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 (λ) is compressed in time when received from a transmitter moving towards a receiver (λ_1) and expanded (Figure 3.15c) in time from a transmitter moving away (λ_2). Consider a transmitter radiating a frequency (f_1). The velocity of propagation of radiowaves in free space (c) is $300 \times 10^6\,\mathrm{ms}^{-1}$ and in seawater it is much slower at approximately $1500\,\mathrm{ms}^{-1}$. After a period of 1 s, one cycle of the transmitted acoustic wave in seawater will occupy a distance of 1500 m.

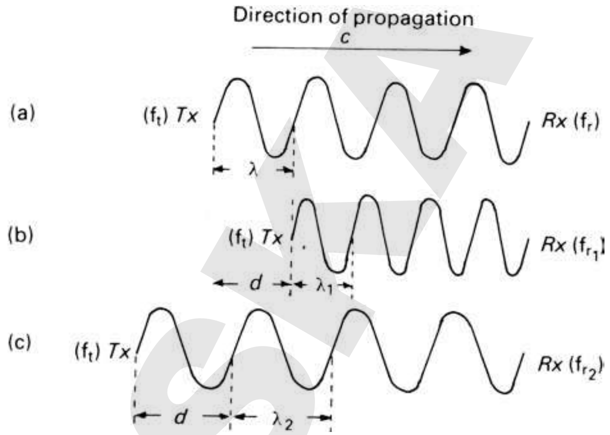


Figure 3.15 Expansion and compression of wavelength.

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).

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

Therefore the apparent wavelength is

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

and the frequency is

$$fr_1 = \frac{c}{\lambda_1} = \frac{c}{\lambda - v/ft} = \frac{cft}{\lambda ft - v} = f_t \frac{c}{c - v}$$

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.

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

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

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

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

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;

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

The Doppler frequency shift is

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

$$f_d = f_t \, x \, \frac{c + v}{c - v} - f_t$$

$$= \frac{cf_t + vf_t - cf_t + vf_t}{c - v}$$

$$= \frac{2vf_t}{c - v}$$

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).

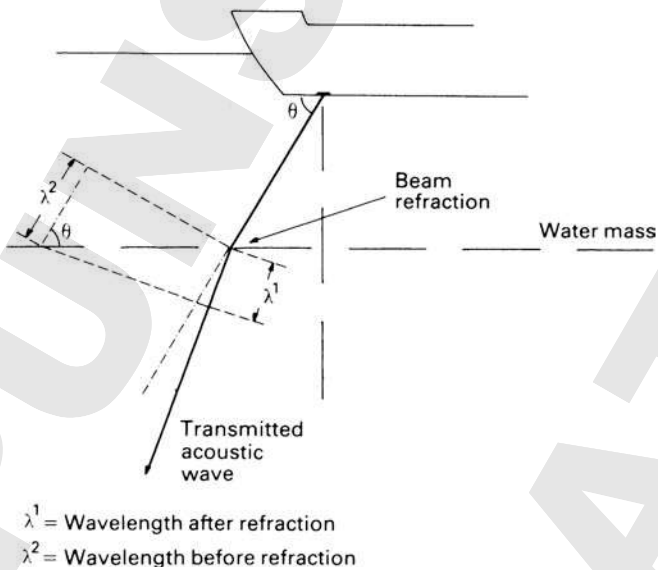


Figure 3.16 Illustration of the change of wavelength that occurs when an acoustic wave crosses a water mass.

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 ($1500\,\mathrm{ms}^{-1}$ 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° 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, $\cos\theta$ = Adjacent/Hypotenuse. Therefore, Adjacent = $C \cos\theta$.

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

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

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.

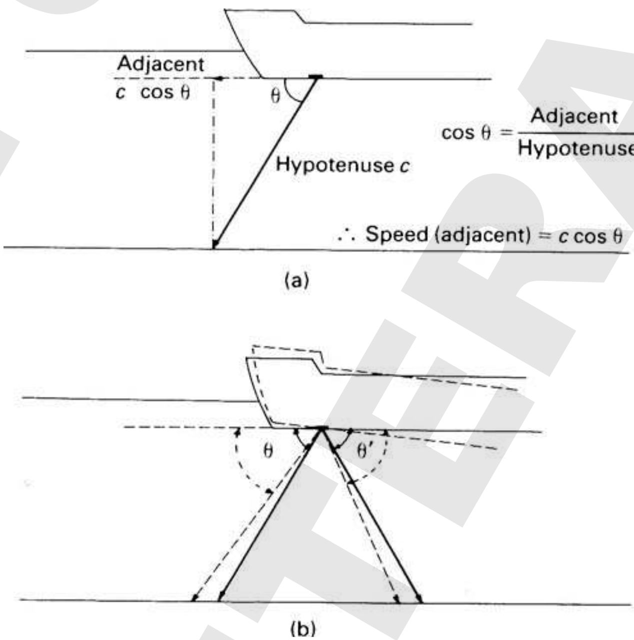


Figure 3.17 (a) Derivation of longitudinal speed using trigonometry. (b) The effect of pitching on a Janus transducer configuration.

