Engineering Notes (Marine Systems)

Ocean Bottom Scanning Sonar

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THIS note describes briefly a sonar technique, that of precision side-looking sonar, which has been refined and used for several years. It allows inspection of the sea floor and objects lying upon the floor at a resolution from $\sim$ 1 in. up to any value suitable to the task at hand, perhaps several feet. With normal attention to system requirements and operational details, the display or recorders can portray the sea floor surface and objects on it in true size, shape, and orientation. The mapping rate for a single system is typically in the range 0.1 to 1 naut mile^2/hr. Thus, we have a simple instrument that bridges the vision gap between optical techniques, which provide perhaps 0.1-in. resolution, 50-ft maximum range, and precision echo sounders. This sonar technique has been successfully applied in water depths ranging from 25 to 17,000 ft. There is no impediment to the eventual use at the greatest depths of the ocean.

One can envision many oceanographic and marine engineering tasks for this new instrument, such as search of the ocean floor for the recovery of hardware (missile parts, instrument packages, sunken ships, or aircraft); bottom surveys for scientific studies (geological, petrological, biological, beach erosion, or acoustic propogation and reflection); bottom surveys for resource exploration (petroleum, ores, or food); navigation by bottom topography; and bottom surveys for site selection (for fixed instruments, observation station, weapon ranges, or underwater cable routes).

Figure 1 shows the geometry of the side-looking sonar technique. Depending upon the specific task and the vehicle rate of advance, the system would be configured either to use a single transmitter-receiver channel, time shared between port and starboard transducers and displays, or dual-signal channels to double the information rate. The transducers are long line arrays of several hundred wavelengths and less than one wavelength height to obtain a very narrow fan beam.

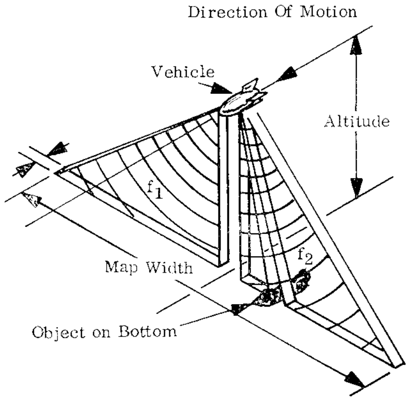

Fig. 1 Geometry of side-looking sonar technique.

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The transducers are mounted to direct these fan beams to the side, perpendicular to the advance of the vehicle. A short pulse of acoustic energy is projected downward and to the side, and as the wave front proceeds through the water, it impinges upon a long narrow strip of the bottom. Energy is backscattered from the strip and returns to the receiver delayed in time by the round-trip transit time to the particular scattering area. Thus, on a relatively flat bottom, a simple time sequential scan of the returning signal can be displayed or recorded. Generally, the display scan is shaped to display the line at a linear bottom range for a fixed operating altitude. The operating altitude is compromised between the desire for maximum range capability and the range resolution requirements of the system. At most ranges the range resolution or the length of the bottom scattering cell is approximately the linear ping length in the water. However at bottom ranges directly below the transducers, the length of the strip determined by the ping length $ct/2$ (where c is the speed of sound and t the pulse time) is the length of the side of a right triangle whose other side is the altitude of the transducer and whose hypotenuse is the altitude plus $ct/2$. The range resolution need then is for the lowest altitude possible and short ping lengths. Typically, the ping length is set at from one-tenth to one-quarter the width of the fan and is limited by the power and bandwidth considerations.

The maximum lateral range is set by the resolution requirements and the advance speed of the vehicles and for maximum utilization of the records is held to something less than 10 times the altitude. The first consideration is that the vehicle advance in the ping-to-ping interval be approximately equal to the width of the fan, or the map strips will not be adjacent. If the advance is too slow, the lines will overlap, and, if too fast, there will be spaces between the lines. The fan width and advance rate is generally adjusted to yield two to ten strips across the target or feature of interest. The second limit on the lateral range (that it be no more than 10 times the altitude) comes about because of the very low ratio of backscattered energy to the incident energy at the very shallow grazing angles. The system thus becomes power limited. Another effect is that multipath signals scattered from shorter range areas begin to arrive and to fill in the shadowed bottom areas. Figure 2 shows how the line-by-line strip map is built up. The normal bottom reverberation areas would appear as an area of over-all medium shade, with targets or projections displayed more intensely. Bottom areas behind these objects would lie in an acoustic shadow zone, and thus from

