Technical Report 1976-1

September 1976

(With Corrections to 1 January 1977).

ACOUSTICS AND ECHO
SOUNDING INSTRUMENTATION

By

S.B. MacPhee

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1.0 THE ECHO SOUNDER

1.1 Introduction

The basic objective of hydrography is to delineate and portray the relief of the sea-bed. The delineation phase is the function of hydrographic surveyors while the portrayal phase is the function of cartographers.

The parameters of a point on the sea-bed are defined by its position on a horizontal reference surface and its position in a vertical reference plane. Its horizontal position is normally given in either geographic or rectangular coordinates while the position in the vertical plane is tied to a similarly well defined reference level. The position in the vertical plane is in fact the depth of the water corrected to chart datum. The echo sounder is the device used to measure the distance from the water surface to the sea-bed. This distance measured is called a SOUNDING. When the corrections have been applied for tide etc. the depth is a REDUCED SOUNDING.

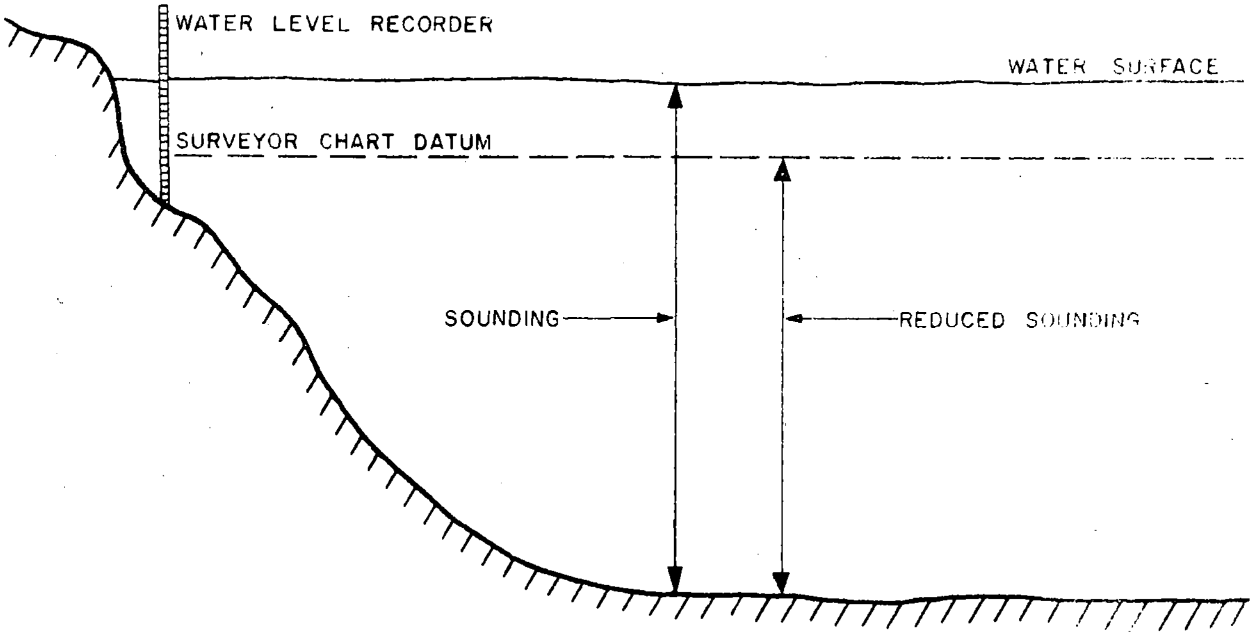

FIGURE 1-1 EXPLANATION OF SOUNDING AND REDUCED SOUNDING

The device used to measure the distance from the water surface to the sea-bed in modern surveys is called an echo sounder and the physical principles describing the operation of this device as applied to the measurement are dealt with in the study of underwater acoustics. This report will therefore cover two different but related concepts:

1. The theory and operation of the electronic echo sounder.
2. The principles governing the propagation of sound in water.

A discussion of the echo sounder and how it operates will first be described and then some time will be spent studying the physical properties of the medium. Finally some typical examples will be given to show how the different parameters tie together in practical hydrographic surveying applications.

1.2 Echo Sounder Operation

The basic reason for the first part of this section is to provide a thorough understanding of how the echo sounder operates. Whether the device is called a depth sounder, depth indicator, echo sounder, fish finder or sonar, the basic principles of operation of a device used to measure distance or depth through the water are the same. The device merely measures the time interval from the transmission of a sonar pulse to the reception of an echo.

For an echo sounder the sonar pulse must travel from the sonar transducer, through the water column, and then be reflected and returned to the same transducer or in some instances to a second transducer, hence the water column is traversed twice from the instant of transmission to the time at which an echo is received. If the velocity of sound in water is known then one can establish the water depth by the formula:

.../3

$D = \frac{Vt}{2}$

$$\text{DEPTH} = \frac{(\text{Time in Sec})(\text{Vel. in M/Sec})}{2}$$

For example if the time is 1.6 Sec. and if the velocity is 1500 M/Sec., then:

$$\text{DEPTH} = \frac{1.6 \times 1500}{2} = 1200 \text{ metres}$$

The velocity of sound in water is dependent upon a number of different parameters and later an explanation will be given on how it is computed.

An understanding of echo sounder operation requires a knowledge of how the sonar pulse is generated, how it gets in the water, how it is received and most important how the time interval is measured.

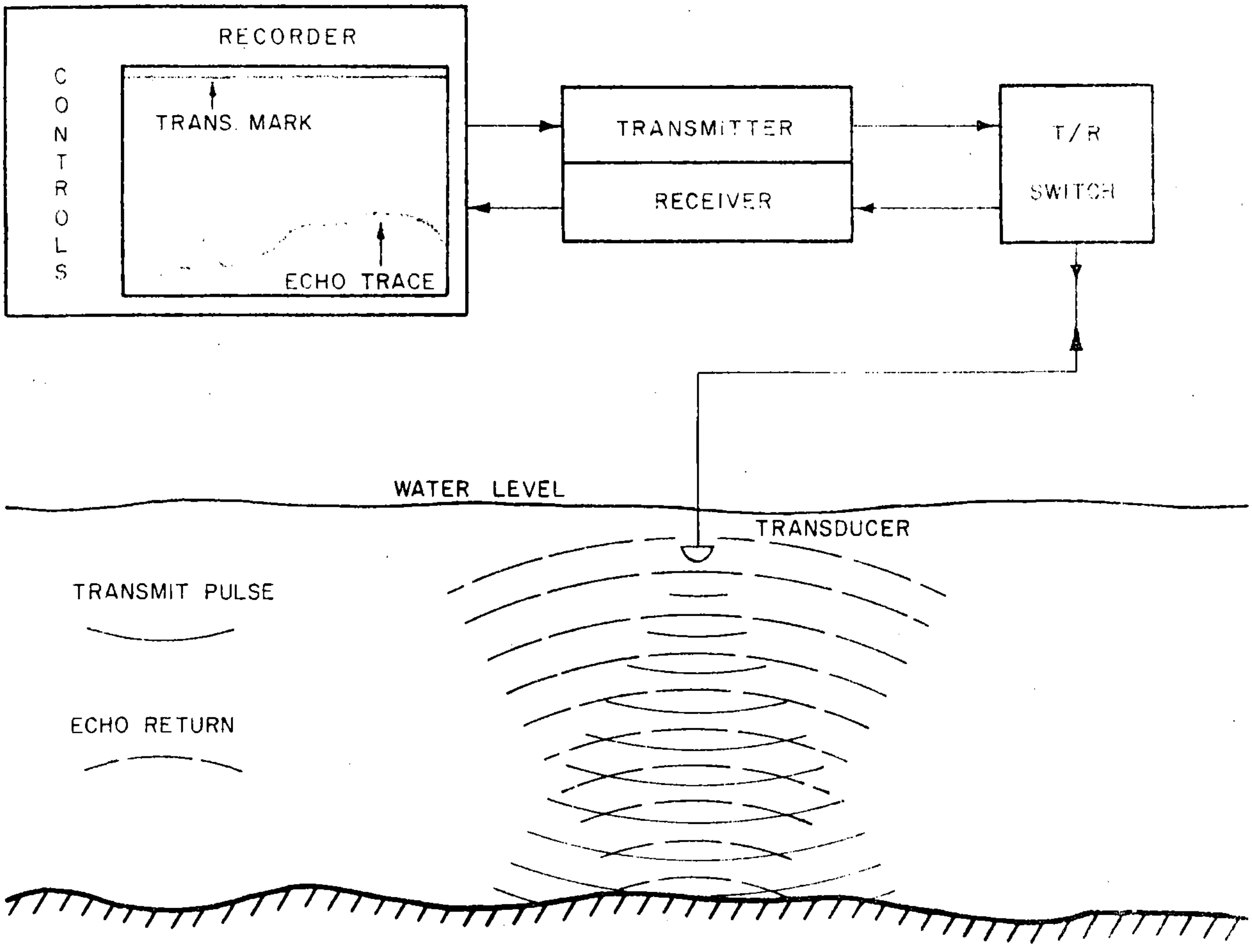

FIGURE 1-2 BLOCK DIAGRAM - BASIC ECHO SOUNDER

The equipment illustrated in Figure 1-2, in smaller systems exists in one enclosure except for the transducer which in all instances is mounted separately. In larger systems, the recorder is normally a separate unit while the Transmitter Receiver and Transmit/Receive (T/R) switch are purchased as a single unit. Later more complicated systems will be discussed but first the operation of each of the units illustrated in Figure 1-2 and some of the terms used in underwater acoustics will be explained.

1.3 The Echo Sounder Recorder

The recorder performs a number of functions. Its two basic functions however are to initiate or key the transmitter and to record the instant of transmission and the instant of echo reception so the time interval between the two may be measured.

For shallow water svstems where there is onlv one pulse in the water at any one time, this is done by keying the transmitter at a fixed repetition rate. The repitition rate (PRR) is the number of times the transmitter is keyed per unit time, usually the number of times per second. In other words a PPR or PRF of 2 pulses per second means that the transmitter is keyed twice a second. Instead of using PRR some persons quote a sweep speed. A PRR of twice/sec is equivalent to a sweep speed of one-half second. The next thing to understand is how this sweep speed or PRR relates to depth. (It should be noted that a number of those definitions change for programmed operation).

In the example given (sweep speed 1/2 sec.) the stylus that marks the graph on the echo sounder recorder would traverse the full width of the paper each 1/2 sec. or twice per second. (More than one stylus is used on some recorders). If an echo return were recorded 4/5 the distance across the graph then knowing the sweep rate and the velocity of the sound in the water one should be able to measure the depth.

The first step would be to determine the time interval from the instant of transmission to echo return. In the example the:

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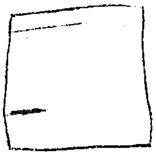

$\frac{4}{5} \times \frac{1}{2} = \frac{8}{10} \cdot \frac{5}{10}$

5

Time Interval = 4/5 x 1/2 = 2/5 sec.

Then Depth = $\frac{2/5 \times 1500}{2}$ = 300 metres

It is assumed that an echo was received before another transmission was initiated. Later deep sea systems where a number of transmissions and echo returns exist in the water column simultaneously will be explained. For deep sea systems, the interpretation of depth is slightly more difficult until one becomes familiar with it.

The paper is moved through the recorder at a selected rate and as the echoes are received the sonar recorder echograph describes the undulations in the sea bottom topography. Sweep rates are normally from 10 per sec. to one every 2 to 10 seconds on conventional sounding systems. As explained earlier, then the recorder keys the transmitter, in most instances when the stylus passes the left hand side of the paper, and it also receives the amplified and processed echo pulse from the receiver and marks the paper at this time so that the time interval from transmission to echo reception may be measured.

The sonar recorder may use dry or wet paper. Dry recording paper is relatively robust, and the record on it is stable, so long as it is kept dry. Damp potassium iodide paper should be dried as soon as possible after the record has been made on it, kept in subdued light, and above all protected from the direct rays of the sun. If it is exposed to sunlight the trace will almost certainly be bleached, and disappear entirely. If a potassium iodide trace is rolled too tightly before it is dry, the various layers may print out on one another, confusing the record.

In order to record depth accurately it is important that the stylus traverse the recorder paper at an accurate and constant rate because depth accuracy is dependent upon an accurate sweep rate. The sweep rate on modern recorders is normally electronically controlled.

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1.4 The Transmitter

The sonar transmitter is the device used to generate the electronic pulse that drives the electroacoustic transducer. A block diagram of a typical sonar transmitter/receiver (transceiver) is shown in Figure 1-3.

The crystal oscillator normally oscillates at 1-10 MHz. From the crystal oscillator the signal is divided down to the operating frequency. A continuous signal at the operating frequency is applied as the input to the low level amplifier. The low level amplifier is gated on only for a fixed period each time a trigger is received from the recorder depending upon the setting of the pulse length switch. The output from the low level amplifier is therefore a pulsed signal used to drive the power amplifier.

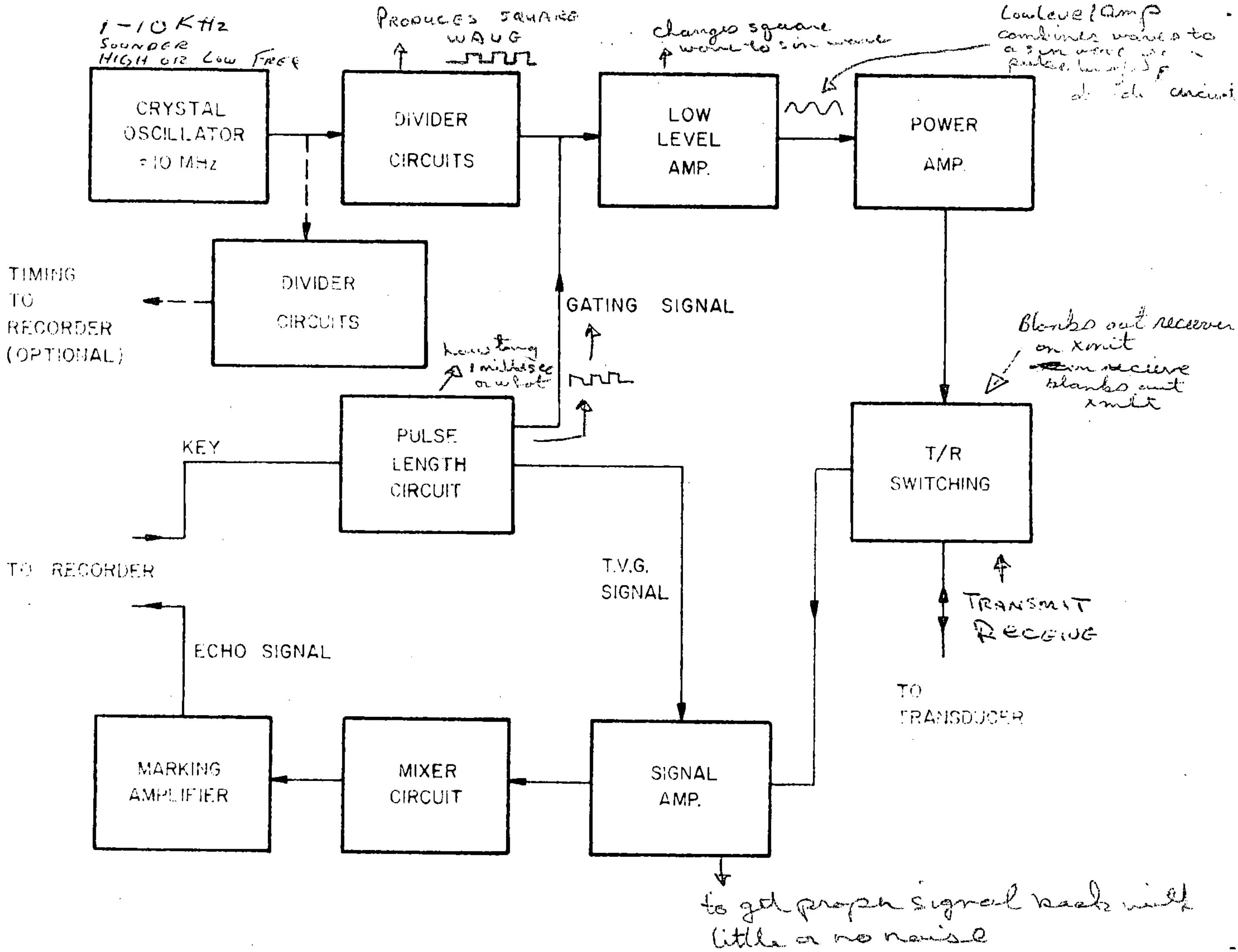
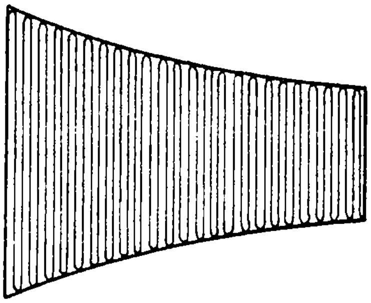


FIGURE 1-3 TYPICAL SONAR TRANSCEIVER

On most systems there is a gain control to control either the gain of the low level amplifier or the gain of the power amplifier. It is most important that the power amplifier output not be fed into the input of the receiver. The receiver is protected on transmit by the T/R switch.

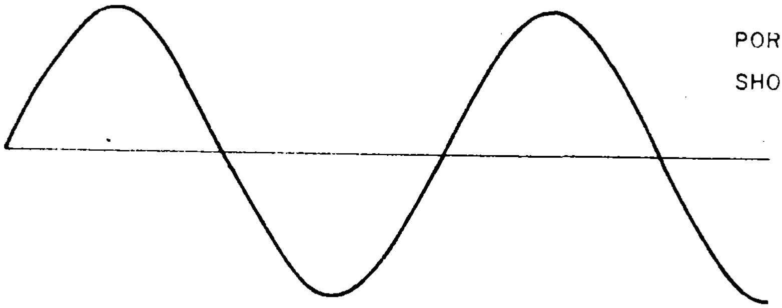
Most systems also employ time varied gain (TVG) on the receiver. The function of TVG is to reduce the gain of the receiver during and immediately after the transmitted pulse so that the high reverberation signal that presents itself at the receiver input immediately after transmit is not amplified as much as the sonar echo. The receiver gain is allowed to return exponentially as a function of time. The transmitted pulse might be any frequency from 3 to 300 KHz, pulse length normally from 0.1 to 50 millisec. and it is shaped as illustrated in Figure 1-4. <u>The transmitted frequency and pulse length are optimally selected for a particular type of operation.</u> Many modern echo sounders are capable of transmitting at two or three different frequencies and have pulse length control over the range 0.1 to 50 mSec.



drops off in power
cause of ringing or blank lines [illegible]
xmission mode.