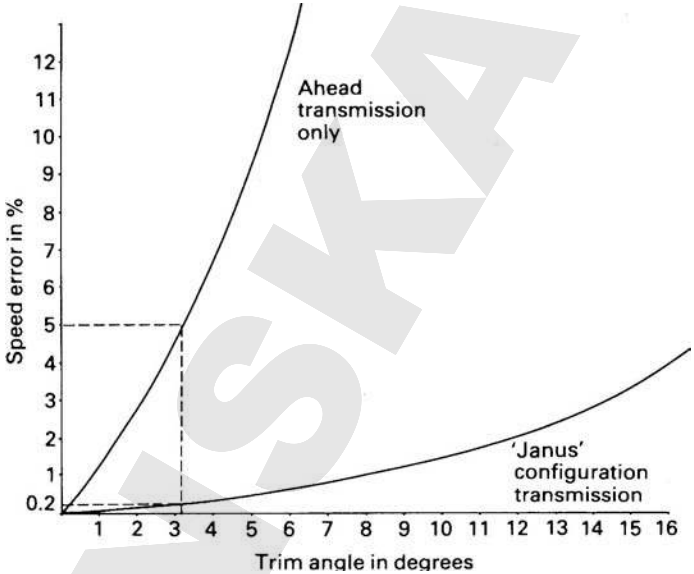


Figure 3.18 Graphs of speed error caused by variations of the vessel's trim.

The Doppler frequency shift formula now becomes:

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

(+ cos 60° + cos 60°′ = 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).

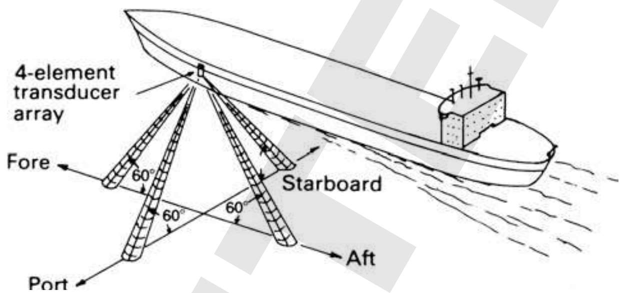


Figure 3.19 Dual axis speed is measured by transmitting sonar pulses in four narrow beams towards the sea bed.

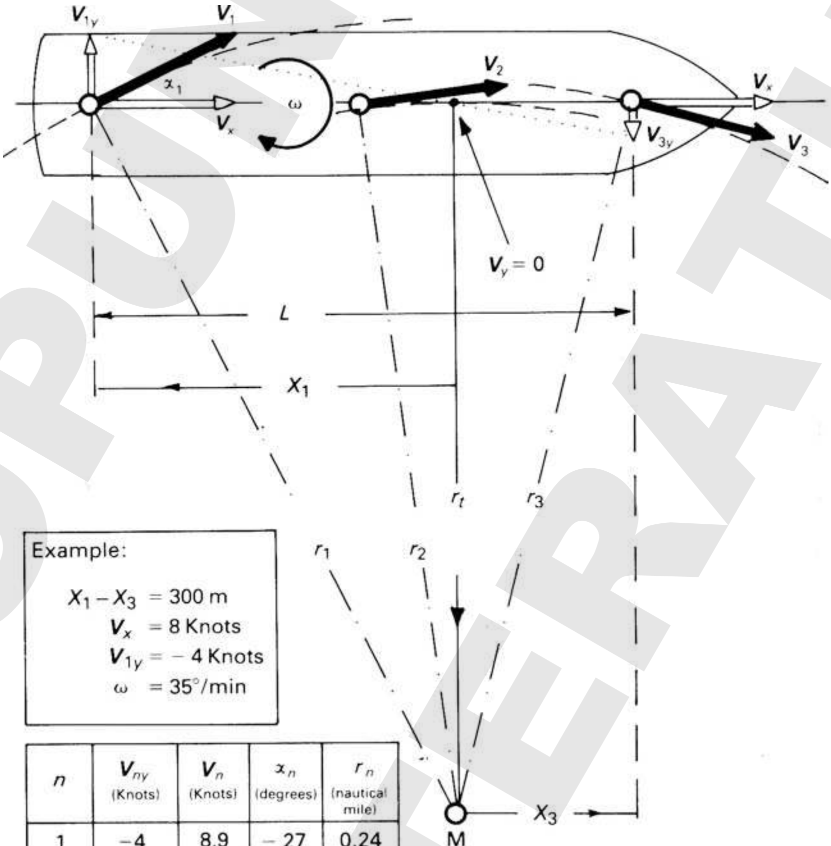
3.6.1 Vessel motion during turn manoeuvres

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 (**Vy**) 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

