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UNDERSEA TECHNOLOGY

SIDE SCAN SONAR

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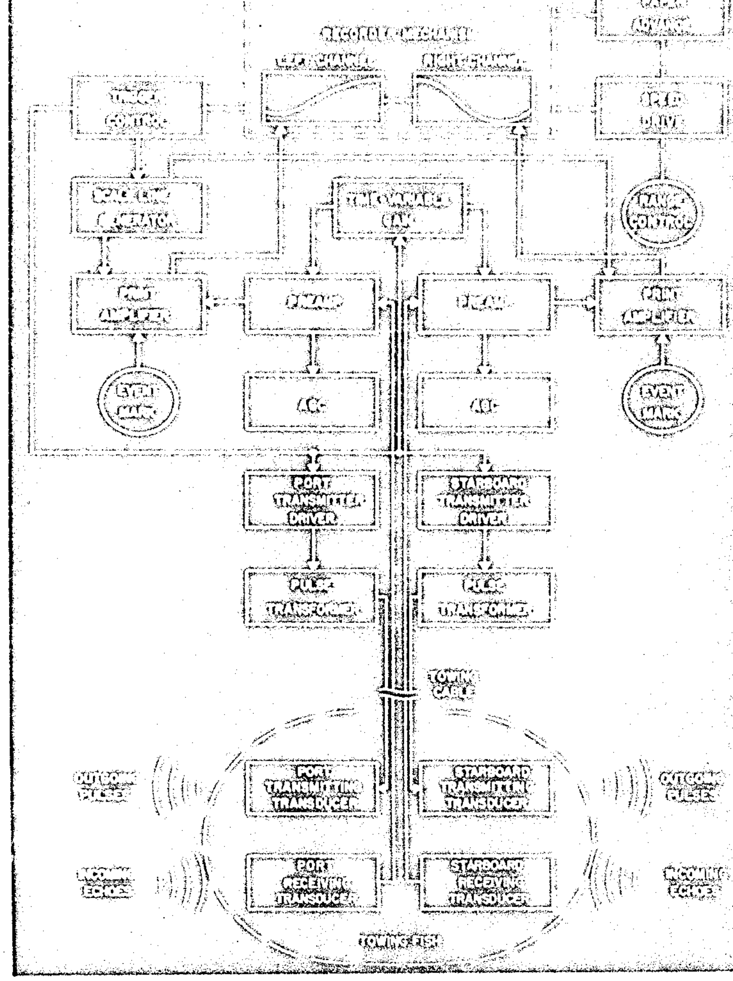

Figure 1. Block diagram of dual channel side scan sonar.

ONE OF THE greatest limitations to man's conquest of the sea is that his best observation tool — his eye — is severely limited in the underwater environment. Here, visibility via the eye, television or photography, is on the order of 30 meters in the best of circumstances, and it is often limited to less than one meter. On the other hand, sound or acoustic energy, is capable of reaching out hundreds and even thousands of meters through the ocean.

One of the most useful tools for undersea acoustic viewing is the side scan sonar which is a compromise between the ultra high resolution, short range acoustic lens imaging systems and the long range, low resolution submarine sonars. This system is able to locate and outline objects and terrain on the ocean floor. The technique consists of repeatedly projecting short pulses of acoustic energy in a fan shaped beam (narrow in the horizontal plane and wide in the vertical plane) from a vessel carrying the system. The return signals from any objects in the path of these pulses are continuously recorded graphically so as to show their lateral displacement. As the vessel proceeds, a plan view of the area covered is produced on the chart. These records frequently resemble a large scale aerial photograph - depressions show up lighter and projections show up darker than the average bottom return. The most important feature of side scan sonar, then, is its ability to produce a permanent, continuous, graphic record of what it "sees". A basic block diagram of a typical dual channel side scan sonar system is shown in Fugure 1.

Transducers

Transducers for side looking sonars are basically line arrays of piezoelectric (barium titanate or lead zirconate titanate) or magnetostrictive elements housed in a towing "fish". Separate arrays for transmitting and receiving are used. In a dual channel system there are thus a total of four arrays, port and starboard transmitting and port and starboard receiving. The transmitting arrays are driven electronically to produce a short, high intensity ultrasonic pulse. Frequencies ranging from 10 KHz to 500 KHz may be used depending on the range and resolution desired. The receiving arrays pick up the acoustic energy returned by objects in the path of the acoustic beam (echoes). These signals are then amplified. processed and recorded. These arrays are designed to have a very narrow horizontal beam with a fairly broad vertical beam. For any given frequency, the beamwidth of the array is a function of the array length. Long arrays give a narrow beam and correspondingly higher resolution. However, if beamwidth is made too narrow, signals can be lost due to slight instability of the towing fish or ship speed.