PULSE ENVELOPE SHAPE

Perfect pulse
not perfected yet



PORTION OF SONAR PULSE TO SHOW INDIVIDUAL CYCLES.

FIGURE 1-4 ECHO SOUNDER PULSE SHAPE

1.5 The Receiver

The receiver, Figure 1-3, is merely a signal amplifier and mixer circuit with a marking amplifier to amplify the signal to the recorder. Some sonars have receivers with automatic gain control or normalized output so that the output signal level is quite independent of the input level. The receiver has a bandwidth wide enough only to receive the shortest pulse and the least amount of noise. If doppler shift is expected the bandwidth must be wide enough to allow for the expected doppler shift as well. There is only a doppler shift if the transducer is not vertical.

1.6 The Transducer

The transducer is the heart of the echo sounding system because it converts the electrical energy to acoustic waves on transmit and converts the acoustic echoes to electrical signals on receive. In older systems, two transducers were used, but in more modern systems a single transducer and a transmit/receiver (T/R) switching arrangement is utilized.

The materials used in the construction of transducers exhibit either magnetostrictive or electrostrictive properties. What this means is that when a change in the strength of an electric or magnetic field takes place at a frequency within the acoustic spectrum, acoustic or pressure waves are generated in the material exhibiting the effect. Sonar transducers are necessarily different from equivalent devices that perform the transducer function in air mainly because of the difference in specific acoustic impedance between air and water. For any underwater transducer to perform properly it must operate with about sixty times the force and one-sixtieth the displacement of a transducer handling energy at the same rate in air. The specific acoustic impedance of water is 150,000 $gm/cm^2/sec$ while for air it is 43 $gm/cm^2/sec$. Transducers are normally described as being of the magnetostrictive, peizoelectric or electrostrictive type.

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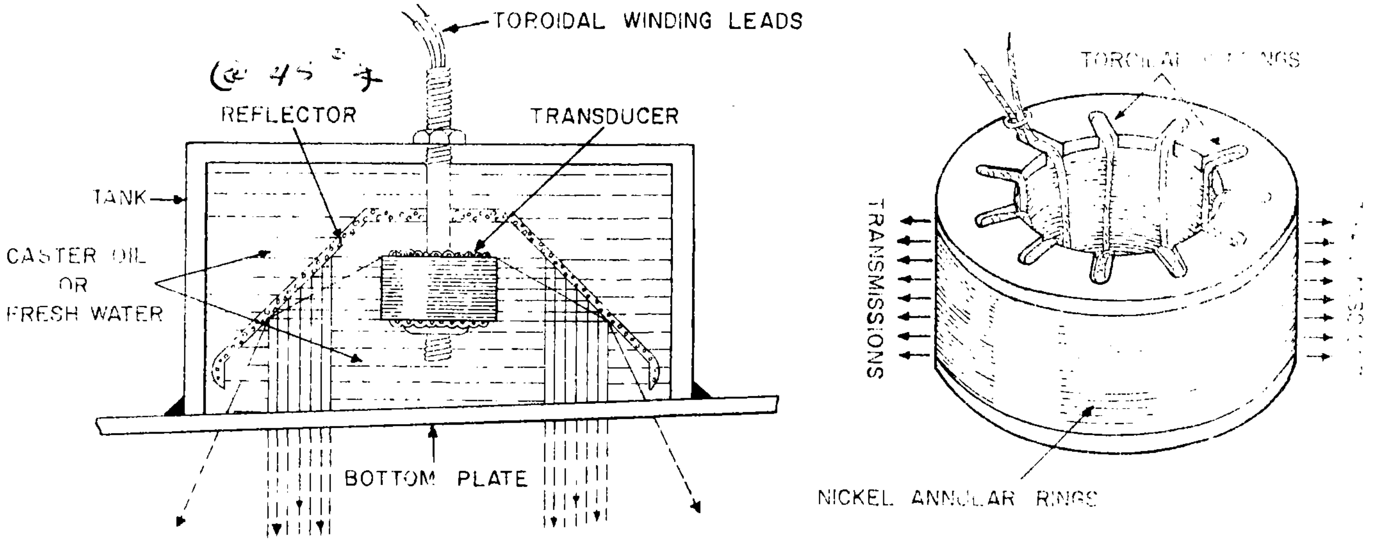
Magnetostrictive Transducers; Magnetostrictive materials are materials that change length in the presence of a magnetic field. The most common magnetostrictive material in use is nickel. The standard method of construction is to cement laminations together to form stacks. The stacks are normally formed from hairpin or circular laminations. The laminations are necessary to reduce eddy current losses. Coils are then wound around the narrow portion of the stacks to carry the exciting current if the element is to be part of a sonar projector. An electromagnetic force (EMF) will be generated in the coil if the element is part of a hydrophone or receiver. On single transducers designed for transmitting and receiving, the coil is excited during transmission and supplies the input signal to the receiver for reception. To design arrays for particular beam shapes, the number of turns on the various coils for each element may be varied and a number of elements configured to form an array. A typical magnetostrictive transducer stack is shown in Figure 1-5(a) and a typical assembly shown in Figure 1-5(b). Magnetostrictive transducers are generally of low impedance.



(A) (B)

FIGURE 1-5 MAGNETOSTRICTIVE TRANSDUCER ASSEMBLY

Piezoelectric Transducers: Certain crystals have the property of changing length when a potential difference is applied to electrodes on the opposite faces of the crystal. The crystal will behave like a spring either compressing or expanding depending on the direction of the impressed electric field. Conversely a voltage will be developed between the electrodes of a crystal if it is exposed to a pressure variation on the surface, making the element reciprocal in its behaviour. The strain produced in a crystal due to the applied voltage on the electrodes is proportional to the voltage and the voltage generated on the electrodes due to the strain is proportional to the strain. Ammonium dihydrogen phosphate (ADP) is the most common crystal for the development of transducer elements. The impedance of piezoelectric transducer elements is generally very high. The principal disadvantage of piezoelectric crystal elements is their inability to be molded to a desired shape. A typical piezoelectric or crystal transducer assembly is as shown in Figure 1-6.

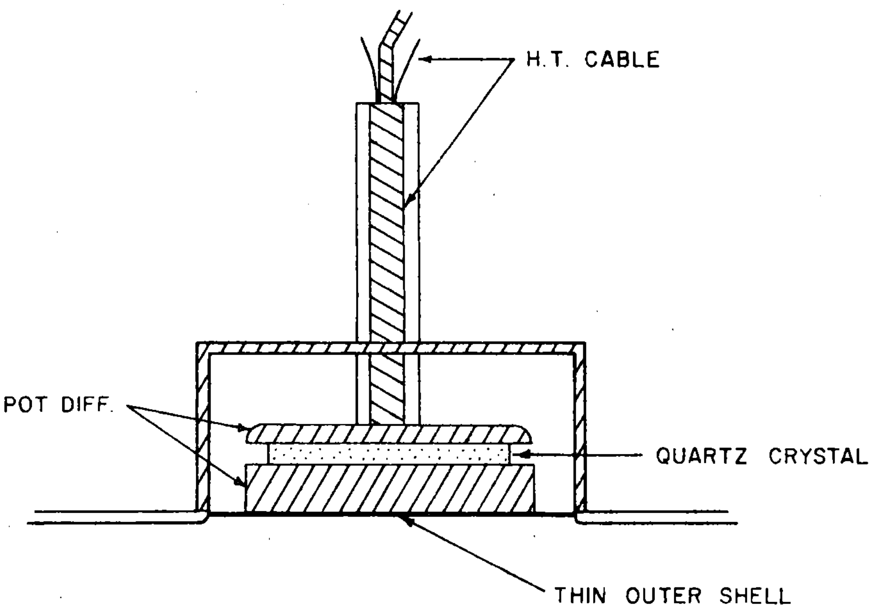
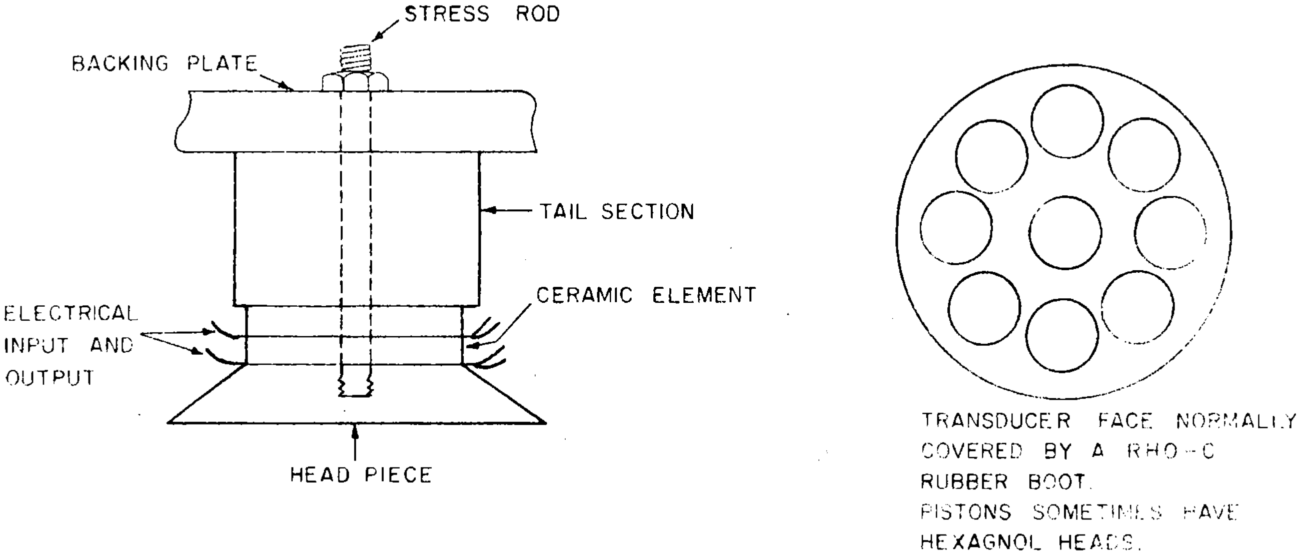


FIGURE 1- 6 PIEZOELECTRIC TRANSDUCER ASSMEBLY

Electrostrictive Transducers: Nearly all insulators change in length when placed in an electric field. Some materials such as Barium Titanate exhibit this behaviour quite strongly. By polarizing electrostrictive ceramics, they are made to behave very similarily to piezoelectric materials except that they have an advantage in that they can be molded into any desired shape. Ceramic elements are normally stacked to form pistons and a number of pistons are combined to form a transducer.

There are a number of methods of construction but the one most commonly used for ceramic transducers is as shown in Figure 1-7. The ceramic elements are stacked and sandwiched between the face and tail of the piston. The piston face, for a projector vibrates as a voltage or electrical pulse is applied across the elements while for a receiving transducer a voltage is induced in the electrical take off as the transducer face is oscillated by the acoustic waves. In most instances, the same transducer is used for the transmit and receive function.



TRANSDUCER FACE NORMALLY COVERED BY A RHO-C RUBBER BOOT.
PISTONS SOMETIMES HAVE HEXAGNOL HEADS.

FIGURE 1-7 ELECTROSTRICTIVE TRANSDUCER

Transducer Beam Patterns: The directional response pattern of a transducer for transmission or reception is defined as the response of a transducer as a function of the direction of the transmitted or incident sound waves in a specified plane and at a specified frequency (American Standard Acoustic Terminology).

Simple sources and uniformly vibrating spherical shells radiate energy equally in all directions, but distributed arrays have unique directivity patterns. Pattern control is important because it is a method of concentrating a given quantity of energy more intensely and also a method of reducing the amplitude of interference on a receiving transducer.

Any single point source radiates energy omnidirectionally. The radiation pattern of a two point source depends upon the number of wavelengths by which the two points are separated. For instance for separations of λ and λ/2 the beam patterns are as shown in Figure 1-8.

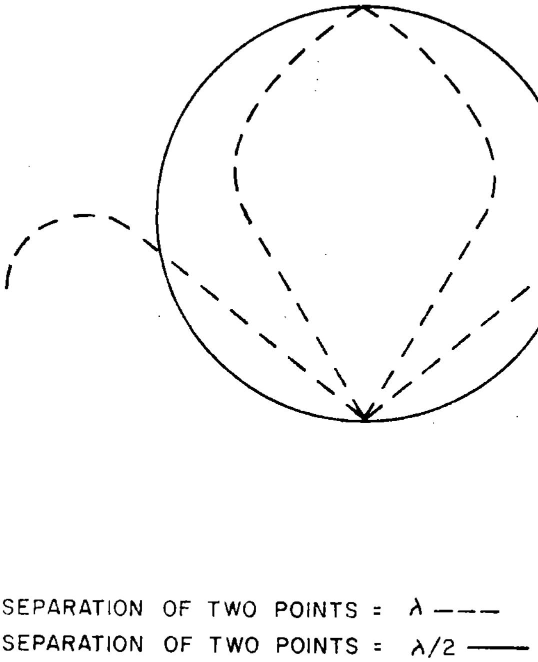


FIGURE 1-8 TRANSDUCER BEAM PATTERNS, TWO POINT SOURCES

If we next consider a continuous line source of length L as shown in Figure 1-10,

energy arriving here is in phase

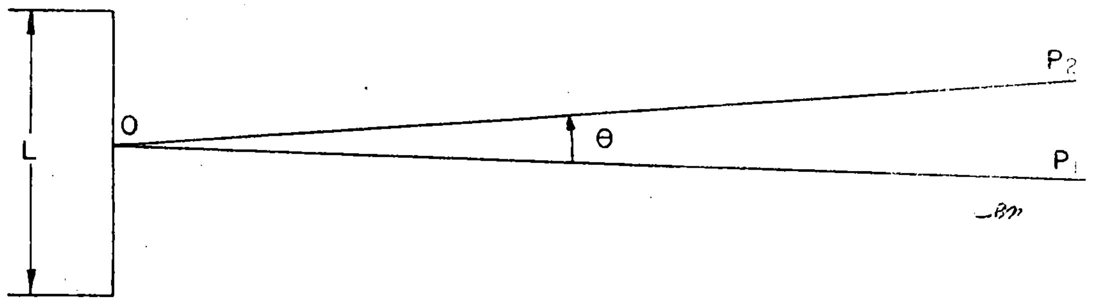


FIGURE 1-9 TRANSDUCER BEAM PATTERNS, CONTINUOUS LINE

then at a point P1 in the far field i.e. OP is at least 10 times as long as L, all the energy can be assumed to be in phase and the energy density at P1 is equal to the sum of all energy required from the total of all elements in the line source. If we consider another point P2 off the acoustic axis by an amount θ then all the energy arriving at point P2 is not in phase and the energy intensity at P2 is less than that at P1.

Without resorting to mathematical calculations but referring to Figure 1-11, it may be stated,

$\lambda = v/f$ $\quad Tan = \frac{a}{L}$

$a = \lambda/2$

energy is out of phase

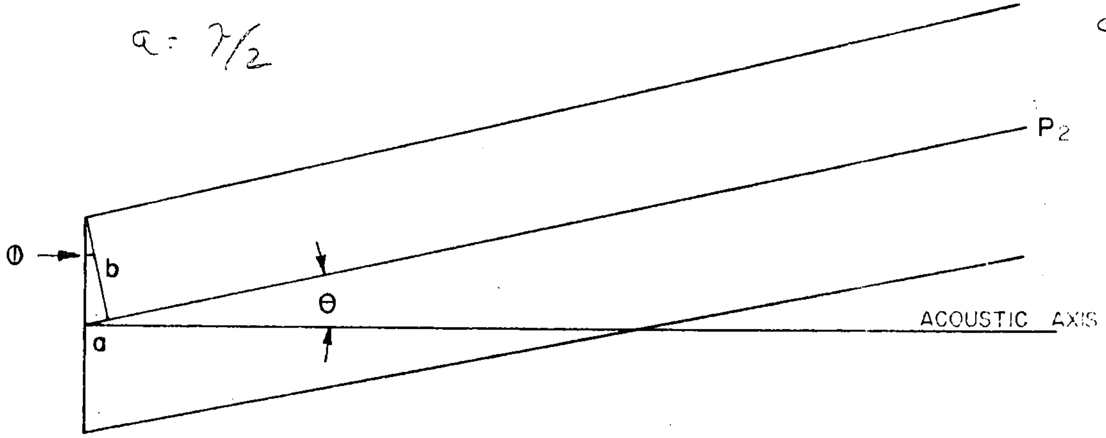


FIGURE 1-10 ALGEBRAIC DETERMINATION OF BEAMWIDTH

that $\theta = \phi$ and that when $a = \lambda/2$ then for this angle ϕ or θ the energy at a point P2 will be 3 db lower than the energy on the acoustic axis. The total beam angle for a transducer is defined as 2θ or the angle between the 3db points.

From the above it is obvious that the beamwidth to the 3 db points is a function of the size of the transducer and a function of the frequency. A circular transducer has a cone shaped beam while a rectangular transducer will have an approximately rectangular beam. For 12 KHz operation a transducer 0.5 metres athwartships by 2 metre fore and aft would have a fan shaped beam and cover a swath 15° on either side of the ships track and insonify an area 3.7° in the fore and aft plane. Plots of beamwidth vs. transducer diameter at various frequencies are shown in Figure 1-11.