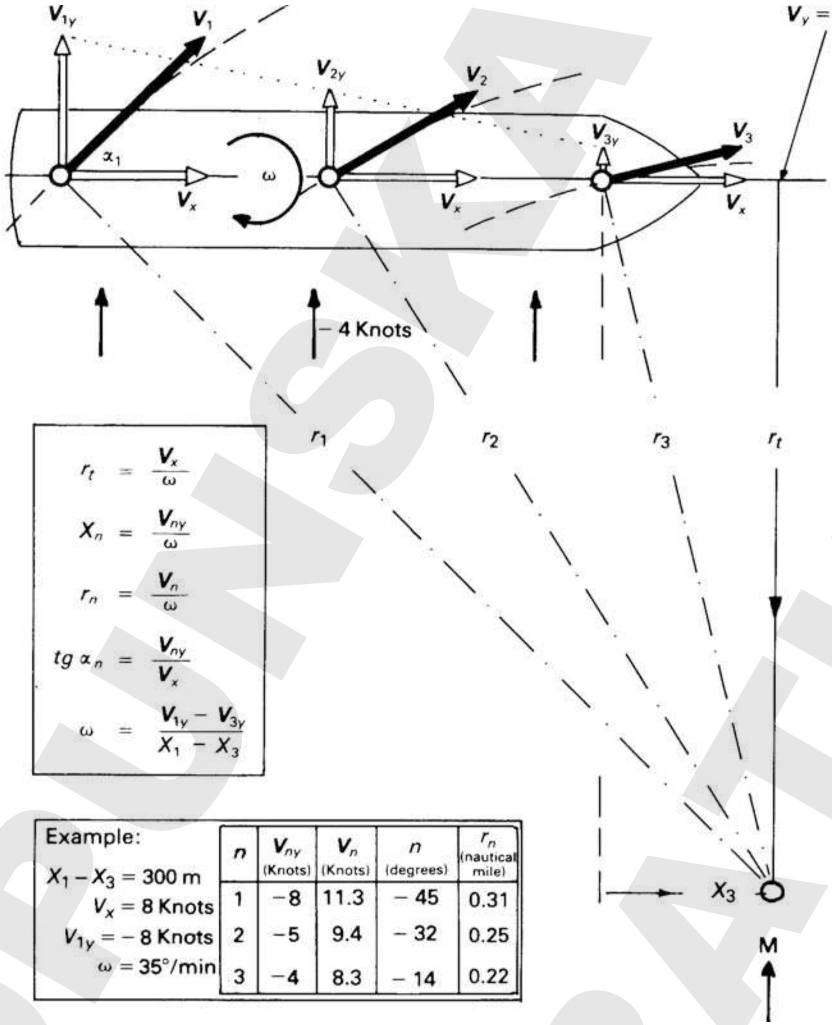


Example:

$X_1 - X_3 = 300$ m
$V_x = 8$ Knots
$V_{1y} = -4$ Knots
$\omega = 35°/\text{min}$

n	V_{ny} (Knots)	V_n (Knots)	α_n (degrees)	r_n (nautical mile)
1	−4	8.9	−27	0.24
2	−1	8.1	−7	0.22
3	+2	8.3	+14	0.22

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



$$r_t = \frac{V_x}{\omega}$$

$$X_n = \frac{V_{ny}}{\omega}$$

$$r_n = \frac{V_n}{\omega}$$

$$tg\,\alpha_n = \frac{V_{ny}}{V_x}$$

$$\omega = \frac{V_{1y} - V_{3y}}{X_1 - X_3}$$

Example:
$X_1 - X_3 = 300$ m
$V_x = 8$ Knots
$V_{1y} = -8$ Knots
$\omega = 35°/\text{min}$

n	V_{ny} (Knots)	V_n (Knots)	n (degrees)	r_n (nautical mile)
1	−8	11.3	− 45	0.31
2	−5	9.4	− 32	0.25
3	−4	8.3	− 14	0.22

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 ($\mathbf{V_{3y}}$) 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, $\mathbf{V}_{3y}$ points to port. The transverse speed development along the ship's length is represented by a dotted line (between $\mathbf{V}_{1y}$ and $\mathbf{V}_{3y}$). 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 ($\mathbf{V}_y = 0$) 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 ($\mathbf{V}_x$) and a transverse direction ($\mathbf{V}_y$). 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:

$$\propto = \text{arc tan} \frac{V_y}{V_x}$$

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, ω = rate of turn (angular velocity), and L = distance between bow and stern points of measurement.

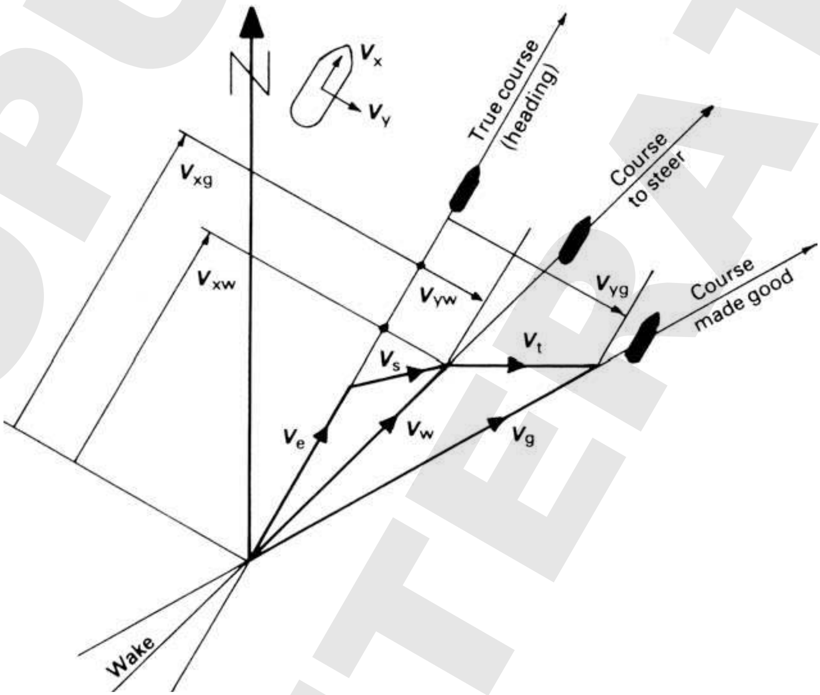


Figure 3.22 External environmental effects of a vessel's track. (Reproduced courtesy of Krupp Atlas Elektronik.)

