Chapter 2

Depth sounding systems

2.1 Introduction

Sonar (*so*und *n*avigation *a*nd *r*anging) is the acronym identifying those systems that rely for their operation on the transmission and reception of acoustic energy in water. The term is widely used to identify all modern systems that propagate acoustic or electromagnetic energy into seawater to determine a vessel's speed or the depth of water under the keel. This book is not concerned with those specialized sonar techniques that are used for locating submerged objects, either fish or submarines. A navigator in the Merchant Navy is interested only in the depth of the water beneath the vessel, an indication of the speed of his ship and the distance run. See Chapter 3 for a description of speed logging equipment.

The first section of this chapter deals with the characteristics and problems that arise from the need to propagate energy in seawater.

2.2 The characteristics of sound in seawater

Before considering the problems of transmitting and receiving acoustic energy in seawater, the effects of the environment must be understood. Sonar systems rely on the accurate measurement of reflected frequency or, in the case of depth sounders, a precise measurement of time and both these parameters are affected by the often unpredictable ocean environment. These effects can be summarized as follows.

- Attenuation. A variable factor related to the transmitted power, the frequency of transmission, salinity of the seawater and the reflective consistency of the ocean floor.
- Salinity of seawater. A variable factor affecting both the velocity of the acoustic wave and its attenuation.
- Velocity of sound in salt water. This is another variable parameter. Acoustic wave velocity is precisely $1505\,\mathrm{ms}^{-1}$ at 15°C and atmospheric pressure, but most echo-sounding equipment is calibrated at $1500\,\mathrm{ms}^{-1}$.
- Reflective surface of the seabed. The amplitude of the reflected energy varies with the consistency of the ocean floor.
- Noise. Either inherent noise or that produced by one's own transmission causes the signal-to-noise ratio to degrade, and thus weak echo signals may be lost in noise.

Two additional factors should be considered.

- Frequency of transmission. This will vary with the system, i.e. depth sounding or Doppler speed log.
- Angle of incidence of the propagated beam. The closer the angle to vertical the greater will be the energy reflected by the seabed.

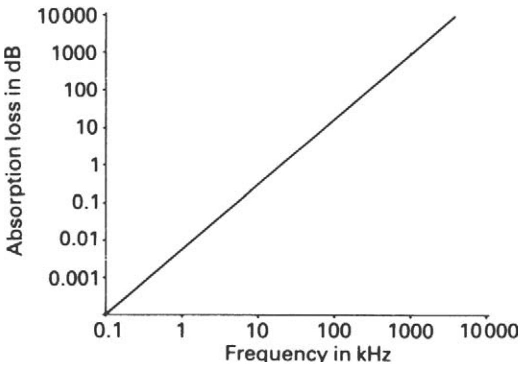


Figure 2.1 A linear graph produced by plotting absorption loss against frequency. Salinity of the seawater is 3.4% at 15°C.

2.2.1 Attenuation and choice of frequency

The frequency of the acoustic energy transmitted in a sonar system is of prime importance. To achieve a narrow directive beam of energy, the radiating transducer is normally large in relation to the wavelength of the signal. Therefore, in order to produce a reasonably sized transducer emitting a narrow beam, a high transmission frequency needs to be used. The high frequency will also improve the signal-to-noise ratio in the system because ambient noise occurs at the lower end of the frequency spectrum. Unfortunately the higher the frequency used the greater will be the attenuation as shown in Figure 2.1.

The choice of transmission frequency is therefore a compromise between transducer size, freedom from noise, and minimal attenuation. Frequencies between 15 and 60 kHz are typical for depth sounders fitted in large vessels. A high power is transmitted from a large magnetostrictive transducer to indicate great depths with low attenuation. Small light craft use depth sounders that transmit in the band 200–400 kHz. This enables compact electrostrictive or ceramic transducers to be used on a boat where space is limited. Speed logs use frequencies in the range 300 kHz to 1 MHz depending upon their design and are not strictly sonar devices in the true definition of the sense.

Beam spreading

Transmission beam diverging or spreading is independent of fixed parameters, such as frequency, but depends upon distance between the transducer and the seabed. The greater the depth, the more the beam spreads, resulting in a drop in returned energy.

Temperature

Water temperature also affects absorption. As temperature decreases, attenuation decreases. The effect of temperature change is small and in most cases can be ignored, although modern sonar equipment is usually fitted with a temperature sensor to provide corrective data to the processor.

Consistency of the seabed

The reflective property of the seabed changes with its consistency. The main types of seabed and the attenuation which they cause are listed in Table 2.1. The measurements were made with an echo sounder transmitting 24 kHz from a magnetostrictive transducer.

Table 2.1 Sea bed consistency and attenuation

Consistency	*Attenuation (dB)*
Soft mud	15
Mud/sand	9
Sand/mud	6
Sand	3
Stone/rock	1

These figures are typical and are quoted as a guideline only. In practice sufficient transmitted power will overcome these losses.

2.2.2 Salinity, pressure and the velocity of the acoustic wave

Since a depth sounder operates by precisely calculating the time taken for a pulse of energy to travel to the ocean floor and return, any variation in the velocity of the acoustic wave from the accepted calibrated speed of 1500 ms^{-1} will produce an error in the indicated depth. The speed of acoustic waves in seawater varies with temperature, pressure and salinity. Figure 2.2 illustrates the speed variation caused by changes in the salinity of seawater.

Ocean water salinity is approximately 3.4% but it does vary extensively throughout the world. As salinity increases, sonar wave velocity increases producing a shallower depth indication, although in practice errors due to salinity changes would not be greater than 0.5%. The error can be ignored except when the vessel transfers from seawater to fresh water, when the indicated depth will be approximately 3% greater than the actual depth. The variation of speed with pressure or depth is indicated by the graph in Figure 2.3.

It can readily be seen that the change is slight, and is normally only compensated for in apparatus fitted on survey vessels. Seasonal changes affect the level of the thermocline and thus there is a small annual velocity variation. However, this can usually be ignored.

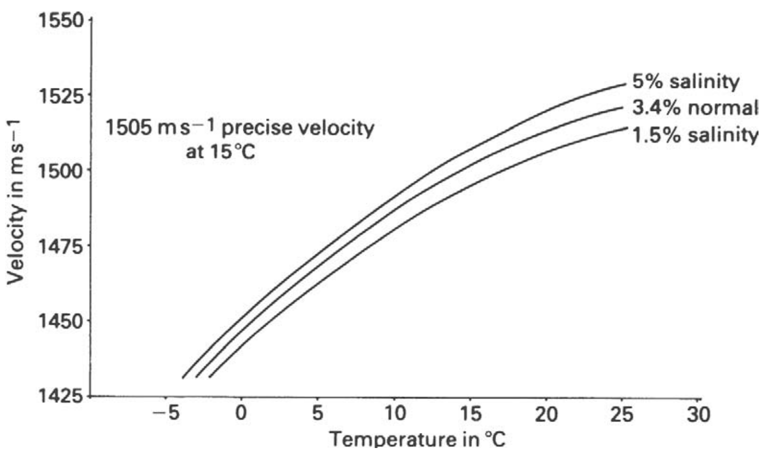


Figure 2.2 Graph showing that the velocity of acoustic energy is affected by both the temperature and the salinity of seawater.

