CHAPTER 7

SONAR

Sonar (derived from the words SOund Navigation And Ranging) uses pulsed transmission of sound waves in water for detecting, tracking, and ranging of underwater objects, and is analogous to radar which uses pulsed transmission of radio waves to detect, track, and determine the range of objects on the surface or in the air. Because ships afloat are partially submerged, sonar is used for the detection of surface ships and submarines, for measuring water depths (depth sounding), and also as a navigational aid. Commercially, sonar is used for detecting shoals of fish.

Sonar equipment may be of an active nature, transmitting sound energy into the water and then obtaining bearing and range information from returning target echoes; or it may be of a passive nature, depending upon the sound originating from the target (such as screw cavitation, machinery noise, and the like) for bearing information.

Before discussing the various sonars, let's briefly review some of the basic principles of sound.

SOUND

Everything you hear is a sound. This statement does not mean, however, that when you hear nothing there is no sound, because many sounds are beyond the frequency range of the human ear. Sound is a mechanical disturbance of the surrounding medium and may be divided into three frequency groups. They are (1) ultrasonic—those frequencies above the audiofrequency range; (2) sonic—those frequencies within the audiofrequency range, and (3) subsonic—those frequencies below the audiofrequency range. As stated in chapter 2, the audio range is from approximately 15 to 20,000 hertz. The actual range of frequencies that the human ear can detect varies with the individuals themselves.

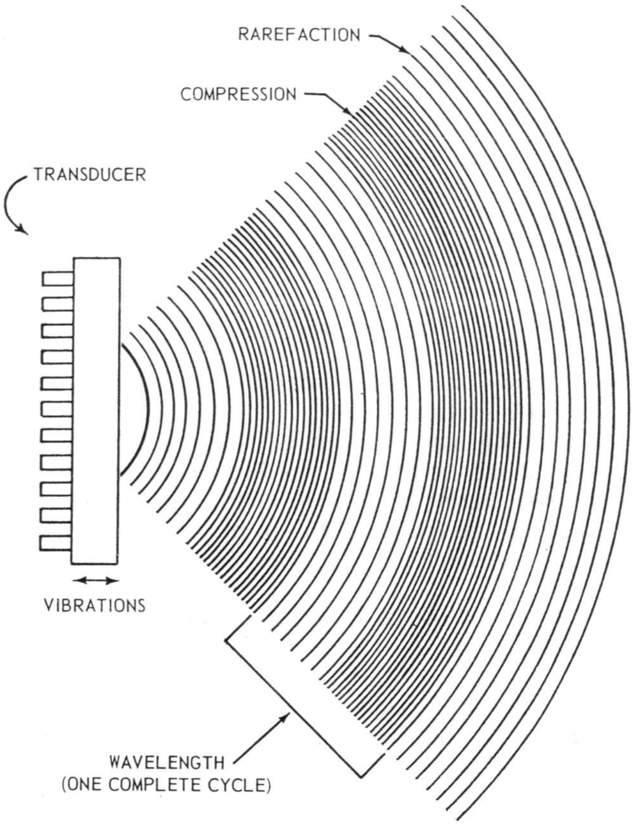
To make use of sound, it is necessary to have a sound source, a medium for the sound to travel through (sound does not travel in a vacuum), and a detector to pick up the sound so that information can be obtained from it.

GENERATION AND TRANSMISSION OF SOUND

Any object that vibrates back and forth disturbs the material surrounding it, whether that material is a gas, solid, or liquid. The object that vibrates is the sound source (fig. 7-1). It may be a bell, a loudspeaker, or a sonar transducer.

A transducer is any device that converts energy from one form to another. In sonar, the transducer contains a diaphragm that is made to vibrate at the frequency of an applied voltage. When the diaphragm moves out, the medium next to it is compressed. As the diaphragm moves back, the particles in the medium move apart, causing a rarefaction or low pressure area next to the diaphragm. When the diaphragm moves out again, a new compression is produced. The out-and-in movement of the diaphragm continues, and the alternate compressions and rarefactions spread in a series of waves called compression waves. Compression waves, propagated through a medium, are sound waves.

The number of complete cycles (one compression and one rarefaction) completed in each second is the frequency of sound wave train. This frequency, of necessity, is the frequency of the vibrating body (source). The speed at which the sound wave train travels outward depends upon the nature of the material or medium surrounding the body. In 35 percent salt water, sound travels at approximately 4800 feet per second at 39°F.



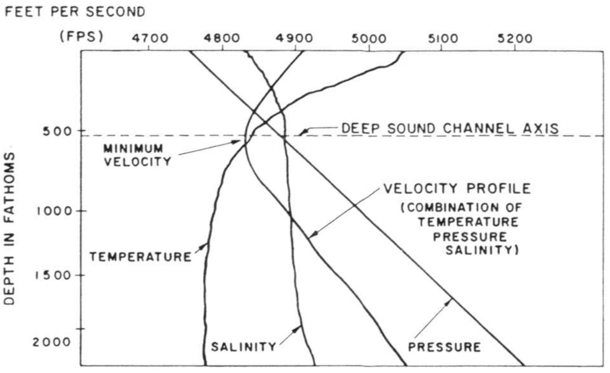
4.221
Figure 7-1.—Producing sound waves.