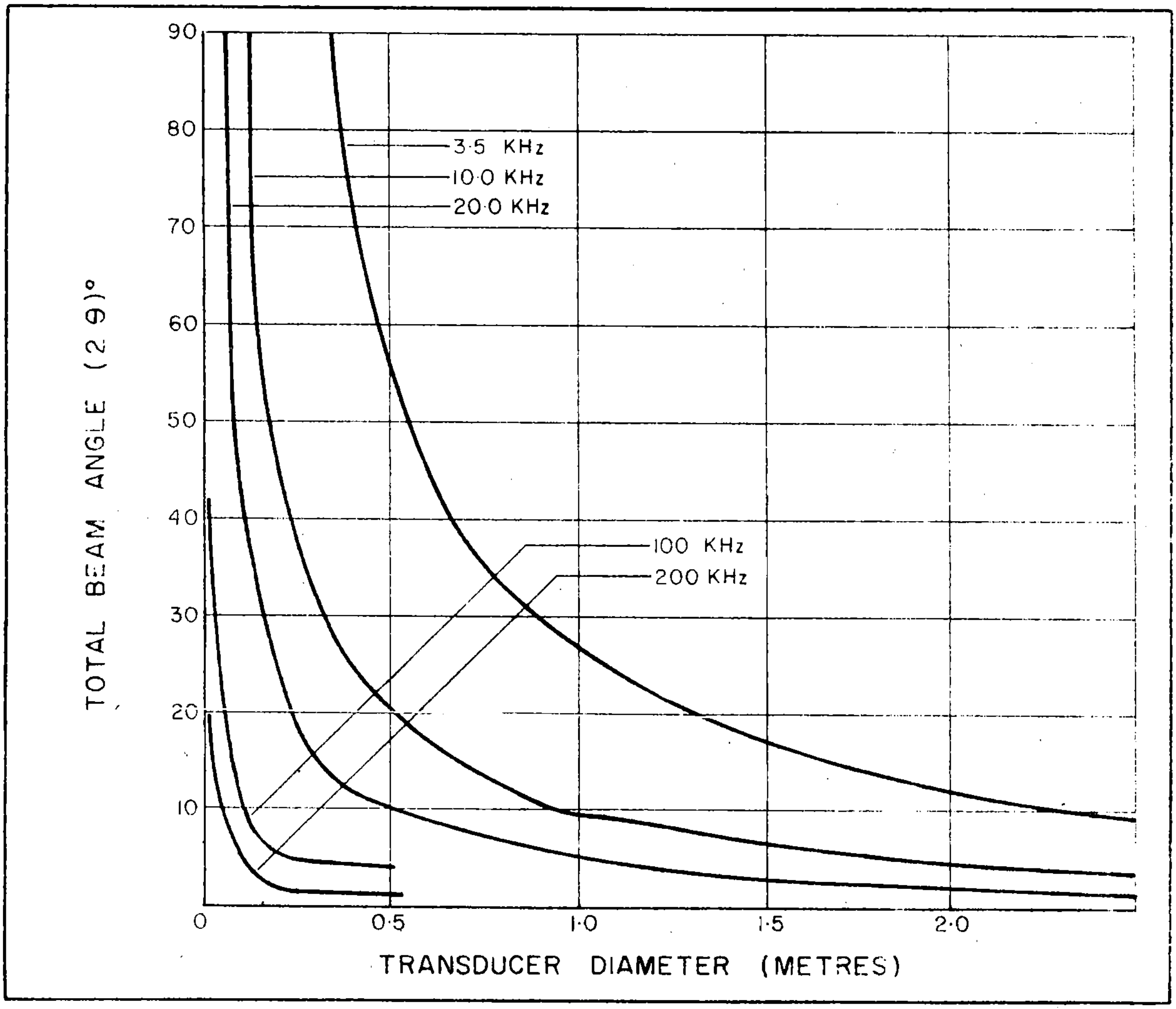


FIGURE 1-11 BEAMWIDTH VERSUS TRANSDUCER DIAMETER

1.7 Phasing

The sonar recorder was discussed in terms of having the recorder key the transmitter when the stylus passed a point on one side of the paper and having the recorder print an echo somewhere on the paper during the same sweep. This is a system that would be most effective for very shallow water. Indeed by halving the sweep speed we could double the time taken to traverse the paper and hence the recording time or depth capability.

Using a system of reducing speed however to obtain additional depth capability would be inefficient because it would reduce the ability to read depth accurately. Small systems are therefore normally only two speed systems, one speed for metres and one for decimeters while larger precision echo sounder recorders may be set up for many speeds because of their many different applications. To display the same reading accuracy whether the depth is 120 metres or 700 metres a phasing system is used on most recorders. The idea of the phasing system is to fire the sonar transmitter at a predetermined time before the stylus reaches the left hand side of the paper so that at zero phase the recorder may read 0 - 150 metres while at the next setting the recorder may record from 100 to 250 metres and then on the next phase the recorder reads 200 to 350 etc. In this way each phase overlaps its neighbour by 50 metres. This is typical although not the only method of phasing. Phasing will be explained first for a simple rotary recorder and then for a 9040-24S system.

Phasing for a Rotary Recorder: Referring to Figure 1-12 it is easily seen that this recorder has a scale of 0 to 150 metres. The 150 metres corresponds to 60° of arc but the phasing is set up so that each phase rotation is 40° with a 20° or 50 metre overlap.

There are therefore nine phases or steps.

When a recorder of this type is initially switched on it is sometimes difficult to establish the correct phase. It must be searched for by switching through the various ranges. If there is considerable doubt about the approximate depth, it is generally safer to start with the zero phase and work upward.

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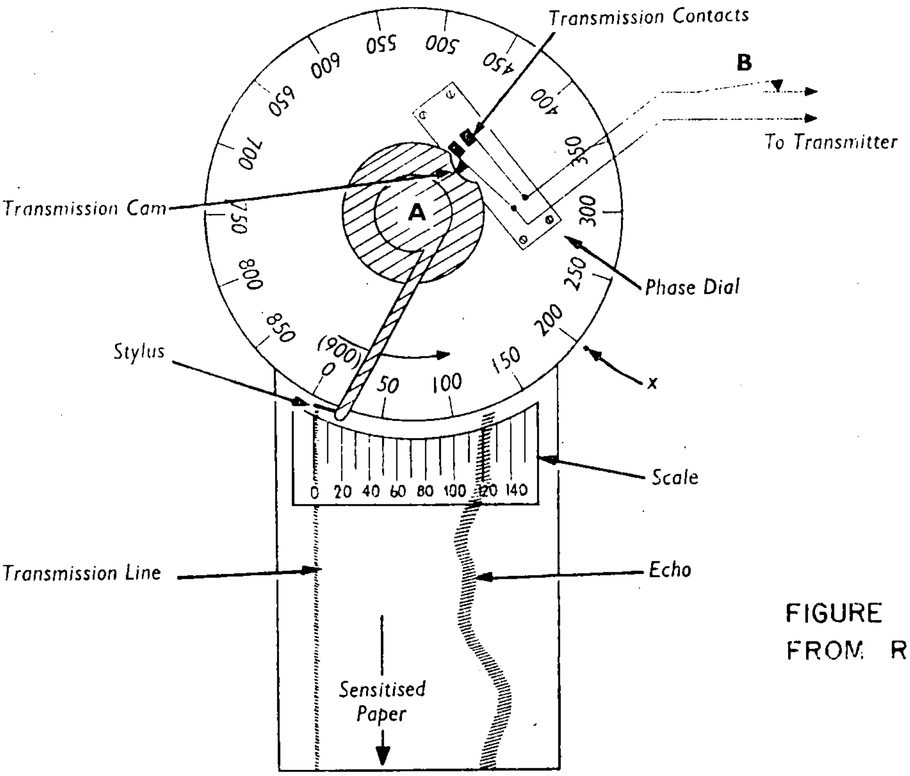

FIGURE OBTAINED FROM REFERENCE 1.

FIGURE 1-12 ECHO SOUNDER ROTARY RECORDER

The two things to be borne in mind are:

a) On the last phase i.e. 800 to 950 metres the transmission mark will appear as a straight line at 900 metres.

b) An echo at 1000 metres can look like an echo at 100 metres.

Phasing for a 9040-24S System: Phasing in a 9040-24S is controlled by the transmitter control circuits. When the range scale selected does not include zero depth, the rate of transmission (the PRF) and the beginning of the measurement interval occur in advance of the instant that the recorder stylus crosses the zero line on the recorder chart. The amount that the "start" occurs in advance of the stylus zero line crossing is directly proportional to the difference between zero range and the lower figure of the range scale selected. In addition to the phasing delay a second delay is normally set by the draft control. This delay is independent of phase selected and is used to apply an appropriate delay depending upon ships draft.

1.8 Programmer Controlled Recorders For Bathymetry

Phasing is not the only method of setting the recorder so that the paper record only spans a portion of the water column. Another method of accomplishing this is by the method of programming.

Standard echo sounder procedure discussed so far consisted of pulsing a transducer located near the ocean surface at the start of each recorder sweep and then printing the return echoes or in the case of phasing having the recorder traverse the paper at a predetermined time after sonar transmission. In each instance however the echo received during a sweep would be from the sonar pulse transmitted at the beginning of the sweep.

In deep water this implies very low data rates. For a water depth of 7500 metres then the time taken from the instant of sonar transmission to echo reception would be approximately 10 sec. In recent times programmable recorders have been produced to alleviate this problem and increase the data rate. Programmable recorders are designed to key the transmitter at a rate several times faster than the transit time for the water column and in this way improve the data rate.

To explain the operation of a programmed precision recorder, shallow water operation will be considered and then deeper operation and then an explanation will be given for a system operating at a one second sweep speed in the programmed mode. Referring to Figure 1-14 if the water depth is less than 750 metres then the transmitted pulse and received echo occur during the same one second sweep. For depths less than 750 metres, it is therefore not necessary that the recorder be programmed.

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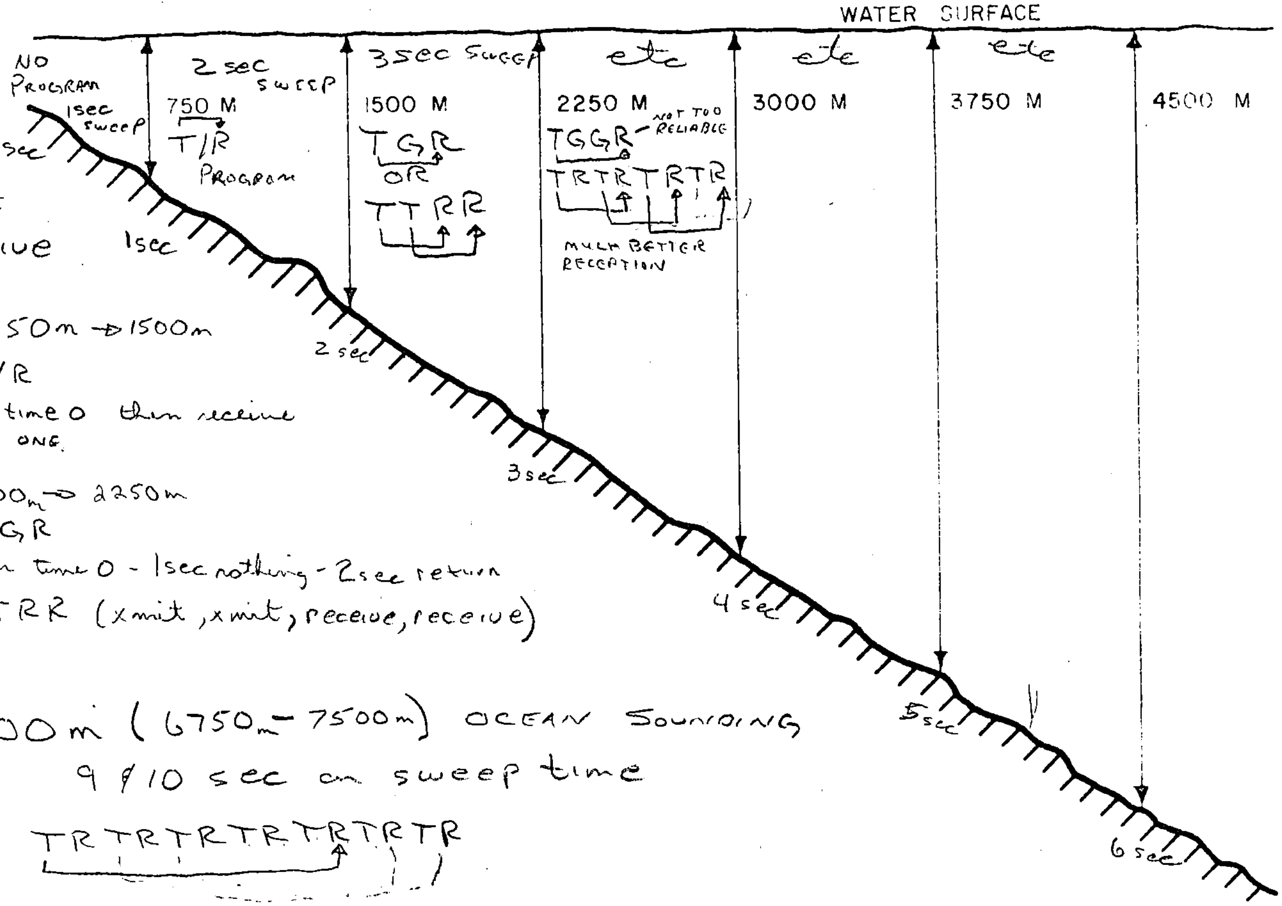
1 Sec Sweep Rate
so in 1sec 0-750m recorded on paper



T= xmit
R= receive

over 750m → 1500m
use T/R
xmit on time 0 then receive
on TIME ONE

over 1500m → 2250m
use TGR
Xmit on time 0 - 1sec nothing - 2sec return
or TTRR (xmit, xmit, receive, receive)

7000m (6750m - 7500m) OCEAN SOUNDING
9/10 sec on sweep time

TRTRTRTRTRTRTR

1-2
3-4
5-6
7-8
9-10
} all use TR programing

FIGURE 1-13 EFFECT OF PROGRAMMING FOR DIFFERENT WATER DEPTHS

If the depth is slightly more than 750 metres then the operator if he wishes to stay on a one second sweep must go to a program length of 2. The echo will then print close to the left hand side of the paper on the sweep following the one on which the transmitter was keyed. If the operator wishes to mute the receiver during the sweep on which the transmitted pulse occurs, he will set his program switches as follows. For the first sweep he will set the switch so that the transmitter will key (T), but so that the recorder will not step and also so that the receiver will be muted, consequently the recorder paper will not be marked. On the second sweep he will set the programme to Record(R). On this sweep the recorder will advance the paper one step, and the

.../19

received echo will mark the paper. The transmitter will however not be keyed. This TR program is the simplest of programs and in addition to being an excellent program for operation in water depths 750 to 1500 metres, it is also effective for deeper water as will be shown later. In the depths of water encountered so far (up to 1500 metres) on a one second sweep the program only served a phasing function because there was only one transmitted pulse in the water at any one time. As the water gets deeper however, to say between 1500 and 2250 metres with a transit time of between 2 and 3 seconds then there is an opportunity to get more than one pulse in the water to improve the echo density. One program to use would be TGR (G stands for Gate and on G the recorder paper does not advance and the receiver is muted) where again the recorder would be only serving a phasing function. If the program TTRR is used, it is evident that for every 12 sweeps, we have six transmissions in the water for the TTRR program while we have only four transmissions in the water for the TRR program. As the water gets deeper the advantages of programming become more and more evident.

If a water depth of 4000 metres is considered then the two way propagation time is between 5 and 6 seconds. On phased operation with one pulse in the water there would be a maximum echo density of one echo every six seconds. With a program of TR and a program length of 2, 4, 6 or 8 the echo density is decreased to a maximum of one echo every two seconds. Another program for this depth would be TTRGTRR with a program length of 7. The maximum echo density would be three echoes in every 7 seconds or echoes on 43% of all sweeps. There are a great number of programs available for every depth interval and it is up to the ingenuity of the operator to select the optimum one. In order to do so he must understand the programming system.

As a final example if a water depth of 7200 metres in a non programmed mode is considered the echo density will have a maximum value of one echo every ten seconds while if a program length of 2 and a TR program is set then the echo density will have a maximum value of one echo every two seconds.

NOTE

Although programmed operation has been discussed in some detail, there are a number of subtleties that have not been touched on. One subtlety is that the functions of the program switches is not always as simple as described. On most recorders, the function of the first switch for each setting is different than for the other switches and on some recorders the sequences may vary. The handbook on each individual recorder will explain the programming in detail for that particular recorder and the appropriate handbooks should always be consulted.

2.0 PROPERTIES OF THE MEDIUM

2.1 Introduction

The two most important properties of the medium are:

1. The effect it has on the propagation velocity of acoustic waves.
2. The effect it has on the attenuation of acoustic waves.

Another important property of the medium is exhibited in the cavitation phenomena that occurs when the instantaneous value of acoustic pressure exceeds the static value. These properties will be explained in some detail in this section.

2.2 Velocity Of Propagation

The velocity of propagation of acoustic waves in a medium is affected by the density and by the elasticity according to the formula:

$$C = \frac{E}{\rho} \text{ where } E \text{ is in dynes / cm}^2$$

Temp ↓ Prop Vel ↑

and ρ is in gm / cm^3

$$\rho = \frac{m}{v}\,\frac{(\text{Gm})}{(\text{cm}^3)} \quad \text{while } E = \frac{pW - pWO}{(V_o - V/V_o)}$$

$pW - pWO$ is the change in total pressure while $V_o - V$ is the proportionate change in volume.

The density of sea water increases as the salinity increases and as the pressure increases. It varies with temperature in such a manner that it passes through a maximum at about 4°C. The elasticity is affected to a much greater proportional degree by the these three factors than is the density.

The velocity of sound in sea water (c) may be written as a function of depth and salinity by using the formula:

.../22

$$C = 4422 + 11.25\ T - 0.0450\ T^2 + 0.0182\ D + 4.3\ (S - 34)$$

where C = Velocity in ft / sec
T = temperature in °F
D = depth below surface
S = salinity in parts / 1000

A formula using metric units is:

$$C = 1449 + 4.6T - 0.055T^2 + 0.003T^3 + (1.39 - 0.012T)(S-35) + 0.017D$$

C = Sound velocity in metrec/sec
T = Temperature in degrees celsius
S = Salinity in parts/1000
D = Depth below surface in metres

There are many formulas available and all are reasonably accurate.

Although it is possible to determine the sound velocity as a function of depth from the measurement of temperature pressure and salinity, it is also possible to measure the speed directly by means of the "sing-around" velocimeter. A block diagram of a typical instrument is shown in Figures 2-1. The pulse generator is a trigger type pulse - forming circuit which produces short fast pulses at a frequency such that the period is somewhat longer than the time interval that one would expect for sound to travel through the fixed distance. The received signal is amplified and triggers the pulse generator to generate the next pulse. The pulse frequency of the pulse generator is a measure of the speed of sound in the liquid as the period is equal to the time necessary for sound to traverse the path from the projector to the receiver. The frequency may be measured with a frequency counter or discriminator. In a typical system the velocimeter is fitted with a pressure sensor and as the velocimeter is lowered, sound velocity is recorded as a function of depth. A computer program or a mathematical formula is then available to compute the average velocity.

