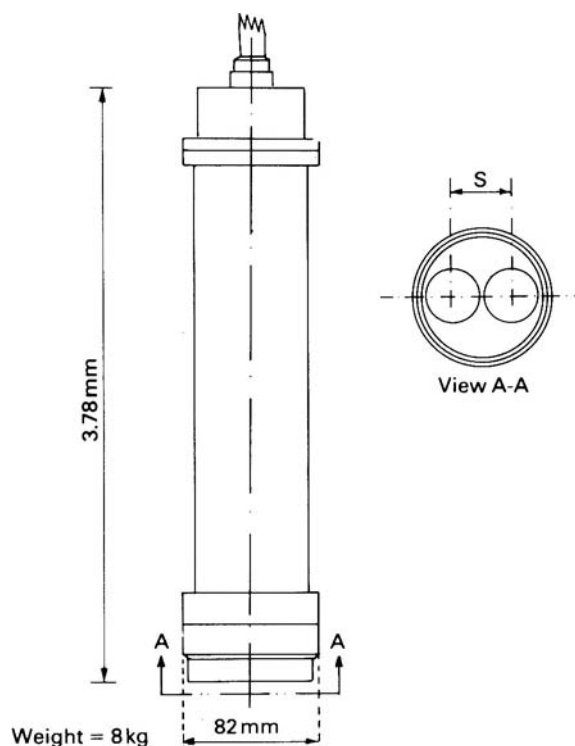
developed across T1. At this time the resultant signal applied to IC1 falls to zero and therefore the demodulator output remains at a constant figure. Any further change in speed results in an imbalance in the secondary of T1 producing a resultant a.c. signal to IC1. As a result, the demodulator output increases or decreases (faster or slower ship's speed) until the balance condition is restored. The speed repeaters will indicate the appropriate change of speed.

### *Distance integration*

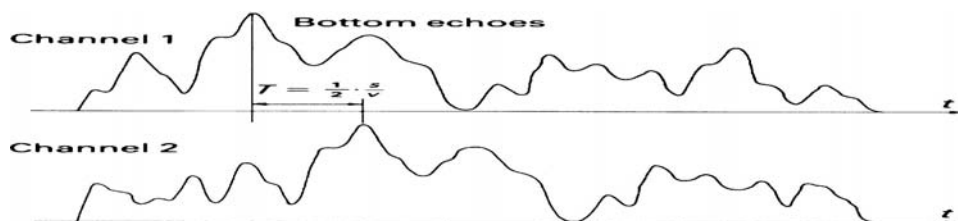
The speed current is passed through a resistive network on the distance integration board, in order that a proportional voltage may be produced for integration. The output of this board is a pulse train, the rate of which is proportional to the indicated speed. The 10 ms pulses are coupled to the relay drive board which holds the necessary logic to give the following outputs: 200 pulses per nautical mile, 100 pulses per nautical mile, and 1 pulse per nautical mile.

## **3.4 Speed measurement using acoustic correlation techniques**

Unlike the previously described speed log, which measure the vessel's speed with respect to water only, the SAL-ICCOT log measures the speed with respect to the seabed or to a suspended water mass. The log derives the vessel's speed by the use of signal acoustic correlation. Simply, this is a way of combining the properties of sonic waves in seawater with a correlation technique. Speed measurement is achieved by bottom-tracking to a maximum depth of 200 m. If the bottom echo becomes weak or



**Figure 3.12** Piezoelectric ceramic transducer for the SAL acoustic correlation speed log.



**Figure 3.13** Illustration of the time delay ( $T$ ) between each channel echo signal.

the depth exceeds 200 m, the system automatically switches to water-mass tracking and will record the vessel's speed with respect to a water mass approximately 12 m below the keel.

The transducer transmits pulses of energy at a frequency of 150 kHz from two active piezoceramic elements that are arranged in the fore and aft line of the vessel (see Figure 3.12). Each element transmits in a wide lobe perpendicular to the seabed. As with an echo sounder, the transducer elements are switched to the receive mode after transmission has taken place.

The seabed, or water mass, reflected signals possess a time delay ( $T$ ) dependent upon the contour of the seabed, as shown in Figure 3.13. Thus the received echo is, uniquely, a function of the instantaneous position of each sensor element plus the ship's speed. The echo signal, therefore, in one channel will be identical to that in the other channel, but will possess a time delay as shown.

The time delay ( $T$ ), in seconds, can be presented as:

$$T = 0.5 \times s \, v$$

where  $s$  = the distance between the receiving elements and  $v$  = the ship's velocity.

In the SAL-ACCOR log (see Figure 3.14), the speed is accurately estimated by a correlation technique. The distance between the transducer elements ( $s$ ) is precisely fixed, therefore when the time ( $T$ ) has been determined, the speed of the vessel ( $v$ ) can be accurately calculated.

It should be noted that the calculated time delay ( $T$ ) is that between the two transducer echoes and not that between transmission and reception. Temperature and salinity, the variables of sound velocity in seawater, will not affect the calculation. Each variable has the same influence on each received echo channel. Consequently the variables will cancel.

It is also possible to use the time delay ( $T$ ) between transmission and reception to calculate depth. In this case the depth ( $d$ ), in metres, is:

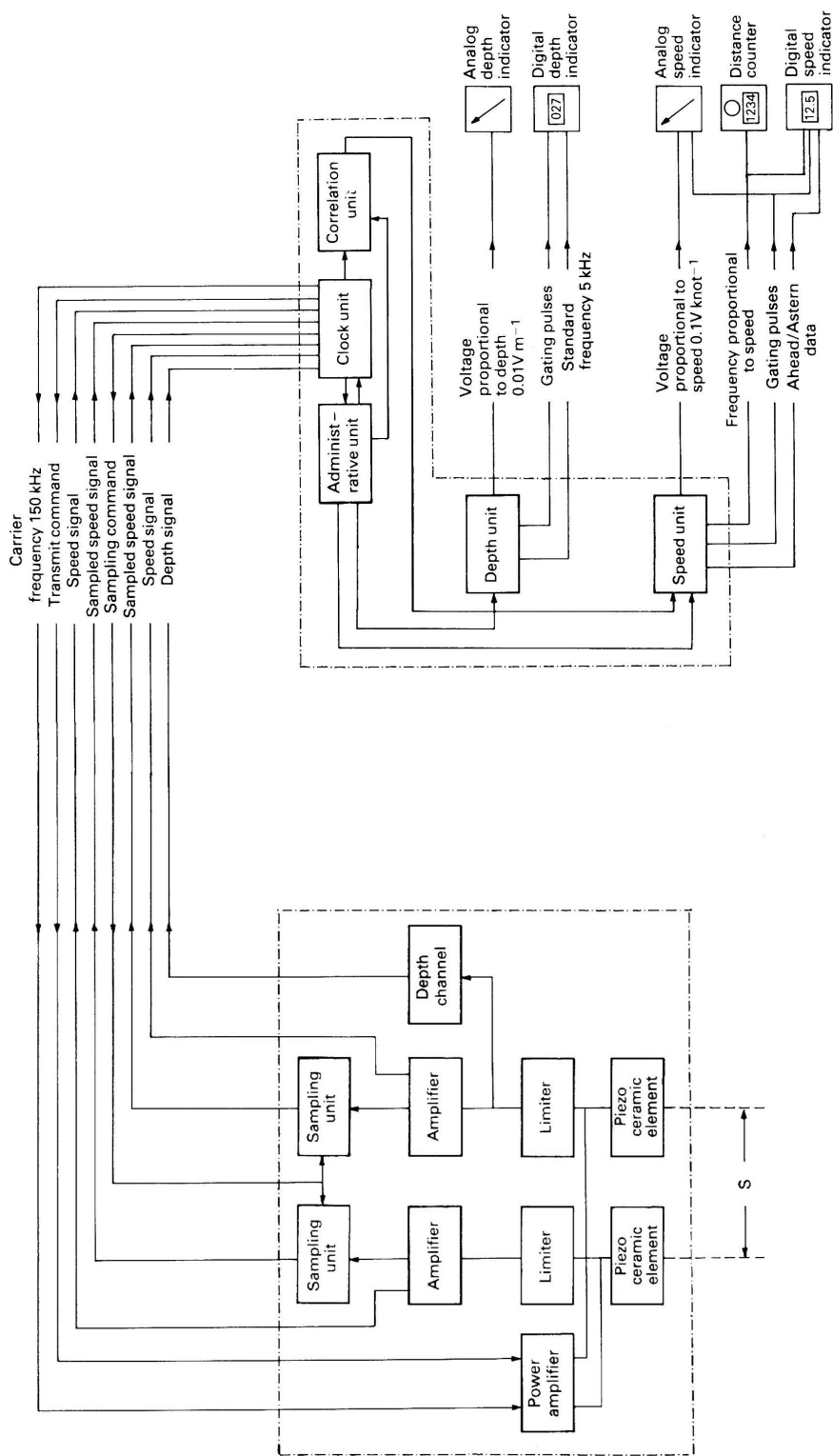
$$d = \frac{T}{2} \times C$$

where  $C$  = the velocity of sonic energy in seawater ( $1500 \text{ ms}^{-1}$ ).

Dimensions of the transducer active elements are kept to a minimum by the use of a high frequency and a wide lobe angle. A wide lobe angle (beamwidth) is used because echo target discrimination is not important in the speed log operation and has the advantage that the vessel is unlikely to 'run away' from the returned echo.

### 3.4.1 System description

Initiating the sequence, the power amplifier produces the transmitted power, at the carrier frequency of 150 kHz, under the command of a pulse chain from the clock unit. Returned echoes are received by two



**Figure 3.14** System diagram of the SAL-ACCOR acoustic correlation speed log. (Reproduced courtesy of SAL Junger Marine.)

independent identical channels and are pre-amplified before being applied to sampling units. Each sampling unit effectively simplifies the echo signal to enable interconnection to be made between transducer and main unit without the risk of signal deterioration. As with other functions, sampling is commanded by a clock unit, which also provides a highly stable 150 kHz for the carrier frequency. This frequency is also used as a standard frequency for the other functions on the electronics board, where it is divided to produce the 5 kHz needed to operate some of the speed indicators.

As the name suggests, the administration block controls most of the electronic functions. This block initiates the transmit/receive cycle, determines whether the system selects B-track or W-track operation and supervises the speed and depth calculations. The unit is effectively a microprocessor operating to a pre-determined program. Actual speed calculation takes place in the correlation block. The process extracts the time delay by correlating the sampled output of each channel.

The speed unit provides the following outputs to drive both speed and distance counters.

- An analogue voltage, the gradient of which is 0.1 V/knot, to drive the potentiometer servo-type speed indicators.
- A pulse frequency proportional to speed. The frequency is 200/36 pulses/s/knot. Pulses are gated into the digital counter by a 1.8-s gate pulse.
- A positive/negative voltage level to set the ahead/astern indication or the B track/W track indication.
- 2000 pulses per nautical mile to drive the stepping motor in the digital distance indicator.

The depth unit provides the following outputs to drive the depth indicators when the echo sounding facility is used.

- An analogue voltage with a gradient of  $0.01 \text{ Vm}^{-1}$ , to drive the analogue depth indicator.
- Pulses of  $2 \text{ ms m}^{-1}$ , which are used to gate a 5 kHz standard frequency into the digital depth indicator.
- A positive/negative voltage level to cause the indicator to display 'normal operation' or 'over-range'.