VELOCITY PROFILE OF THE OCEAN

The temperature, pressure, and salinity of sea water all affect the velocity of sound in the medium of the ocean. In each case, as the values of these variables increase, so does the speed of sound increase, or: higher temperature = higher velocity; higher pressure = higher velocity; and higher salinity = higher velocity.

Because sound will refract, or "bend" from areas of high velocity to those of low velocity, oceanographers say the "sound is lazy." Each of the variables affecting the speed of sound in ocean water is therefore important.

The effects of temperature, pressure, and salinity combine to form a velocity profile for the ocean (figure 7-2). Temperature is the variable exerting the greatest impact upon velocity near the surface. Relatively abrupt and large changes may occur in the first few hundred feet of depth. The temperature of the ocean levels off, often after the first few thousand fathoms, and remains at about 30°F., so that it is less important as a variable at great depths. Pressure as shown on the graph, is a steadily increasing effect, becoming greater as the depth increases and thereby increasing velocity in a linear function. Salinity varies less throughout the deep ocean areas, and has relatively less effect on the speed of sound than temperature and pressure.



120.87
Figure 7-2.—Velocity profile for the ocean.

The velocity profile, resulting from these effects, shows a point of minimum velocity, normally occurring between 500 and 700 fathoms below the surface. This area, where the speed of sound is lowest, is called the deep sound channel axis. Below the channel, pressure causes velocity to increase, and above it, temperature has the same tendency. Within this area, low frequency sounds can travel thousands of miles at the reduced velocities they seek.

SOUND PATHS AND MODES OF DETECTION

Most submarine detection by shipboard sonars is made using the surface duct path of sound travel. This is so, because most sonars in today's ships are capable of only this mode of operation and because submarines operate in the first few hundred feet of water, or in the surface duct. As the ocean's sound velocity profile shows, temperature has much more effect near the surface than do either of the other variables causing sound to refract.

Information about the sea's temperature is gained from a device called a bathythermograph, which is described in the next chapter.

Thermal Gradients

Thermal gradients are indices of the changes in temperature vs depth near the surface. There are three types of thermal gradients:

NEGATIVE GRADIENTS.—A negative gradient exists where an increase in depth is accompanied by a decrease in temperature. Sound in a negative gradient will bend down, seeking the lower velocity caused by cooler water (fig. 7-3).

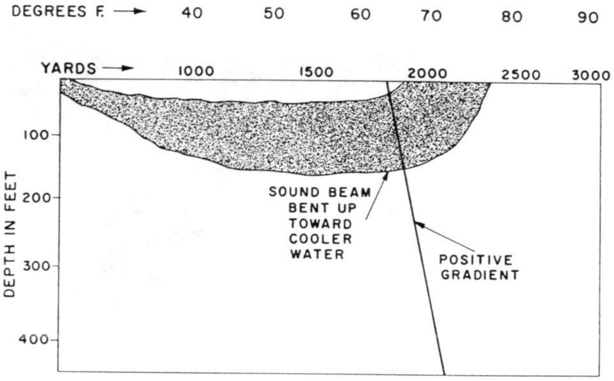
POSITIVE GRADIENT.—A positive gradient is one where cooler water overlies warm, and an increase in depth yields a rise in temperature. Sound will refract upward toward the surface where the cooler water produces lower velocities (fig. 7-4).

ISOTHERMALS.—Isothermals are the third type of gradient, and exist where a change in depth shows no change in temperature. Sound in an isothermal will bend slightly upward because of the effect of pressure. Lower pressures result in lower velocities; the reduced pressure at the surface will be sought by sound where temperature does not change (fig. 7-5).

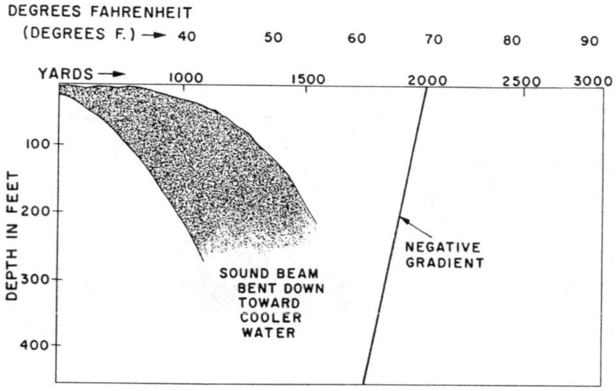
Layer Depth

Layer depth is defined as the "greatest depth at which the maximum temperature is found." Layer depths are the most important single factor determining sonar ranges in the surface duct. A layer can be caused by an isothermal condition terminating in a negative gradient (fig. 7-6) or a positive gradient into a negative (fig. 7-7). Sound in either the isothermal or positive gradients will bend upward causing it to return to the surface; while sound in negative gradients will bend downward resulting in shorter ranges. Generally, the deeper the layer, the greater the surface duct sonar range (figs. 7-6 & 7-7).