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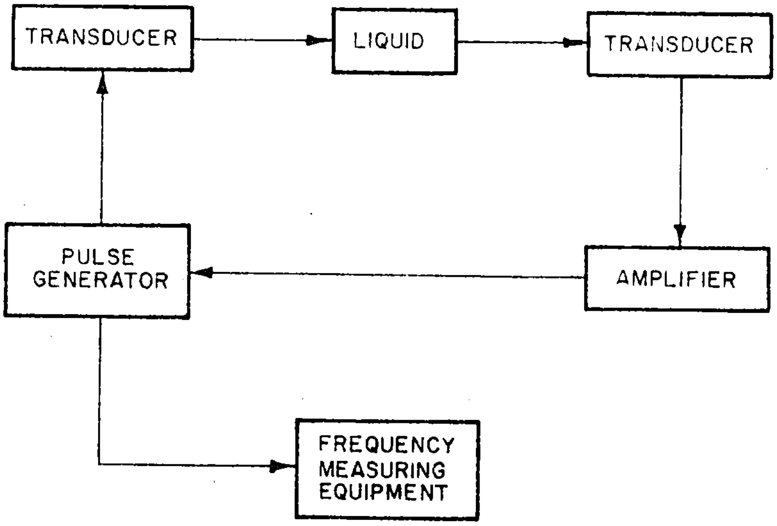

FIGURE 2-1 BLOCK DIAGRAM OF SING-AROUND VELOCIMETER

The simplest method of obtaining velocity is to consult "Matthews Tables." "Tables of The Velocity of Sound in Pure Water and Sea Water" have been prepared by D.H. Matthews that give the correction to be applied for different areas depending upon depth. The correction is applied to an assumed velocity of 1463 or 1500 metre/sec. Matthews Tables are used quite extensively.

2.3 Propagation Losses Of Acoustic Waves

There are two factors that contribute to the propagation loss of sound waves as they travel through homogenous water. The first factor is the spreading loss and the second is the absorption loss. The spreading loss is independent of frequency and is merely the inverse square law loss as a result of the insonified area becoming larger. The insonified area increases 4 times as the distance is doubled to decrease the intensity to 1/4 its original value for a doubling in distance. Spreading loss is illustrated in Figure 2-2.

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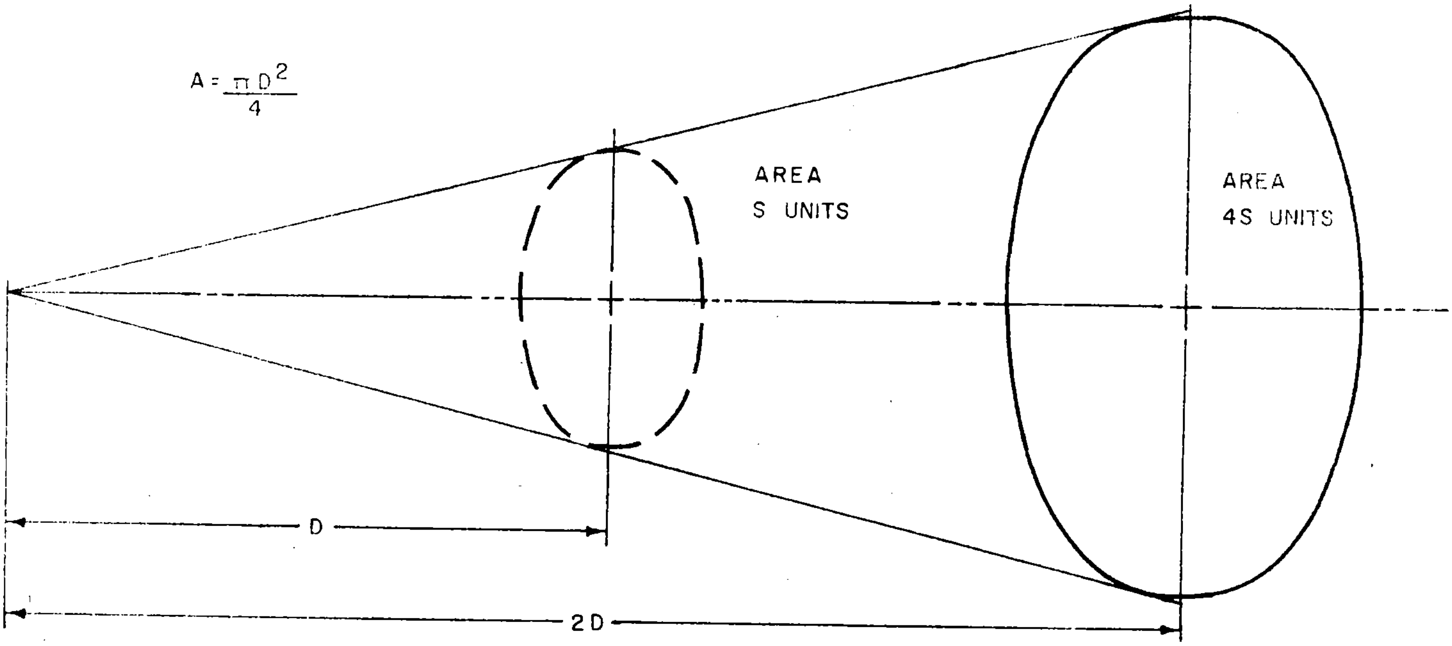

FIGURE 2-2   ILLUSTRATION OF SPREADING LOSS

The spreading loss is not constant in all cases because of bending of the beam due to temperature changes but in homogenous water it may be taken as:

Spreading loss L_{SPR} = 20 Log dist. (Yd.)

The absorption loss is really a dissipation loss or absorption loss in the medium. The absorption loss increases with frequency approximately as shown in Figure 2-3.

There are two other losses that should also be considered. Those are the reflection loss and the scattering loss. The reflection loss occurs when there is discontinuity or boundary in the medium. The typical reflection losses also occur when there is a sharp temperature gradient. Some of the energy will penetrate through the gradient and some will be reflected, depending upon the nature of the discontinuity.

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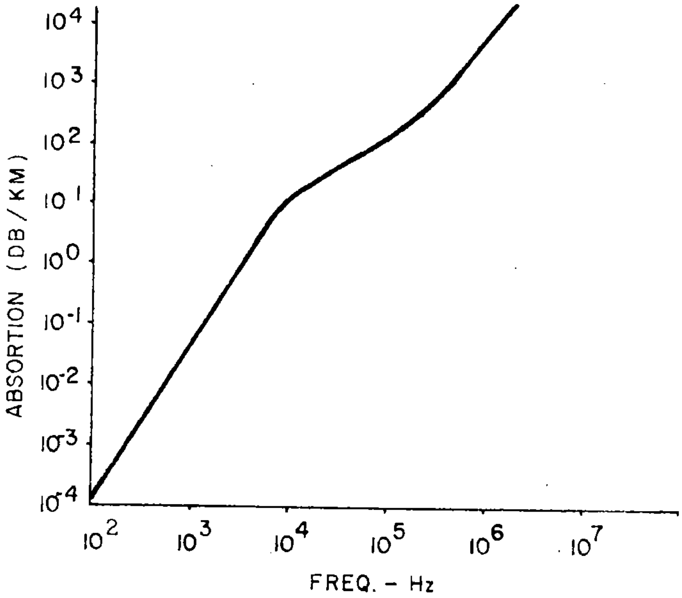

FIGURE 2-3 ABSORPTION OF SOUND IN SEA WATER AT VARIOUS FREQUENCIES

Scattering losses are caused by non homogenous materials in the medium, varying in size from particles of dust and micro-organisms to schools of fish. The most significant scattering effect is caused by the deep scattering layer. The deep scattering layer (DSL) is an important layer of organisms that is normally found in the deep ocean. The DSL is at about 400 metres during the day. At night it rises to approximately one hundred to two hundred metres. It produces a heavy shadow on an echo sounder trace and has often been a source of false shoal reporting in deep water. In most instances the bottom is visible through the deep scattering layer although sometimes only faintly.

It is clear therefore, that the predicted depth for a system will not always be achieved because conditions are not always the same. The reduction in acoustic energy accounted for by spreading and absorption are based on the assumption that the sound rays follow straight lines. Sound rays in the sea are however often bent and this greatly modifies the matter in which

.../26

spreading takes place. The scattering caused by micro-organisms, air bubbles, fish etc. also modifies the absorption coefficient. The combination of spreading and absorption are often referred to as the attenuation loss. The attentuation loss is therefore the absorption loss plus an additional amount caused by scatter. The total losses in the medium as a function of frequency are illustrated in Figure 2-4.

2.4 Cavitation

The upper limit to the normal behaviour of water as an acoustics medium is determined by the fact that when the instantaneous value of acoustic pressure exceeds the static pressure, the resultant pressure becomes negative for a portion of each cycle and the integrity of the water is destroyed. The production of small voids or cavities in the water which occurs under this condition is known as CAVITATION. The acoustic intensity at the sea surface corresponding to the equality between static and acoustic pressures is approximately 0.3 W cm^{-2}. A cavitation threshold of one atmosphere is therefore equivalent to a plane wave intensity of 0.3W cm^{-2}.

For an actual sonar projector because of the effect of the non-uniform sound field at the face of the projection cavitation for long pulse systems occurs when the acoustic pressure is approximately 1/2 the theoretical limit or 0.15 W cm^{-2}. The cavitation threshold as a function of depth may be obtained from the formula:

$$Ic = 0.15 \left[Pc(0) + \frac{h}{10} \right]^2 \text{ W cm}^{-2}$$

where Pc(0) is the pressure at zero depth measured in atomospheres, and Ic the cavitation threshold at a depth h, where h is in metres.

If we assume that Pc is one atmosphere at the sea surface then for a depth of 10 metres the cavitation threshold will be 0.6 W cm^{-2}.

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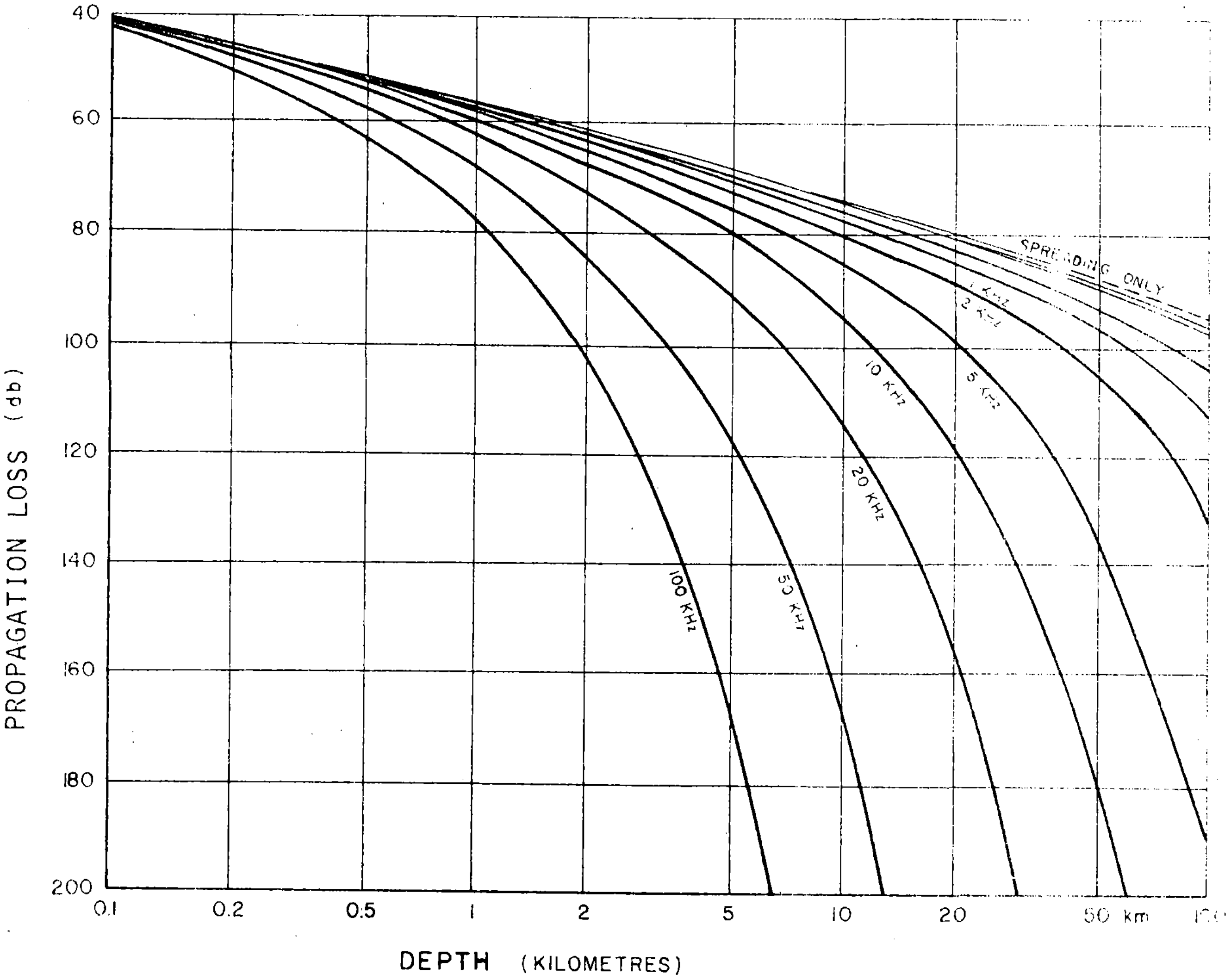


FIGURE 2-4 PROPAGATION LOSS VERSUS RANGE AT VARIOUS FREQUENCIES. FIGURE OBTAINED FROM REFERENCE 13

The cavitation threshold of a projector may be raised by increasing the frequency or by decreasing the pulse duration. For a 1 Msec pulse at 15 KHz the cavitation threshold is approximately 1 Watt cm^{-2}. The threshold level is notably sensitive to temperature, dissolved air content and several other features, not the least being the particular criteria used to establish the onset of cavitation.

Cavitation is important in the practical application of sonar because it places an upper limit on the power than can be applied to a transducer of a given size and also because of the noise it causes. In other words cavitation is a noisy process because initially as the pressure is reduced it becomes less than the pressure at which the air already in solution can remain in solution. Air must therefore escape immediately into each cavity together with a certain amount of water vapour.

When the total pressure in the neighbourhood of the cavity resumes its positive value the cavity collapses to the points where the pressure of the acquired air is the same as the hydrostatic pressure. The result is an air bubble which must remain in the water for some time. The partial collapse is however accompanied by the release of acoustic energy.

Cavitation is one of the prominent components of ship's noise and it is a constant nuisance in echo sounding. Sometimes when a ship is operating in high sea states abnormally high
aeration attenuation and poor echo strengths are encountered as a result of the water quenching. This sometimes occurs in shallow water or near shores where there are strong currents. It is believed that the excessive reductions in acoustic energy are caused by entrapped air in the acoustic path.

.../29

3.0 → DESIGN CONSIDERATION FOR AN ECHO SOUNDER

A great deal can be learned about the operation of an echo sounder by investigating the manner in which an acoustics engineer selects the operating frequency and other parameters in the design of a system. ①The first thing one must consider is the purpose for which the echo sounder is being designed. Designing an echo sounder for operation to depths up to 10,000 metres is far different than designing a system for sounding in shallow water②The next thing to consider is whether the system is being designed to have sub-bottom capability or for echo sounding only. If the system is to have a capability for sub-bottom profiling, it will preferrably have an operating frequency of 3.5 KHz or lower. From Figure 1-11 it is evident that a really large transducer is required for operations at 3.5 KHz, unless a very broad beam width can be tolerated.

The designer will require information on the propagation loss as illustrated in Figure 2-4 and information on the bottom loss so that he can predict the target strength required.③Target strength is a measure of the effective reflecting capability of the bottom vs. the reflecting power of a spherical reflector 4 metres in diameter. An object in the path of a transmitted sound pulse intercepts a quantity of the acoustic power and re-radiates something less than the intercepted quantity. The effectiveness of the object as a target is determined by the fraction of the power returned to the receiver. This effectiveness is defined as the target strength. The target strength of a sphere 4 metres in diameter is taken as 0 Db. For spheres of other diameters, the target strength is:

$$\text{T.S.} = 10 \text{ Log } \frac{\alpha^2}{4}$$

where α = radius in yards

The sea bottom is of course not a sphere and because of the many different types of sea bottoms from mud to boulders,

.../30

there is a great deal of variability in the target strength. There has been a considerable amount of research carried out in this field, and a typical set of results for a transducer with a directivity index of 17 Db is shown in Figure 3-1.

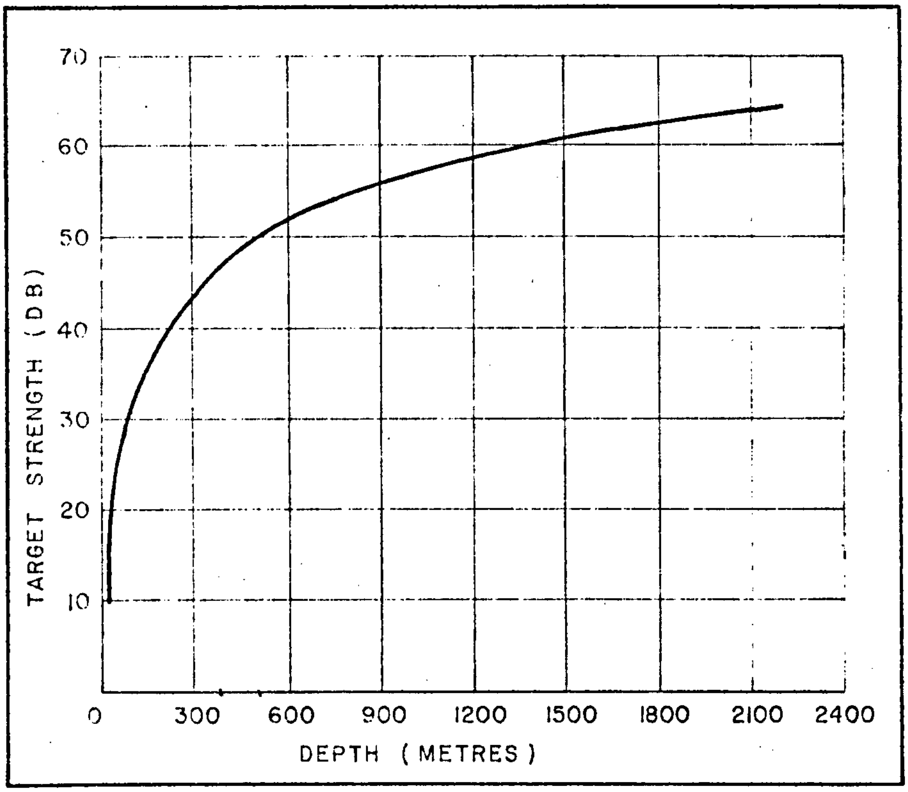


FIGURE 3-1 TARGET STRENGTH AS A FUNCTION OF DEPTH

The sonar engineer must also know how much power can be projected from a transducer of a given surface area to avoid cavitation and also how much transmitter power he can feasibly develop. At the surface the theoretical cavitation threshold is approximately 0.3 W cm^{-2}.