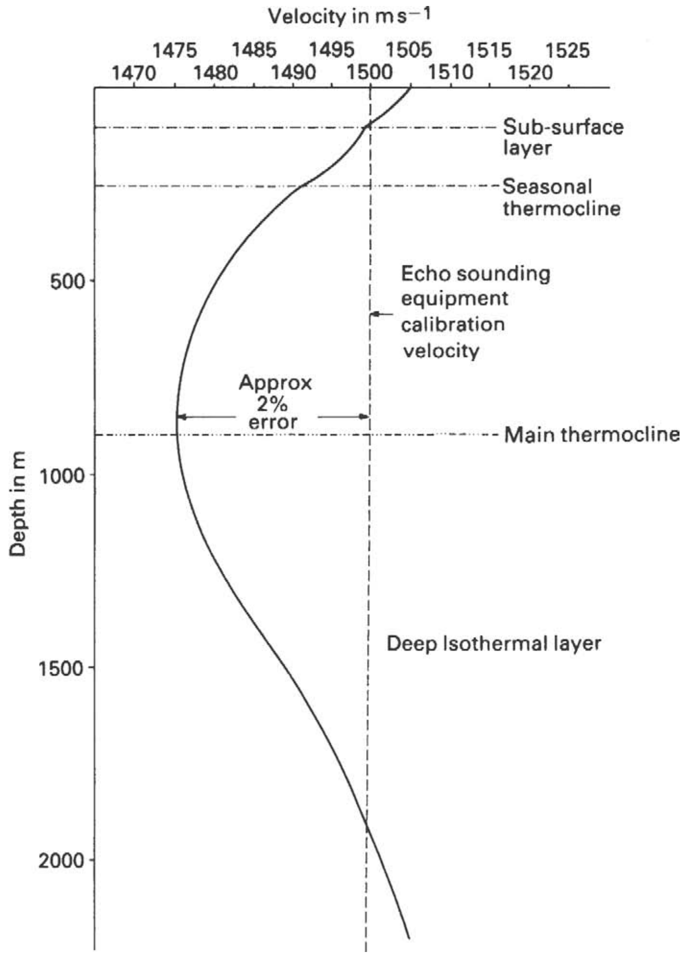


Figure 2.3 Variation of the velocity of acoustic waves with pressure.

2.2.3 Noise

Noise present in the ocean adversely affects the performance of sonar equipment. Water noise has two main causes.

- The steady ambient noise caused by natural phenomena.
- Variable noise caused by the movement of shipping and the scattering of one's own transmitted signal (reverberation).

Ambient noise

Figure 2.4 shows that the amplitude of the ambient noise remains constant as range increases, whereas both the echo amplitude and the level of reverberation noise decrease linearly with range. Because of beam spreading, scattering of the signal increases and reverberation noise amplitude falls more slowly than the echo signal amplitude.

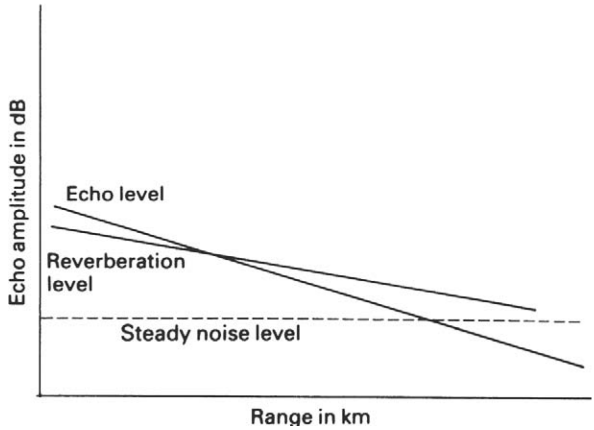


Figure 2.4 Comparison of steady-state noise, reverberation noise and signal amplitude.

Ambient noise possesses different characteristics at different frequencies and varies with natural conditions such as rainstorms. Rain hitting the surface of the sea can cause a 10-fold increase in the noise level at the low frequency (approx. 10 kHz) end of the spectrum. Low frequency noise is also increased, particularly in shallow water, by storms or heavy surf. Biological sounds produced by some forms of aquatic life are also detectable, but only by the more sensitive types of equipment.

The steady amplitude of ambient noise produced by these and other factors affects the signal-to-noise ratio of the received signal and can in some cases lead to a loss of the returned echo. Signal-to-noise ratio can be improved by transmitting more power. This may be done by increasing the pulse repetition rate or increasing the amplitude or duration of the pulse. Unfortunately such an increase, which improves signal-to-noise ratio, leads to an increase in the amplitude of reverberation noise. Ambient noise is produced in the lower end of the frequency spectrum. By using a slightly higher transmitter frequency and a limited bandwidth receiver it is possible to reduce significantly the effects of ambient noise.

Reverberation noise

Reverberation noise is the term used to describe noise created and affected by one's own transmission. The noise is caused by a 'back scattering' of the transmitted signal. It differs from ambient noise in the following ways.

- Its amplitude is directly proportional to the transmitted signal.
- Its amplitude is inversely proportional to the distance from the target.
- Its frequency is the same as that of the transmitted signal.

The signal-to-noise ratio cannot be improved by increasing transmitter power because reverberation noise is directly proportional to the power in the transmitted wave. Also it cannot be attenuated by improving receiver selectivity because the noise is at the same frequency as the transmitted wave. Furthermore reverberation noise increases with range because of increasing beamwidth. The area covered by the wavefront progressively increases, causing a larger area from which back scattering will occur. This means that reverberation noise does not decrease in amplitude as rapidly as the transmitted signal. Ultimately, therefore, reverberation noise amplitude will exceed the signal noise amplitude, as shown in Figure 2.4, and the echo will be lost. The amplitude of both the echo and reverberation noise decreases linearly with range. However, because of beam spreading, back scattering increases and reverberation noise amplitude falls more slowly than the echo signal amplitude. Three totally different ‘scattering’ sources produce reverberation noise.

- Surface reverberation. As the name suggests, this is caused by the surface of the ocean and is particularly troublesome during rough weather conditions when the surface is turbulent.
- Volume reverberation. This is the interference caused by beam scattering due to suspended matter in the ocean. Marine life, prevalent at depths between 200 and 750 m, is the main cause of this type of interference.
- Bottom reverberation. This depends upon the nature of the seabed. Solid seabeds, such as hard rock, will produce greater scattering of the beam than silt or sandy seabeds. Beam scattering caused by a solid seabed is particularly troublesome in fish finding systems because targets close to the seabed can be lost in the scatter.

2.3 Transducers

A transducer is a converter of energy. RF energy, when applied to a transducer assembly, will cause the unit to oscillate at its natural resonant frequency. If the transmitting face of the unit is placed in contact with, or close to, seawater the oscillations will cause acoustic waves to be transmitted in the water. Any reflected acoustic energy will cause a reciprocal action at the transducer. If the reflected energy comes into contact with the transducer face natural resonant oscillations will again be produced. These oscillations will in turn cause a minute electromotive force (e.m.f.) to be created which is then processed by the receiver to produce the necessary data for display.

Three types of transducer construction are available; electrostrictive, piezoelectric resonator, and magnetostrictive. Both the electrostrictive and the piezoelectric resonator types are constructed from piezoelectric ceramic materials and the two should not be confused.

2.3.1 Electrostrictive transducers

Certain materials, such as Rochelle salt and quartz, exhibit pressure electric effects when they are subjected to mechanical stress. This phenomenon is particularly outstanding in the element lead zirconate titanate, a material widely used for the construction of the sensitive element in modern electrostrictive transducers. Such a material is termed ferro-electric because of its similarity to ferromagnetic materials.

The ceramic material contains random electric domains which when subjected to mechanical stress will line up to produce a potential difference (p.d.) across the two plate ends of the material section. Alternatively, if a voltage is applied across the plate ends of the ceramic crystal section its length will be varied. Figure 2.5 illustrates these phenomena.

The natural resonant frequency of the crystal slice is inversely proportional to its thickness. At high frequencies therefore the crystal slice becomes brittle, making its use in areas subjected to great stress forces impossible. This is a problem if the transducer is to be mounted in the forward section of a large merchant vessel where pressure stress can be intolerable. The fragility of the crystal also imposes limits on the transmitter power that may be applied because mechanical stress is directly related to power. The power restraints thus established make the electrostrictive transducer unsuitable for use in depth sounding apparatus where great depths need to be indicated. In addition, the low transmission frequency requirement of an echo sounder means that such a transducer crystal slice would be