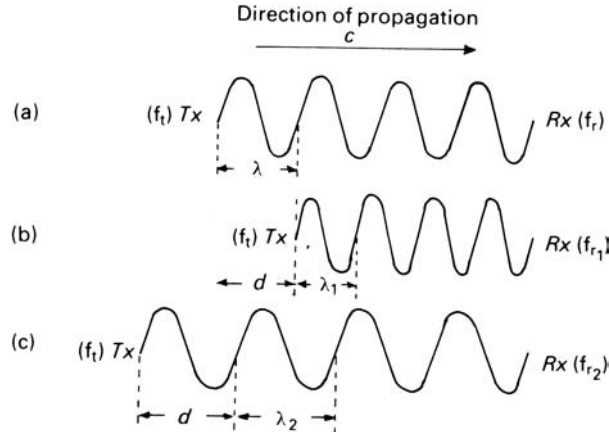
When correctly installed and calibrated, a speed accuracy of  $\pm 0.1$  knot is to be expected. Distance accuracy is quoted as 0.2%. The SAL-ICCOR speed log can be made to measure the vessel's transverse speed with the addition of a second transducer set at  $90^\circ$  to the first.

### 3.5 The Doppler Principle

In the early 19th century, Christian Doppler observed that the colour emitted by a star in relative movement across the sky appeared to change. Because light waves form part of the frequency spectrum, it was later concluded that the received wavelength must be changing and therefore the apparent received frequency must also change. This phenomenon is widely used in electronics for measuring velocity.

Figure 3.15(b) shows that the wavelength ( $\lambda$ ) is compressed in time when received from a transmitter moving towards a receiver ( $\lambda_1$ ) and expanded (Figure 3.15c) in time from a transmitter moving away ( $\lambda_2$ ). Consider a transmitter radiating a frequency ( $f_1$ ). The velocity of propagation of radiowaves in free space ( $c$ ) is  $300 \times 10^6 \text{ ms}^{-1}$  and in seawater it is much slower at approximately  $1500 \text{ ms}^{-1}$ . After a period of 1 s, one cycle of the transmitted acoustic wave in seawater will occupy a distance of 1500 m.





**Figure 3.15** Expansion and compression of wavelength.

If the transmitter moves towards an observer at speed ( $v$ ) it will, at the end of 1 s, have travelled a distance ( $d$ ) towards the receiver. Each transmitter wave has now been shortened because of the distance travelled by the transmitter towards the observer. By definition, a shorter wavelength defines a higher frequency ( $f_r$ ). The shortened wavelength, or higher frequency, received is directly proportional to the speed of movement of the transmitter.

In Figure 3.15(b), the transmitter has moved towards an observer by a distance ( $d$ ). This is the distance travelled during the time of generating one cycle ( $T$ ).

$$T = \frac{1}{f_t} \quad \text{and} \quad d = v \times T = \frac{v}{f_t}$$

Therefore the apparent wavelength is

$$\lambda_1 = \lambda - \frac{v}{f_t}$$

and the frequency is

$$f_{r1} = \frac{c}{\lambda_1} = \frac{c}{\lambda - v/f_t} = \frac{c f_t}{\lambda f_t - v} = f_t \frac{c}{c - v}$$

For a moving transmitter that is approaching a receiver, the received frequency is apparently increased. The reverse is true of a transmission from a transmitter moving away from an observer, when the wavelength will be stretched and the frequency decreased.

$$\lambda_2 = \lambda + v/f_t$$

$$f_r = f_t \frac{c}{c + v}$$

If an observer moves at velocity ( $v$ ) towards a stationary sound source, the number of cycles reaching the receiver per second is increased, thus the apparent received frequency is increased. The received frequency is

$$f_r = f_t + v/\lambda$$

and

$$1/\lambda = f/c$$

therefore

$$f_t + f_v/c = f_t(1 + v/c) = f_t \frac{c + v}{c}$$

If the observer now moves away from the stationary transmitter the apparent received frequency is;

$$f_r = f_t \frac{c - v}{c}$$

If, as in the Doppler speed log, both the observer and the sound source (transmitter and receiver) are moving towards a reflecting surface, the received frequency is;

$$f_r = f_t \frac{c}{c - v} \times \frac{c + v}{c} = f_t \frac{c + v}{c - v}$$

The Doppler frequency shift is

$$f_d = f_r - f_t \text{ (or } f_t - f_r)$$

$$\begin{aligned} f_d &= f_t \times \frac{c + v}{c - v} - f_t \\ &= \frac{cf_t + vf_t - cf_t + vf_t}{c - v} \\ &= \frac{2vf_t}{c - v} \end{aligned}$$

The velocity of radio waves ( $c$ ) is always far in excess of  $v$  and therefore the expression above can be simplified to;

$$f_d = \frac{2vf_t}{c}$$

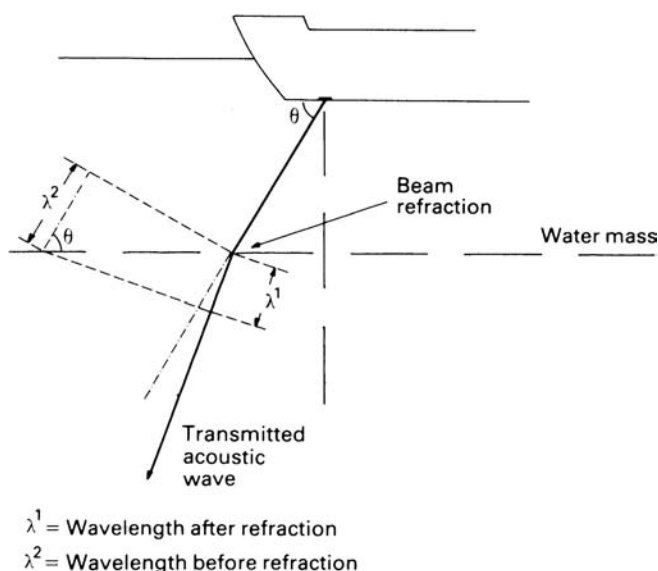
where  $f_d$  = Doppler frequency shift in cycles per second,  $v$  = relative speed in the direction of the transmitted wave,  $f_t$  = transmitted frequency, and  $c$  = velocity of propagation of the radio wave.

### 3.6 Principles of speed measurement using the Doppler effect

The phenomenon of Doppler frequency shift is often used to measure the speed of a moving object carrying a transmitter. Modern speed logs use this principle to measure the vessel's speed, with respect to the seabed, with an accuracy approaching 0.1%.

If a sonar beam is transmitted ahead of a vessel, the reflected energy wave will have suffered a frequency shift (see Figure 3.16), the amount of which depends upon:

- the transmitted frequency
- the velocity of the sonar energy wave
- the velocity of the transmitter (the ship).



**Figure 3.16** Illustration of the change of wavelength that occurs when an acoustic wave crosses a water mass.

The frequency shift, in hertz, of the returned wave is:

$$fd = ft - fr$$

where  $ft$  = the transmitted wave frequency, and  $fr$  = the received wave frequency.

The Doppler shift formula, for a reflected wave, is given as:

$$fd = \frac{2vft}{c}$$

where  $v$  = the velocity of the ship, and  $c$  = the velocity of the sonar wave ( $1500 \text{ ms}^{-1}$  in seawater).

Obviously there can be no objects directly ahead of a vessel from which the acoustic wave may be reflected. The wave is therefore transmitted towards the seabed, not vertically as with echo sounding,

but ahead at an angle of  $60^\circ$  to the horizontal. This angle has been found to be the optimum angle of incidence with the seabed, which will reflect a signal of sufficient strength to be received by the transducer. The shape of the seabed has no effect on the frequency shift. Provided that the seabed is not perfectly smooth, some energy will be reflected.

The angle between the horizontal plane and the transmission must now be applied to the basic Doppler formula:

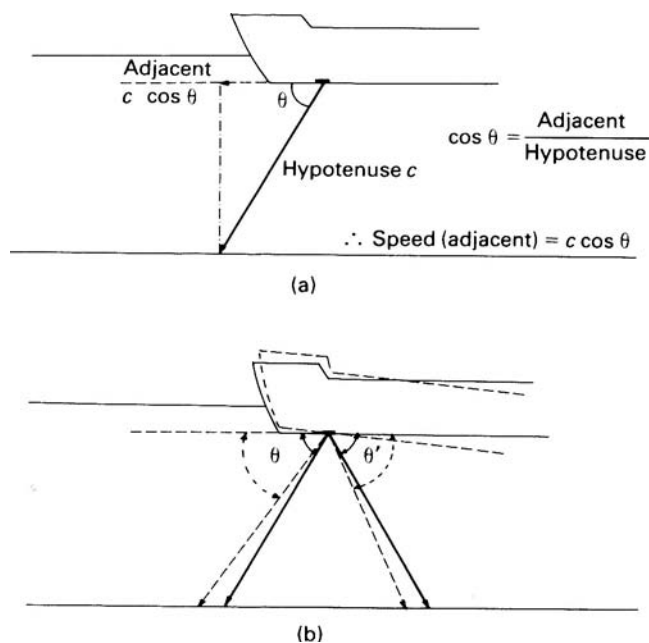
$$fd = \frac{2vft\cos\theta}{C} \text{ (in hertz)}$$

Figure 3.17(a) shows this angle. Using trigonometry,  $\cos\theta = \text{Adjacent}/\text{Hypotenuse}$ . Therefore,  $\text{Adjacent} = C \cos\theta$ .

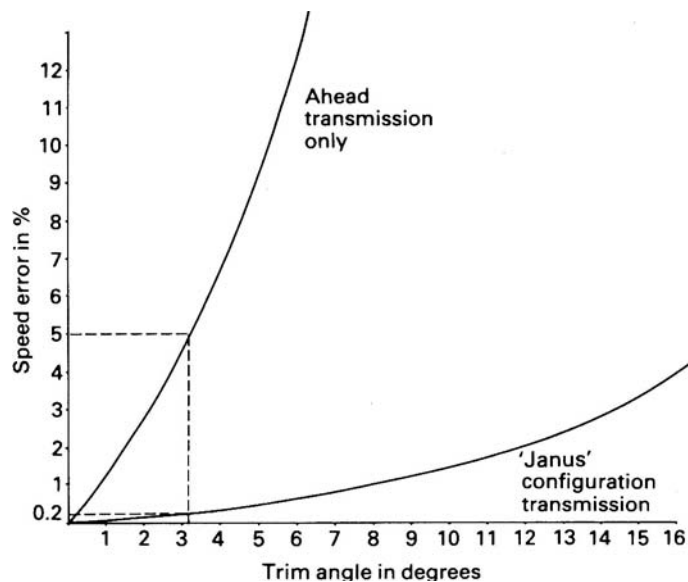
Given a propagation angle of  $60^\circ$ ,  $\cos\theta = 0.5$

$$fd = \frac{2vft\cos\theta}{C} = \frac{vft}{C}$$

It follows that if the angle changes, the speed calculated will be in error because the angle of propagation has been applied to the speed calculation formula in this way. If the vessel is not in correct trim (or pitching in heavy weather) the longitudinal parameters will change and the speed indicated will be in error. To counteract this effect to some extent, two acoustic beams are transmitted, one ahead and one astern. The transducer assembly used for this type of transmission is called a 'Janus' configuration after the Roman god who reputedly possessed two faces and was able to see into both the future and the past. Figure 3.17(b) shows the Janus assembly.