More sophisticated designs incorporate arrays with shading for side lobe reduction and specially tailored vertical patterns. Some systems also use a "focused" beam which is essentially a curved array which allows equal acoustic path lengths from a given distance. Present focused systems suffer from the same depth of field problems as large telephoto lenses. That is, the system is in focus over only a small part of the area of interest.

Pulse Length

As a general rule, short pulse lengths give the best results with a side scan sonar—providing the best range resolution and minimizing average power drain. However, bandwidth and, correspondingly, noise must increase as pulse length decreases. There is little need to reduce the pulse length to less than the resolving power of the recording process used. In a typical system the recorder can resolve about 15 centimeters on a full scale range of 40 meters. Therefore, a pulse length of about 0.1 millisecond (7.5 cm) is used.

Signal Processing

In order to maximize the usefulness of the sonar records, the incoming echoes must be carefully processed. The received electrical signals are very weak, so that state-of-the-art, low-noise amplifiers and filters must be employed to insure that the system is limited by acoustic or thermal noise and not by electrical noise. Limiters are used so that unusually strong signals do not paralyze the amplifiers.

Signal amplification must be varied in time to compensate for spreading and attenuation losses and bottom characteristics. Ideally, gain-versus-time should be set to obtain a uniform level of backscatter througnout the range of interest. This curve will vary depending on the type and slope of the bottom, the height of the transducer off the bottom, and the vertical beam pattern of the transducer. Generally, several controls are utilized to optimize this time-variable-gain.

In rocky terrain with very high backscatter, the gain function must be reduced and, therefore, the detection probability will also be reduced. In smooth areas with low backscatter, the gain is simply run up to maximum permissible level (depending on noise and other conditions). In this latter case, detection probability of discrete targets (such as a wreck on smooth flat sand) is increased although overall record quality may not be high.

Recorder

The recorder utilizes a moving stylus or a resilient helix electrode to move an electrical point of contact across the recording paper. At the beginning of a sweep the transmitting transducers are pulsed and for the remainder of the sweep the echoes are received and recorded. Successive sweeps are laid side-by-side so that coherent targets or terrain patterns can be recognized by the eye. This method of placing sweeps side by side creates an integration effect which allows the eye to spot targets in poor signal-to-noise conditions.

If two channels are desired, two helices or styli are used, and these sweep out from the center of the chart to cover the terrain on both sides of the towing fish. Some systems pulse left and right channels alternately to simplify the electronics, but this puts fewer "pings" on a target and cuts down the probability of detection. If transducer back radiation and reception is held to a minimum, it is possible to pulse and record both sides simultaneously.

Range

Uusally the first question asked about any type of sonar is, "What is its range?". Unfortunately, the answer to this question depends on a great number of factors, many of which are often unknown. However, one can at least get an order of magnitude calculation of range by starting with the basic equation of active pulse sonars:

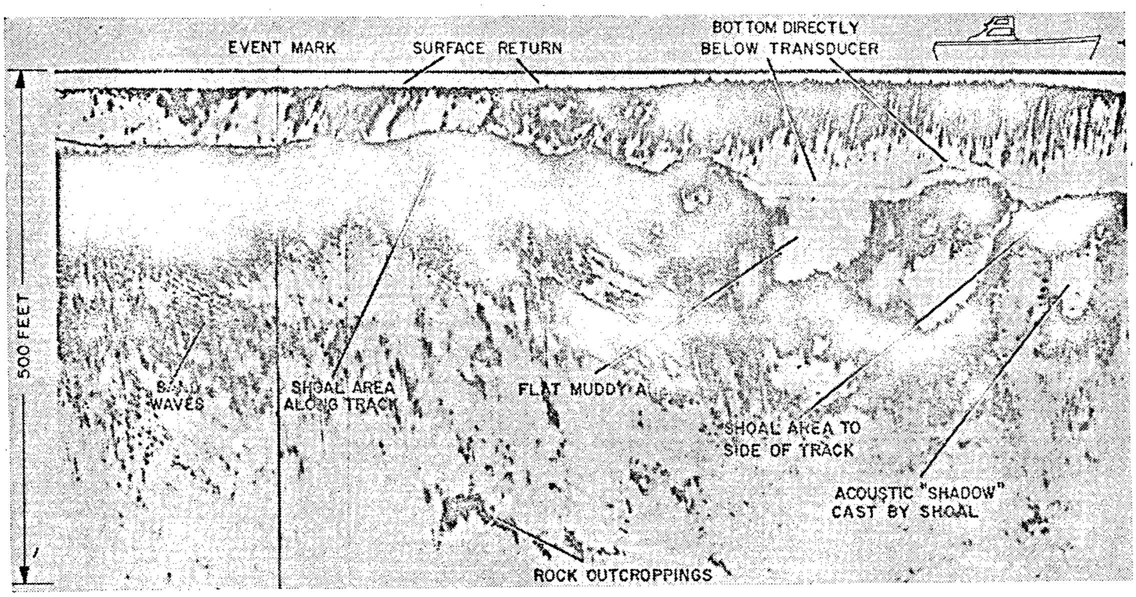

Figure 3. Record made with side scan sonar off Marblehead, Mass., showing several type of terrain, 260 kHz pulse was used.