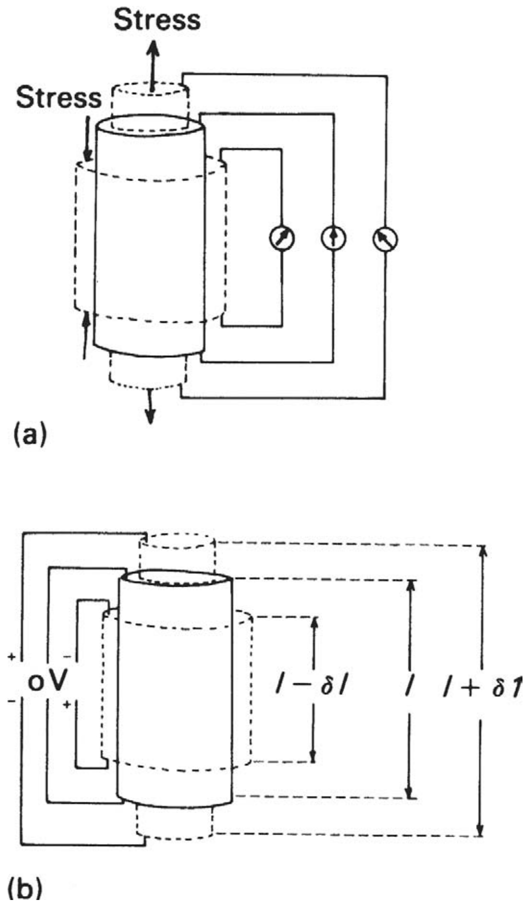


Figure 2.5 (a) An output is produced when a piezoelectric ceramic cylinder is subjected to stress. (b) A change of length occurs if a voltage is applied across the ends of a piezoelectric ceramic cylinder.

excessively thick and require massive transmitter peak power to cause it to oscillate. The crystal slice is stressed by a voltage applied across its ends, thus the thicker the crystal slice, the greater is the power needed to stress it.

The electrostrictive transducer is only fitted on large merchant vessels when the power transmitted is low and the frequency is high, a combination of factors present in Doppler speed logging systems. Such a transducer is manufactured by mounting two crystal slices in a sandwich of two stainless steel cylinders. The whole unit is pre-stressed by inserting a stainless steel bolt through the centre of the active unit as shown in Figure 2.6.

If a voltage is applied across the ends of the unit, it will be made to vary in length. The bolt is insulated from the crystal slices by means of a PVC collar and the whole cylindrical section is made waterproof by means of a flexible seal. The bolt tightens against a compression spring permitting the crystal slices to vary in length, under the influence of the RF energy, whilst still remaining mechanically stressed. This method of construction is widely found on the electrostrictive transducers used in the Merchant Navy. For smaller vessels, where the external stresses are not so severe, the simpler piezoelectric resonator is used.

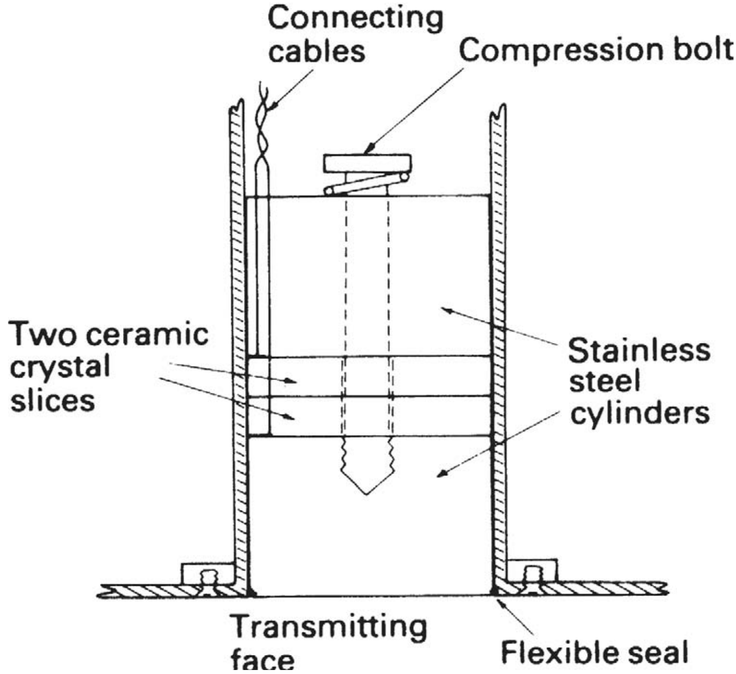


Figure 2.6 Construction details of a ceramic electrostrictive transducer.

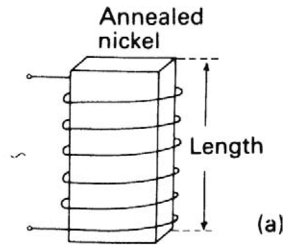
2.3.2 Piezoelectric resonator

This type of transducer makes use of the flexible qualities of a crystal slice. If the ceramic crystal slice is mounted so that it is able to flex at its natural resonant frequency, acoustic oscillations can be produced. The action is again reciprocal. If the ceramic crystal slice is mounted at its corners only, and is caused to flex by an external force, a small p.d. will be developed across the ends of the element. This phenomenon is widely used in industry for producing such things as electronic cigarette lighters and fundamental crystal oscillator units for digital watches. However, a ceramic crystal slice used in this way is subject to the same mechanical laws as have previously been stated. The higher the frequency of oscillation, the thinner the slice needs to be and the greater the risk of fracture due to external stress or overdriving. For these reasons, piezoelectric resonators are rarely used at sea.

2.3.3 Magnetostrictive transducers

Figure 2.7 shows a bar of ferromagnetic material around which is wound a coil. If the bar is held rigid and a large current is passed through the coil, the resulting magnetic field produced will cause the bar to change in length. This slight change may be an increase or a decrease depending upon the material used for construction. For maximum change of length for a given input signal, annealed nickel has been found to be the optimum material and consequently this is used extensively in the construction of marine transducers.

As the a.c. through the coil increases to a maximum in one direction, the annealed nickel bar will reach its maximum construction length $(l+\delta l)$. With the a.c. at zero the bar returns to normal (l). The current now increases in the opposite direction and the bar once again constricts $(l-\delta l)$. The frequency



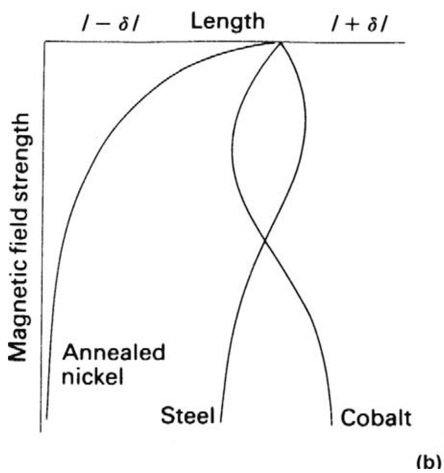


Figure 2.7 (a) A bar of ferromagnetic material around which is wound a coil. (b) Relationship between magnetic field strength and change of length.

of resonance is therefore twice that of the applied a.c. This frequency doubling action is counteracted by applying a permanent magnet bias field produced by an in-built permanent magnet.

The phenomenon that causes the bar to change in length under the influence of a magnetic field is called ‘magnetostriction’, and in common with most mechanical laws possesses the reciprocal quality. When acoustic vibrations cause the bar to constrict, at its natural resonant frequency, an alternating magnetic field is produced around the coil. A minute alternating current is caused to flow in the coil and a small e.m.f. is generated. This is then amplified and processed by the receiver as the returned echo.

To limit the effects of magnetic hysteresis and eddy current losses common in low frequency transformer construction, the annealed nickel bar is made of laminated strips bonded together with an insulating material. Figure 2.8 illustrates the construction of a typical magnetostrictive transducer unit. The transmitting face is at the base of the diagram.

Magnetostrictive transducers are extremely robust which makes them ideal for use in large vessels where heavy sea pounding could destroy an unprotected electrostrictive type. They are extensively used with depth sounding apparatus because at the low frequencies used they can be constructed to an acceptable size and will handle the large power requirement of a deep sounding system. However,

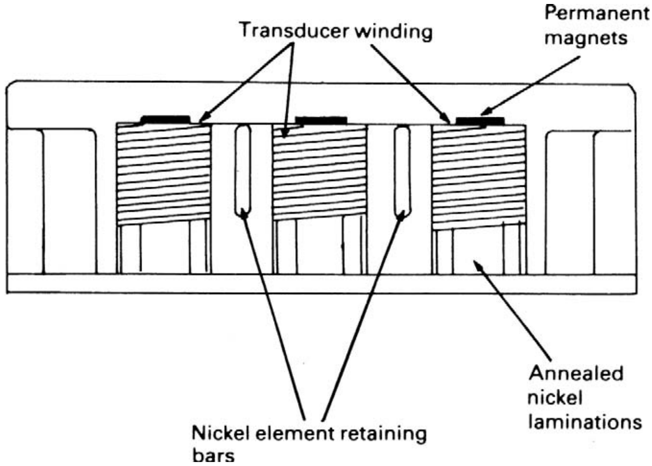


Figure 2.8 Cross-section of a magnetostrictive transducer. (Reproduced courtesy of Marconi Marine.)

magnetic losses increase with frequency, and above 100 kHz the efficiency of magnetostrictive transducers falls to below the normal 40%. Above this frequency electrostrictive transducers are normally used.