**Figure 3.17** (a) Derivation of longitudinal speed using trigonometry. (b) The effect of pitching on a Janus transducer configuration.



**Figure 3.18** Graphs of speed error caused by variations of the vessel's trim.

The Doppler frequency shift formula now becomes:

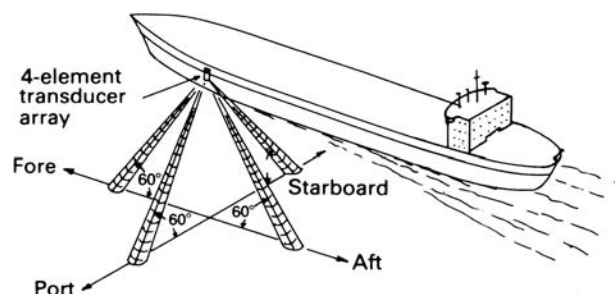
$$fd = \frac{2vft}{C} (+ \cos\theta + \cos\theta')$$

( $+ \cos 60^\circ + \cos 60^\circ = 1$ ) therefore the transmission angle can effectively be ignored.

As Figure 3.17(b) shows, in heavy weather one angle increases as the other decreases effectively cancelling the effects of pitching on the speed indication.

Figure 3.18 shows the advantage of having a Janus configuration over a single transducer arrangement. It can be seen that a 3° change of trim on a vessel in a forward pointing Doppler system will produce a 5% velocity error. With a Janus configuration transducer system, the error is reduced to 0.2% but is not fully eliminated.

The addition of a second transducer assembly set at right angles to the first one, enables dual axis speed to be indicated (Figure 3.19).



**Figure 3.19** Dual axis speed is measured by transmitting sonar pulses in four narrow beams towards the sea bed.

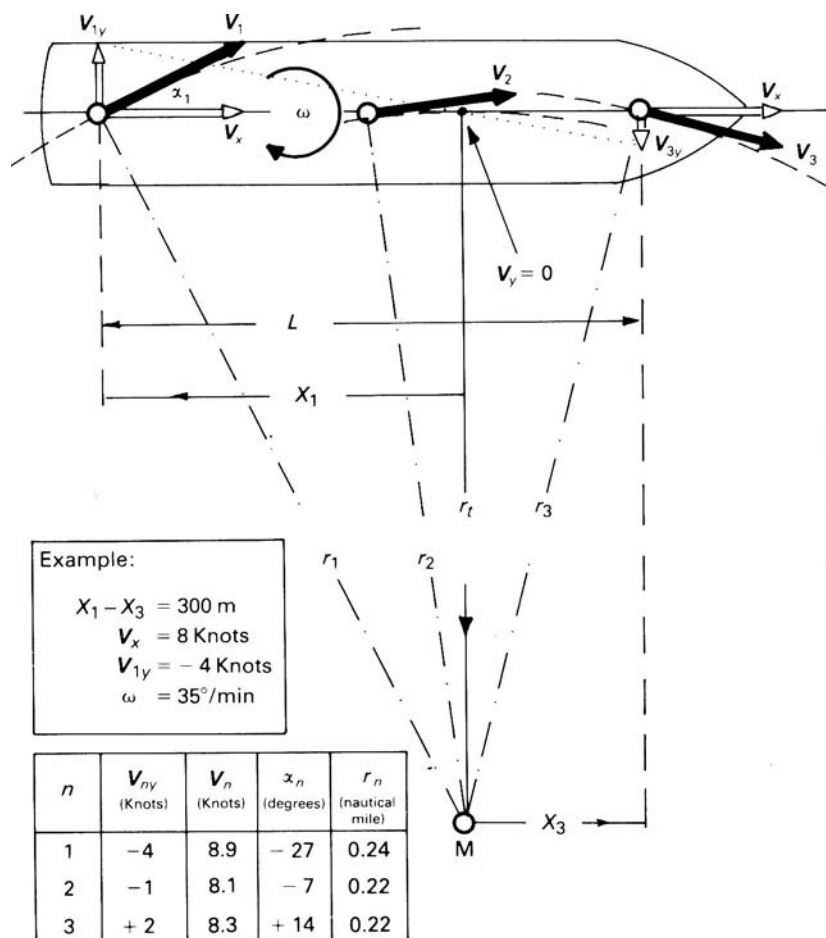
### 3.6.1 Vessel motion during turn manoeuvres

A precise indication of athwartships speed is particularly important on large vessels where the bow and stern sections may be drifting at different rates during docking or turning manoeuvres.

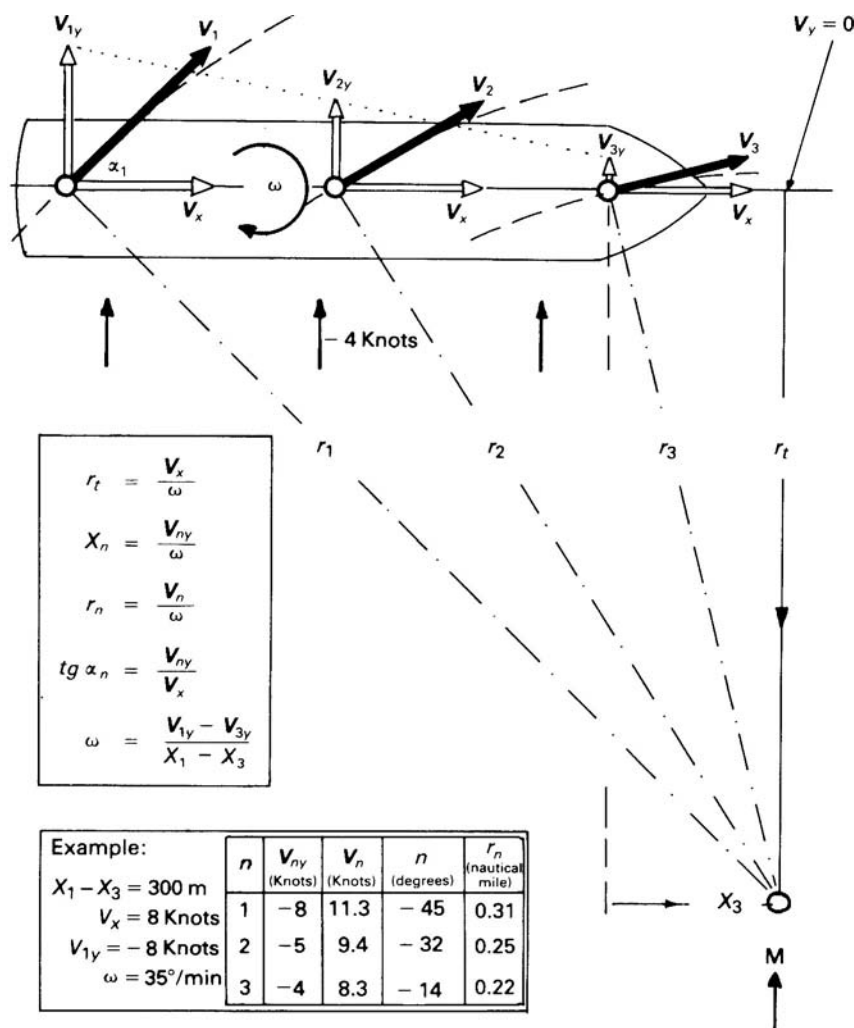
#### *Speed vectors during a starboard turn*

A dual axis Doppler speed log measures longitudinal and transverse speed, at the location of the transducers. If transducers are mounted in the bow and stern of a vessel, the rate of turn can be computed and displayed. This facility is obviously invaluable to the navigator during difficult manoeuvres.

Figure 3.20 shows the speed vectors plotted from bow and stern transducer data when a ship is turning to starboard without the effect of water current. When the rudder is put hard over, the transverse speed indication vector ( $V_y$ ) can point either to the side to which the rudder has been moved or to the other side. This will depend upon the longitudinal speed, the angular speed (rate of turn) and



**Figure 3.20** Speed vectors during a starboard turn with no current. (Reproduced courtesy of Krupp Atlas Elektronik.)



**Figure 3.21** Speed vectors for a starboard turn under the influence of a four knot current .  
 (Reproduced courtesy of Krupp Atlas Elektronik.)

weather/tide conditions. If the longitudinal speed and transverse speeds at two points of the vessel are known, the ship's movement is completely determinable. The bow transverse speed vector ( $V_{3y}$ ) points to starboard, the direction of the ship's turning circle.

Under the influence of the 4-knot current, shown in Figure 3.21, however,  $V_{3y}$  points to port. The transverse speed development along the ship's length is represented by a dotted line (between  $V_{1y}$  and  $V_{3y}$ ). The intersection of this line with the longitudinal axis produces a point at which the ship has longitudinal speed but no transverse speed. This point ( $V_y = 0$ ) is normally positioned, approximately, in the fore third of the vessel (see Figure 3.20) if the ship is to turn along a circle about point M (the instantaneous centre of rotation). The effect of current from the starboard side causes point  $V_y = 0$  to be ahead of the vessel and the ship to turn around point M in Figure 3.21, which is shifted forward relative to that shown in Figure 3.20. It is obvious therefore that an accurate indication of transverse speeds at various points along the vessel enables the navigator to predict the movement of his ship.

*Speed components with the rudder amidships*

Dual axis Doppler logs are able to measure accurately the ship's speed in a longitudinal direction ( $V_x$ ) and a transverse direction ( $V_y$ ). The data derived from these measurements enables the navigator to predict the course to steer in order to optimize the performance of the vessel. By measuring both speed components (i.e. the velocity vector) it is possible to optimize the vessel's course by computing the drift angle:

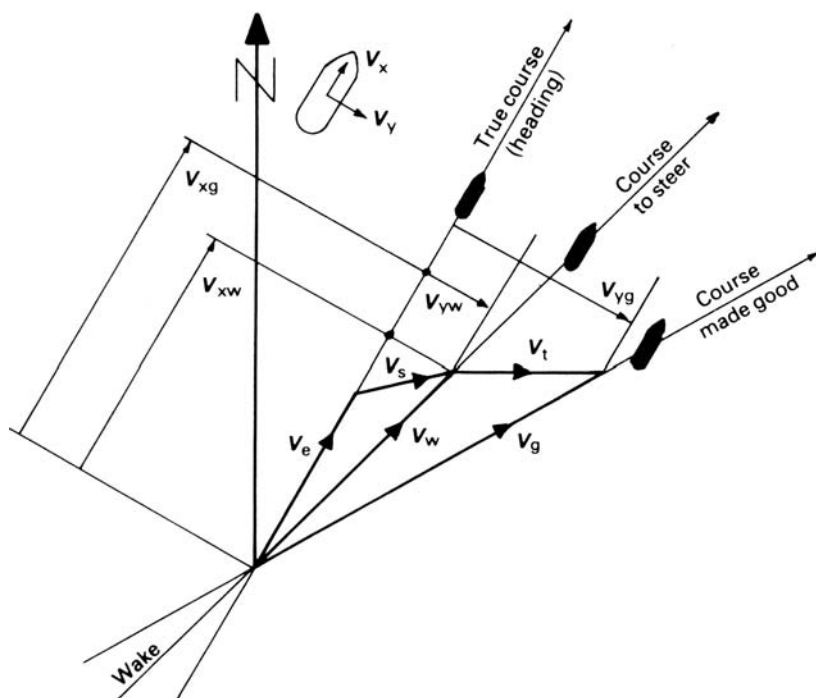
$$\alpha = \arctan \frac{V_y}{V_x}$$

In the water-tracking mode this is the leeward angle (caused by wind) which is the angle between the true course (heading) and the course-made-good (CMG) through the water. In the bottom-tracking mode, it is the angle due to wind and tidestream between the heading and the CMG over the ground. With the help of a two-component log the ship can be navigated so that heading steered plus drift angle measured by the log, results exactly in the intended chart course (see Figure 3.22).