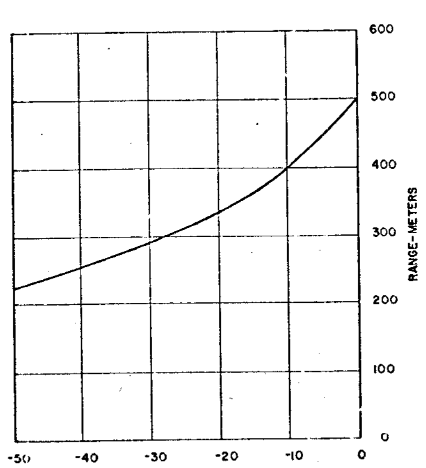

Figure 2. Estimated range capability vs target strength for 260 kHz side scan sonar.

$$2\,Nw = Ls + Ts - N + DI - Rd$$

where

- Nw = propagation loss, one way
- Ls = source level (db re 1 μ bar at 1 meter)
- Ts = target strength
- N = noise level
- DI = directivity index of transducer
- Rd = recognition differential

(All terms are expressed in db ref 1 μ bar.)

In a typical EG&G International system at 260 KHz, the source level is 120 db re 1μ bar at 1 meter, the directivity index is 26 db and a nominal noise level is —26 db for a 10 KHz bandwidth. A signal to noise level of 6 db is normally sufficient with the graphic recording technique. Using values of range vs propagation loss (due to spreading and attenuation) given in J. W. Horton, *Fundamentals of Sonar* (U. S. Naval Institute), we obtain data shown in Figure 2 which is a plot of estimated range capability versus target strength for this particular system.

These calculations and curves give a starting point, but many other factors can act to affect the range. For instance, some ships or sea conditions produce air bubbles which can obstruct the sound passage. Of course, it is useful to get as clear as possible from these bubbles. In addition, all sonars are sensitive to ray bending due to temperature, salinity, and other variations in the water. Many sonars (particularly CTFM or continuous transmission frequency modulation systems) are severely limited by reverberation which is, in simple terms, the degree to which the active sonar disturbs its own acoustic environment. Fortunately, the extremely short pulses normally used in side scan produce very little reverberation problem. Since high frequencies are used, these sonars are usually not bothered by ship noise or other manmade noise.

Record Interpretation

Initially, side scan sonar records tend to be confusing to the operator, simply because the eye is not trained to interpret this type of presentation. However, with sufficient experience, the charts reveal extensive information of targets and terrain on the ocean floor. To begin, one must become familiar with the basic characteristics of the sonar display.

Figure 3 shows a typical sonar record made with a 260 KHz sonar off Marblehead, Massachusetts. The first line at the top of the record represents the outgoing pulse. The next line represents the reflection from the surface of the water. This gives an indication of how deep the transducer is in the water (distance A in Figure 4. Even though the transducer points to the side, the surface and bottom are such good targets that they are received by the side lobes of the transducer.

Following the surface return are echoes from the water surface. These only show up in side scan if the

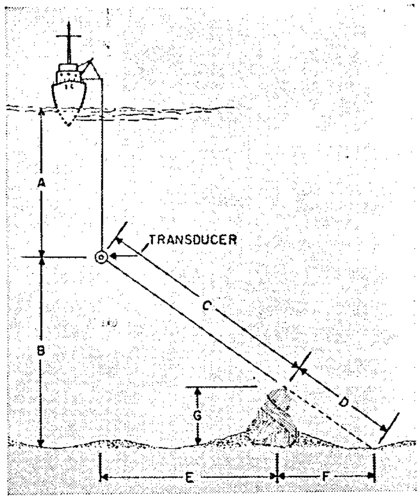

Figure 4. The geometry of side scan sonar. A = distance of transducer to water surface, B = distance of transducer to bottom, C = slant range transducer to object, D = slant range extent of acoustic shadow, E = bottom distance to object, F = length of acoustic shadow on bottom, G = height of object.