2.3.4 Transducer siting

The decision of where to mount the transducer must not be made in haste. It is vital that the active face of the transducer is in contact with the water. The unit should also be mounted well away from areas close to turbulence that will cause noise. Areas close to propellers or water outlets must be avoided.

Aeration is undoubtedly the biggest problem encountered when transducers are wrongly installed. Air bubbles in the water, for whatever reason, will pass close to the transducer face and act as a reflector of the acoustic energy.

As a vessel cuts through the water, severe turbulence is created. Water containing huge quantities of air bubbles is forced under and along the hull. The bow wave is aerated as it is forced above the surface of the sea, along the hull. The wave falls back into the sea at approximately one-third the distance along the length of the vessel from the bow. A transducer mounted aft of the position where the bow wave re-enters the sea, would suffer badly from the problems of aeration. Mounting the transducer ahead of this point, even in the bulbous bow, would be ideal. It should be remembered, however, that at some stage maintenance may be required and a position in the bulbous bow may be inaccessible.

A second source of aeration is that of cavitation. The hull of a vessel is seldom smooth and any indentations or irregularities in it will cause air bubbles to be produced leading to aeration of the transducer face. Hull irregularities are impossible to predict as they are not a feature of the vessel's design.

2.4 Depth sounding principles

In its simplest form, the depth sounder is purely a timing and display system that makes use of a transmitter and a receiver to measure the depth of water beneath a vessel. Acoustic energy is transmitted perpendicularly from the transducer to the seabed. Some of the transmitted energy is reflected and will be received by the transducer as an echo. It has been previously stated that the velocity of sound waves in seawater is accepted to be $1500\,\mathrm{ms}^{-1}$. Knowledge of this fact and the ability to measure precisely the time delay between transmission and reception, provides an accurate indication of the water depth.

$$\text{Distance travelled} = \frac{\text{velocity} \times \text{time}}{2}$$

where velocity = $1500\,\mathrm{ms}^{-1}$ in salt water; time = time taken for the return journey in seconds; and distance = depth beneath the transducer in metres. Thus if the time taken for the return journey is 1 s, the depth of water beneath the transducer is 750 m. If the time is 0.1 s the depth is 75 m, and so on.

The transmitter and transducer, must be capable of delivering sufficient power and the receiver must possess adequate sensitivity to overcome all of the losses in the transmission medium (seawater and seabed). It is the likely attenuation of the signal, due to the losses described in the first part of this chapter, which determines the specifications of the equipment to be fitted on a merchant vessel.

2.4.1 Continuous wave/pulse system

The transmission of acoustic energy for depth sounding, may take one of two forms.

- A continuous wave system, where the acoustic energy is continuously transmitted from one transducer. The returned echo signal is received by a second transducer and a phase difference between the two is used to calculate the depth.
- The pulse system, in which rapid short, high intensity pulses are transmitted and received by a single transducer. The depth is calculated by measuring the time delay between transmission and reception.

The latter system is preferred in the majority of applications. Both the pulse length (duration) and the pulse repetition frequency (PRF) are important when considering the function of the echo sounding apparatus.

Continuous wave system

This system is rarely used in commercial echo sounding applications. Because it requires independent transmitters and receivers, and two transducer assemblies it is expensive. Also because the transmitter is firing continually, noise is a particular problem. Civilian maritime echo sounders therefore use a pulsed system.

Pulsed system

In this system the transmitter fires for a defined period of time and is then switched off. The pulse travels to the ocean floor and is reflected back to be received by the same transducer which is now switched to a receive mode. The duration of the transmitter pulse and the pulse repetition frequency (PRF) are particularly important parameters in this system

The pulse duration effectively determines the resolution quality of the equipment. This, along with the display method used, enables objects close together in the water, or close to the seabed, to be recorded separately. It is called target or echo discrimination. This factor is particularly important in fish finding apparatus where very short duration pulses (typically 0.25 or 0.5 ms) are used.

Echo discrimination *(D)* is:

$$D = V \times l \text{ (in metres)}$$

where V = the velocity of acoustic waves, and l = pulse length.

For a 0.5 ms pulse length:

$$D = 1500 \times 0.5 \times 10^{-3} = 0.75\,\text{m}$$

For a 2 ms pulse length:

$$D = 1500 \times 2 \times 10^{-3} = 3\,\text{m}$$

Obviously a short pulse length is superior where objects to be displayed are close together in the water. Short pulse lengths tend to be used in fish finding systems.

A short pulse length also improves the quality of the returned echo because reverberation noise will be less. Reverberation noise is directly proportional to the signal strength, therefore reducing the pulse length reduces signal strength which in turn reduces noise. Unfortunately, reducing the signal strength in this way reduces the total energy transmitted, thereby limiting the maximum depth from which satisfactory echoes can be received. Obviously, a compromise has to be made. Most depth sounders are fitted with a means whereby the pulse length can be varied with range. For shallow ranges, and for better definition, a short pulse length is used. On those occasions where great depths are to be recorded a longer pulse is transmitted.

For a given pulse length, the PRF effectively determines the maximum range that can be indicated. It is a measure of the time interval between pulses when transmission has ceased and the receiver is awaiting the returned echo.

The maximum indicated range may be determined by using the following formula:

$$\text{Maximum range indication } (r) = \frac{v \times t}{2} \text{ (in metres)}$$

where v = velocity of sound in seawater (1500 ms^{-1}) and t = time between pulses in seconds. If the PRF is one per second (PRF = 60), the maximum depth recorded is 750 m. If the PRF is two per second (PRF = 120) the maximum depth recorded is 375 m.

The maximum display range should not be confused with the maximum depth. For instance, if the PRF is one per second the maximum display range is 750 m. If the water depth is 850 m, an echo will be returned after a second pulse has been transmitted and the range display has been returned to zero. The indicated depth would now be 100 m. A system of 'phased' ranges, where the display initiation is delayed for a pre-determined period after transmission overcomes the problem of over-range indication.

2.4.2 Transmission beamwidth

Acoustic energy is radiated vertically downwards from the transducer in the form of a beam of energy. As Figure 2.9 shows the main beam is central to the transducer face and shorter sidelobes are also produced. The beamwidth must not be excessively narrow otherwise echoes may be missed, particularly in heavy weather when the vessel is rolling. A low PRF combined with a fast ship speed

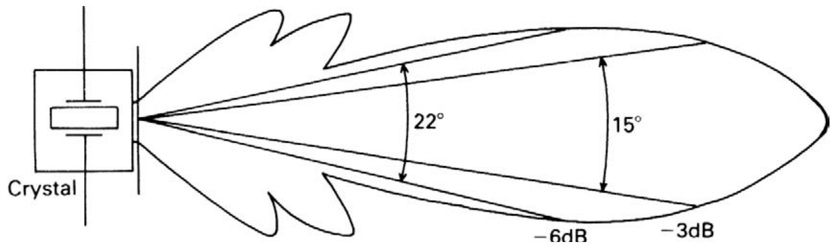


Figure 2.9 Transmission beam showing the sidelobes.