The transverse speed at the stern is computed from the transverse speed of the bow, the ship's rate of turn and the ship's length as follows:

$$V_{q2} = V_{q1} - \omega L$$

where  $V_{q2}$  = stern transverse speed,  $V_{q1}$  = bow transverse speed,  $\omega$  = rate of turn (angular velocity), and  $L$  = distance between bow and stern points of measurement.



**Figure 3.22** External environmental effects of a vessel's track. (Reproduced courtesy of Krupp Atlas Elektronik.)



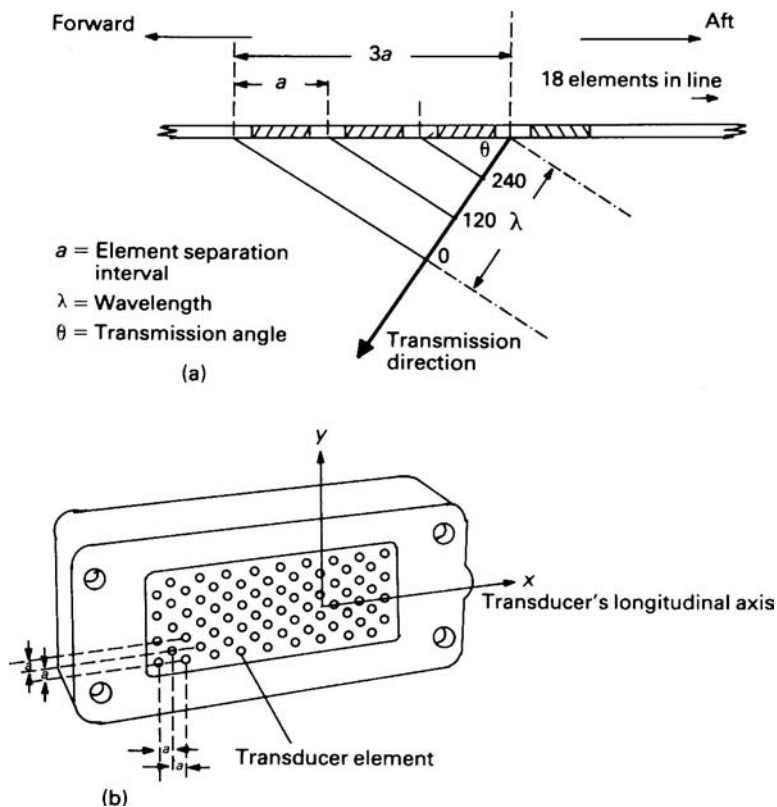
### 3.6.2 Choice of frequency/transducer

As with depth sounding, the size of the transducer can be kept within reasonable limits by using a high frequency. This is particularly important in the situation where many elements are to be mounted in the same assembly. Unfortunately, as has already been discussed, attenuation losses increase exponentially with the transmission frequency. The choice of frequency is therefore a compromise between acceptable transducer size and the power requirements of the acoustic wave in order to overcome the signal losses due to the transmission media. Frequencies used in speed logging systems vary widely and are usually in the range 100 kHz to 1 MHz.

The factor with the greatest effect on speed accuracy is the velocity of the acoustic wave in seawater. Propagation velocity is affected by both the salinity and the temperature of the seawater through which the wave travels. However, velocity error due to these two factors can be virtually eliminated by mounting salinity and temperature sensors in the transducer array. Data from both sensors are processed to provide corrective information for the system. Alternatively, the Krupp Atlas Alpha transducer system effectively counteracts the effects of salinity and temperature by the use of a phased beam.

#### *ALPHA transducer array*

The necessity of a tilted beam normally dictates that the transducer protrudes below the keel and therefore may suffer damage. It is possible to produce the required angle of propagation by the use of



**Figure 3.23** (a) Principle of the alpha transducer array. (b) A 72-element alpha transducer array.

a number of flush fitting transducers. The Krupp Atlas Alpha (Atlas Low Frequency Phased Array) multiple transducer 'Janus' assembly uses ( $4 \times 18 = 72$ ) flush fitting elements in each of the fore and aft positions. In theory any number of elements may be used, but the spacing of the elements must not exceed certain limits in order to keep unwanted side lobes down to an acceptable level.

Figure 3.23(a) is a cut-away bow section of a vessel fitted with an Alpha transducer array. For clarity, only a three-element assembly is shown. If the three elements are fed with in-phase signal voltages the beam formed would be perpendicular. However, if the signal voltages to each element are phase delayed, in this case by  $120^\circ$ , the main lobe is propagated at an angle (which under these conditions is about  $50^\circ$ ). In this case the elements are fed with three sine waves each shifted clockwise by  $120^\circ$ . For the Janus configuration the same elements are fed alternately clockwise and counter clockwise. The Alpha system also overcomes the external factors that influence the velocity of acoustic waves in salt water and is thus able to counteract the unwanted effects of salinity and temperature change.

The standard Doppler formula, from which velocity is calculated, comprises a number of parameters, two of which are variable. Ideally the vessel's speed ( $v$ ) should be the only unknown factor in the formula, but unfortunately the velocity of acoustic waves ( $C$ ) is also a variable. Since speed accuracy depends upon the accuracy of acoustic wave velocity in salt water it is advantageous to eliminate ( $C$ ) from the formula.

$$fd = \frac{2vft}{C} \cos\theta$$

With the Alpha system, the angle of propagation ( $\theta$ ) is a function of the velocity of acoustic waves because of the geometry and mode of activating the multiple elements (see Figure 3.23(a)). The angle of propagation is:

$$\cos\theta = \frac{\lambda}{3a} = \frac{C}{3aft}$$

where  $a$  = the transducer element spacing and is therefore a fixed parameter.

$$\lambda = \frac{C}{ft} = \text{one acoustic wavelength in salt water}$$

If the two earlier equations in this section are now combined, the Doppler frequency shift is:

$$fd = \frac{2v}{3a}$$

$3a$  is a fixed parameter and therefore  $v$  is now the only variable. Two modes of operation are possible.

### 3.6.3 Choice of transmission mode

#### *Continuous wave mode (CW) transmission*

Two transducers are used in each of the Janus positions. A continuous wave of acoustic energy is transmitted by one element and received by the second element. Received energy will have been reflected either from the seabed, or, if the depth exceeds a predetermined figure (20 m is typical), from

a water mass below the keel. Problems can arise with CW operation particularly in deep water when the transmitted beam is caused to scatter by an increasing number of particles in the water. Energy due to scattering will be returned to the transducer in addition to the energy returned from the water mass. The receiver is likely to become confused as the returned energy from the water mass becomes weaker due to the increasing effects of scattering. The speed indication is now very erratic and may fall to zero. CW systems are rarely used for this reason.

### *Pulse mode operation*

To overcome the problems of the CW system, a pulse mode operation is used. This is virtually identical to that described previously for depth sounding where a high energy pulse is transmitted with the receiver off. The returned acoustic energy is received by the same transducer element that has been switched to the receive mode. In addition to overcoming the signal loss problem, caused by scattering in the CW system, the pulse mode system has the big advantage that only half the number of transducers is required.

### *Comparison of the pulse and the CW systems*

- Pulse systems are able to operate in the ground reference mode at depths up to 300 m (depending upon the carrier frequency used) and in the water track mode in any depth of water, whereas the CW systems are limited to depths of less than 60 m. However, CW systems are superior in very shallow water, where the pulse system is limited by the pulse repetition frequency (PRF) of the operating cycle.
- The pulse system requires only one transducer (two for the Janus configuration) whereas separate elements are needed for CW operation.
- CW systems are limited by noise due to air bubbles from the vessel's own propeller, particularly when going astern.
- Pulse system accuracy, although slightly inferior to the CW system, is constant for all operating depths of water, whereas the accuracy of the CW system is better in shallow water but rapidly reduces as depth increases.

### **3.6.4 Environmental factors affecting the accuracy of speed logs**

Unfortunately environmental factors can introduce errors and/or produce sporadic indications in any system that relies for its operation on the transmission and reception of acoustic waves in salt water.

- *Water clarity.* In exceptional cases the purity of the seawater may lead to insufficient scattering of the acoustic energy and prevent an adequate signal return. It is not likely to be a significant factor because most seawater holds the suspended particles and micro-organisms that adequately scatter an acoustic beam.
- *Aeration.* Aerated water bubbles beneath the transducer face may reflect acoustic energy of sufficient strength to be interpreted erroneously as sea bottom returns producing inaccurate depth indications and reduced speed accuracy. Proper siting of the transducer, away from bow thrusters, for instance, will reduce this error factor.
- *Vessel trim and list.* A change in the vessel's trim from the calibrated normal will affect fore/aft speed indication and an excessive list will affect athwartship speed. A Janus configuration transducer reduces this error.

- *Ocean current profile.* This effect is prevalent in areas with strong tides or ocean currents. In the water track mode, a speed log measures velocity relative to multiple thermocline layers several feet down in the water. If these layers are moving in opposite directions to the surface water, an error may be introduced.
- *Ocean eddy currents.* Whilst most ocean currents produce eddies their effect is minimal. This problem is more likely to be found in restricted waters with big tidal changes or in river mouths.
- *Sea state.* Following seas may result in a change in the speed indication in the fore/aft and/or port/starboard line depending upon the vector sum of the approaching sea relative to the ship's axis.
- *Temperature profile.* The temperature of the seawater affects the velocity of the propagated acoustic wave (see Figure 2.2 in Chapter 2). Temperature sensors are included in the transducer to produce corrective data that is interfaced with the electronics unit.

### 3.7 Doppler speed logging systems

There are many maritime Doppler speed logging systems available, ranging from simple and inexpensive units designed for the leisure market to the complex rugged units fitted on modern merchant vessels, and they all rely for the operation on the first principles described in this chapter. The difference between the cheaper leisure Doppler logs and those designed for a more demanding environment, lies in their construction, their reliability under pressure, the facilities they offer, and the fact that they are type-approved for use on ocean trading vessels.

#### 3.7.1 The Sperry SRD-500 Dual Axis Doppler Speed Log System

One of the traditional manufacturers Sperry Marine Inc., now a part of Litton Marine Systems, produces and markets a dual axis log, the SRD-500 (see Figure 3.24), which is a fine example of how microtechnology may be used in signal processing and data presentation in a modern Doppler speed log.