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

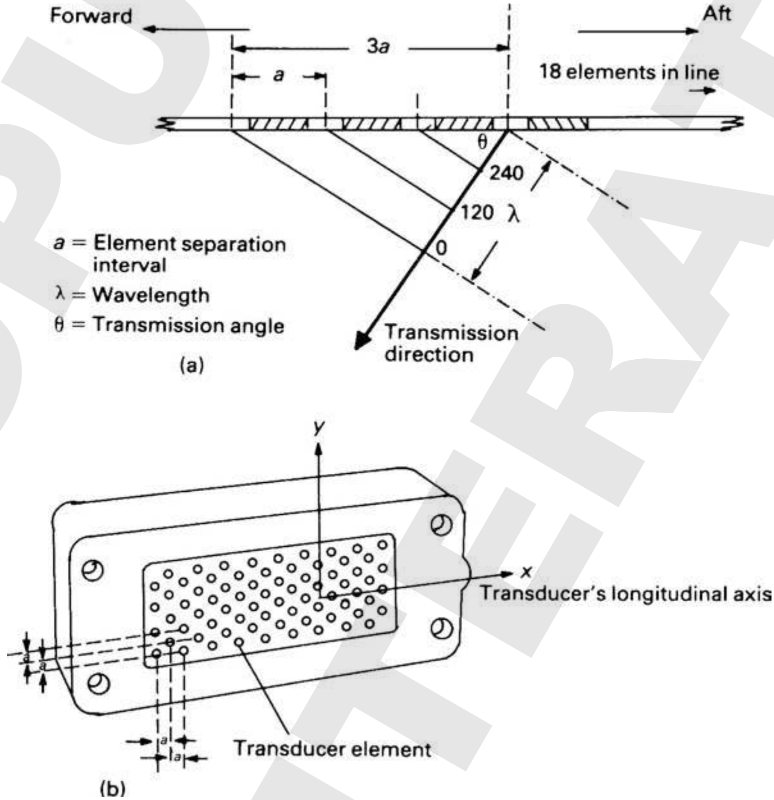


Figure 3.23 (a) Principle of the alpha transducer array. (b) A 72-element alpha transducer array.

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°, the main lobe is propagated at an angle (which under these conditions is about 50°). In this case the elements are fed with three sine waves each shifted clockwise by 120°. 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 (θ) 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:

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

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 ± 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 ± 0.1 knots below 2 knots speed and ± 0.05 knots above 2 knots. Accuracy when water tracking is ± 0.1 knots below 10 knots, ± 0.025 knots in the range 10–25 knots, and ± 0.1 knot above 25 knots.

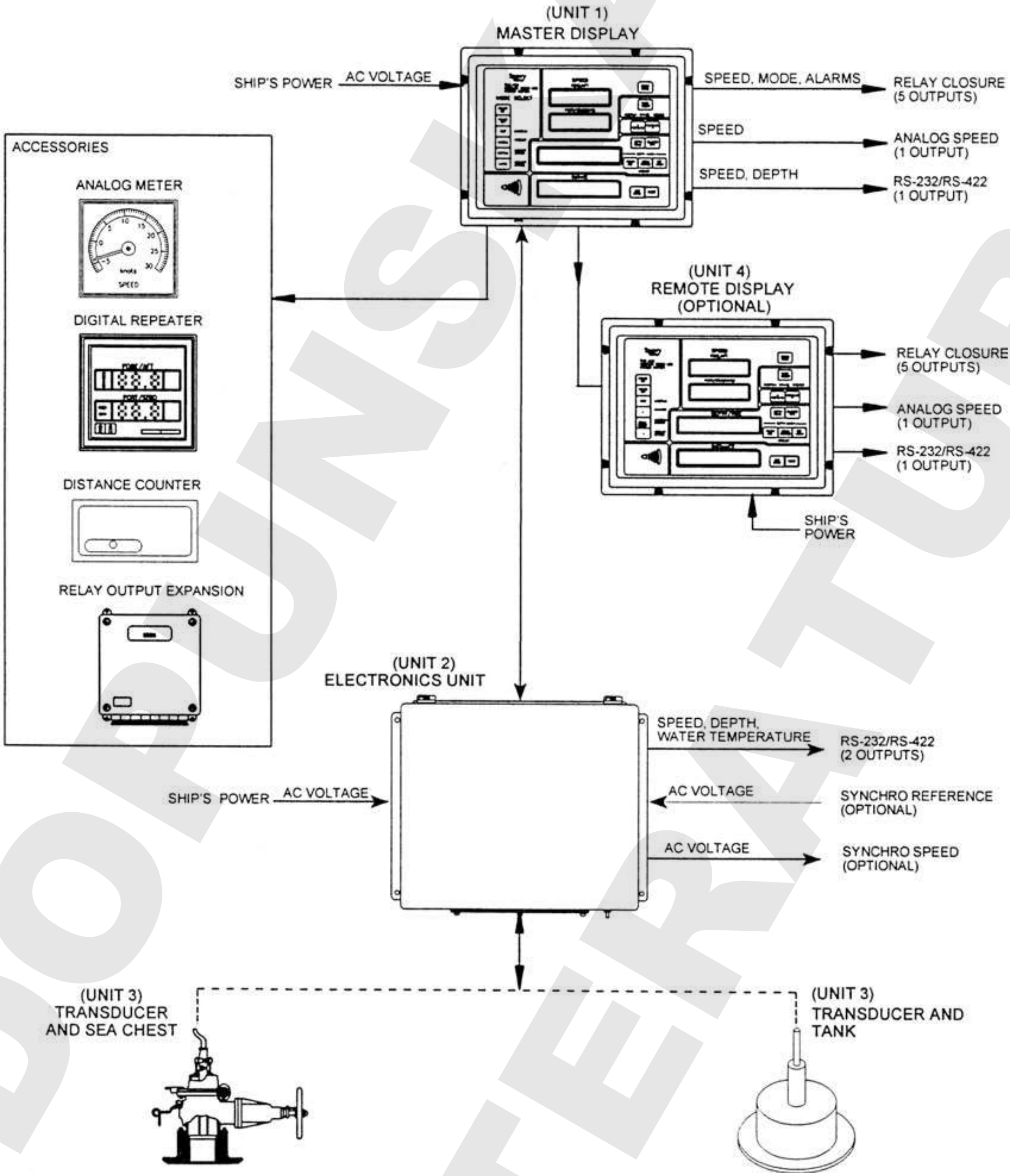


Figure 3.24 Sperry SRD-500 dual axis Doppler speed log system. (Reproduced courtesy Litton Marine Systems.)