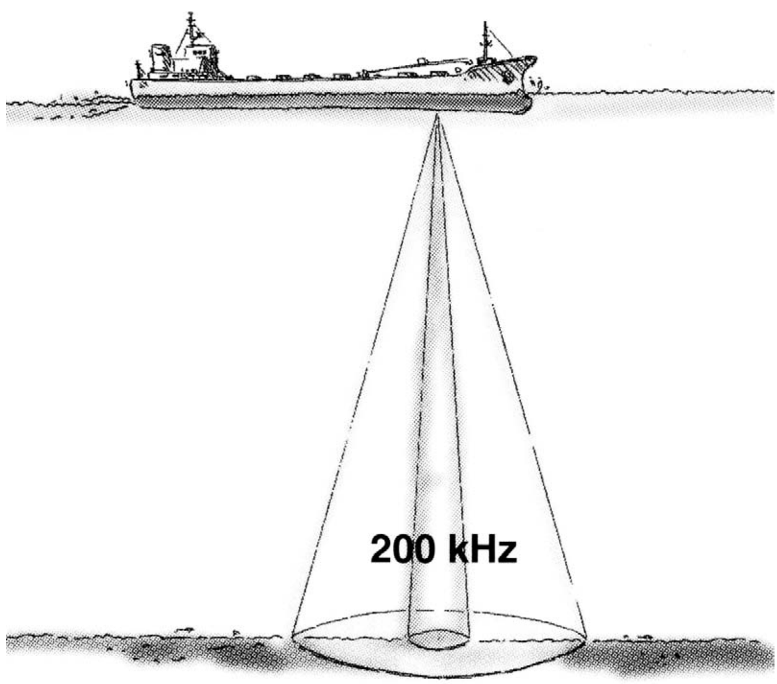


Figure 2.10 Typical beamwidths for echo sounders transmitting low and high frequencies. (Reproduced courtesy Furuno Electric Co. Ltd.)

can in some cases lead to the vessel ‘running away’ from an echo that could well be missed. In general, beamwidths measured at the half-power points (–3 dB), used for depth sounding apparatus are between 15° and 25°. To obtain this relatively narrow beamwidth, the transducer needs to be constructed with a size equal to many wavelengths of the frequency in use. This fact dictates that the transducer will be physically large for the lower acoustic frequencies used in depth sounding.

In order to reduce the transducer size, and keep a narrow beamwidth, it is possible to increase the transmission frequency. However, the resulting signal attenuation negates this change and in practice a compromise must once again be reached between frequency, transducer size and beamwidth. Figure 2.10 shows typical beamwidths for a low frequency (50 kHz) sounder and that of a frequency four times greater.

2.5 A generic echo sounding system

Compared with other systems, echo sounder circuitry is relatively simple. Most manufacturers of deep sounding systems now opt for microprocessor control and digital displays, but it was not always so. Many mariners preferred the paper-recording echo sounder because the display was clear, easy to read and provided a history of soundings.

Marconi Marine's 'Seahorse' echo sounder (Figure 2.11) was typical of the standard paper-recording echo sounder. Built in the period before microprocessor control, it is used here to describe the relatively simply circuitry needed to produce an accurate read-out of depth beneath the keel. From the description it is easy to see that an echo sounding system is simply a timing device.

The system used a transmission frequency of 24 kHz and two ranges, either manually or automatically selected, to allow depths down to 1000 m to be recorded. The shallow range was 100 m and operated with a short pulse length of 200 μs, whereas the 1000 m range uses a pulse length of 2 ms. Display accuracy for the chart recorder is typically 0.5% producing indications with an accuracy of ±0.5 m on the 100 m range and ±5 m on the deepest range.

2.5.1 Description

Receiver and chart recorder

When chart recording has been selected, transmission is initiated by a pulse from a proximity detector which triggers the chart pulse generator circuit introducing a slight delay, pre-set on each range, to ensure that transmission occurs at the instant the stylus marks zero on the recording paper. This system trigger pulse or that from the trigger pulse generator circuit when the chart is switched off, has three functions:

- to initiate the pulse timing circuit
- to operate the blanking pulse generator
- to synchronize the digital and processing circuits.

The transmit timing circuit sets the pulse length to trigger the 24 kHz oscillator (transmission frequency). Pulse length is increased, when the deep range is changed, by a range switch (not shown). Power contained in the transmitted signal is produced by the power amplifier stage, the output of which is coupled to the magnetostrictive transducer with the neon indicating transmission.

When the transmitter fires, the receiver input is blanked to prevent the high-energy pulse from causing damage to the input tuned circuits. The blanking pulse generator also initiates the swept gain circuit and inhibits the data pulse generator. During transmission, the swept gain control circuit holds the gain of the input tuned amplifier low. At cessation of transmission, the hold is removed permitting the receiver gain to gradually increase at a rate governed by an inverse fourth power law. This type of inverse gain control is necessary because echoes that are returned soon after transmission ceases are of large amplitude and are likely to overload the receiver.

The echo amplitude gradually decreases as the returned echo delay period increases. Thus the swept gain control circuit causes the average amplitude of the echoes displayed to be the same over the whole period between transmission pulses. However, high intensity echoes returned from large reflective objects will produce a rapid change in signal amplitude and will cause a larger signal to be coupled to the logarithmic amplifier causing a more substantial indication to be made on the paper. The logarithmic amplifier and detector stages produce a d.c. output, the amplitude of which is logarithmically proportional to the strength of the echo signal.

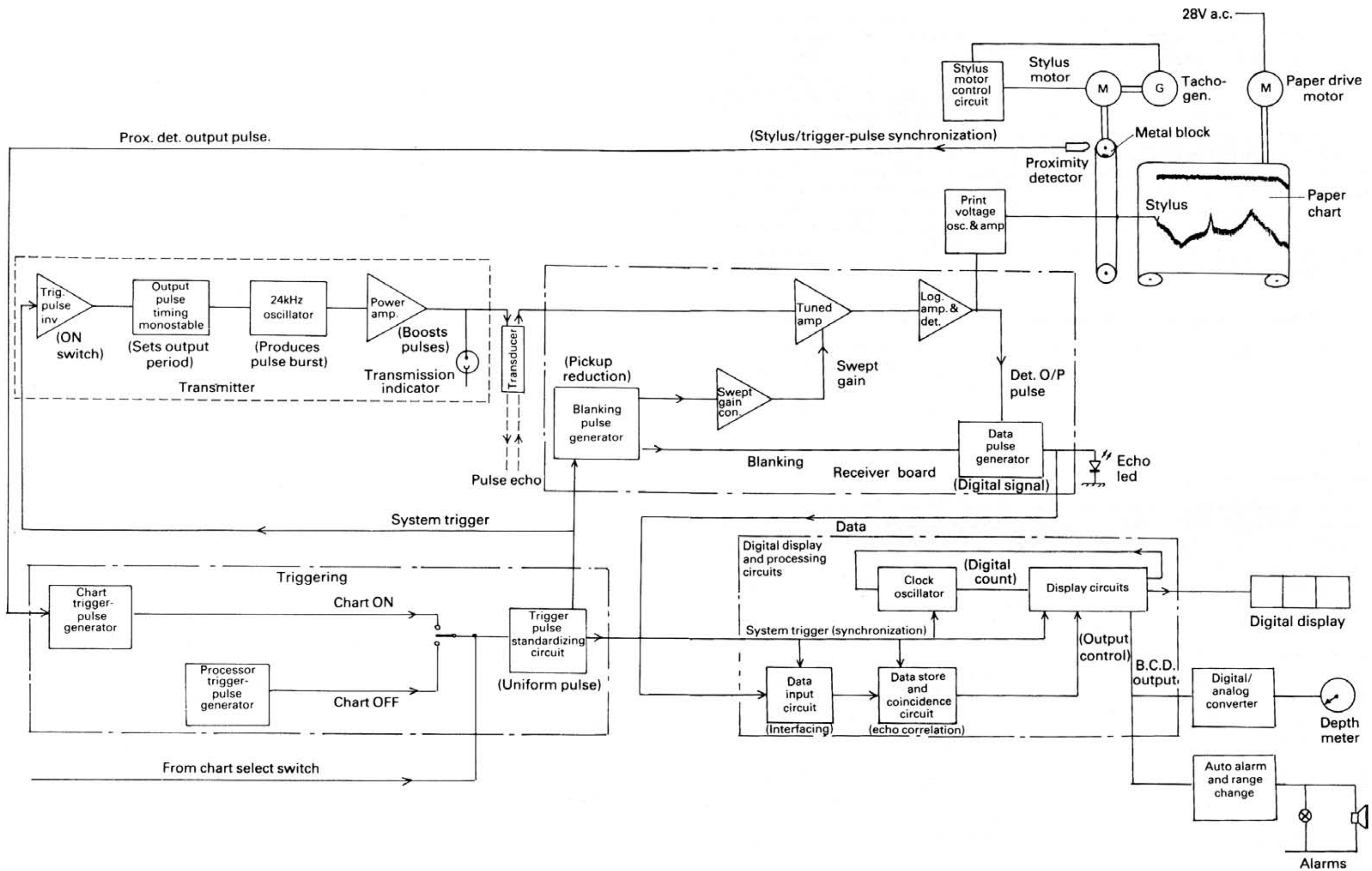


Figure 2.11 A block schematic diagram of the Seahorse echo sounder. (Reproduced courtesy of Marconi Marine.)