The cavitation threshold increases with depth and is higher at higher frequencies. In addition the theoretical limit may be exceeded for short sonar pulses because it takes the water column a finite time to cavitate. The cavitation threshold at 100 KHz is approximately 20 times as high as at 10 KHz and a decrease in pulse length from 5 to 0.5 Msec will double the threshold. It is therefore important to study those phenomena closely when developing an acoustic design. In this chapter a cavitation threshold of 0.3 W cm^{-2} will be assumed for 10 KHz and a threshold of 6 W cm^{-2} at 100 KHz. A cavitation threshold of 0.3 W cm^{-2} rather than 0.15 W cm^{-2} as discussed in Section 2.4 is assumed because for the pulse lengths to be used the threshold will be twice as high as for long pulse systems. The cavitation at a depth h in metres may then be obtained from the formula:

$$Ic = 0.3 \left[Pc(0) + \frac{h}{10} \right] \text{ W cm}^{-2}$$

One property of a transducer which has been mentioned but not explained thus far but which the sonar engineer must consider is the property known as the directivity index or D.I. The directivity index for sound reception is a measure of the amount by which a hydrophone array through its beam pattern discriminates against noise in favour of signal. The directivity index of a projector is the difference measured in Db between the level of energy on the acoustic axis of the projector and the level that would be produced by an isotropic radiator radiating the same total amount of acoustic power. Since most transducers for sonar use are reciprocal, the D.I. of a transducer is the same for transmission as for reception. Expressed as an equation:

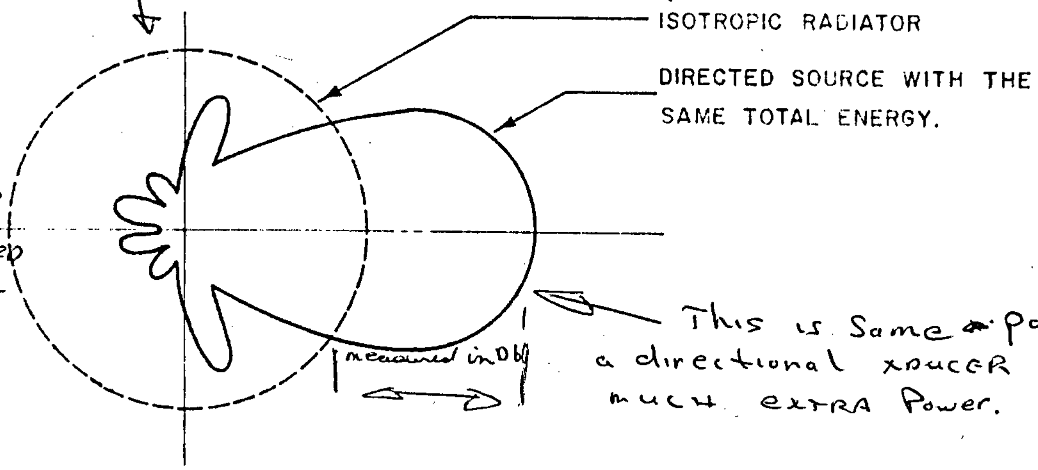
$$D.I. = 10 \text{ Log } \frac{I_D}{I\ non_D}$$

if the intensity represented by the directional pattern is I_D and the intensity represented by the nondirectional pattern is $Inon_D$. A pictorial representation of the directivity index of a transducer is shown in Figure 3-2 and a nomograph for finding the directivity index of circular and linear piston arrays as a function of frequency and dimensions is given in Figure 3-3.

.../32

This Shows xoucer RADIATING a certain amount of energy in omni.

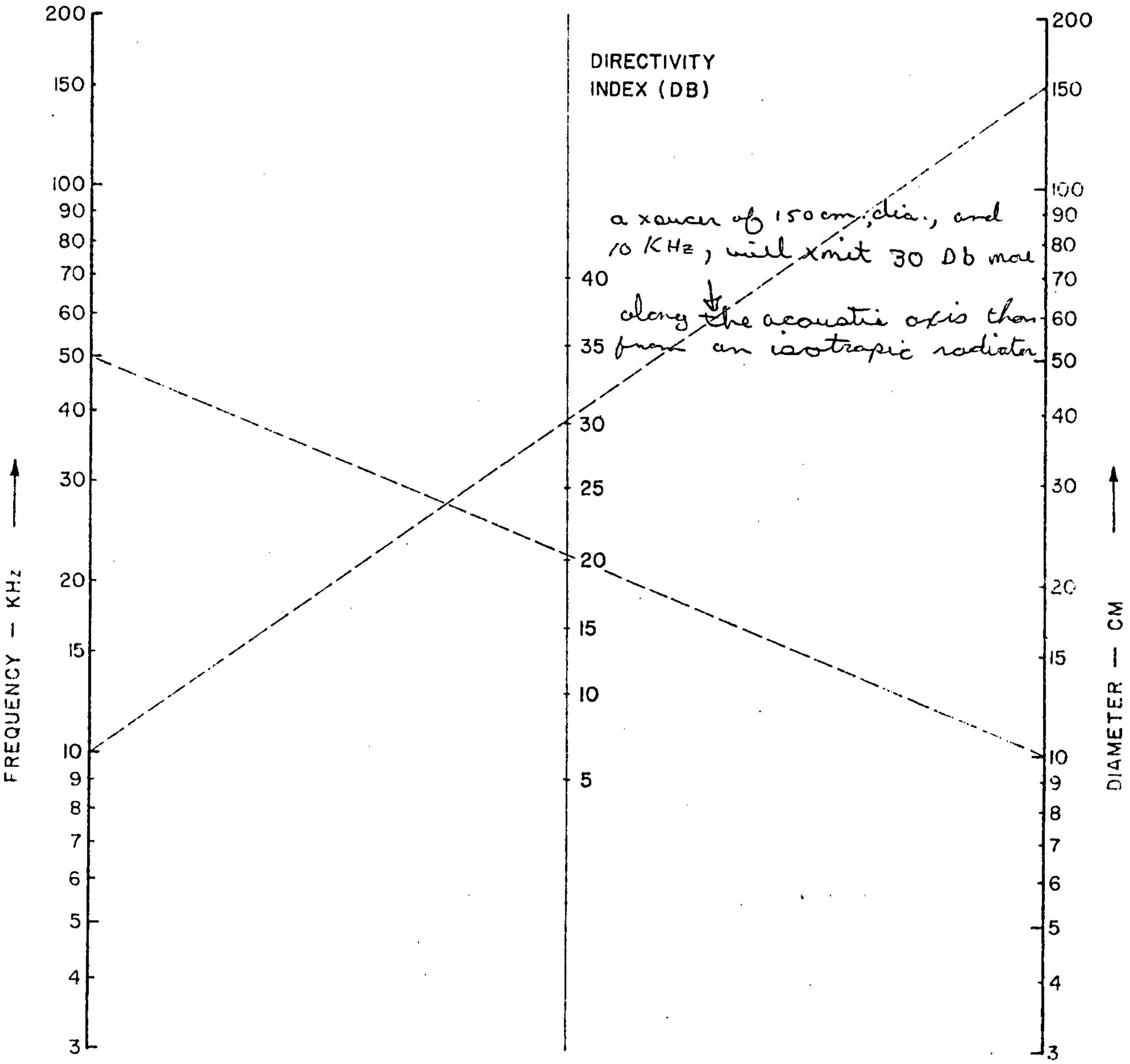
360° RADIATOR



Reference or Test Radiator to have a standard xoucer to test against.

This is Same power with a directional xoucer giving this much extra Power.

FIGURE 3-2 PICTORIAL REPRESENTATION OF DIRECTIVITY INDEX



a xoucer of 150 cm. dia., and 10 KHz, will xmit 30 Db more along the acoustic axis than from an isotropic radiator

FIGURE 3-3 DIRECTIVITY INDEX NOMOGRAM

The next step for the sonar engineer is to write the sonar equation and then use it to decide on an optimum design. The sonar equation, which ties together the effects of the medium the equipment and the target, may be written in terms of signal excess in the following manner:

$$\text{SIGNAL EXCESS} = L_S - 2N_W + N_{TS} - L_N - N_{BW} + DI_R - N_D$$

L_S = Source Level = $71.6 + 10\text{Log } P_A + DI_T$ in Db //1 ubar

$2N_W$ = 2 way transmission loss (Absorption + spreading) in Db

N_{TS} = Target Strength in Db

L_N = Level of Noise over 1 Hz passband in Db //1 ubar

N_{BW} = Increased noise due to wider band width in Db

DI_R = Directivity index on Receive in Db

N_D = S/N ratio required for processing in Db

// means with respect to

NOTE

Throughout this report acoustic intensities are given in Db //1 ubar, i.e. Db // 1 dyne cm^{-2}. Although in recent times it is more common to to express acoustic intensities in Db //1 uPASCAL. The conversion factor for going from Db //1 ubar to Db //1 uPa is to add ~~100~~ 50 to quantity expressed in Db //1 ubar i.e. 120 Db //1 ubar = ~~220~~ 170 Db //1 uPa. The reference intensity of 1 uPa has replaced the ubar almost entirely in the scientific literature and it has been adopted as the American National Standard for acoustic intensity. The one main advantage of the new system is that with a reference level as low as 1 uPa, it is very seldom that negative levels appear.

.../34

Assuming that we are considered a system for operation to 7,000 meters we can now decide on what type of system we required. First we will consider a 10 KHz system and an allowable maximum transducer diameter of 1/2 meter.

If the transducer diameter is 1/2 meter then assuming a draft of three meters:

$$P_A \text{ (max)} = 0.3\ (1.0 + 3/10)^2 \text{ (Area in sq. cm.)}$$

$$P_A \text{ (max)} = (0.3)(1.7)\ \frac{(2500\Pi)}{4} = 1000 \text{ W}$$

To find the directivity index (D.I.) the beam width to the -3Db points is first obtained from Figure 1-11 and then the D.I. computed, calculated or obtained from a nomograph. The beam width to the 3db points is 18° and the D.I. is 20 (obtained from Figure 3-3).

Assuming that the transducer is 50% efficient the maximum electric power is therefore 2000 watts and the maximum acoustic power 1000 watts. The source level is:

$$L_S = 71.6 + 10 \text{ Log } P_A + DI_T$$

$$L_S = 71.6 + 10 \text{ Log } 1000 + 20$$

$$L_S = 121.6 \text{ Db //1 ubar}$$

$$2\ N_W = 180 \text{ Db (from Figure 1-11)}$$

$$N_{TS} = 50 \text{ Db (from Figure 2-5)}$$

L_N is a function of sea state and type of ship at any operating frequency. It is also dependent upon ships speed. In most instances the ship's radiated noise is the largest component of Ln. Ln is a function of type of ship, sea state and several other factors decreasing at higher frequencies. A set of noise level figure at various frequencies are shown in Figure 3-4. The curves have not been drawn from measured values but are sufficiently typical for illustration purposes. If we assume a speed of 10kt

.../35

then the noise level (Ln) over a 1 Hz bandwidth is approximately -46 Db //1 ubar and the increased noise due to an assumed bandwidth of 1 KHz would be 10 Log 1000 = 30 Db. The directivity index on receive would be 20 Db the same as on transmit and the signal to noise ratio required for processing would be approximately 6 Db.

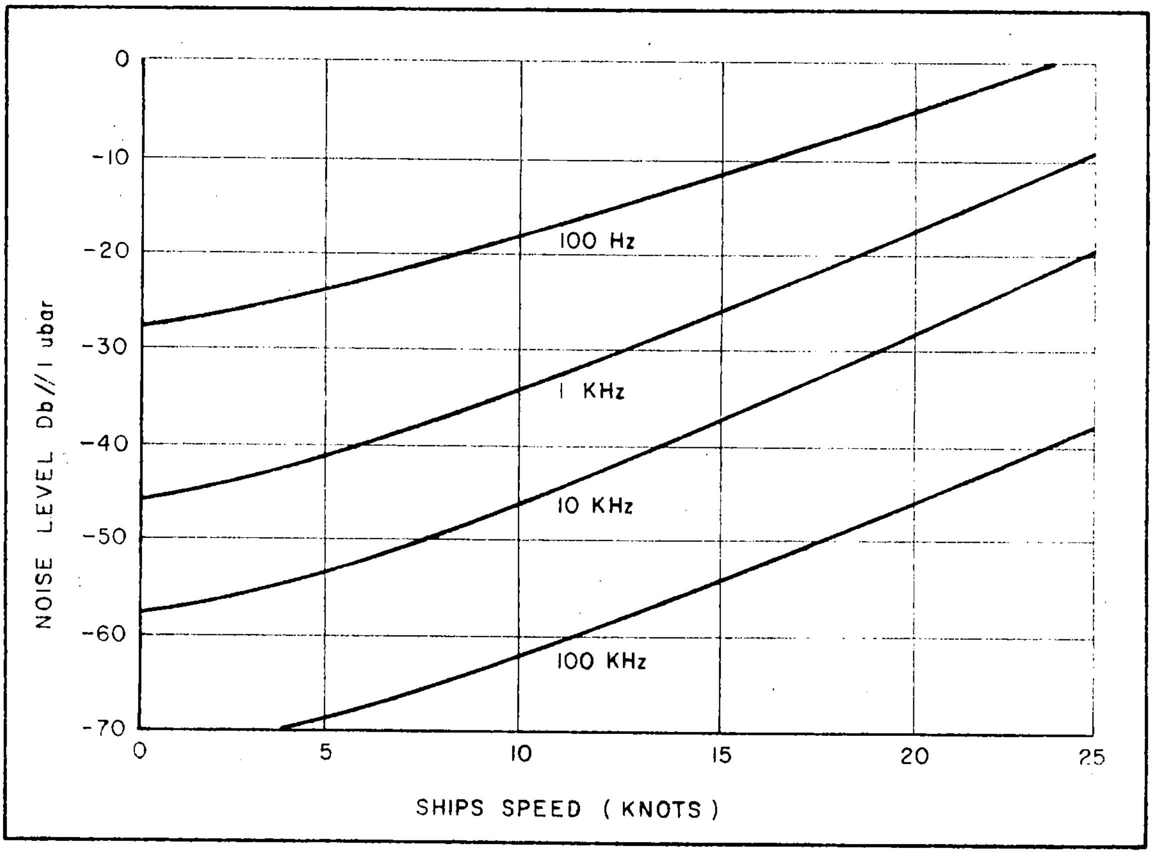


FIGURE 3-4 INCIDENT NOISE LEVEL AS A FUNCTION OF SPEED

If we rewrite the sonar equation and put all those figures together, the result will be as follows:

SIGNAL EXCESS = $L_S - 2N_W + N_{TS} - L_N - N_{BW} + DI_R - N_D$

SIGNAL EXCESS = 121.6 - (180) + (50) - (-46) - (30) + (20) - (6)

SIGNAL EXCESS = 22 Db

.../36

What has been shown is that for the example given with the conditions as estimated there would be a signal excess of 22 Db. The system should therefore work under the specified conditions i.e. to a depth of 7,000 metres. If instead of the 22 Db figure a negative figure were obtained above the analysis would have shown that the system was not capable of operating to 7,000 metres.

In our calculations many estimates were made on noise level, propagation attenuation, bottom strength etc. and all those estimates would have to be carefully considered before one could justifiably say that the system would operate to the specified conditions. In the example given, how the acoustics engineer uses the sonar equation to optimize a design was not demonstrated in detail. What was shown is a method that the hydrographer or technician can use together with the specifications of an equipment to demonstrate whether or not it will operate in a particular water depth. Items like incident noise level at the face of the transducer and bottom strength can however only be estimated. A close study of the information given will show that by modifying the various factors like frequency, transducer size, transmitter power level etc. the sonar engineer can indeed optimize a design.

The calculations done were for a large system operating at a relatively low frequency and with a relatively wide beam width. It is suggested that the reader:

(1) repeat the calculations and come up with an optimum design for a system to operate on an 80 ft vessel to 5,000 metre and to have a total beam angle of less than 3°.

(2) Optimize a design for a system to be used with depth capability of 500 metres for use on a 30 foot survey launch.

4.0 NARROW BEAM ECHO SOUNDERS

4.1 General Discussion

A narrow beam echo sounder is considered to be a sounding system in which the transducer beamwidth to the half power (-3Db) points is 5° or less. Narrow beam echo sounders normally utilize transducers mechanically or electronically stabilized in pitch and roll to ensure that the transducer face is effectively level on transmit and receive. There is no point in making the transducer beamwidth narrow if the transducer beam pattern pitches and rolls in unison with the ship.

There are a number of reasons for using a narrow beam echo sounding system for oceanographic and hydrographic surveys. The basic reasons however are:

Reasons For Narrow Beam

(1) To be able to obtain information vertically beneath the ship and not off to one side if the ship is operating over a steep bottom slope.

(2) To improve the quality of the information obtained.

The improvements to be obtained from using a narrow beam echo sounder are quite apparent if one studies records from a narrow beam system and from a conventional system for surveys over irregular bottom topography. It should be pointed out however that a great deal of information is missed if only a narrow beam system is used. To achieve the most in sea bottom delineation a narrow beam system should be operated in conjunction with a broad beam system. In the following paragraphs narrow beam sounding systems as developed by various companies will be discussed.

4.2 Raytheon System

One of the greatest drawbacks in the development of narrow beam echo sounder systems is caused by the large physical dimensions of the transducer required to produce the narrow beamwidth at frequencies where the attenuation is sufficiently low to allow strong echo returns in deep water. For example, at 12 KHz, a transducer 3.7 metres in diameter is required to produce a 2° beamwidth to the -3Db points, while at 3.5 KHz a transducer of 12.5 metres in diameter is required for the same beamwidth. A one metre diameter transducer at 12 KHz has a total beamwidth of 7 1/2 degrees at the half power points.

It is clear from those examples and from Figure 1-11, that developing narrow beam echo sounders from conventional linear techniques, although effective, is a brute force method. An advantage may be obtained by raising the frequency but it must be borne in mind that as the frequency is raised the two-way attenuation is correspondingly raised according to well known laws. One way around this problem is to employ the principle of non-linear acoustics. This principle although well documented many years ago, was not developed into hardware until quite recently. Raytheon Corporation have developed the first marketable system and they are leaders in this field of research. Their system is called the Finite Amplitude Depth Sounding System (FADS).

The FADS technique involves the transmission of two high frequencies simultaneously, both of large amplitude. Because of the slight non-linearity of the water, the two frequencies are mixed in the area in front of the transducer to produce a parametric signal at the difference frequency. The water column in essence serves as a mixer or modulator and generates a secondary sonar transmission in the water at a frequency equal to the difference frequency of the two primary sources. The low frequency has the narrow beamwidth of the high frequency components, does not have side lobes, and has an attenuation factor corresponding to a linear system operating at the difference frequency. In a system of this nature a single stabilized transducer is used with matrixed elements to accommodate all three frequencies or separate transducers are designed for "transmit" and "receive", the projector being a matrixed high frequency transducer and the hydrophone a broad beam low frequency transducer. It is not necessary that the "receive" transducer have a narrow beamwidth although a higher directivity index does improve the signal/noise ratio.