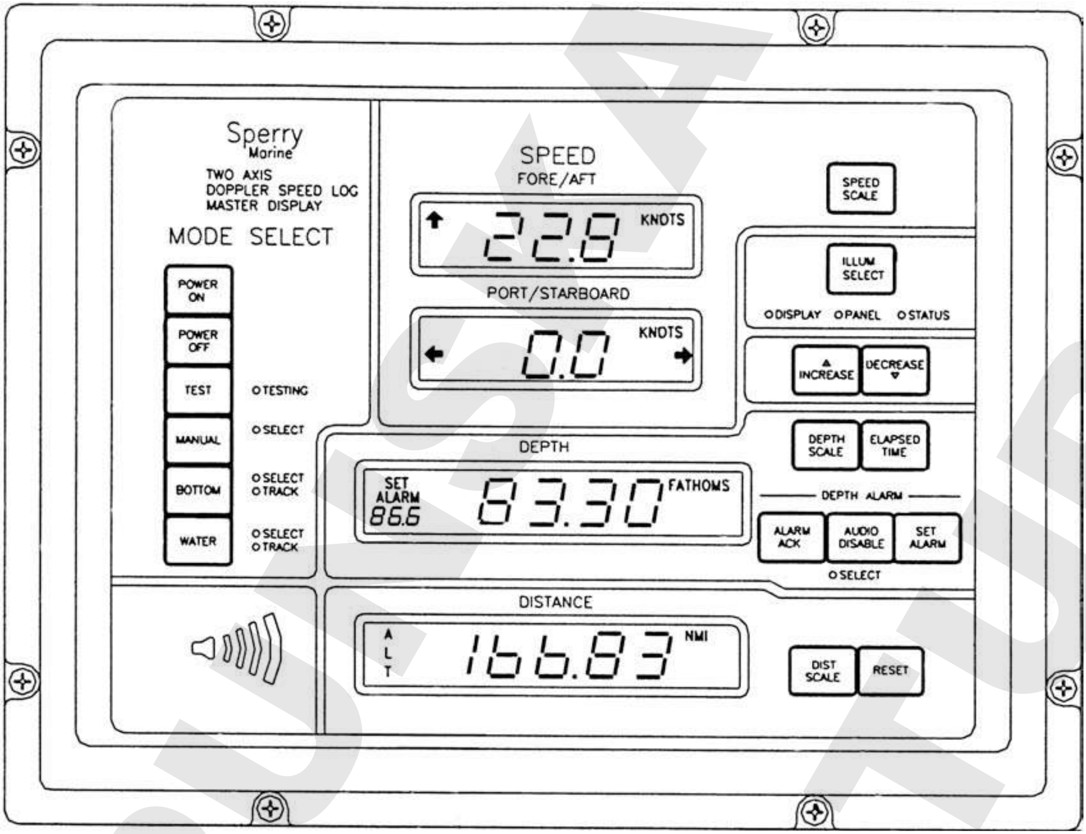


Figure 3.25 Master display unit, controls and indicators. (Reproduced courtesy of Litton Marine Systems.)

- *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.

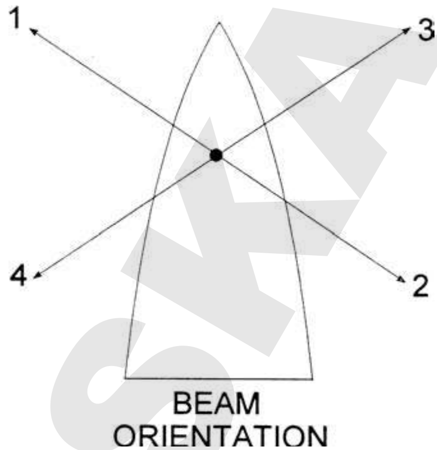


Figure 3.26 Transducer beam orientation. (Reproduced courtesy of Litton Marine Systems.)

Because the beams are aligned at 45° 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° 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).