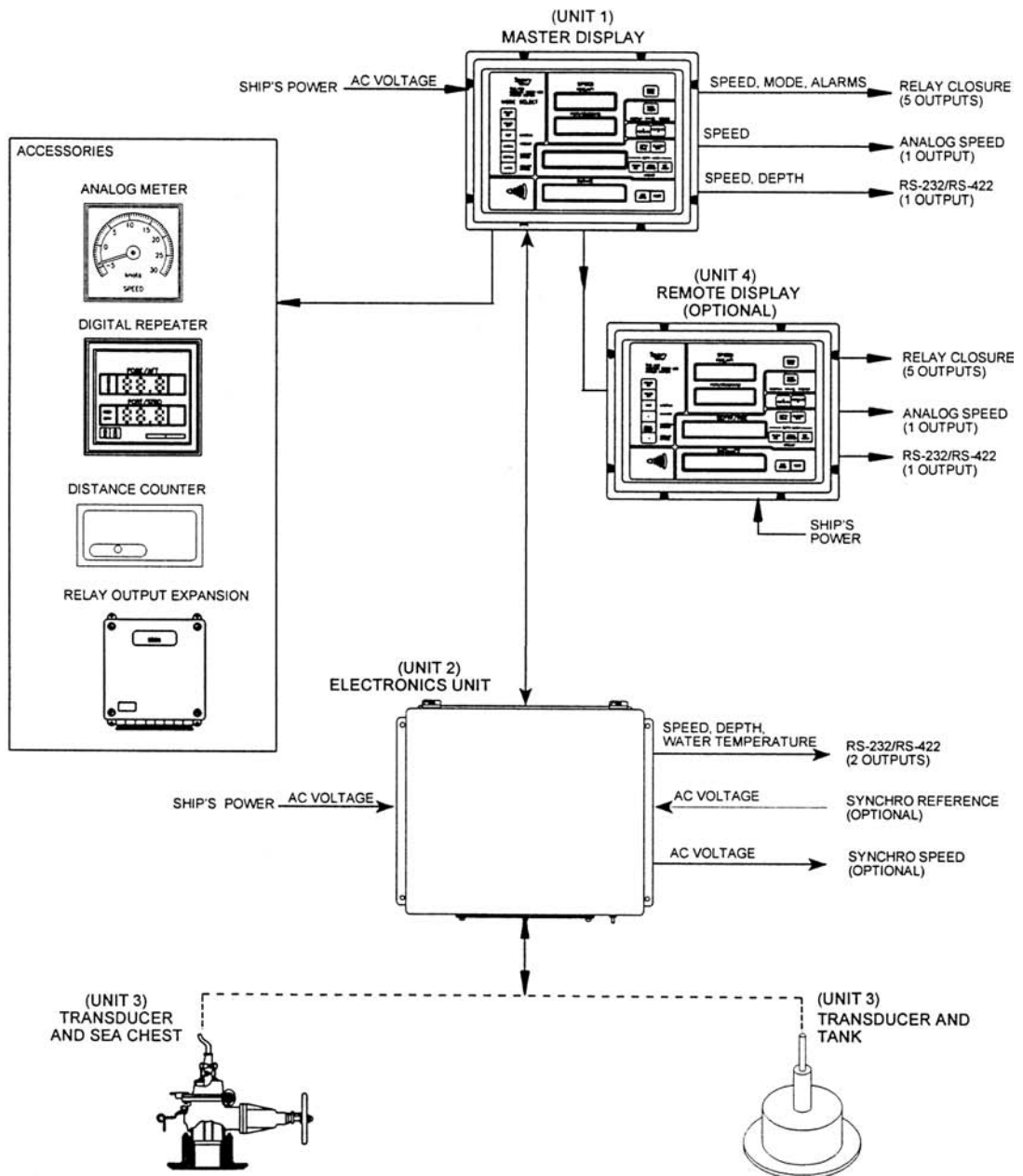
The SRD 500 is a dual axis speed log capable of indicating speed along the fore and aft axis, in the range -20 to 50 knots, and along the port and starboard axis, range  $\pm 10$  knots, using a four-element electrostrictive transducer assembly. Additional electronic signal processing circuitry enables an echo sounding function, when bottom tracking speed mode is available.

The transmission frequency is 307.2 kHz and the radiated power is 15–20 W.

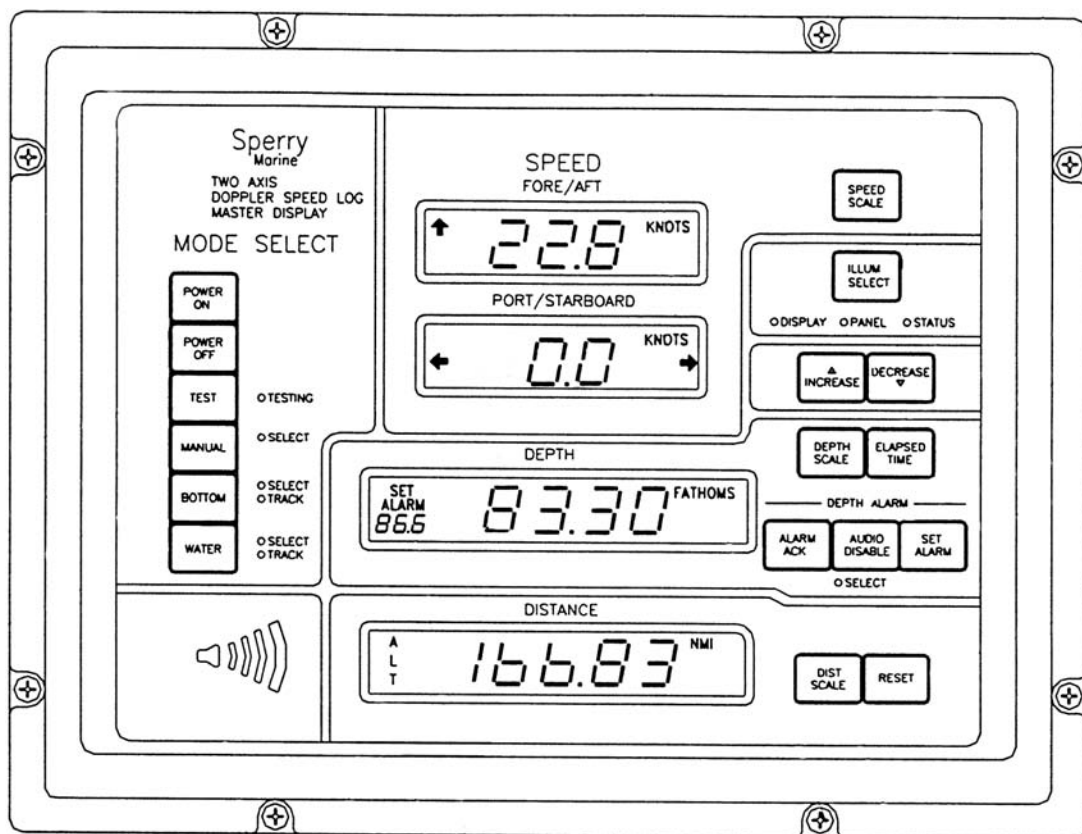
#### *Display unit*

The SRD-500 main navigation display is shown in Figure 3.25. Whilst many of the unit controls will be familiar to navigators, a few are listed below to show how the company has used electronic processing to get the most out of the system. For ease of viewing, the equipment uses illuminated liquid crystal displays.

- *Speed display.* This shows the vessel's fore/aft speed in knots, m/s (metres per second) or ft/s (feet per second). The speed range is 0–20 knots astern and 0–50 knots ahead. Bottom-tracking speed accuracy is  $\pm 0.1$  knots below 2 knots speed and  $\pm 0.05$  knots above 2 knots. Accuracy when water tracking is  $\pm 0.1$  knots below 10 knots,  $\pm 0.025$  knots in the range 10–25 knots, and  $\pm 0.1$  knot above 25 knots.



**Figure 3.24** Sperry SRD-500 dual axis Doppler speed log system. (Reproduced courtesy Litton Marine Systems.)

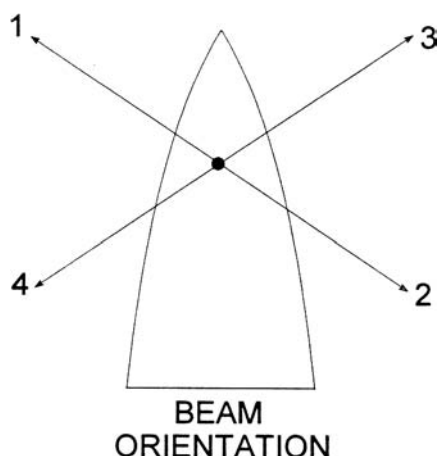


**Figure 3.25** Master display unit, controls and indicators. (Reproduced courtesy of Litton Marine Systems.)

- *Port/starboard display.* This indicates athwartship speed in knots, m/s or ft/s. The range is 0–10 knots.
- *Depth/time display.* This indicates water depth to the seabed, in fathoms, metres or feet, when in either water or bottom-tracking mode, providing the depth is within 200 m. The depth indication circuitry also includes a depth alarm.
- *Distance display.* This shows the distance run in nautical miles or km. Depending upon the selected mode and depth, the display indicates over-the-bottom distance or, when the unit is water tracking, the distance travelled through the water. If the ALT characters are showing, the system tracks both bottom and water simultaneously and provides both outputs to external devices. This display also provides a numerical indication which, when used in conjunction with the system manual, provides clues to any system malfunction.

### System description

The Sperry SRD-500 uses a four-element piezoelectric and prism transducer assembly with the four heads aligned as shown in Figure 3.26.



**Figure 3.26** Transducer beam orientation. (Reproduced courtesy of Litton Marine Systems.)

Because the beams are aligned at  $45^\circ$  to the ship's fore/aft and port/starboard axes, each returned signal will hold data about the fore/aft and port/starboard speed of the vessel. Each beam is inclined at  $20^\circ$  to the vertical axis. When the ship is moving ahead, beams 1 and 3 will contain a positive Doppler shift (a compression of the transmitted wavelength) whereas beams 2 and 4 will hold corresponding data.

The data line XMIT from the Processor Board initiates transmission (see Figure 3.27). Four independent transmit amplifiers are pulsed to generate 15–20 W of power causing the four piezoelectric elements to oscillate at 307.2 kHz and transmit acoustic energy pulses towards the seabed.

Sensors in the transducer assembly monitor the seawater temperature and provide, via an A to D converter, corrective data for the central processor.

Returned echoes from either the seabed or scattered from water particles, are received by the transducer elements and coupled to the Receive Amplifier and Frequency Comparison Board. The signals are amplified, gain controlled and then fed to a limiter circuit where the received signal amplitude is monitored and a receive signal strength indicator (RSSI) level is produced. The four levels (RSSI1–4) are coupled back to the processor, which uses the data to determine bottom detection, signal quality and to set the receiver gain. The four-channel signal data is then coupled to frequency comparators that are clocked by the frequency correlation and processing circuitry. From here the data is coupled with address information to the parallel interface and serial I/O boards for distribution.

The RSSI signals generated by the receive circuitry are used to determine the range to the seabed. Individual depths are computed for each beam. The minimum (shallowest) is used to determine if the water depth is sufficient for the log to operate in Water Track mode. The ability of the log to operate in Water Track mode requires a minimum of 3 m depth below the transducer. In deep water the ability to operate in Bottom Track mode is based on obtaining bottom-returned pulses on at least three beams. The displayed depth is an average of the individual depths indicated by the beams. System operation is commanded at start up by the Navigation Display Unit (see Figure 3.28)

These routines are performed when the system is switched on or the manual button is pressed. This includes initializing all program variables, the setting-up of peripheral components and communication controllers and the recall of display configuration data stored in NVRAM (non-volatile random access memory).