One disadvantage of non-linear systems is that they do require higher transmitter power levels to provide the same source level at the lower frequency than do linear systems. This though is not too serious for major ship fittings where there is normally adequate ships' service power and space for housing the necessary transmitting electronics. Maximum conversion efficiency is achieved by careful selection of the primary frequencies for a required secondary frequency. Conversion efficiency may also be increased by increasing the acoustic intensity because the rate of attenuation of acoustic waves is not constant but is a complicated function of intensity and frequency. There has been a great deal published on parametric optimization as a function of source level and conversion ratio. The attenuation losses that one might expect are in the order of 20-40Db for downshift ratios in the range of three to twenty.

In summary the net effect is that higher primary source levels are required because of the conversion loss but the higher source levels are quite easily achieved because at the higher primary frequencies the cavitation threshold is higher and the power source is not normally difficult to obtain. A block diagram of a Raythoen FADS system is shown in Figure 4-1.

4.3 General Instruments System

Most narrow beam echo sounders have one basic limitation and this is particularly apparent if the sounder is to be used for hydrographic surveys. The limitation is that it gives no information on either side of the ship's track. This one shortcoming is significant enough to make it mandatory that broadbeam systems be operated in conjunction with conventional narrow beam systems for maximum information recovery. General Instruments Corporation have developed a multibeam deep sea oceanographic and hydrographic sounder to alleviate this problem of conventional narrow beam systems. The General Instruments system permits full coverage of a significant swath symmetrically placed about the

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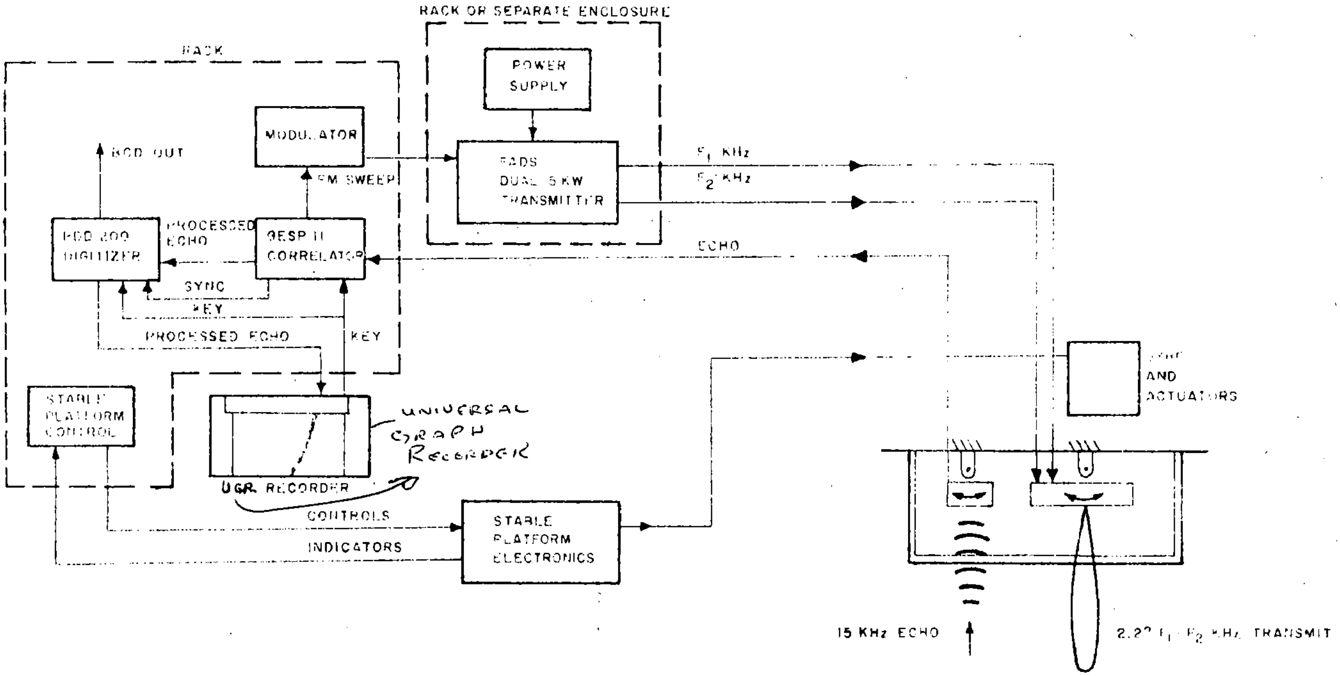

FIGURE 4-1 BLOCK DIAGRAM RAYTHEON FADS SYSTEM

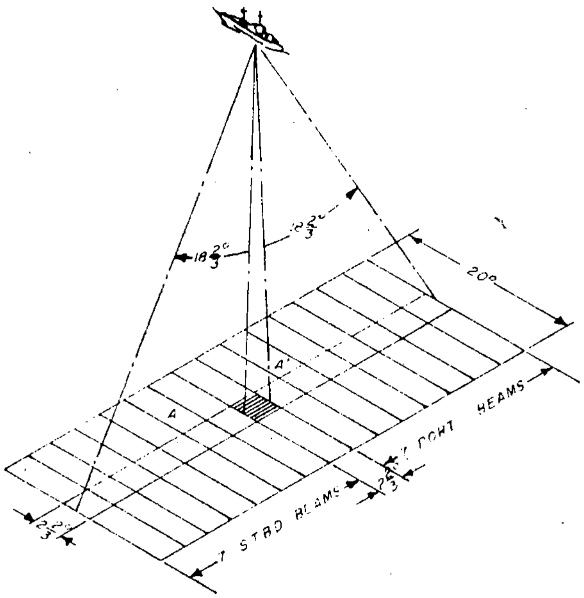

FIGURE 4-2 MULTIBEAM PATTERN, GENERAL INSTRUMENTS SYSTEM

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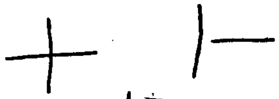


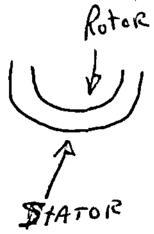
one of two types

xducer mounted for aft regime mounted across ships keel

ship's track with a resolution corresponding to an effective beamwidth of approximately 2.5°. This is achieved by taking full advantage of a multiple crossed fan beam configuration. Beam formation is achieved with separate orthogonal fan beam arrays for transmitting and receiving the acoustic energy. The narrow beam echo sounder multibeam pattern as developed by the General Instruments Corporation is shown in Figure 4-2.

The projector is a high power linear array at a frequency of 12.15 KHz mounted in the fore and aft direction. The beam pattern from this array spans more than 40° in the athwartships direction and approximately 2 1/2 degrees in the fore and aft direction. The transmitting array is made up of twenty projectors and is electronically stabilized by using twenty separate power amplifiers all fed through phase resolvers obtaining their vertical orientation from a vertical gyro. The transmitting array is stabilized in pitch only.

The receiving array is approximately three metres long and is made up of forty hydrophones mounted athwartships. The signals from the forty hydrophones are amplified and phase shifted to provide quadrature inputs to the beam forming network. A precise contribution in both amplitude and phase of each hydrophone signal is combined by a resistive network to form the fifteen or sixteen received beams. The synthesized received beams are fed to a roll compensator from where the vertical beam is obtained. The vertical beam is interpreted from the two most nearly vertical beams if no one beam is sufficiently vertical.



Rotor moves against ships roll to compensate for roll. Stator moves with ship

This system supplies a great deal of information on the athwartships bottom profile. The only difficulty is in storing and handling the great quantity of data obtained. Digital plotters, graphic recorders, oscilloscopes and digital computers have all been employed for this purpose. This system is large and complicated for fitting on existing ships but conceptually is the most important system available for installation in new vessels.

4.4 Electroacustic GMBH System

Electroacustic GMBH (ELAC) have been active in the development of narrow beam sounding systems for a number of years and probably were responsible for the first narrow beam sounder fitting. ELAC systems have been fitted and used extensively in German Research ships such as "Planet and Valdivia" and "Meteor II". The newest ELAC system is the VM 11. This system has an extremely narrow beamwidth, ± 1.4° at the -3Db points and it operates at 30 KHz. It is a stabilized transducer system with a transducer as shown in Figure 4-3. The ELAC system is a high power system capable of operating to depths exceeding 6000 metres. The main drawback of the system is its vulnerability to ice damage. Because of its large size (transducer diameter of 1 metre) it would also be very expensive for fitting on an existing vessel.

not good in deep water
6000 m maybe!

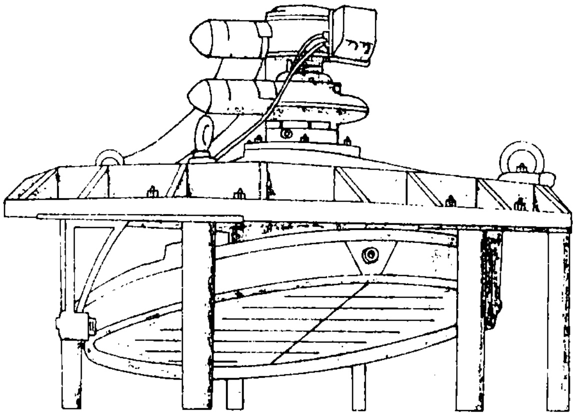


FIGURE 4-3 STABILIZED TRANSDUCER ELAC SYSTEM

4.5 EDO Western Corporation System

EDO Western Corporation have a large number of narrow beam echo sounder fittings of various configurations and complexities. EDO systems are for the most part tri-frequency systems with narrow beam capabilities at the highest frequency, and progressively wider beamwidths as the frequency is decreased.

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The EDO systems use vertical gyro reference error signals applied to solid state hydraulically actuated servo control systems to maintain a level transducer. They have also packaged a similar system in a towed body.

One of the unique features of the EDO system is that for operation in an ocean environment where floating ice may be encountered, they utilize massive gate valves so that the transducer may be protected while it is not being operated. By closing the gate valve the transducer may also be removed for servicing while the ship is at sea. A typical EDO Western System is shown in Figure 4-4. There are many more narrow beam systems available but it is hoped that the brief descriptions of the four systems will provide the reader with adequate information to assess their potential.

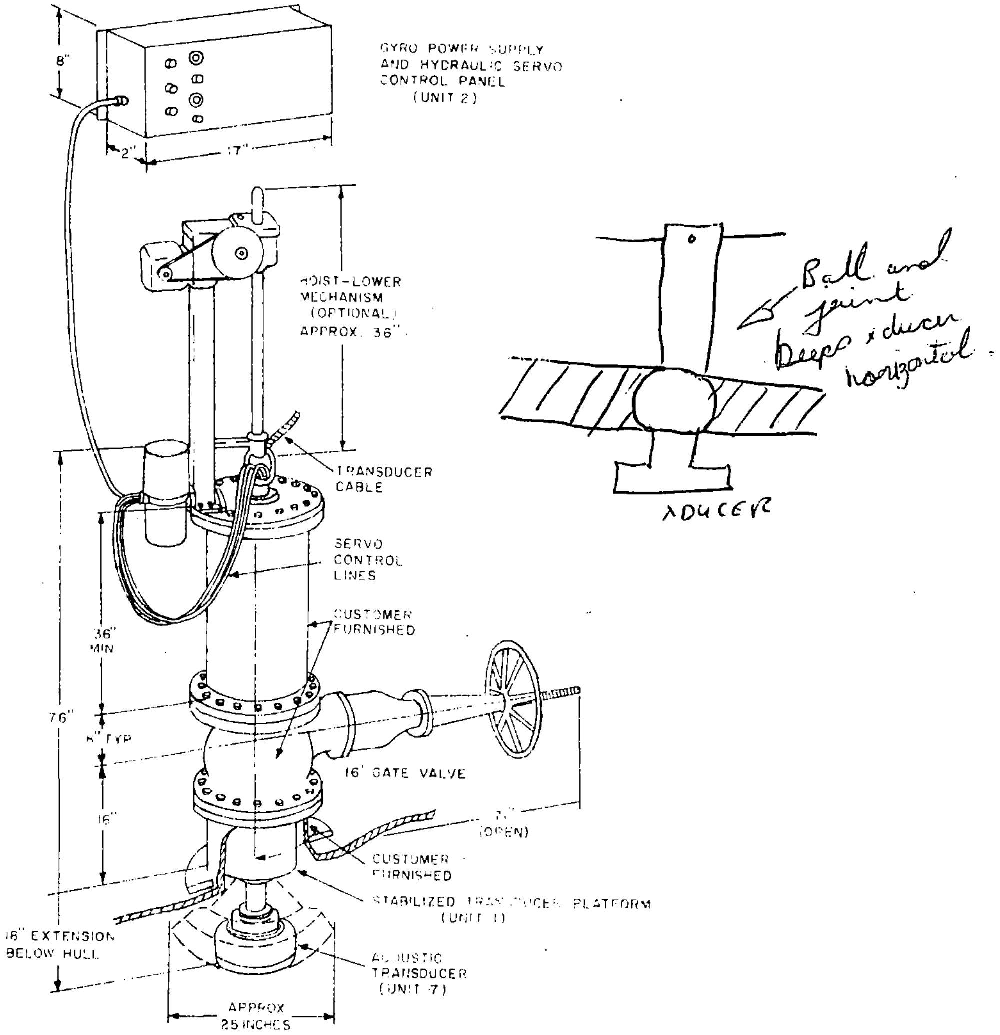

FIGURE 4-4 TRANSDUCER ASSEMBLY EDO WESTERN MODEL 554 SYSTEM

5.0 SIDE SCAN SONAR

A side scan sonar system consists of a transceiver, a recorder, a tow fish fitted with transducers and a winch and cable assembly to deploy and recover the fish. A basic side scan system is illustrated in Figure 5-1, and typical beam patterns are shown in Figure 5-2.

Side scan sonars are normally fitted with two transducers, one directed to the port side and one to the starboard side. The transducers are tilted down approximately 10° below the horizontal and any obstructions on the bottom if large enough to be detected will appear as dark spots on the record followed by a loss of signal caused by the shadow effect (On some systems the convention is reversed). In operation it is standard practise to have the centre of the paper record represent the tow fish. Information on the port side will then be shown left of the centre line while information on the starborard side will be shown right of the centre line. This is achieved by using a dual helix recorder and by transmitting into the port and starboard transducers on consecutive sweeps. Side scan sonar systems operate over the frequency range 6-400 KHz with ranges from a maximum of 100 metres for small systems to up to 20 Km for major systems.

Since its introduction in 1958, side scan sonar has become a widely used tool for sea floor investigations. The side scan technique for insonifying the sea floor provides a unique ability to create continuous wide area pictures of sea bottom features.

The side scan technique is interpretative rather than quantitative, at ~~least with respect~~ to water depth measurement. It derives its information from reflected acoustic energy and in operation, it bears a remarkable similarity to a photographic technique in that it produces a continuous coherent plan view of a relatively broadly scanned area. The objective of the side scan technique is to produce a form of planimetric image providing a detailed presentation of the sea bottom features and characteristics

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so that qualitative interpretations can be made. The instrument transmits fan shaped beams that spread downward to either side of the fish in a plane perpendicular to the fish. The side scan recorder displays the signals from the insonified area in such a way that bottom targets are shown in their relative position to the vessel, as it passes through the observation area. The measurement technique has some errors due to scale differences in the slant ranges if they are scaled directly off the recorder.

Targets at the same range return signals proportional to their target strength and some targets although of the same size return different amplitude signals because of different reflectivity characteristics. The target strength in addition to being affected by reflectivity and size is also affected by the aspect of the target. All of those variables make side scan interpretation a very exacting science especially if the recordings are made on a standard wet or dry paper graphic recorder where the dynamic range of the recording medium is only about 23 to 26 db. Because of this limited dynamic range, the received signal is amplified with a Time Varied Gain receiver to provide varying amounts of amplification depending upon the range of the echo. Theoretically, the TVG should be adjustable so that all targets of equal strength appear on the record with equal darkness. Recently there have been several successful attempts to record side scan data on magnetic tape for processing at a later date.

Variability in the signal return from a side scan and hence the information content of the side scan method basically arises from variations in reflectivity of the surface of the seabed materials for the sonic frequencies and incident angles used in a particular instrument system. Every system attempts to minimize signal variability due to other parameters not directly related to sea bottom information such as attenuation, volume scattering, etc.

Side scan sonar can be a powerful complementary tool for hydrographic surveys. Although in its present form, it will not replace vertical sounding for accurate depth determination, it can indicate for the hydrographers' further attention, areas of rough topography and possible shoal water between standard survey lines. Because side scan operations generally require extra manpower, additional technical skills, and reduced ship speed (5 knots) it is doubtful that they should be undertaken routinely on every sounding line. It is envisaged that side scan sonar would be best employed on a widely-spaced grid or selectively where reconnaissance indicates rough topography.

The hydrographer might also regard a systematic network of side scan sonar strips through his array of sounding lines as a further check on the quality of his data coverage. It is conceivable that post survey comparison of sonar-detected sea floor projections (shoals) with those detected conventionally will yield some probability figures for the occurrence of undetected sea floor irregularities. Such an approach might have been ideally tested in the Beaufort Sea where submarine pingos, having base diameters (few hundred metres) less than survey line spacing (1 to 2 km), rise from an otherwise regular seabed.