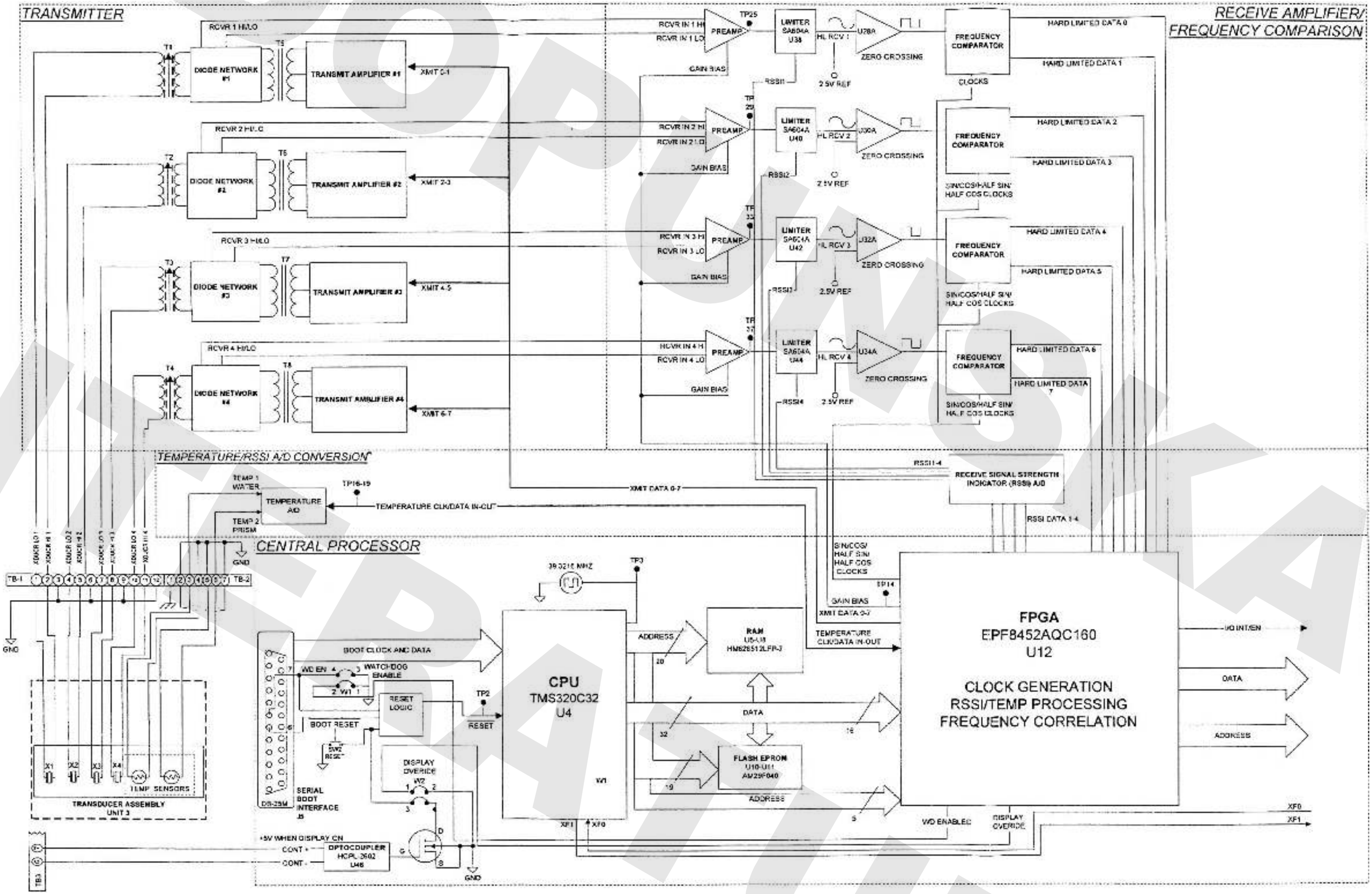


Figure 3.27 Electronics unit functional block diagram. (Reproduced courtesy of Litton Marine Systems.)

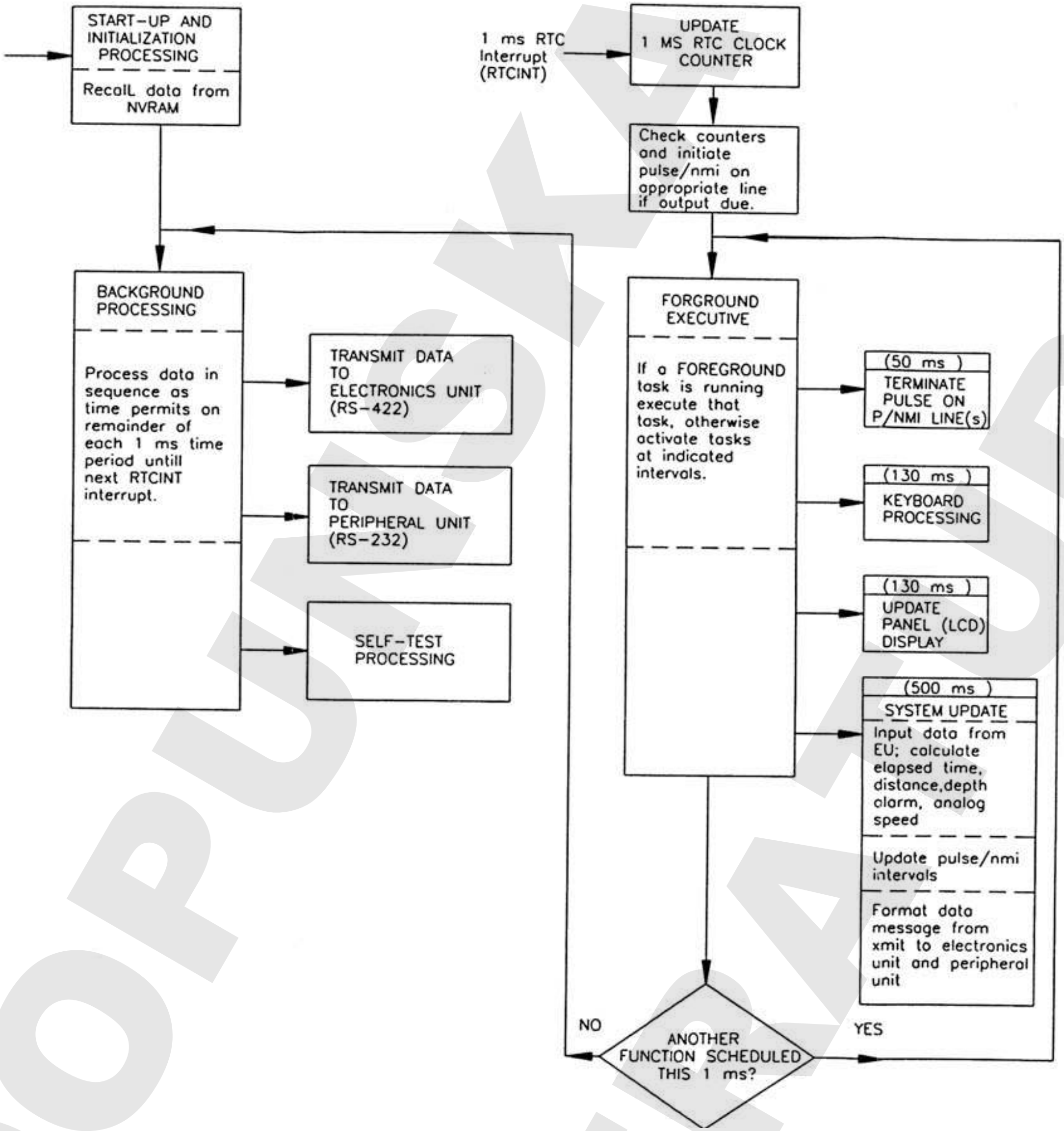


Figure 3.28 Display unit start-up flow chart. (Reproduced courtesy of Litton Marine Systems.)