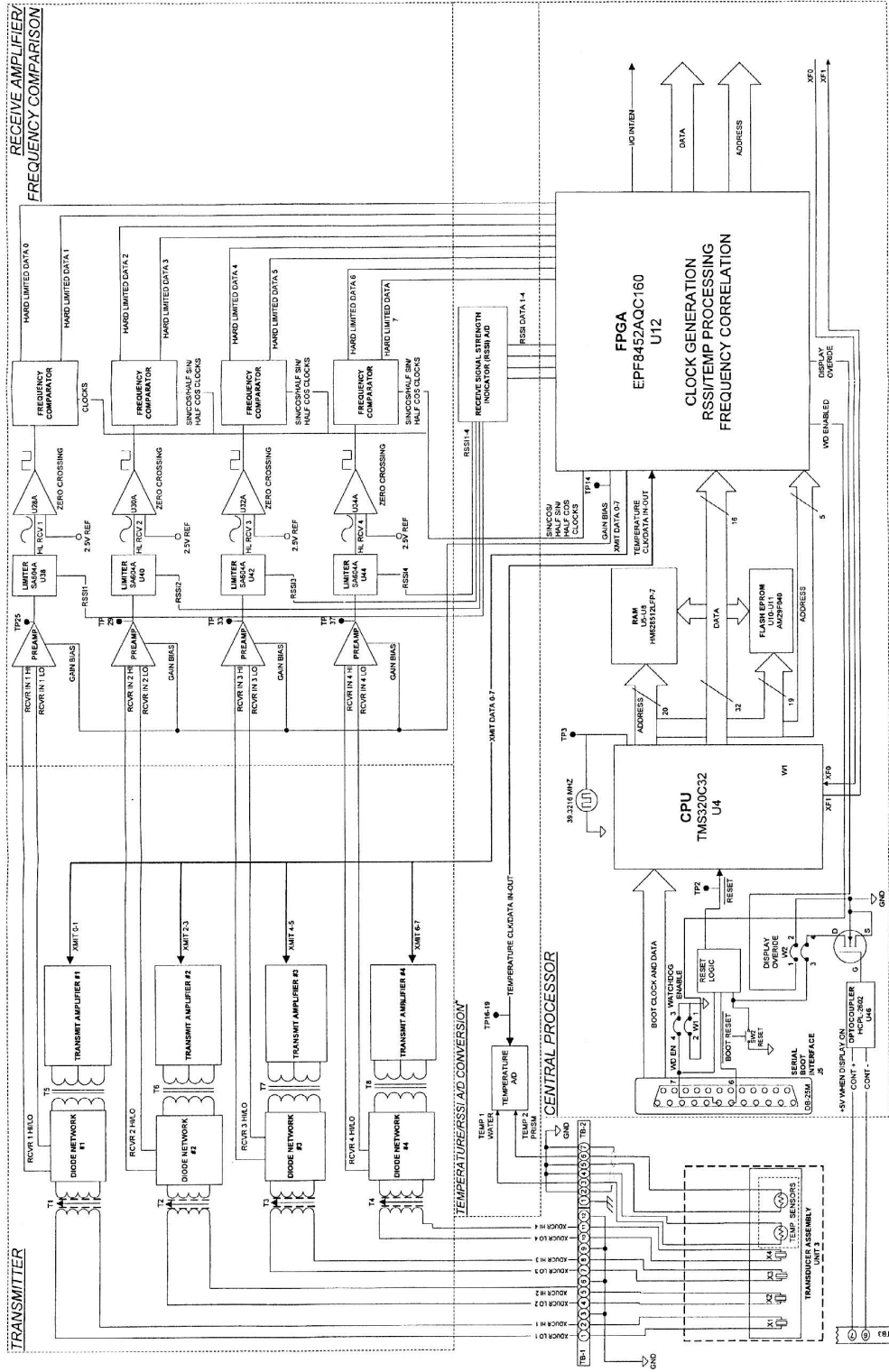
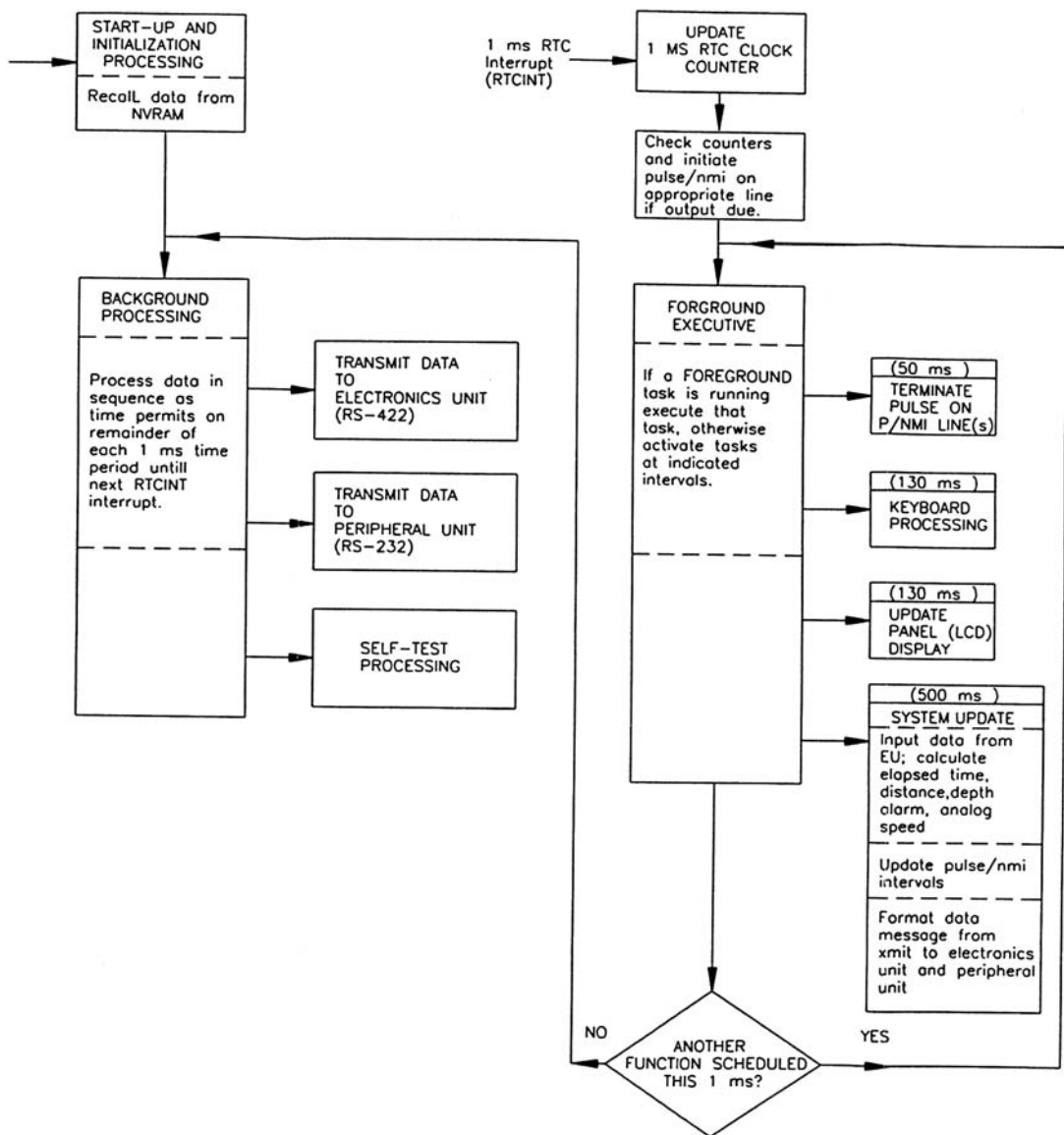


Figure 3.27 Electronics unit functional block diagram. (Reproduced courtesy of Litton Marine Systems.)





**Figure 3.28** Display unit start-up flow chart. (Reproduced courtesy of Litton Marine Systems.)

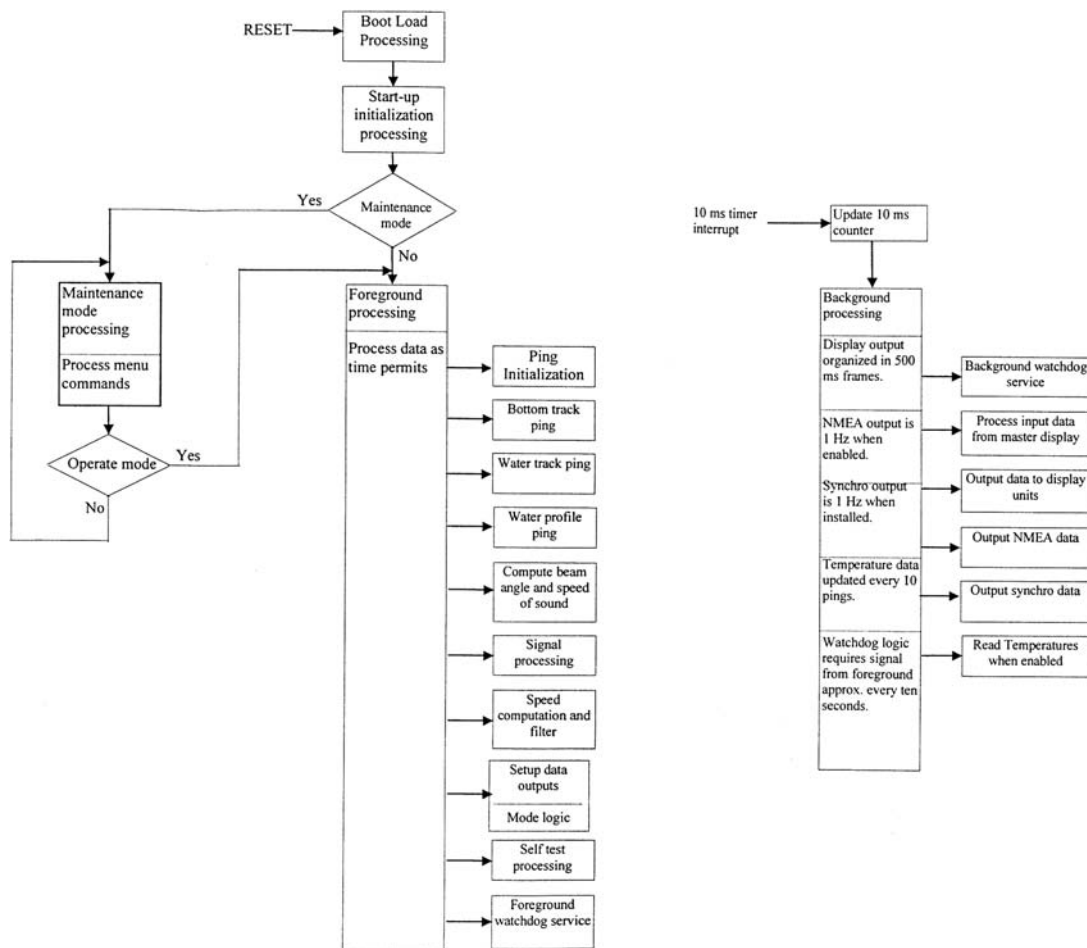
The foreground executive processing routines are initiated by a 1-ms real-time interrupt line (RTCINT), which instructs the circuitry to perform the following.