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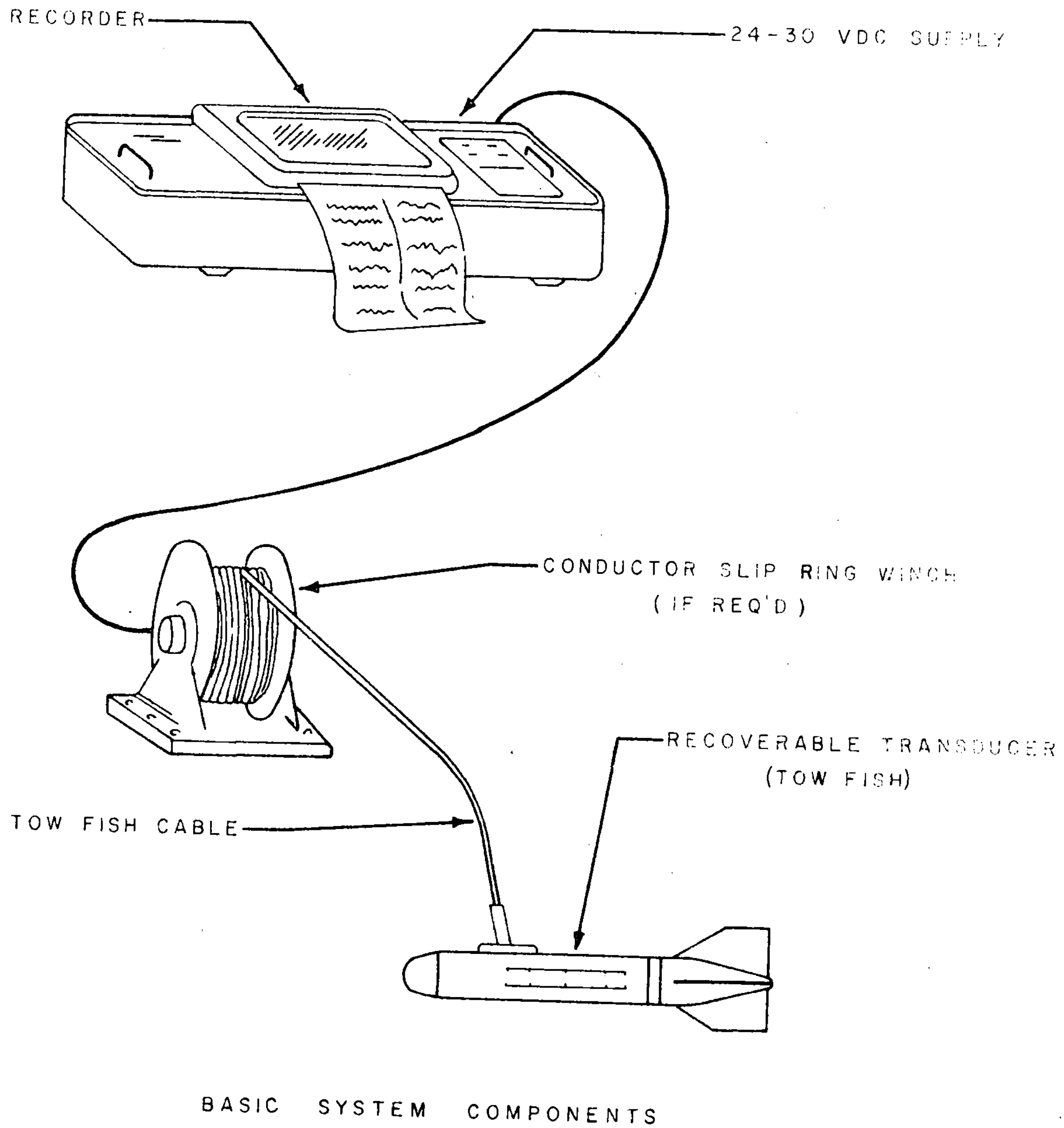

FIGURE 5-1 SIDE SCAN SONAR SYSTEM (COURTESY EG & G)

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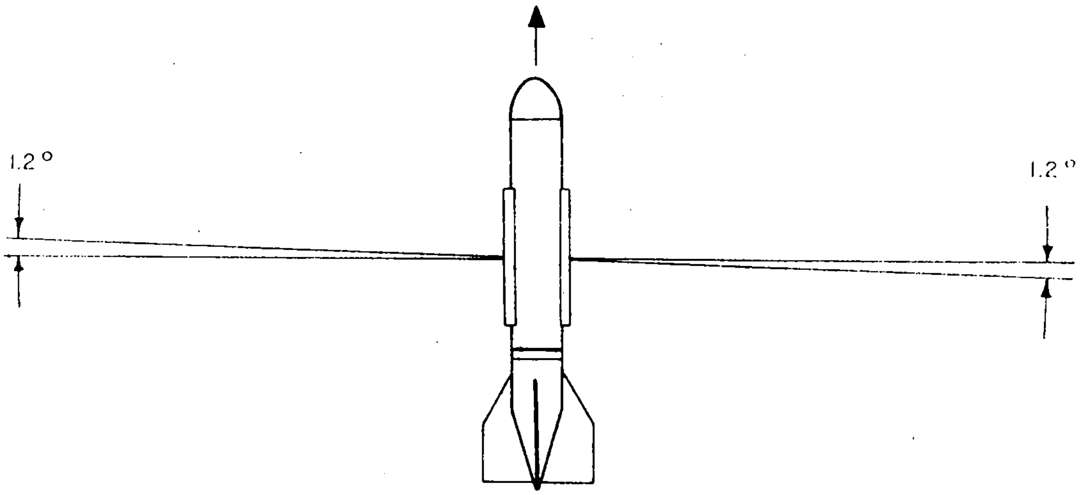
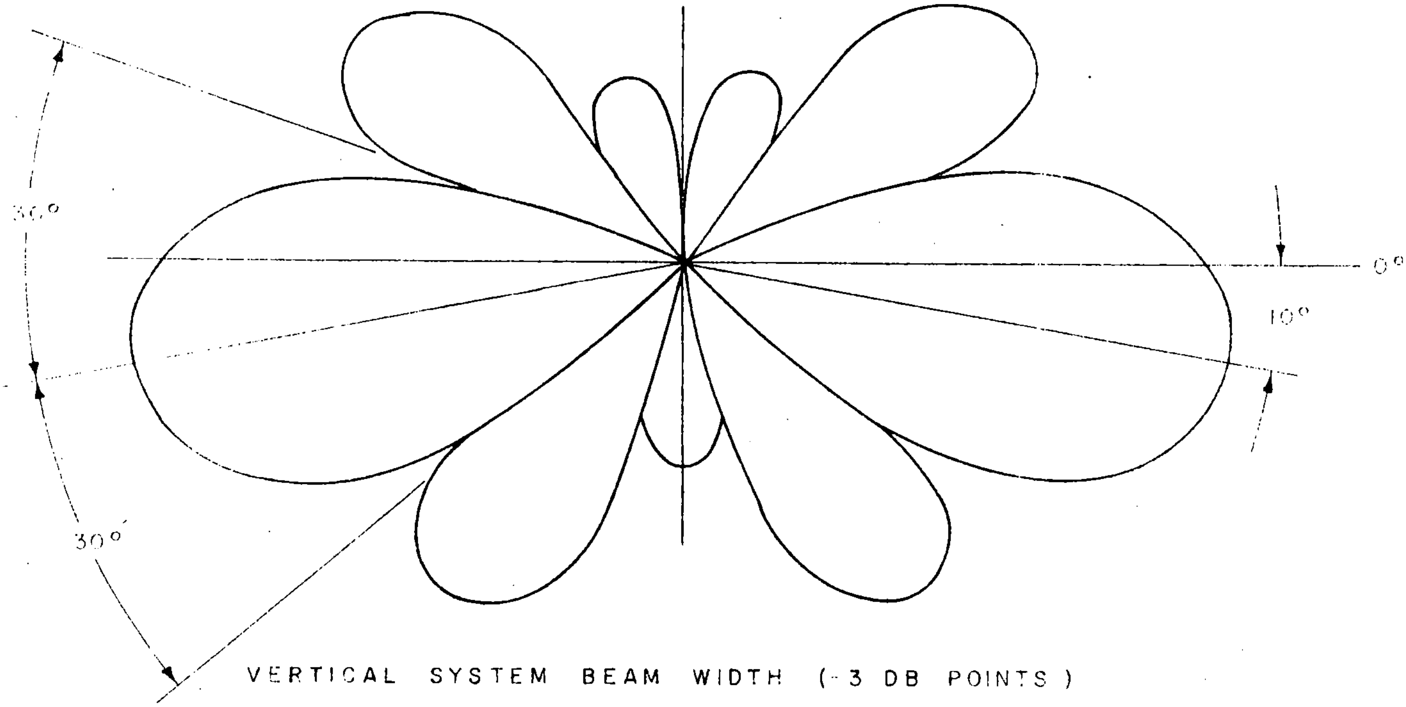


HORIZONTAL SYSTEM BEAM WIDTH (3 DB POINTS)



VERTICAL SYSTEM BEAM WIDTH (-3 DB POINTS)

FIGURE 5-2 TRANSDUCER BEAM PATTERNS, SIDE SCAN SONAR SYSTEM (COURTESY EG & G)

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6.0 ACOUSTIC BEACONS & TRANSPONDERS AND THEIR APPLICATIONS IN ACOUSTIC POSITIONING

Acoustic beacons and transponders differ from the beacons used on land mainly because they are designed to operate over a sea water path while the beacons used on land are designed to operate over an atmospheric path. Because of the path differences the energy from acoustic beacons is propagated as acoustic waves while the energy from beacons used on land propagates as electromagnetic waves.

Acoustic beacons differ from acoustic transponders because the former can only be programmed before deployment while the latter may be programmed after deployment through a command system. The acoustic beacon is simply an acoustic energy source that may be programmed to transmit acoustic pulses at a predetermined frequency and predetermined PRF. The device has a great number of uses. One of the most common is as a means of locating items on the sea bottom. If an acoustic beacon is lowered with a sea bottom instrument package, then a receiver on the ship may be used to receive the signals from the acoustic beacon and the ship may be positioned over the undersea package. Another common use of the beacon is to determine how far an instrument package is from the sea bottom. By receiving the direct energy from the beacon and also the reflected energy from the bottom the distance may be displayed on a precision echo sounder recorder. The procedure is considerably enhanced if the PRF of the beacon is the same as the recorder PRF or a multiple of it.

The acoustic transponder in addition to being an energy source like the beacon also has a receiving section. The transponder may therefore be controlled by an acoustic source on the ship. One of the advantages of this method is that energy is conserved. For example if an instrument package is placed on the bottom, it may be desirable to leave it there for up to sixty days. If an acoustic beacon is used for location, the beacon must be pre-programmed to transmit continually or to commence transmission after a fixed time period. If a transponder is used it may be pre-programmed to transmit only on command. The acoustic transponder will therefore be in a quiescent state and will conserve energy until transmissions

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are required. One of the most common uses of acoustic transponders is for initiating the action of anchor releases so that instrument packages may be freed from the bottom on command.

A more important use for acoustic transponders in recent years is for the development of acoustic positioning systems. Acoustic positioning systems employ acoustic beacons or transponders as the devices that are lowered into the water. Acoustic positions are therefore positions relative to the positions of those beacons or transponders. When the geographic coordinates of those reference markers have been determined the relative positions can then be converted to true positions. The first step in an operation involving transponders or beacons is normally therefore to obtain the positions of the reference markers so that all relative positions may be converted to geographic coordinates. In some instances however, only relative positions are required and the actual geographic positions of the reference markers becomes of secondary importance. In those instances, the positions of the beacons with respect to one another and with respect to the ship carrying out a survey in the area are of primary importance.

There are numerous acoustic positioning reference systems that may be employed but the two most common ones are known as the short baseline configuration and the long baseline configuration. The short baseline configuration may employ beacons or transponders while the long baseline configuration is designed to use transponders only. In the short baseline beacon configuration position indication is derived from a bearing measurement method. The system consists of a ship mounted hydrophone array, processing electronics and a single bottom mounted beacon that is used for the reference. The method used to obtain a bearing measurement of the beacon in ship coordinates is illustrated in Figure 6-1. By measuring the difference in the time of arrival of the acoustic energy at the hydrophones, the bearing to the beacon can be accurately measured. The system is considerably enhanced if the effect of ship's roll and pitch can be removed in the processing electronics. Users of the short baseline beacon configuration are primarily interested in accuracy when nearly over the beacon. An example of this is a well drilling operation

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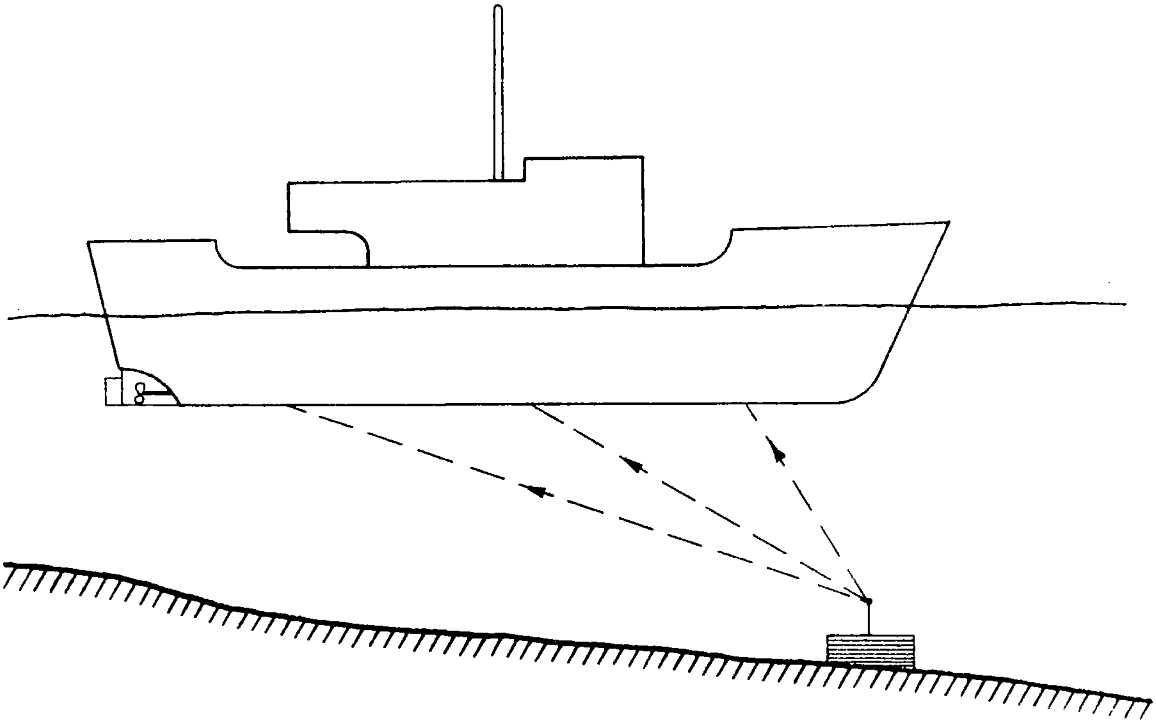

FIGURE 6-1 SHORT BASELINE ACOUSTIC POSITIONING SYSTEM UTILIZING A BEACON

where the drilling vessel is over the wellhead and the beacon is mounted on or near the wellhead structure.

The short baseline transponder configuration derives its position indication from a range-bearing measurement method. The system consists basically of the same elements as the short baseline beacon configuration except that the shipboard system contains an interrogator and more complicated electronic processing and the subsea unit is a transponder rather than a beacon. The prime advantage of the short baseline transponder configuration is in its ability to extend the range of operation of a short baseline system to several times water depth.

Long baseline systems utilize transponders as the bottom mounted units and obtain position reference by range-range methods. A typical long baseline system employing three transponders is shown in Figure 6-2. By interrogating from the ship and measuring

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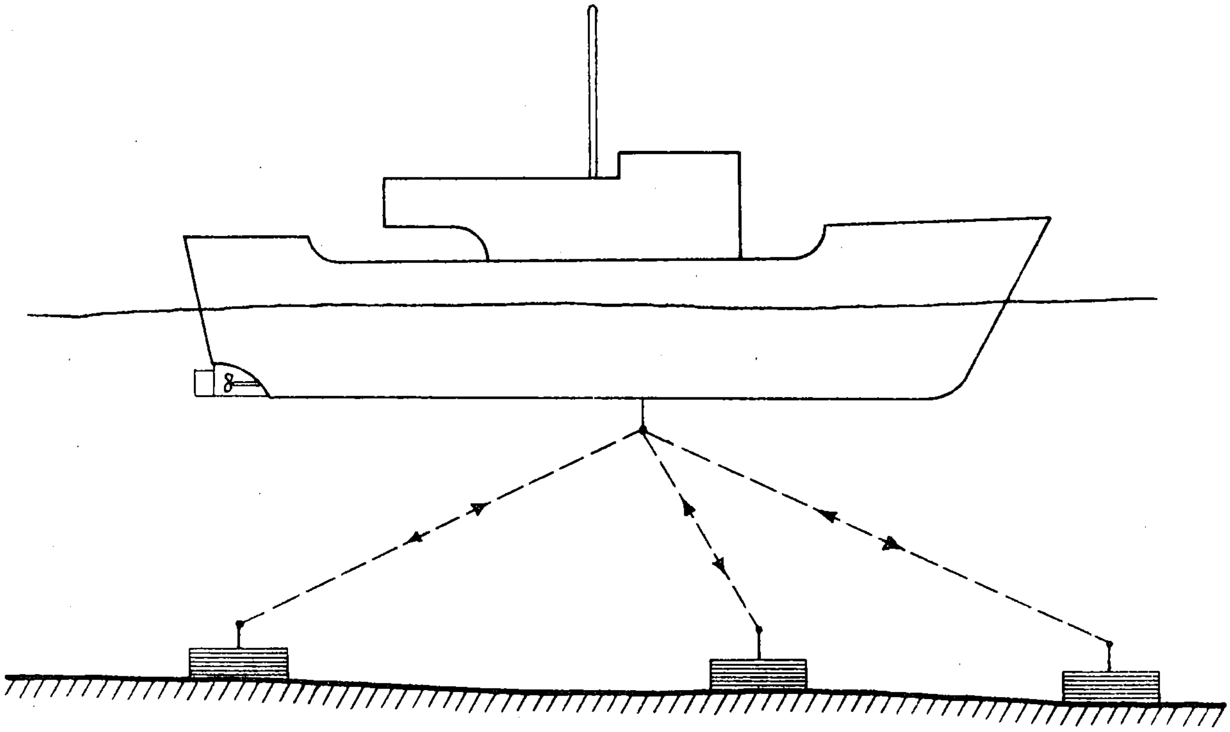

FIGURE 6-2 LONG BASELINE ACOUSTIC POSITIONING SYSTEM

the time interval from the instant of interrogation to time of arrival of the return pulses from each of the transponders the slant range to each transponder may be determined. A knowledge of the depth of each transponder, the delay time of each transponder, propagation characteristics of sound in water and various other parameters must also be known to determine slant range and eventually ship's location with respect to the transponder grid. The number of transponders used in a long baseline system is dependent only on the geometry and size of the area to be surveyed. Transponders must however be identifiable and must not interfere with one another. Relative positioning accuracy with a long baseline system and with baseline lengths in the order of 5 km is normally better than ± 10 metres.

Short baseline systems require more elaborate shipboard fittings while long baseline systems require additional hardware in the water. Both short and long baseline systems have their merits. It is obvious however that short baseline systems lend them to station keeping while long baseline systems are more convenient for extended surveys.

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Echo must be 6 db or 4X larger as noise or no echo on graph

7.0 CORRELATION ECHO SOUNDER PROCESSORS

In recent times correlation echo sounder processors (CESP's) or correlators have become quite a standard part of deep sea sounding systems. A block diagram of a typical deep sea depth sounding system employing a correlator is as shown in Figure 7-1. The reason for using a correlator is to enhance sounding capability and this is accomplished with a correlator because a correlation echo sounding system can operate with a lower signal to noise ratio. This means that while for conventional echo sounding systems where the signal has to be approximately two to four times larger than the noise level for effective processing the signal may be recognized and processed with a correlation system even though it is approximately twenty db below the level of the noise.