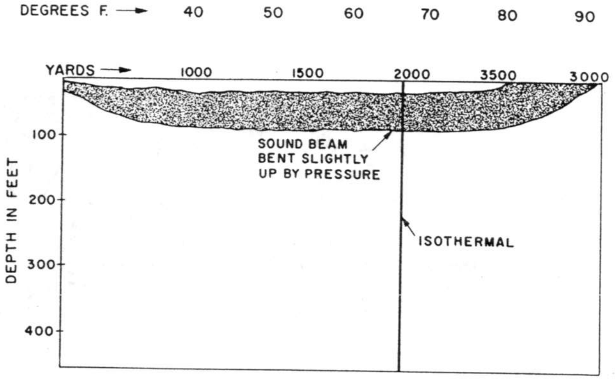
BOTTOM BOUNCE.—For long-range search in water depths over 500 fathoms, a bottom reflection or bottom bounce mode of operation may be conducted with newer sonar equipments.



71.30(120C)
Figure 7-4.—Positive gradient.



71.31(120C)
Figure 7-3.—Negative gradient.



120.88
Figure 7-5.—Isothermal gradient.

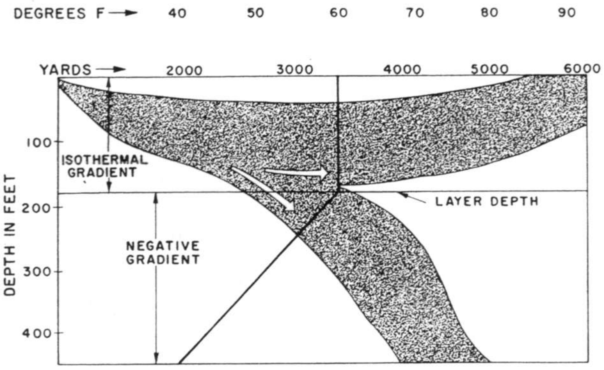


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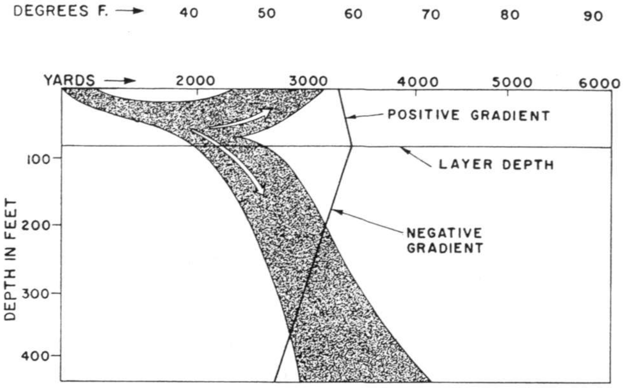
Figure 7-6.—Isothermal gradient into a negative gradient.

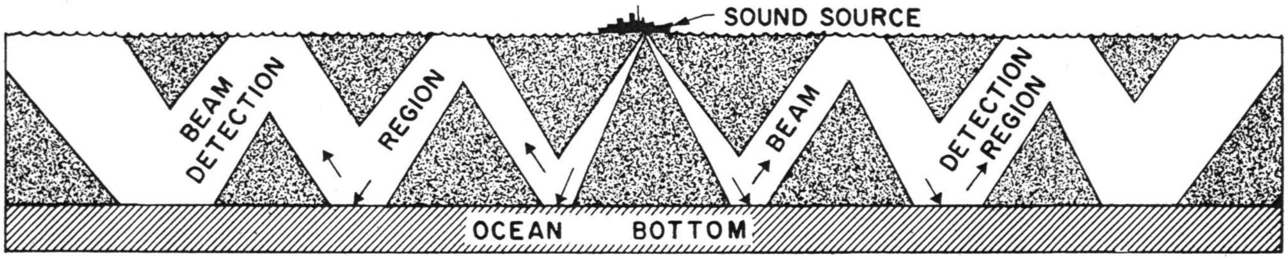


120.90

Figure 7-7.—Positive gradient into a negative gradient.

The bottom bounce effect is accomplished by using automatically selected transducer angles to reflect the sound beam up from the ocean floor. Preselected transmission angles cause sound to be reflected from the bottom into regions not normally possible with the velocity structure. The bottom bounce effect is illustrated in figure 7-8.

Bottom bounce is in part successful because the angle of the ray path (0° to 42°) is such that the sound energy is affected to a lesser degree by velocity changes than the more nearly horizontal ray paths of other transmission modes. Transmission loss for bottom bounce can usually be predicted on the combined basis of: (1) spherical spreading along the slant range to the receiver; (2) absorption loss dependent on water temperature and frequency of sound source; (3) a loss associated with successive bottom reflections; and (4) bottom composition. Long range paths can occur with water depths greater than 1000 fathoms depending on bottom slope, but at shallower depths multiple bounce paths develop which produce high intensity loss. For this reason, bottom bounce is not used in less than 500 fathoms. It is estimated that 85 percent of the ocean is deeper than 1000 fathoms, and bottom slopes are generally less than or equal to one degree (as an average figure). However, the slope must be 3 degrees or less before any bottom bounce operation is possible. On this basis, relatively steep angles can be used for single bottom reflection to ranges of approximately 20,000 yards. With steep grazing angles, transmission is relatively free from thermal effects in the surface region and the major part of the sound path is in nearly stable water.