In the chart recorder display, electrosensitive paper is drawn horizontally beneath a sharp stylus. The paper is tightly drawn over the grounded roller guides by a constant speed paper-drive motor. Paper marking is achieved by applying a high voltage a.c. signal to the stylus which is drawn at 90° to the paper movement, across the surface of the paper on top of the left-hand roller. The paper is marked by burning the surface with a high voltage charge produced through the paper between the stylus and ground. Depending upon the size of the returned echo, the marking voltage is between 440 and 1100 V and is produced from a print voltage oscillator running at 2 kHz. Oscillator amplifier output is a constant amplitude signal, the threshold level of which is raised by the d.c. produced by a detected echo signal. Thus a high-intensity echo signal causes the marking voltage to be raised above the threshold level by a greater amount than would be caused by a detected small echo signal.

For accurate depth marking it is essential that the stylus tracking speed is absolutely precise. The stylus is moved along the paper by a belt controlled by the stylus d.c. motor. Speed accuracy is maintained by a complex feedback loop and tacho-generator circuit.

Digital circuits

The digital display section contains the necessary logic to drive the integral three-digit depth display, the alarm circuit, and the remote indicators. Pulse repetition frequency (PRF) of the clock oscillator is pre-set so that the time taken for the three-digit counter to count from 000 to 999 is exactly the same as that taken by the paper stylus to travel from zero to the maximum reading for the range in use. The counter output is therefore directly related to depth.

When the chart recorder is switched off, the digital processing section and the transmitter are triggered from the processor trigger pulse generator circuit. Both the transmit and receive sections work in the same way as previously described. A low logic pulse from the trigger pulse standardizing circuit synchronizes the logic functions. The d.c. output from the receiver detector is coupled via a data pulse generator circuit to the interface system. Unfortunately in any echo sounder it is likely that unwanted echoes will be received due to ship noise, aeration or other factors.

False echoes would be displayed as false depth indications on the chart and would be easily recognized. However, such echoes would produce instantaneous erroneous readings on the digital counter display that would not be so easily recognized. To prevent this happening echoes are stored in a data store on the processing board and only valid echoes will produce a reading on the display. Valid echoes are those that have indicated the same depth for two consecutive sounding cycles. The data store, therefore, consists of a two-stage counter which holds each echo for one sounding cycle and compares it with the next echo before the depth is displayed on the digital display.

The display circuit consists of three digital counters that are clocked from the clock oscillator circuit. Oscillator clock pulses are initiated by the system trigger at the instant of transmission. The first nine pulses are counted by the lowest order decade counter which registers 1–9 on the display least significant figure (LSF) element. The next clock pulse produces a 0 on the LSF display and clocks the second decade counter by one, producing a 1 in the centre of the display. This action continues, and if no echo is received, the full count of 999 is recorded when an output pulse from the counting circuit is fed back to stop the clock.

Each time transmission takes place the counters are reset to zero before being enabled. This is not evident on the display because the data output from the counters is taken via a latch that has to be enabled before data transfer can take place. Thus the counters are continually changing but the display data will only change when the latches have been enabled (when the depth changes). If an echo is received during the counting process, the output is stopped, and the output latches enabled by a pulse from the data store. The new depth is now displayed on the indicator and the counters are reset at the start of the next transmission pulse.

With any echo sounder, it is necessary that the clock pulse rate be directly related to depth. When the shallow (100 m) range is selected a high frequency is used which is reduced by a factor of 10 when the deep range (1000 m) is selected.

Modern echo sounders rely for their operation on the ubiquitous microprocessor and digital circuitry, but the system principles remain the same. It is the display of information that is the outward sign of the advance in technology.

2.6 A digitized echo sounding system

The Furuno Electric Co. Ltd, one of the world's big manufacturers of marine equipment, produces an echo sounder, the FE606, in which many of the functions have been digitized. Transmission frequency is either 50 or 200 kHz depending upon navigation requirements. A choice of 50 kHz provides greater depth indication and a wider beamwidth reducing the chance that the vessel may 'run away' from an echo (see Figure 2.10).

The pulse length increases with depth range from 0.4 ms, on the shallow ranges, to 2.0 ms on the maximum range. This enables better target discrimination on the lower ranges and ensures that sufficient pulse power is available on the higher ranges. Pulse repetition rate (sounding rate) is reduced as range increases to ensure adequate time between pulses for echoes to be returned from greater depths.

The system shown in Figure 2.12 is essentially a paper recorder and two LCD displays showing start depth and seabed depth. As before, transmission is initiated at the instant the stylus marks the zero line on the sensitive paper by a trigger sensor coupled to the control integrated circuits. Depending upon the range selected, the pulse length modulates the output from the transmit oscillator, which is power amplified and then coupled via a transmit/receive switch to the transducer.

A returned echo is processed in the receiver and applied to the logic circuitry. Here it is processed to determine that it is a valid echo and then it is latched through to a digital-to-analogue converter to produce the analogue voltage to drive the print oscillator. Thus the depth is marked on the sensitive paper at some point determined by the time delay between transmission and reception, and the distance the stylus has travelled over the paper.

2.7 A microcomputer echo sounding system

As you would expect, the use of computing technology has eliminated much of the basic circuitry and in most cases the mechanical paper display system of modern echo sounders. Current systems are much more versatile than their predecessors. The use of a computer enables precise control and processing of the echo sounding signal. Circuitry has now reached the point where it is virtually all contained on a few chips. However, the most obvious changes that users will be aware of in modern systems are the display and user interface.

Once again there are many manufacturers and suppliers of echo sounders or, as they are often now called, fish finders. The Furuno navigational echo sounder FE-700 is typical of many. Depending upon requirements the system is able to operate with a 200 kHz transmission frequency giving high-resolution shallow depth performance, or 50 kHz for deep-water sounding.

Seabed and echo data is displayed on a 6.5 inch high-brightness TFT colour LCD display which provides the navigator with a history of soundings over a period of 15 min, much as the older paper recording systems did (see Figure 2.13).