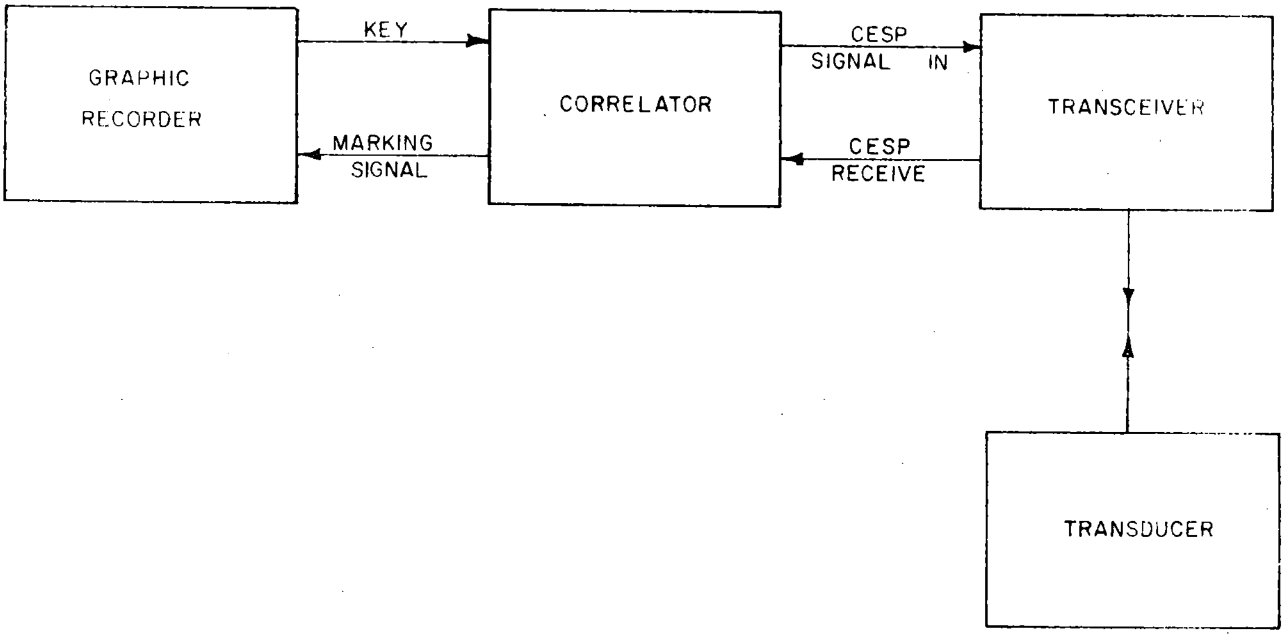

FIGURE 7-1 DEEP SEA SOUNDING SYSTEM EMPLOYING A CORRELATOR

The correlator is able to improve the operational capability of a system without increasing transmitter power by using the technique of replica correlation. In this technique a large bandwidth signal of relatively long duration is transmitted while

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a sample of the transmitted signal is stored in a reference memory and then used as a replica against which returning echoes are correlated. In the systems in use by the Canadian Hydrographic Service the transmitted signal is normally 50 m Sec long and is generated as an FM sweep signal over a bandwidth of two kilohertz i.e., it is swept from 11.0 to 13.0 KHz if the transducer has a resonant frequency of 12 KHz.

Since the processor compares all received signals to a stored replica of the transmitted signal and rejects those which are not similar, any input noise not having the transmitted characteristics does not correlate and is not displayed on the graphic recorder. This presents a marked improvement over standard short pulse operation where any signal energy in the pass band of the receiver such as that caused by waves, cavitation and other forms of incoherent energy are amplified and appear on the recorder as noise that sometimes masks out sonar echoes.

Correlators are reasonably expensive to purchase and although they do improve the operational capability of deep sea echo sounder systems they are still not used extensively. It is expected that they will be used more as digitizers are introduced as a part of most deep sea sounding systems.

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SHALLOW WATER - DATA RATE HIGH

DEPTH 30m GATE ON 5m - NO RETURN 2 echo's DOUBLE GATE 10m

- " " " " " " AGAIN 20m etc

Must know what Pulse is Returning and xmitting

8.0 DIGITIZERS

Digitizers are devices used to digitize the depth data obtained with echo sounders. In their simplest form they convert the time interval from the instant of transmission to echo reception into a digital format so that it may be displayed visually and so that it is available for input into a shipboard data acquisition system. Facilities are available on most digitizers so that corrections may be made for ship's draft and variations of sound velocity in water. A block diagram of a typical depth digitizing system is shown in Figure 8-1.

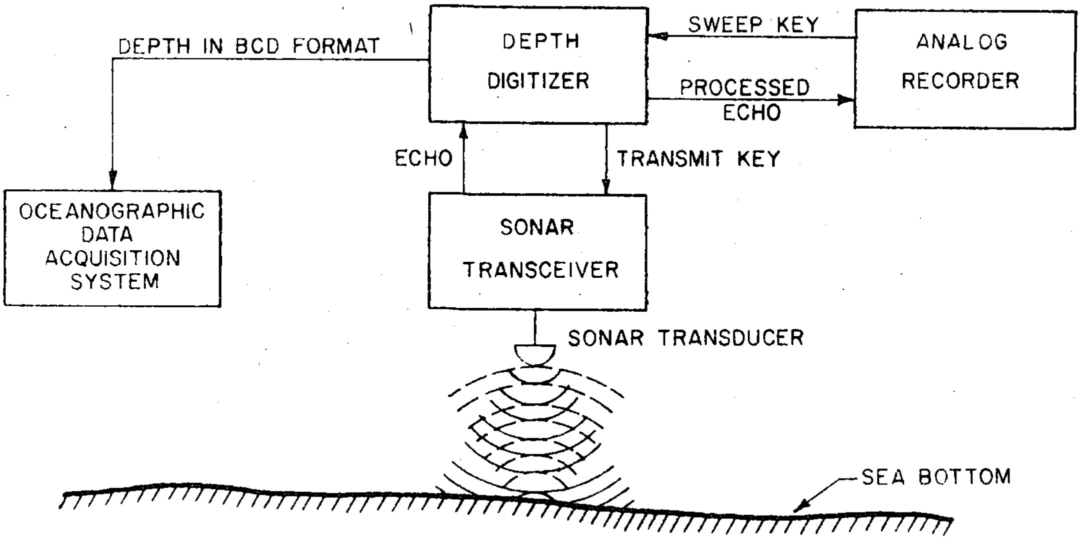

FIGURE 8-1 TYPICAL DEPTH DIGITIZING SYSTEM

Basically digitizers fall into two categories, those designed for shallow water operation and those designed for deep water operation. The reason for the different design consideration are due to the differences in data rate.

Equipments designed for digitizing in shallow water (less than 100 metres) are generally able to process echoes at a rate much faster than one/second. With this high data rate they normally incorporate averaging features to improve the accuracy of the depth measurement. Shallow water digitizers are not automatically programmed and process only one pulse during the time interval for the water column. Since the pulse repetition frequency is high, this is completely adequate for efficient operation in shallow water.

Deep water digitizers are designed for optimum performance in water depths greater than 1000 metres and are normally automatically programmed to change the transmission sequence as the depth changes. They are designed to process pulses at a faster rate than the propagation time for the water column and normally operate with two to five transmitted pulses in the water simultaneously. Even with this multiple pulse operation, the data rate in deep water is not high enough to utilize averaging circuits to improve performance, so this feature is not incorporated.

Deep water digitizers may be used in shallow water, but their increased complexity coupled with the fact that they do not utilize averaging circuits reduces their effectiveness. Shallow water digitizers may be used in water depths up to and exceeding 1,000 metres, but since they operate with only one pulse in the water at any one time, their effectiveness decreases as the water depth increases.

Depth is displayed on the front panel of a digitizer normally to the nearest 0.1 metres. The digitizer presents data to the data acquisition system at a predetermined rate usually in metres and tenths of metres. The time interval corresponding to depth is measured by counting the number of cycles of a crystal-controlled oscillator during the propagation interval. The frequency of the oscillator is determined by the assumed sound velocity and the units in which data is being recorded.

Most digitizers are designed to set a digital gate symetrically about the position of the last echo. The digital gate has a width of 10 or 20 metres for deep water systems and much less for shallow water systems with its position being updated to follow sea bottom undulations. The digital gate is very effective in preventing the triggering of the 'stop' circuitry in the digitizer by ship's radiated noise. Since the digital

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gate is quite narrow, it is most important that the echo density be high to ensure that after missing several echoes due to cavitation or ship's radiated noise, the next strong echo will still be within the listening area.

Digitizers are becoming a more and more common accessory in echo sounding systems and recent sounders have been designed to incorporate the digitizer as part of the sounder.

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9.0 ELECTRONIC SWEEPING

Early hydrographers obtained depth measurements with lead line and obtained position of survey vessels by visual and/or mechanical means. At about the time of the second world war, electronic echo sounders came into use and electronic positioning systems soon followed.

Echo sounders are a vast improvement over lead line techniques, because of the increased speed of obtaining information, less physical exertion and because they provide a permanent record. They are also a vast improvement because they offer continuous coverage on any survey line. Although this coverage is continuous it does not provide complete information on the bottom topography. With a conventional echo sounding system operating in ten metres of water, a line spacing of five metres would be required to approximate total bottom coverage. Total bottom coverage is therefore seldom obtained and when it is, the technique is normally to do it by mechancial means. The most common example is a sweep scow operating with a sweeping boom in the St. Lawrence River to sweep the navigation channel and to obtain pre and post dredging data.

Side scan sonar has been used by hydrographers to interpret between the sounding lines but for the most part a side scan sonar will only delineate the existence of shoals and obstructions rather than measure their amplitude. Side scan sonar nevertheless is an important survey tool, although it does not provide the total bottom coverage required to carry out electronic sweeping in areas of navigation hazards.

The most important advance in electronic sweeping in recent years has been the introduction of the multiple beam echo sounder. A number of companies manufacture multibeam echo sounders, the most common being the Ross, Raytheon and General Instruments types. The Ross and Raytheon equipments employ a number of separate transducers all fitted in buoyant dragforms that are separated mechanically and towed by the survey launch or surface vessel. The approach by General Instruments Corporation is

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different. General Instruments Corporation have patented a cross fan-beam technique and in the remainder of this Section the operation of this equipment will be described.

The BOSUN system developed by General Instruments Corporation consists of transducers, console, data logger, digital compass, magnetic tape transport and pitch and roll sensors. The system is large and complicated and the data stored on the magnetic tape noramlly includes sounding data for the area surveyed together with positioning data. Computer programs have been developed so that all data is software corrected and the system together with a computer and plotter is capable of producing a contoured field sheet.

The 36 KHz transducer assembly in the BOSUN system consists of two identical projector/hydrophone arrays, one port and one starboard. Each projector produces a 5° x 90° fan-beam with the broad axis of the beam perpendicular to the ship's track. The hydrophones receive the reflected energy and the signals are phase-delayed and summed to form 11 adjacent 5° x 30° listening cones whose major axes lay perpendicular to that of the projector fan-beams. The receiving fan-beams intersect the projected fan-beams in 11 adjacent 5° squares along the insonified strip. On a flat bottom, in 30 metres of water, a 5° square is equivalent to a coverage of 2.6 x 2.6 metres for the vertical beam and 2.6 x 5.3 metres for the outermost beam. The system time-shares the port and starboard arrays, alternately making 11 simulteneous slant-range measurements. A one-beam overlap of the two arrays produces a 21-beam system giving a cross-track coverage of approximately 2.6 times depth along a 5° x 105° strip perpendicular to the ship's track. The beam formation on transmit and receive is illustrated in Figure 9-1 and a simplified diagram of beam geometry illustrated in Figure 9-2.

Pitch and roll information is required to make accurate slant-range measurements. Pitch errors may be minimized by a null-pitch keying mode in which the projector transmits only when the pitch is within an adjustable ($\pm 2^{\circ}$ to $\pm 5^{\circ}$) "window" with respect to vertical. The roll is digitized within a range of $\pm 20^{\circ}$ and with a specified accuracy of $\pm 1^{\circ}$.

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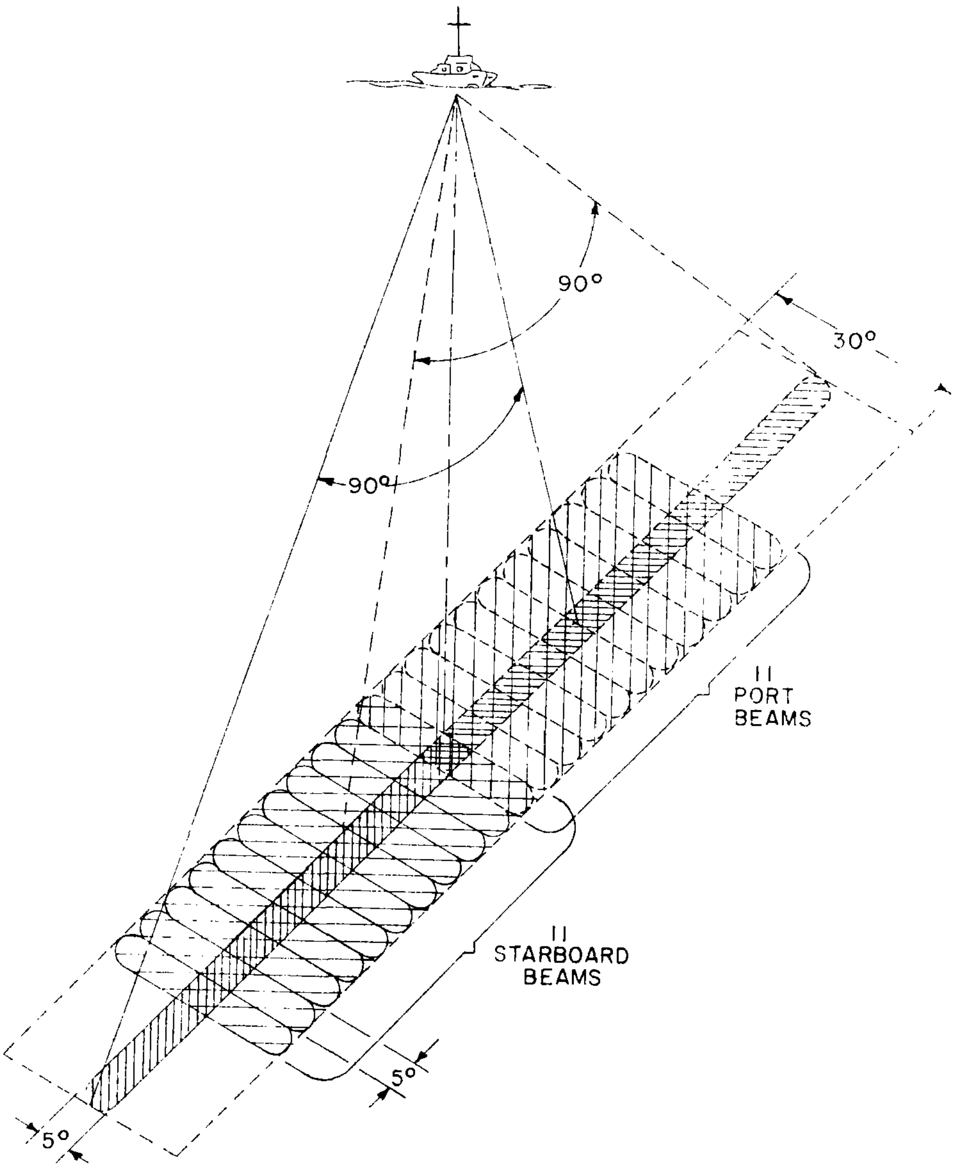

FIGURE 9-1 BOSUN MULTI-BEAM SONAR, BEAM FORMATION

The controls for the operation of the sonar portion of the system are contained in a console. Functions such as keying (null-pitch, external, or internal), gain (manual or time-varied) projector attenuation and range are selectable by the operator. A video display of the 21 beams is roll-compensated and provides a monitor for the analogue output of the system. The most vertical beam, selected by the roll-compensating circuit, is available for a graphic recorder.

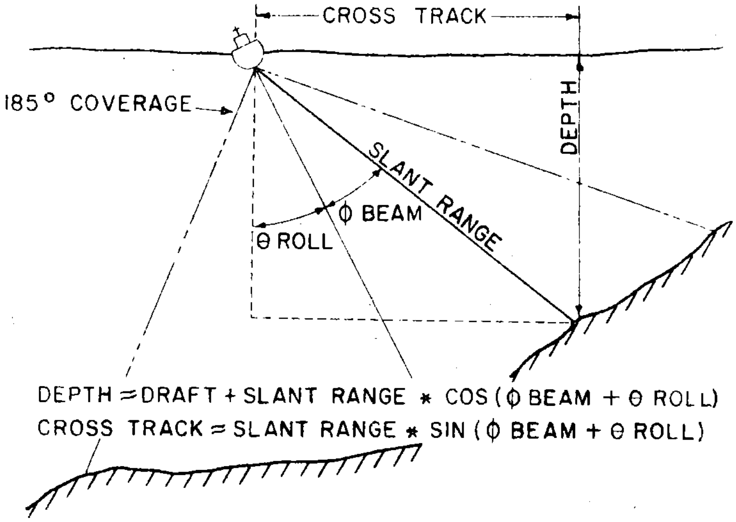

FIGURE 9-2 BOSUN MULTI-BEAM SONAR, SIMPLIFIED DIAGRAM OF BEAM GEOMETRY

The BOSUN system has been described in some detail because it is felt that it is typical of the type of equipments that will in the future be available for electronic sweeping. In addition to total bottom coverage over a wide swath the BOSUN system also provides very good bottom delineation.

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10.0 SYSTEMS IN USE

Any section on "Systems in Use" is bound to be out of date very soon. This is because the Canadian Hydrographic Service has been quite progressive in obtaining new echo sounding systems and evaluating them while they are still in the prototype stage. The last few years have witnessed a steady decline in the number of Kelvin Hughes rotary type sounders and an increase in the number of Raytheon Ross and Atlas Sounders.

Since this report has been prepared for classroom instruction, and since the systems will change with time it is not practical to present information on particular systems. Instead, the systems in use at the time the lectures are presented will be explained in detail.

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11.0 ACKNOWLEDGEMENTS

The contributions of Regional Hydrographers Headquarters Training Staff as well as the students of Hydrography II 1976, who made a number of valuable suggestions, are acknowledged. I also acknowledge the diligence of Mrs. Ada McAdam in typing the report and Mr. Edward Belec in preparing a number of the illustrations.