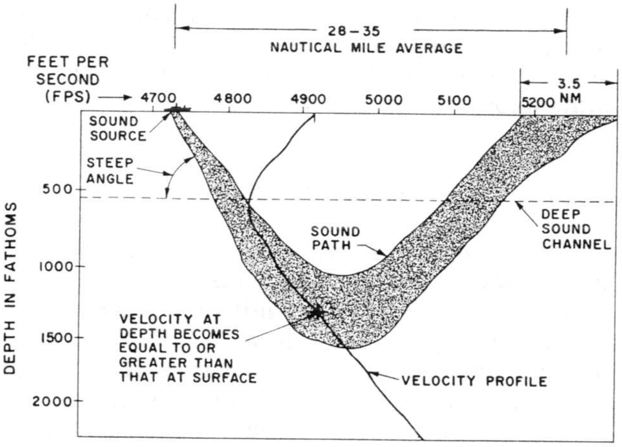
51.7(120C)

Figure 7-8.—Bottom bounce.

Each bottom reflection is received from a limited range, and the maximum range of reception for each reflection is defined by the limiting ray which depends on bottom slope and the sound velocity profile. The minimum range of reception is determined by the critical angle ray. Where rays strike the bottom at angles more horizontal than the critical angle ray, there is perfect reflection, and the interval of best reception is between the limiting ray and the critical angle ray.

The rays which strike the bottom at angles steeper than the critical angle ray are partially refracted into the bottom with energy loss; this loss increases with increasing frequency of the source and grazing angle.

CONVERGENCE ZONE DETECTION.—Convergence zone detection (fig. 7-9) is made possible by a phenomenon in the ocean which causes sound, after reaching a great depth, to return to the surface approximately thirty miles from its source. In discussing this mode of detection, and the deep sound channel detection in the following paragraph, we are no longer concerned with the shallow water and layer depths discussed above. In order for sound to travel the convergence zone path, two criteria must be met; (1) The sound must travel through the point of minimum velocity, or deep sound channel, at a steep angle (if it reaches this area at a shallow angle as shown in figure 7-10, it will be trapped, or ducted); and (2) the sound must reach a depth at which the velocity profile (fig. 7-9) shows a speed equal to or greater than that at the surface. When this point is reached, the effect on velocity due to pressure will cause the sound to return by a path similar to the one it followed going down.



51.8.1(120C)
Figure 7-9.—Convergence zone detection (steep angle).

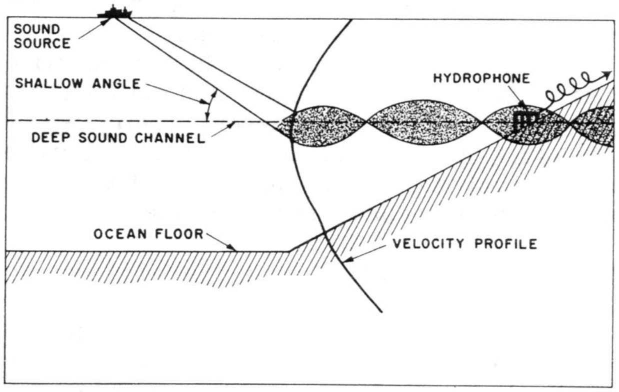
DEEP SOUND CHANNEL DETECTION.—The fourth path of sound travel again involves the velocity profile. If sound enters the deep sound channel, in the vicinity of 500-700 fathoms, at a shallow angle, it can be trapped since it tends to remain at low velocity. The shallow angle allows the sound to be influenced gradually and once trapped, low frequency sounds can be ducted over thousands of miles. Systems using hydrophones on the ocean floor make use of this path of sound travel.

TRANSDUCERS

A transducer is a device that converts energy from one form into another. An example is the changing of electrical energy into mechanical energy or vice versa. This is the principle by which sonar transducers operate.

MAGNETOSTRICTIVE PROCESS

Magnetostriction is a process whereby changes occur in metals when they are subjected



51.8.2(120C)
Figure 7-10.—Convergence zone detection (shallow angle).

to a magnetic field. If a tube made of nickel is placed in a magnetic field, for example, it changes length as a result of the magnetostrictive effect.

The elements of the transducer each have nickel laminations pressed in a thermoplastic material and wrapped with a coil of wire. Permanent magnets are so mounted that they provide energy for polarizing the nickel, thus establishing an operating bias for the system. During transmission when alternating current is passed through the coil, the tubes shorten on lengthen with each half-cycle of the alternating current. The resultant displacement of a diaphragm attached to the ends of the nickel tubes causes sound frequency vibration to be transmitted through the water.

ELECTROSTRICTIVE PROCESS

The electrostrictive process in transducers relies on the ability of certain manmade ceramics to produce a mechanical force when a voltage is applied; or conversely, produce a voltage when a mechanical force is applied.