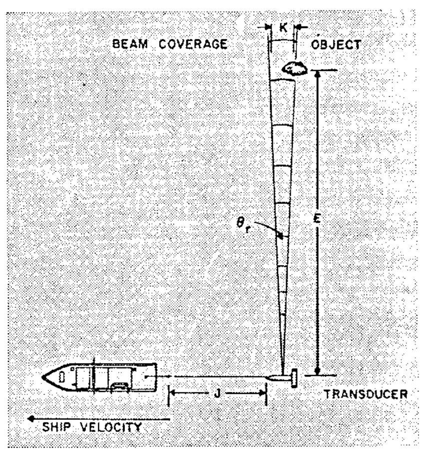

Figure 5. Horizontal plane coverage of side scan sonar.

water is rough and the transducer is being towed shallow.

The next line to show up represents the bottom directly below the transducer (distance B in Figure 4). After this bottom echo, the actual side scan echoes from the bottom terrain are seen. A light area indicates either a smooth area with very low backscatter return or an acoustic "shadow" behind a target which projects from the ocean floor.

From these records one can see that a great deal of qualitative data about the terrain can be obtained directly. However, if the sonar is to be used to take quantitative data or to locate a particular object, one must look more carefully at the parameters and the distortions or the sonar "picture". This knowledge helps the user to set up the various parameters of the system (range scales, paper speed, towing height off bottom, towing speed and so forth) for optimum results.

For instance, the record is normally distorted, in that distance measured across the chart is not the same as distance along the length of the chart. Full scale distance across the chart is determined by stylus speed and the speed of sound in water so that

$$R = \frac{CT}{2} = \frac{C}{2F}$$

R = full scale range in meters
C = speed of sound in meters/second
T = time for one sweep in seconds (time for the sound to travel to a range and to return)
F = sweep repetition rate in sweeps/second or lines/second

Determination of distance along the chart requires, in addition, a knowledge of boat speed and of the chart speed rate. Chart speed is normally measured in number of lines per centimeter.

One centimeter of paper represents a distance along a track of $2(SRL)/C$ meters where

S = boat speed in meters/second
L = paper feed rate in lines/centimeter

The next thing to consider is the angular coverage of the horizontal beam of the sonar. Figure 5 shows this coverage. Since the angle is small, the distance covered at a given range is approximately as follows:

$$K = E\theta_r$$

where K = distance covered, in meters, at a range E in meters, θ_r = system horizontal beamwidth in radians.

This value is approximate since the specular nature of the target can alter the result. In other words, a strong reflecting target can appear in the beam longer than a weaker, more directional target of the same size.

Using formulas in the two preceding paragraphs, one can get an estimate of what range scale, paper speed, and boat speed are practical for a given size object. Obviously one does not want to set up conditions where a small target will receive only a single ping and will show up as only a tiny speck on the record. On the other hand, when searching for large underwater objects of geologic features, one can go to higher boat speeds and longer range scales to cover a larger area in a shorter time.

A third consideration in side scan records is that all distances are slant ranges from the transducer to the target. Figure 4 shows the slant range geometry. For an object projecting from the ocean floor, one can estimate the object size by the length of the acoustic shadow which is cast. On most records of this type one can read the values C, B, and D directly from the chart. Using these values and basic geometric relationships, one can calculate the values of F and E, the object height and distance, respectively, as follows. (See Figure 4 for explanation of letter symbols.)

$$G = \frac{BD}{C+D}$$

$$E = \sqrt{(C+D)^2 - B^2} - \sqrt{D^2 - \left(\frac{BD}{C+D}\right)^2}$$

For surveys where actual quantitative data is desired, the transducer towing geometry may also need to be considered to take into account the distance of the transducer from the ship's navigation point. For more complex targets more elaborate calculations are required, but it is still possible to get a reasonable estimate of the object size and shape.

Some recorders have been built using a nonlinear sweep to correct for the slant range distortions. However, such an arrangement must assume a given stable transducer height off the bottom. This tends to be rarely possible, particularly in terrain with steep slopes.

Side scan sonar system records quickly reveal a great deal of information about the general nature of bottom terrain. By taking a closer look at the parameters involved, the systems can be used effectively for a given task. Once the geometry is understood, a certain amount of quantitative data can actually be obtained. It is expected that as commercial systems become more readily available and as operators become more experienced, these systems will be used more extensively for a multitude of tasks on the sea floor. ▶

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The author, Martin Klein, is shown with an experimental model of the EG&G scan sonar.

Martin Klein received his B.S.E.E. from the Massachusetts Institute of Technology in 1962. He is now a senior project engineer with EG&G International, Inc. and is program manager for development of high resolution sonar systems. He has participated in design and field operation of various oceanographic systems including acoustic transponders, seismic and sonar recorders, array hydrophones and sonar systems for *Trieste II* and the *Soucoupe* Diving Saucer.

Mr. Klein is a member of the IEEE, the Marine Technology Society and the Institute of Navigation.