- Keyboard Data Processing: reads and processes any input from the keypad.
- Panel Processing: updates the LCD displays with the latest stored variables.
- System Update: incorporates the latest data from the Electronics Unit into the system variables for processing. Also formats data messages for transmission to the Electronics Unit and to peripheral equipment.

When the Foreground Executive processing routine has completed its tasks, the Background Processing Routine is initiated. This runs until the next RTCINT pulse arrives to retrigger the sequence. Background Processing enables the following actions.

- Data Message Output: enables the outputting of formatted data to both the Electronic Unit and Peripheral Units.
- Self-Test Processing: initializes the self-test program.

The system control flow chart, shown in Figure 3.29, illustrates the main functions. During operation, the foreground processing unit commands all system functions: determining, amongst other things, whether the log is in water or bottom-track mode, processing returned signal information, and operating the self-testing procedure. At 10-ms intervals the background processing subroutine commands data outputs to external navigation equipment and reads input from the master display.



**Figure 3.29** System control flow chart. (Reproduced courtesy of Litton Marine Systems.)

### *Built-in test circuitry*

In common with most computer-controlled equipment, the system operates a self-test procedure every time it is switched on and performs a fault detection routine at regular intervals during operation. Fault diagnosis routine and testing can be performed manually via the Master Display Unit keypad. During a manual test sequence all LEDs are illuminated and the LCD digits are sequentially displayed. If the test is successful, PASS is displayed in the Distance display. If not, a fault code number is displayed.

As an example of this, the number 402 indicates that the Water Temperature reading is faulty and that the probable faulty component is the temperature sensor in the transducer or the wiring between it and the processing card 2A1. As a further indication of the depth to which the system is able to diagnose faults, the other codes are listed below.

- Codes 101 or 102: keypad faults in the Master Display Unit.
- Codes 201–208: communication faults between the Display Unit and the Main Electronics Unit.
- Codes 255 and 265: RS-232/422 outputs faulty from the Display Unit.
- Codes 301–308 and 355–365: refer to faults in the Main Electronics Unit.
- Codes 401–403: temperature measurement faults.
- Codes 490 and 491: memory test faults.
- Codes 520–524: transmit/receive ping faults.
- Codes 600–604 and 610–614: noise level and sensitivity faults.
- Codes 620–630: receive/transmit signal faults.

### *Output data formats*

Output data sent to remote navigation systems is formatted in the standard protocol for Interfacing Marine Electronics Navigation Devices developed by the National Marine Electronics Association NMEA 0183 (see Appendix 3 for full details). A second output, in Sperry Marine Format, is intended primarily for the direct printout of speed data.

#### *Display unit – serial data output format*

The serial data output port of each display is configured so that the data can be communicated to peripheral processing devices. Data can be interfaced using RS-232 or RS-422 protocols.

Descriptions of the Sperry SRD-500 communications data format are given in Table 3.1. Examples of NMEA 0183 format messages sent by the RS 422 interface at 4800 bauds are as follows.

```
Speed message format: $VDVBW,swww.ww,sxx.xx,A,syy.yy,szz.zz,A*cc<CR><LF>
Depth message format: $VDDRU,ddd.dd,A,,V,*cc<CR><LF>
Water Track format:   $VDVBW,16.24,-0.62,A,,,V*25
                     $VDDRU,,V,,V,*7D
```

The Sperry Marine Format, intended primarily for the direct printout of speed data, is shown in Table 3.2.

Data output is transmitted in ASCII coded format and is structured to be displayed or printed in six-headed columns on a standard page with a width of 80 characters and a length of 56 lines. The serial data interface is set up with 8 data and 2 stop bits and no parity. No handshaking lines are used. Messages are never repeated. A new set of data is formatted for transmission every 0.5 s.

**Table 3.1** Sperry SRD-500 communications data format – NMEA 0183. (Reproduced courtesy of Litton Marine Systems)

<i>Data field</i>	<i>Description</i>
\$	Message header character
VD	Talker ID
VBW	Message type (speed bottom/water)
DPT	Message type (depth with keel offset)
DRU	Message type (depth)
MTW	Message type (water temperature)
XDR	Message type (transducer measurements)
G	Generic
eee.ee	Percentage good; first, second, and last 'e' omitted if not used
PCB1	Beam one ID for bottom speed
PCW1	Beam one ID for water speed
S	Sign – for aft/port speeds, omitted for fore/stbd speeds
ww.ww	Fore/Aft water speed (knots); first and last 'w' omitted if not used
xx.xx	Port/Stbd water speed (knots); first and last 'y' omitted if not used
zz.zz	Port/Stbd bottom speed (knots); first and last 'z' omitted if not used
ddd.dd	Depth (meters); first, second and last 'd' omitted if not used
oo.oo	Keel offset (decimeters); first and last 'o' omitted if not used
ttt.tt	Temperature (C°); first, second and last 't' omitted if not used
A	Data status (A = valid, V = invalid)
*	Message data trailer
cc	Checksum; 8 bit running XOR of character between \$ and*
<CR>	Carriage return
<LF>	Line feed

*Electronics Unit – serial data output*

There are two bi-directional auxiliary ports (Aux 1 and Aux 2) in the Electronics Unit, each of which can be selected to output NMEA 0183 format data directly to peripheral devices.

The baud rate can be selected between 1200 and 115200 and defaults to 4800. Message words are 8 data bits long with selectable parity, a single Start bit and selectable Stop bits (one or two). The default communication setting for Aux 2 complies with NMEA 0183 version 2.1 recommendation: one Start bit, eight data bits, one Stop bit, no parity and a 4800 baud rate.

Both output serial ports send NMEA messages at a 1-s (1 Hz) data rate for speed, depth and water temperature; and at a 10-s rate (0.1 Hz) data rate for 'percent good pings for Bottom Speed' and 'percent good pings for Water Speed'.

*Examples of output data formats*

Speed message format:

\$VDVBW,www.ww,sxx.xx,A,syy.yy,szz.zz,A\*cc<CR><LF>

Depth message format:

\$VDDPT,ddd.dd,oo.oo(keel offset)\*cc<CR><LF>

Water temperature message format:

\$VDMTW,ttt.tt,C\*cc<CR><LF>

**Table 3.2** Sperry SRD-500 display unit – serial output data format (Sperry ASCII) (Reproduced courtesy of Litton Marine Systems)

<i>Data</i>	<i>Format</i>	<i>Comments</i>
Operating mode	EUTEST^ OPTTEST^ BOTTOM^ WATER^ WATBOT^ MANUAL^	7 character field
Fault code	FFF^^^ ^*^^^	6 character field FFF = 3 digit fault code ^*^ = no fault
F/A bottom speed	svv.vv^m/s^^^  ^^^*****^^^	13 character field s = sign bit (-blank) vv.vv = speed value, zero fill if necessary m/s = unit indicator speed undefined
F/A water speed	same as F/A bottom	
P/S bottom speed	same as F/A bottom	
P/S water speed	same as F/A bottom	
Depth (altitude)	^ddd.d^m^m^cle  ^^*****^^^cle	13 character field ^^^d.d if altitude < 10 m ^^dd.d if altitude < 100 m ^ddd.d if altitude >= 100 m m = unit indicator c = carriage return l = line feed e = end of text character Depth defined

Note: a '^' character represents a blank character

Percent good pings for Bottom Speed message format:

\$VDXDR,G,eee.ee, ,PCB1,G,eee.ee, ,PCB2,G, ... ,PCB3,G, ... ,PCB4\*cc<CR><LF>

Percent good pings for Water Speed message format:

\$VDXDR,G,eee.ee, ,PCW1,G,eee.ee, ,PCW2,G, ... ,PCW3,G, ... ,PCW4\*cc<CR><LF>

To decode the above symbols, see Table 3.1.

### *Message example for Water Track Speed*

\$VDVBW, 2.0,-0.25,A,,,V\*

\$VDDPT,2.5,-1.0,\*79

\$VDMTW,18.4,C\*0C

\$VDXDR,G,000,PCB1,G,000,PCB2,G,000,,PCB3,G,000,,PCB4\*58

\$VDXDR,G,100,,PCW1,G,100,PCW2,G,100,,PCW3,G,100,,PCW4\*58

As an example, the first line of this message may be simply decoded as follows.

\$ (header) VD (talker ID) VBW (speed bottom/water) s (aft/port speeds) 2.0 (aft speed in kts) s (aft/port speeds) 0.25 (port speed in kts) A (data status).

The above description is only a simple outline of how the NMEA 0183 protocol is used to interface data from this speed log with other electronic systems. Refer to Appendix 3 for a more detailed description of the protocol.

### 3.7.2 The Furuno Doppler Sonar DS-50 System

Another respected manufacturer of marine equipment, Furuno, produces a Doppler sonar system, the DS-30, based on the principles of Doppler speed measurement. Whilst the system principles are the same as with other speed logs in this category, Furuno have made good use of the data processing circuitry and a full colour 10-inch wide LCD display to present a considerable amount of information to a navigator. The display modes are shown in Figure 3.30.

The system uses a triple beam, 440 kHz pulsed transmission and from the received Doppler shifted signal calculates longitudinal, thwartship speeds and depth beneath the keel at the bow.

In addition, a Laser Gyro may be fitted on the stern to provide a further data input of transverse speed and rate of turn information (see Figures 3.21 and 3.31). Position data from a GPS receiver may also be input to the CPU.

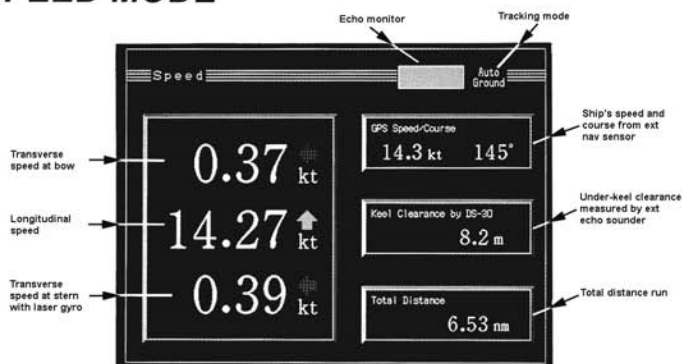
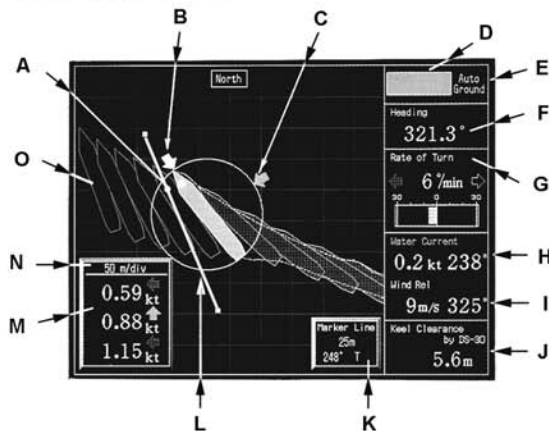
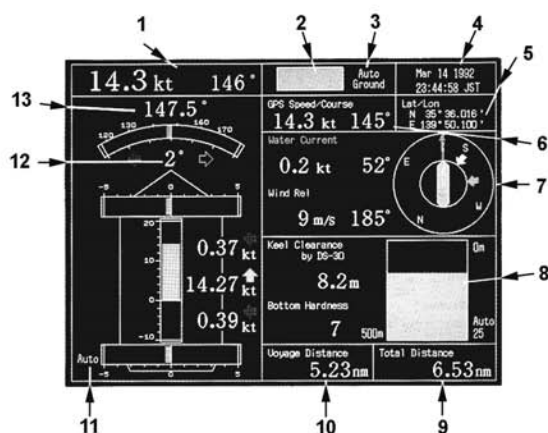
There are three principle modes of data display.