When ferroelectric material such as lead zirconate titanate compound is placed in an electric field, it changes in dimensions. This effect is very similar to the piezoelectric effect found in some natural crystals whose oscillations change in step with changing electrical or mechanical forces. For the ceramic material to acquire the piezoelectric characteristic however, an extremely high voltage is initially applied to the material for several minutes to polarize it permanently to give an operating bias to the system. Then, as alternating current is applied, the material will shorten or lengthen with each half-cycle to set up mechanical vibrations at the desired frequency.

Ceramic tranducers have high sensitivity, high stability with changing temperature and pressure, and relatively low cost. Their greatest advantage lies in the mechanical properties of the material, which allow construction of almost any reasonable shape or size.

CYLINDRICAL ARRAY

A cylindrical array (fig. 7-11) illustrates a transducer made up of many individual elements stacked in vertical columns called staves. Each stave (shaded area, fig. 7-11) has nine elements, and the total number of staves arranged in cyclindrical form gives a 360° search in azimuth. The physical size of the individual elements in the transducer is related to the operating frequency and power output. The power output required determines the physical dimensions of the array.

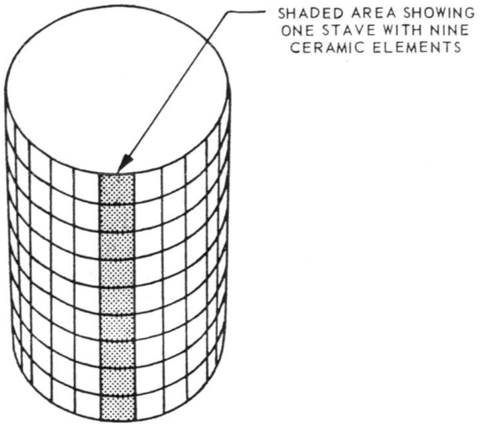


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Figure 7-11.—Cylindrical array arrangement.

TYPES OF SONAR

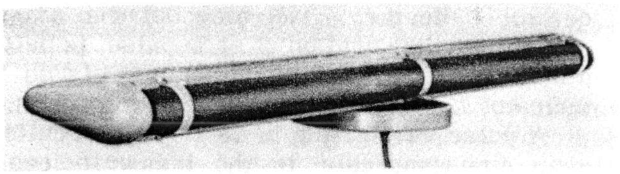
The two general types of sonar are referred to as active sonar and passive sonar. The active sonar is a transmitting (pinging) and receiving apparatus. It is capable of transmitting underwater sounds that strike targets and are returned in the form of echoes. The echoes so returned are received and presented in a manner to indicate the range and bearing of the target. Passive sonars do not transmit sound. They merely listen for sounds produced by the target to obtain accurate bearing. Estimated range information can be obtained by triangulation.

Active sonars normally are associated with surface ships, whereas passive sonars are used primarily by submarines. Submarines also have active sonars. Integrated sonar systems aboard ASW vessels often employ passive equipment in conjunction with active equipment to extend their capabilities.

PASSIVE SONAR

Passive sonar depends entirely upon the target's noise as the sound source. So efficient is passive sonar that sounds many miles away may be identified and their source tracked.

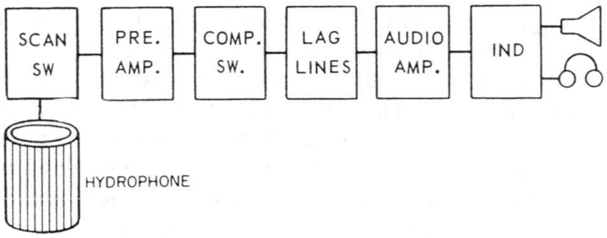
An electoacoustic transducer, called the hydrophone (fig. 7-12), is used to detect underwater sounds. The hydrophone contains either a ceramic material or a metal alloy that reacts to mehcanical stress. When subjected to stress, such as that caused by sound waves striking the hydrophone, the material vibrates or undergoes a change in size. These vibrations or changes in size cause a small voltage output from the hydrophone. The frequency of the output voltage is essentially the same as that of the received sound waves.



72.62

Figure 7-12.—Hydrophone.

Passive sonars at one time used the single line hydrophone system, which was trained physically to obtain bearing information. Today's passive sonars utilize a hydrophone array, consisting of a number of hydrophones connected together around a cylinder. Although the array is not trained physically, a directional effect is obtained electrically by employing a compensator switch. The switch is rotated and positioned by the sonar operator at the control console. A simplified block diapgram of the array type of passive sonar is shown in figure 7-13.



76.55

Figure 7-13.—Block diagram of array type of passive sonar.

When the sound waves are received by the individual hydrophones, they are converted to electrical energy. The electrical signal from each hydrophone in the array is then fed to a separate preamplifier. After amplification, the signals are collected by the compensator switch as it samples the output of each preamplifier. From the switch, the collected signals enter the lag lines. The position of the switch indicates the direction from which signals are being received.