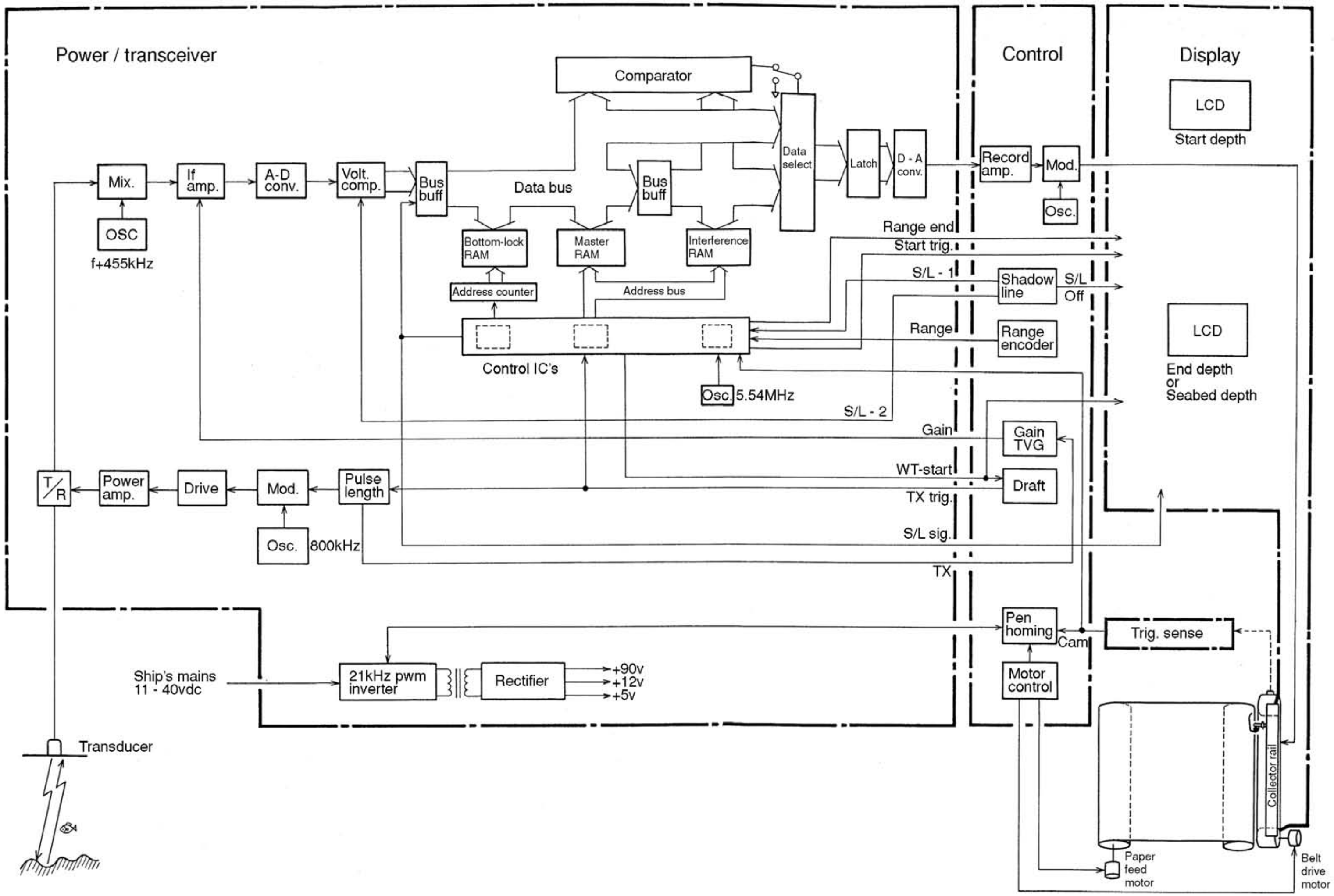


Figure 2.12 Furuno FE-606 echo sounding system. (Reproduced courtesy of Furuno Electric Co.)

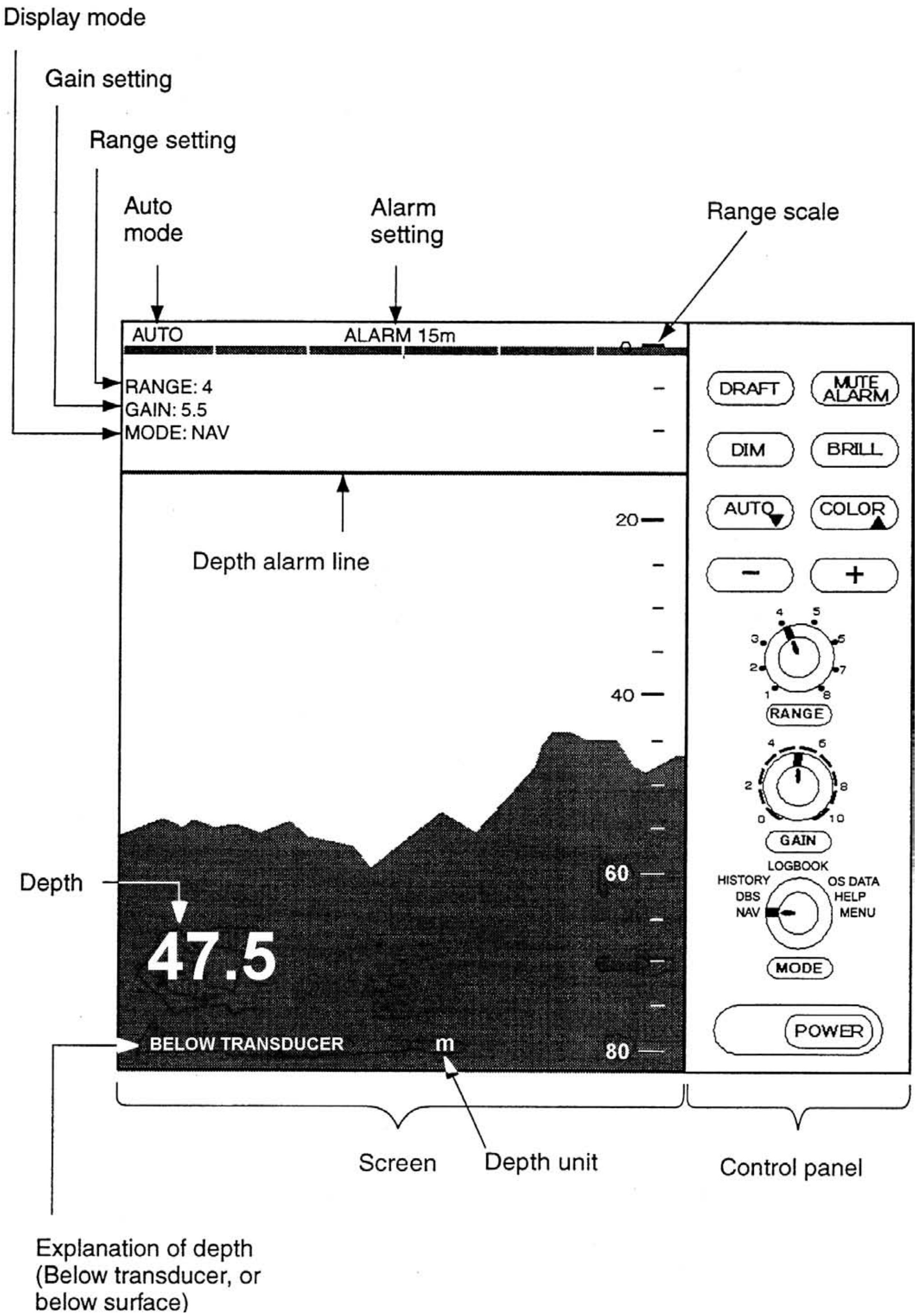


Figure 2.13 Furuno FE-700 LCD TFT data display (Navigation Mode.) (Reproduced courtesy of Furuno Electric Co.)

Depths, associated time, and position are all stored in 24-h memory and can be played back at any time. This is a useful function if there is any dispute following an accident.

The main depth display emulates a cross-sectional profile of the ocean over the past 15 min. At the top of the display in Figure 2.13, the solid zero line marks the ocean surface or transducer level whichever is selected. At 15 m down, a second line marks the depth at which the alarm has been set. The undulating line showing the ocean floor depth is shown varying over 15 min from 58 to 44 m and the instantaneous depth, also shown as a large numerical display, is 47.5 m. Other operation detail is as shown in the diagram. What is not indicated on the display is the change of pulse length and period as selected by range.

As shown in Table 2.2, the pulse length is increased with the depth range to effectively allow more power to be contained in the transmitted pulse, whilst the pulse period frequency is reduced to permit longer gaps in the transmission period allowing greater depths to be indicated

Table 2.2 Echo sounder range vs pulse length vs PRF

Depth (metres)	*Pulse length (ms)*	*PRF (pulses per minute)*
5, 10 and 20	0.25	750
40	0.38	375
100	1.00	150
200	2.00	75
400 and 800	3.60	42

In addition to the standard navigation mode, Furuno FE-700 users are provided with a number of options adequately demonstrating the capability of a modern echo sounder using a TFT LCD display (see Figure 2.14). All the selected modes display data as a window insert on top of the echo sounder NAV mode display.

There are four display-mode areas.

- OS DATA mode. Indicates own ship position, GPS derived course, time and a digital display of water depth.
- DBS mode. Provides a draft-adjusted depth mode for referencing with maritime charts.
- LOGBOOK mode. As the name suggests, provides a facility for manually logging depths over a given period.
- HISTORY mode. Provides a mixture of contour and strata displays. The contour display can be shifted back over the past 24 h whilst the strata display (right-hand side of display) shows sounding data over the last 5 min.

2.8 Glossary

The following lists abbreviations, acronyms and definitions of specific terms used in this chapter.