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.

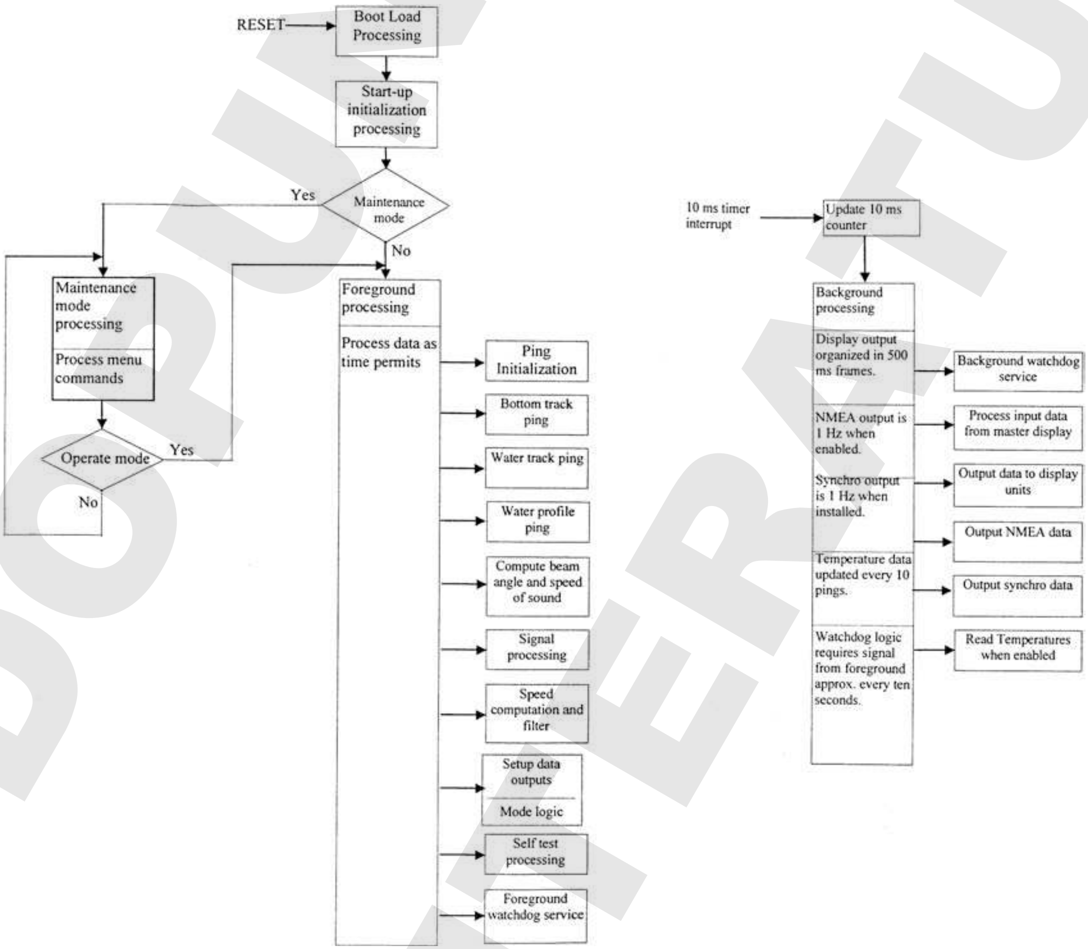


Figure 3.29 System control flow chart. (Reproduced courtesy of Litton Marine Systems.)

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,sww.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)

Data field	*Description*
$	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,sww.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)

Data	*Format*	*Comments*
Operating mode	EUTESTâ OPTESTâ BOTTOMâ WATERâ WATBOTâ MANUALâ	7 character field
Fault code	FFFâââ â*ââââ	6 character field FFF = 3 digit fault code â*â = no fault
F/A bottom speed	svv.vvâm/sâââ âââ*****âââââ	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)	âddd.dâmâmâcle ââ*****âââcle	13 character field âââd.d if altitude < 10 m ââdd.d if altitude < 100 m âddd.d if altitude > = 100 m m = unit indicator c = carriage return l = line feed e = end of text character Depth defined

Note: a 'â' 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 Furono 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 or 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.