The circular arrangement of the hydrophones causes the signals to be out of phase with one another at the output of the preamplifiers. For the signals to be usable, they must be placed in phase with one another. This action is accomplished in the lag lines by delaying the first received signals a proportional amount until the last received signals catch up. Once the signals are in phase, they are additive. As a result, we have a strong signal to feed to the audio amplifier.

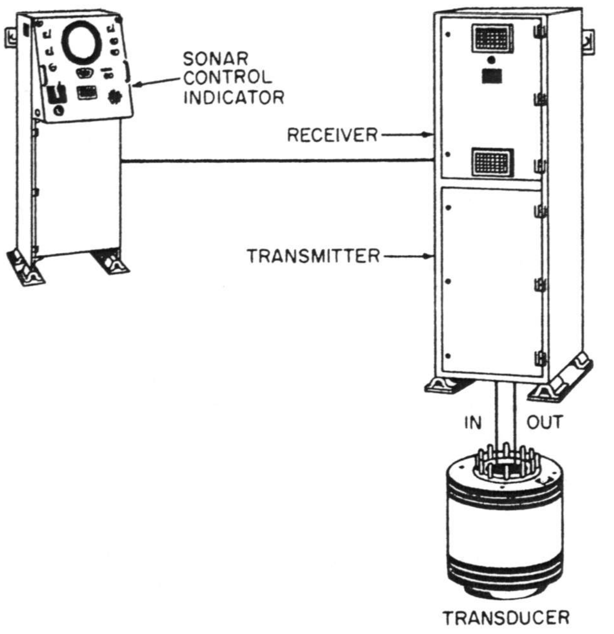
From the audio amplifier, the signal is fed to the indicator, and there it is presented both visually and audibly.

ACTIVE SONAR

The major components of a simplified active sonar system are similar to those seen in figure 7-14. In this set, the sonar transmitter consists of an audiofrequency oscillator and an amplifier. The transmitter feeds a short powerful pulse to the transducer for transmission into the water. The signal pattern is transmitted in 360° of azimuth in an omnidirectional pulse.

The transducer converts electrical signals into sound waves. It also changes the received sound echoes back to electrical signals.

Another important part of the active sonar system is the sonar receiver. It functions much the same as the conventional superheterodyne receiver. In this unit, the extremely small audiofrequency electrical signals resulting from the echo are amplified and converted to stronger signals that can be heard through a loudspeaker. The sonar receiver also feeds the amplified echo signal into the various video indicating devices such as the cathode-ray tube (CRT) on the control indicator.



71.47
Figure 7-14.—Simplified active sonar system.

Types of Transmission Modes

There are two widely used transmission modes. These are the omnidirectional transmission mode (ODT) and the rotational direction transmission mode (RDT). Omnidirectional transmission involves the radiation of sound energy in all directions to produce a 360° circular radiation pattern. This nondirectional sonar tranducer also receives returning echoes from all directions and converts them to intelligible video and audio information, thus providing indications of all underwater objects around the ship.

Rotational direction transmission involves the transmission of a directional beam which can be pointed through 360 degrees. An analogous effect can be obtained by holding a flashlight horizontally and turning it on and off (pulsing) while rotating yourself clockwise to complete a circle (azimuth). By electronically scanning in this manner, the transducer can also receive echoes from all degrees of azimuth.

Transmission

The functions of the principal components in a scanning sonar system are understood best by breaking them down into three basic operations: transmission, reception, and presentation. In the following discussion, refer to the block diagram in figure 7-15. This illustration shows the keying pulses and transmitted output signals in solid lines; returning echo signals are indicated by dotted lines.

Initiating keying pulses is an automatic function of the keying circuits in the sonar control indicator. The time between pulses, as well as the duration of each pulse, is determined by the position of the controls on the indicator console.

A pulse originating in the keying circuits is sent simultaneously to the transmit-receive (T/R) switch and to the transmitter. When this pulse is received by the transmit-receive switch, the transducer is switched from the receiver circuits to the transmitter circuits, and it remains connected there until the outgoing signal is transmitted. At the end of the transmission, the switch automatically reconnects the transducer to the receiver circuits.

The key pulse triggers the audio oscillator in the sonar transmitter. The signal generated by the oscillator is amplified to the required power level, and then is delivered to the transducer via the transmit-receive switch. The signal is applied simultaneously to all of the transducer staves (fig. 7-11), and a sound pulse is emitted in all directions.

The acoustical wave released into the water by the tranducer continues outward, ever expanding as it goes. When this wave strikes an object capable of reflecting the sound, a small portion is reflected back to the transducer.

Reception

When a portion of the transmitted signal is returned to the transducer, it is converted to an electrical signal for use by the equipment. After conversion the signal is fed to a preamplifier (via the transmit-receive switch) for amplification to a usable energy level. Each stave of the transducer has its own preamplifier. The outputs of the preamplifiers are sent to the transducer scanning assembly for distribution to the receiver. The transducer scanning assembly contains a video scanning switch and an audio scanning switch.