- The Speed Mode showing all the normal speed/depth/distance indications.
- The Berthing Mode which, with the additional inputs from a laser gyro at the stern, shows a vessel's movements during low speed manoeuvres (see Figure 3.31).
- The Nav Data Mode with a display reminiscent of an integrated navigation system.

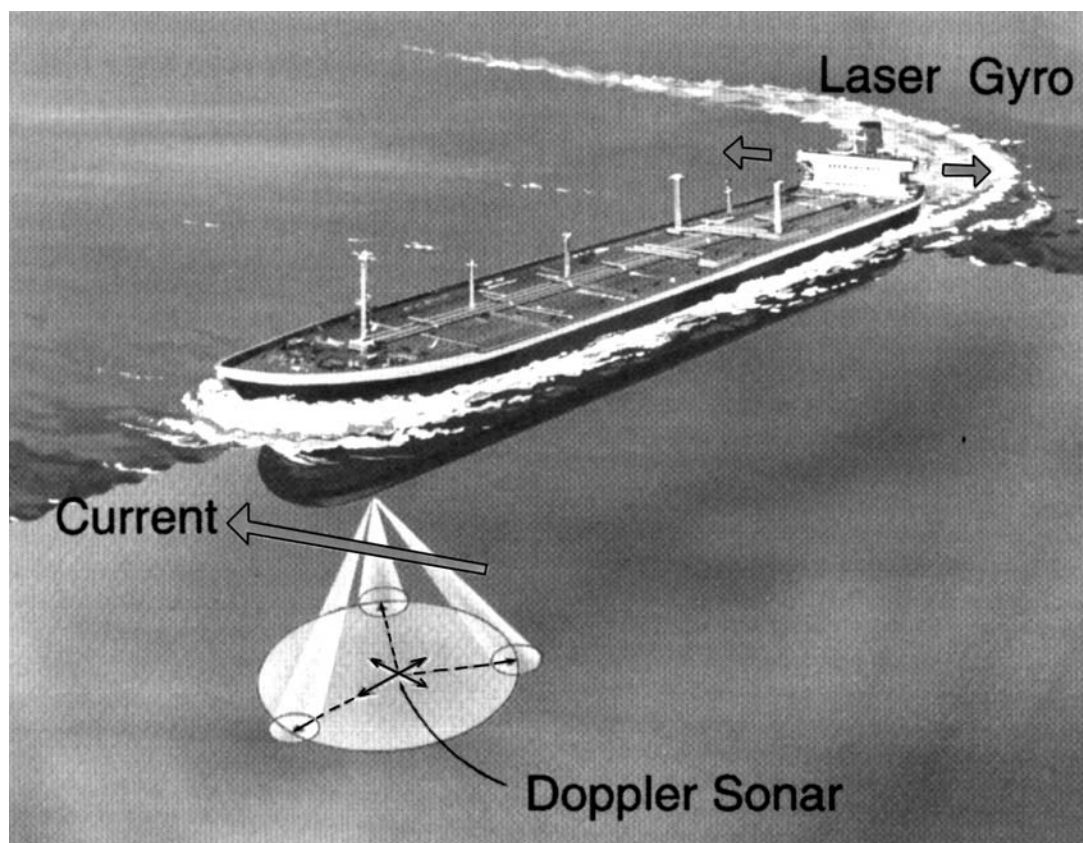
#### *Berthing Mode display*

The display diagram key shows the following.

- A Intersection of perpendicular from ship's ref. point to marker line.
- B Yellow arrowhead showing wind direction.
- C Blue arrowhead showing current direction.
- D Echo monitor.
- E Tracking mode.
- F Heading (input from gyro).
- G Rate of turn (measured by laser gyro).
- H Readout of speed and direction of water current.
- I Readout of wind speed and direction (input from wind sensors).
- J Under-keel clearance measured by an external echo sounder.
- K Range and bearing (true) to marker line.
- L Marker line.
- M Ship's speed: transverse, longitudinal and transverse at stern with laser gyro.
- N Grid scale and presentation mode.
- O Ship's predicted motion.

**SPEED MODE****BERTHING MODE****NAV DATA MODE**

**Figure 3.30** Furuno Doppler Sonar DS-30 display modes. (Reproduced courtesy of Furuno Electric Co.)



**Figure 3.31** Triple beam transducer configuration of the Furuno Doppler Sonar Log. Note the forces acting on the vessel during a starboard turn under the influence of a cross-current from the port side. (Reproduced courtesy of Furuno Electric Co.)

### *Nav Data Mode display*

The display diagram key for this mode shows the following.

- 1 Ship's speed and course.
- 2 Echo monitor.
- 3 Tracking mode and echo level indicator.
- 4 Date and time.
- 5 Position (input from external sensors).
- 6 Ship's speed and course (input from external sensors).
- 7 Current speed and direction (app.088°) and wind speed and direction (app. 038°).
- 8 Graphic presentation of under-keel clearance.
- 9 Total distance run.
- 10 Voyage distance from reset.
- 11 Ship's transverse speed at bow, longitudinal speed and transverse speed at stern with laser gyro.
- 12 Drift angle (deviation of course over ground from ship's course).
- 13 Course heading.



### 3.8 Glossary

<b>Aeration</b>	The formation of bubbles on the transducer face causing errors in the system.
<b>ALPHA (Atlas Low Frequency Phased Array) transducer</b>	A flush fitting transducer using multiple elements to create the transmitted beam.
<b>Beamwidth</b>	The width of the transmitted acoustic pulsed wave. The beam spreads the further it travels away from a transducer.
<b>BITE</b>	Built-in test circuitry. A self-test or manually operated diagnostic system.
<b>CW mode</b>	Continuous wave transmission. Both the transmitter and receiver are active the whole time. Requires two transducers.
<b>Distance integrator</b>	The section of a speed log that produces an indication of distance travelled from speed and time data.
<b>Doppler principle</b>	A well-documented natural phenomenon enabling velocity to be calculated from a frequency shift detected between transmission and reception of a radio signal.
<b>E.M. log</b>	An electronic logging system relying on the induction of electromagnetic energy in seawater to produce an indication of velocity.
<b>G/T</b>	Ground-tracking or ground referenced speed.
<b>NMEA</b>	National Marine Electronic Association. Interfacing standards.
<b>Pitot log</b>	An electromechanical speed logging system using changing water pressure to indicate velocity.
<b>Pulse mode</b>	Acoustic energy is transmitted in the form of pulses similar to an echo sounding device or RADAR
<b>Transducer</b>	The transmitter/receiver part of a logging system that is in contact with the water. Similar to an antenna in a communications system.
<b>Translating system</b>	The electronic section of a logging system that produces the speed indication from a variety of data.
<b>W/T</b>	Water-tracking or water referenced speed.

### 3.9 Summary

- To be accurate, speed must be calculated with reference to a known datum.
- At sea, speed is measured with reference to the ocean floor (ground-tracking (G/T)) or water flowing past the hull (water-tracking (W/T)).
- Traditionally, maritime speed logging devices use water pressure, electromagnetic induction, or the transmission of low frequency radio waves as mediums for indicating velocity.
- A water pressure speed log, occasionally called a Pitot log:
  - (a) measures W/T speed only;
  - (b) requires a complex arrangement of pressure tubes and chambers mounted in the engine room of a ship and a Pitot tube protruding through the hull;
  - (c) produces a non-linear indication of speed which must be converted to a linear indication to be of any value. This is achieved either mechanically or electrically in the system;
  - (d) speed indication is affected by the non-linear characteristics of the vessel's hull and by the vessel pitching and rolling;
  - (e) possesses mechanical sections that require regular maintenance.

- An electromagnetic speed log:
  - (a) measures W/T speed only;
  - (b) produces a linear speed indication;
  - (c) operates by inducing a magnetic field in the salt water flowing past the hull and detecting a minute change in the field;
  - (d) produces a varying speed indication as the conductivity of the seawater changes.
  - (e) Indication may be affected by the vessel pitching and rolling in heavy weather.
- Speed logs that use a frequency or phase shift between a transmitted and the received radio wave generally use a frequency in the range 100–500 kHz. They also use a pulsed transmission format.
- A log using the acoustic correlation technique for speed calculation:
  - (a) can operate in either W/T or G/T mode. G/T speed is also measured with respect to a water mass;
  - (b) measures a time delay between transmitted and received pulses;
  - (c) produces a speed indication, the accuracy of which is subject to all the environmental problems affecting the propagation of an acoustic wave into salt water. See Chapter 2.
- Doppler frequency shift is a natural phenomenon that has been used for many years to measure velocity. If a transmitter (TX) and receiver (RX) are both stationary, the received signal will be the same frequency as that transmitted. However, if either the TX or the RX move during transmission, then the received frequency will be shifted. If the TX and/or RX move to reduce the distance between them, the wavelength is compressed and the received frequency is increased. The opposite effect occurs if the TX and/or RX move apart.
- A Doppler speed logging system:
  - (a) transmits a frequency (typically 100 kHz) towards the ocean floor and calculates the vessel's speed from the frequency shift detected;
  - (b) measures both W/T and G/T speed;
  - (c) produces a speed indication, the accuracy of which is subject to all the environmental problems affecting the propagation of an acoustic wave in salt water;
  - (d) uses a Janus transducer arrangement to virtually eliminate the effects of the vessel pitching in heavy weather;
  - (e) may use more than one transducer arrangement. One at the bow and another at the stern to show vessel movement during turn manoeuvres.

### 3.10 Revision questions

- 1 A speed indication is only of value if measured against another parameter. What is the speed indication, produced by a pressure tube speed log, referenced to?
- 2 What is the approximate velocity of propagated acoustic energy in seawater?
- 3 In a pressure tube speed logging system, why is the complex system of cones required in the mechanical linkage?
- 4 What is the speed indication produced by an electromagnetic log referenced to?
- 5 How does the non-linearity of a ship's hull affect the speed indication produced by an electromagnetic speed log?
- 6 Does the amount of salinity in the water affect the speed indication produced by an acoustic correlation speed log?
- 7 Why do all Doppler speed logs use a Janus configuration transducer assembly?
- 8 How does aeration cause errors in the speed indicated by a Doppler log?

- 9 Using the  $V_x$  and  $V_y$  speed components produced by a Doppler speed log, how is it possible to predict a vessel's drift rate?
- 10 Why are pulsed transmission systems used in preference to a continuous wave mode of operation?
- 11 Why are water temperature sensors included in the transducer assembly of a Doppler speed logging system?
- 12 How may the distance run be calculated in a speed logging system?