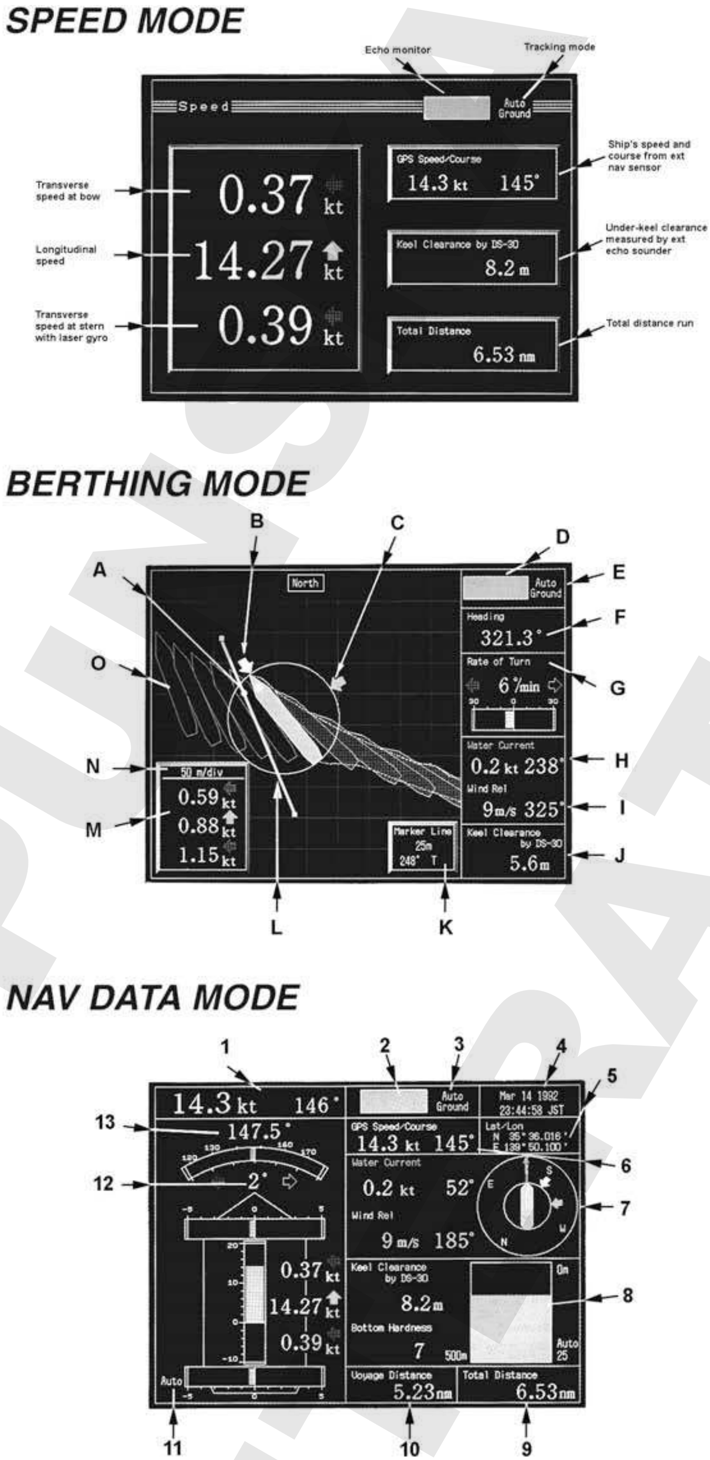


Figure 3.30 Furuno Doppler Sonar DS-30 display modes. (Reproduced courtesy of Furuno Electric Co.)

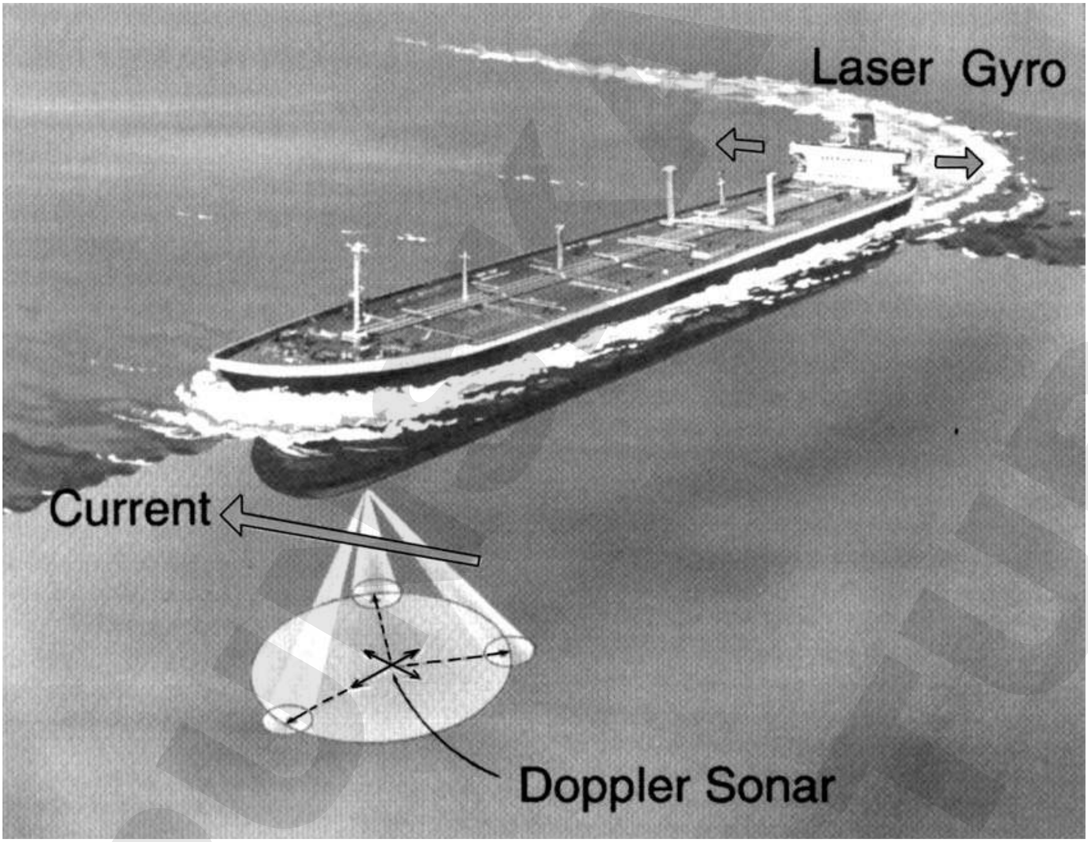


Figure 3.31 Triple beam transducer configuration of the Furuno Doppler Sonar Log. Note the forces acting on the vessel during a starboard turn under the influence of a cross-current from the port side. (Reproduced courtesy of Furuno Electric Co.)

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.