The video scanner rotates continuously, thereby sampling the echoes from each element of the transducer, giving an effect similar to

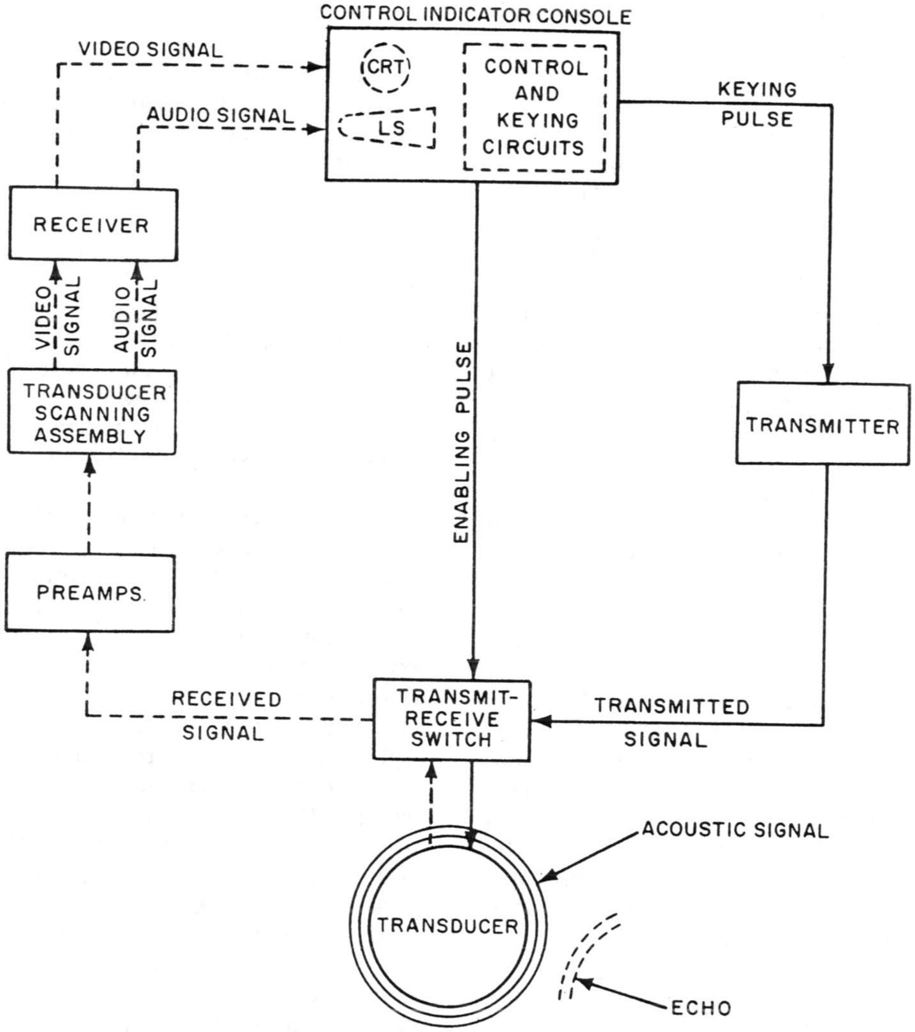


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Figure 7-15.—Block diagram of a basic scanning sonar system.

that produced by a rapidly rotating and highly directional transducer. The received signal at the receiver input comprises both video and audio signals (fig. 7-15).

The audio scanner does not rotate continuously. It is positioned as desired by the sonar operator. In this manner, audio signals can be received from any particular direction. The output from the audio scanning switch is applied to the audio channel of the receiver.

In the receiver, the video and audio signals are detected and amplified, as necessary, for presentation in the control indicator console.

Presentation

For the returning echo to be of any value, it must be presented in such a manner that the information it represents can be interpreted.

Before entering the receiver, the returning echo is converted from acoustical energy to electrical energy in the transducer, from which it is sent to the video scanning switch (not shown). The rotation of this switch is synchronized with the sweep presentatation, and the echo appears as a brightening of the sweep on the CRT at the bearing from which it originated. The sweep, seen on the CRT as an expanding circle, is adjusted to expand at a rate proportional to half the speed of sound in water. This adjustment is necessary because the transmitted pulse must travel to the target and return.

For a target 2000 yards away, as an example, the sound must travel a distance of 4000 yards. By adjusting the sweep on the CRT to travel at half the speed of sound, the sweep reaches a point equivalent to 2000 yards from the center of the scope at the same time the sound energy returns to the transducer. This energy, or echo, produces a brightening on the scope at a distance from the scope center. The distance can be measured to find the range to the target.

The audio signal is sent from the receiver to the loudspeaker or headset. Together with the CRT information, the audio intelligence is utilized in ascertaining the nature of the target.

A line called the cursor is printed on the scope after each sweep. Because of the long persistency of the cathode-ray tube, the target echo remains visible for a short time to determine range and bearing. The operator can control the direction (bearing) and length (range) of the cursor with the bearing and range handwheels. By placing the tip of the cursor on the target, he can read the target's true bearing and range from the dials located on the sonar control indicator.

Various switches and controls also are located on the sonar control indicator. Their purpose is to give a better target presentation. These switches and controls are explained in the equipment technical manual supplied with each sonar equipment.