Aeration Aerated water bubbles clinging to the transducer face cause errors in the system.

Ambient noise Noise that remains constant as range increases.

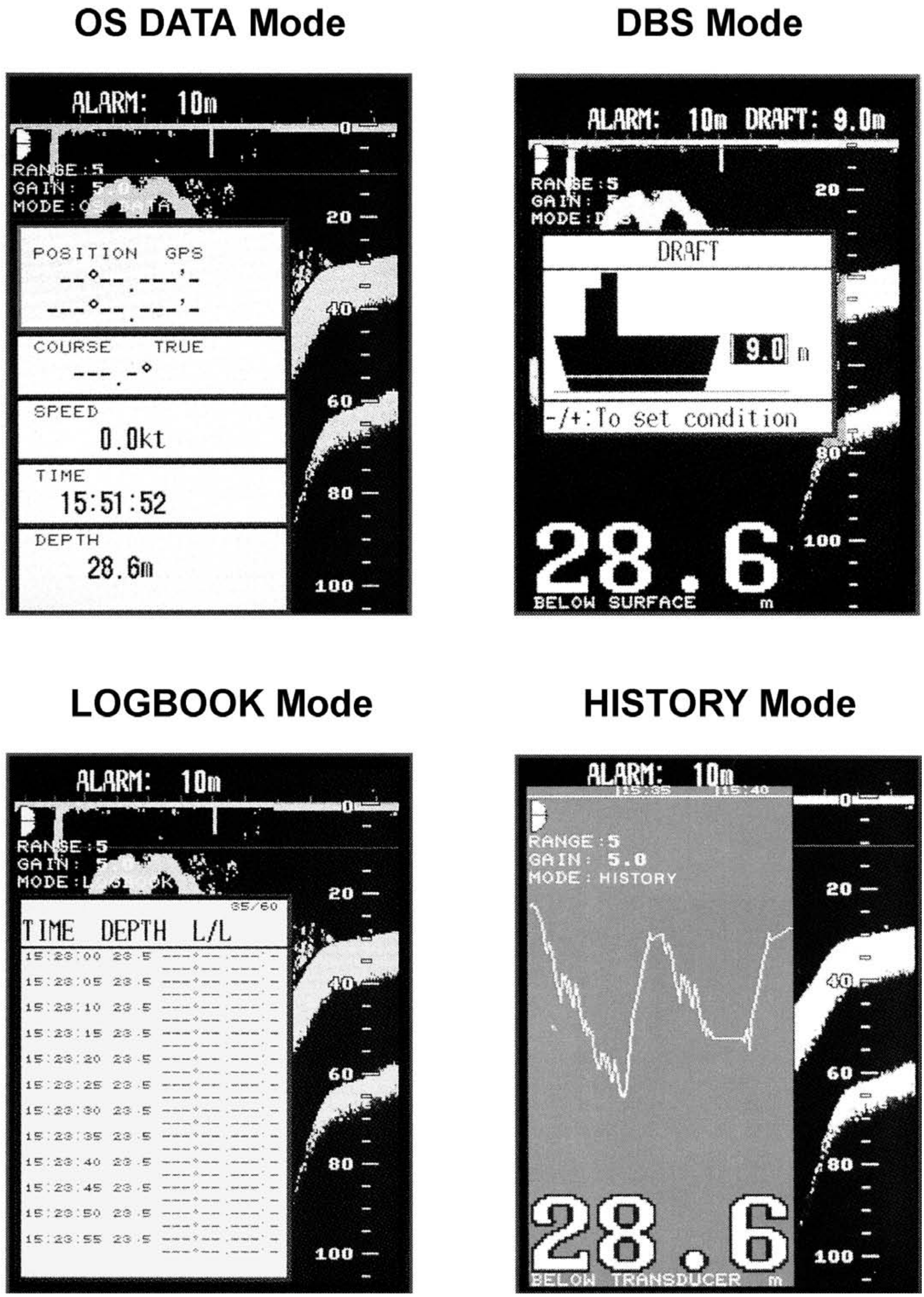


Figure 2.14 Different display modes demonstrating the flexibility of a microcomputer-controlled echo sounder. (Reproduced courtesy of Furuno Electric Co.)

Beam spreading	The transmitted pulse of energy spreads as it travels away from the transducer. The use of a wide beam will cause noise problems in the receiver and a narrow beam may lead to an echo being missed as the vessel steams away from the area.
Chart recorder	A sensitive paper recording system which, when the surface is scratched by a stylus, marks the contour of the ocean floor.
Continuous wave system	An echo sounding system that uses two transducers and transmits and receives energy at the same time.
Electrostrictive transducer	A transducer design based on piezoelectric technology. It is used when a higher transmission frequency is needed such as in speed logging equipment or fish-finding sounders.
Magnetostrictive transducer	A design based on magnetic induction. A large heavy transducer capable of transmitting high power. Used in deep sounding systems.
Pulse duration (length)	The period of the transmitted pulse when the transmitter is active.
Pulse repetition frequency (PRF)	The number of pulses transmitted per minute by the system. Similar to RADAR
Pulse wave system	A system that, like RADAR, transmits pulses of energy from a transducer which is then switched off. The received energy returns to the same transducer.
Reverberation noise	Noise that decreases as range increases.
Sonar	*So*und *n*avigation *a*nd *r*anging.
Velocity	Speed of acoustic waves in seawater; 1505 ms^{-1} or approximated to1500 ms^{-1}.

2.9 Summary

- Sonar stands for *so*und *n*avigation *a*nd *r*anging.
- Sound travels relatively slowly in seawater at 1505 ms^{-1}. This is approximated to 1500 ms^{-1} for convenience.
- The velocity is not a constant, it varies with the salinity of seawater. Ocean salinity is approximately 3.4%.
- Transmitted signal amplitude is attenuated by saltwater and the ocean floor from which it is reflected.
- Noise caused by sea creatures and ocean activity is a major problem affecting sonar equipment.
- The temperature of the seawater affects the velocity of the acoustic wave and consequently affects the accuracy of the displayed data. Temperature sensors are contained in the transducer housing to produce corrective data.
- Transducers are effectively the antennas of sonar systems. They transmit and receive the acoustic energy.
- There are two main types of transducer in use; magnetostrictive and electrostrictive. Magnetostrictive transducers are large and heavy and tend to be used only on large vessels. Electrostrictive transducers are lighter and often used in speed logging systems and on smaller craft.
- Low frequencies are often used in deep sounding systems typically in the range 10–100 kHz.
- The depth below the keel is related to the time taken for the acoustic wave to travel to the ocean floor and return. Put simply if the delay is 1 s and the wave travels at 1500 ms^{-1} then the depth is $0.5 \times 1500 = 750$ m.

- Pulsed systems, like those used in maritime RADAR, are used in an echo sounder. The pulse length or duration determines the resolution of the equipment. A short pulse length will identify objects close together in the water. If all other parameters remain constant, the pulse repetition frequency (PRF), the number of pulses per minute, determines the maximum range that can be indicated.
- The width of the transmitted beam becomes wider as it travels away from the transducer. It should not be excessively narrow or the vessel may 'run away' from, or miss, the returned echo.
- Modern echo sounding equipment is computer controlled and therefore is able to produce a host of other data besides a depth indication.

2.10 Revision questions

1. Why do deep sounding echo sounders operate with a low transmission frequency?
2. For a given ocean depth, how is it possible for returned echoes to vary in strength?
3. If a vessel sails from salt water into fresh water the depth indicated by an echo sounder will be in error. Why is this and what is the magnitude of the error?
4. Noise can degrade an echo sounder display. How does narrowing the transmitted beamwidth reduce system noise and at what cost?
5. Why are electrostrictive transducers used in maritime applications in preference to piezoelectric resonators?
6. Why do marine echo sounding systems use pulsed transmission and not a continuous wave mode of operation?
7. Many echo sounders offer the ability to vary the transmission pulse duration. Why is this?
8. How are the pulse repetition frequency (PRF) and the maximum depth, indicated by an echo sounding system, related?
9. Why is the siting of an echo sounder transducer important?
10. What do you understand by the term target discrimination?
11. What effect may a narrow transmission beamwidth have on returned echoes if a ship is rolling in heavy seas?