VARIABLE DEPTH SONAR

The thermal layer in the ocean is one of the problems affecting the ability of sonar to detect and maintain contact with a submarine. These layers reflect or bend sonar signals so that a submarine lying or cruising below a particular layer may go undetected. To overcome this obstacle, the variable depth sonar (VDS) was developed.

To differentiate between the two types of sonars, the conventional sonars are sometimes referred to as hull systems while the VDS are referred to as towed transducer systems.

Because the target depth usually is unknown, a combined use of VDS and hull-mounted sonar provides coverage for both deep and shallow targets. (VDS alone does not always give adequate coverage for shallow operating targets.)

When used in this manner, there are four operating conditions which can be selected by the operator. They are (1) hull transmit and receive, (2) towed transmit and receive, (3) towed transmit and hull receive, and (4) hull transmit and towed receive. Operating frequency of the towed transducer is derived from the existing shipboard sonar equipment.

The general function of the VDS equipment is to make use of the pulsed power for the transmission of sonar signals by the shipboard sonar equipment. This pulsed power is transmitted via the electrical cable that extends through the center of the mechanical armor of the tow cable to the towed transducer. The transducer, operating on acoustic principles, converts the electrical energy to mechanical energy and transmits it to the surrounding water. When the transmitted sound wave strikes an object with adequate reflective characteristics, a portion of the total energy is reflected back to the towed transducer. The direction of the echo indicates the bearing of the object. The transducer then converts the mechanical energy of the echo into an electrical signal, whose magnitude and phase are determined by the intensity of the received echo. This electrical signal is transmitted up through the tow cable to the sonar system for display and interpretation.

A later type of VDS is the IVDS (independent variable depth sonar) which has its own hoist and sonar system independent of ships sonar system.

MINE HUNTING SONAR

Until relatively recent years minesweeping was the only available means for eliminating the danger of mines in naval warfare. It still is one of the prime methods of removing or neutralizing these hazards to safe navigation, but supplementing this plan is the procedure of detecting the actual location of the mines so that sweeping operations may be employed in only the exact required locations.

In many instances, the known location of mines is sufficient to neutralize their effectiveness. Marking the location of a minefield with buoys permits ship traffic to remain clear of the danger area. Thus no further action is required when this obstruction can be bypassed safely and expeditiously.

Mine hunting includes all measures for detecting, accurately locating, identifying, and clearing mines individually. The location of mines by means of high-resolution, short-pulse sonar, mine detecting sets is becoming increasingly successful. Mine hunting sonar aids in distinguishing between mines and the accumulated debris cluttering the bottoms of busy harbors and their approaches.

FATHOMETER (DEPTH-SOUNDING SONAR)

The depth of the sea can be measured by several methods. One is by dropping a weighted, distance-marked line (lead line) to the bottom of the water, and observing the depth directly from the line. The chief disadvantage of this method of determining depth is that its use is limited to very shallow water.

Sound is another method of measuring depth. A sound pulse is transmitted, aimed at the bottom of the sea, and its echo is heard. The time between transmission and echo reception is considered in relation to the speed of sound through water, then the depth is determined thereby. Depth-sounding sonars, or fathometers, apply this principle of sound physics to determine the distance to the bottom of the sea.

Usually, depth-sounding sonars are called fathometers. They operate on the same principle as submarine-detecting sonars, but, because of the reduced power requirement, they are much smaller in size and have fewer components. A representative block diagram of a depth-sounding sonar system is shown in figure 7-16.

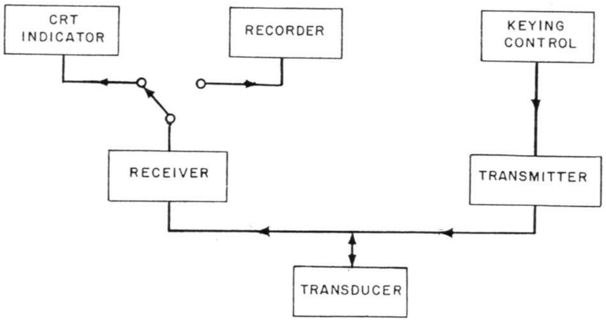

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Figure 7-16.—Block diagram of depth-sounding sonar system.

When the system is keyed (either automatically or manually), a pulse is generated in the transmitter. The pulse is amplified and applied simultaneously to the transducer and the receiver circuit. The transducer converts the signal to acoustical energy and transmits it downward into the water.

The returned bottom echo is converted by the transducer to electrical energy and applied to the receiver. The received signals are amplified and presented on the recorder or the cathode-ray tube indicator.

SONAR ACCESSORIES

In many instances, it is difficult to categorize an equipment as an accessory because of its role in the overall sonar system. For example, the remote indicator is seldom thought of as an accessory. It is not essential to the operation of the basic sonar system, consequently it is an accessory. The bathythermograph is isolated from any sonar system. The information obtained from the bathythermograph is necessary, however, for the effective utilization of sonar.

The foregoing accessories and others are described and illustrated in the next chapter.