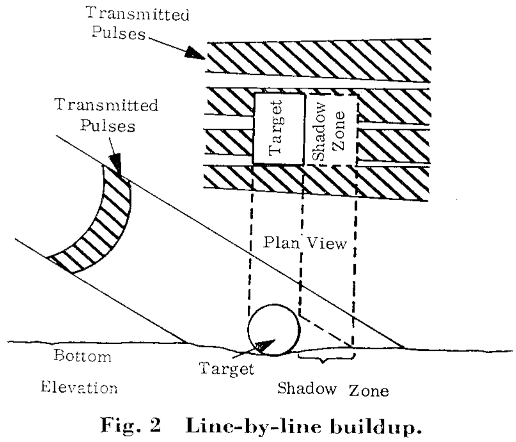

Fig. 2 Line-by-line buildup.

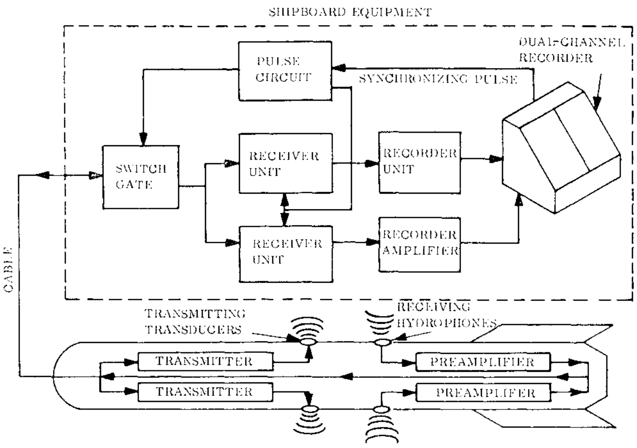

Fig. 3 Block diagram, towed sonar system.

these no signal is received. The net effect of these system considerations can be summarized by a rule of thumb: The over-all mapping width will be from 300 to 1000 times the resolution of the system. We have built sonars for different applications with such characteristics for effective resolutions up to 80 in.

Figure 3 shows a sonar built in 1964 which has been used in water depths from 50 to 17,000 ft. The lower section outlines a vehicle towed behind a ship. It is connected to the shipboard section, shown at the top, by a combination electrical-strain tow cable, whose mechanical and electrical characteristics are suitable for the tow depths and speeds. Cables of the double- or triple-layer, preformed spiral-type are available for towing to 20,000 ft. Vehicle altitude is maintained within acceptable limits in most of the systems by winching, and the electrical signals are conducted through slip rings on the winch. All of the signals are telemetered over a single two-wire link, which is generally a coaxial cable in the core of the tow cable. In some high-resolution, side-looking sonars, the transducer beams are very finely focused with a limited depth of focus, so that the vehicle altitude must be adjusted by a sensing elevator servo, and automatic bottom-contour following results. This same sonar is adapted to submersible use by eliminating the vehicle and tow cable. The transducers are hung on the hull, and the transmitter-preamplifier package can be either inside or outside the pressure hull. An external pressure-proof package was the choice for the TRIESTE sonar; for the ALUMINAUT sonar, only the transducers were outside.

Returning to the block diagram, keying pulses originated at the shipboard console in synchronism with the display scan are telemetered over the cable to pulse the vehicle transmitters. The received signals after preamplification are returned to the shipboard receiver, where time-varied gain circuits remove the predictable amplitude-time variations resulting from

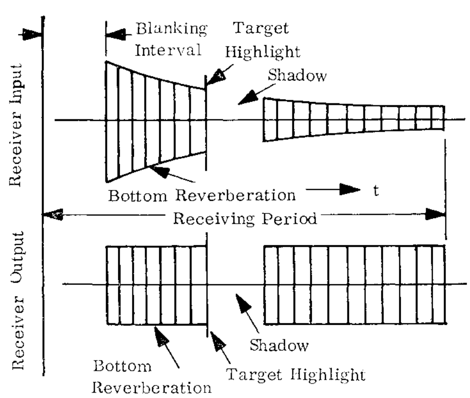

Fig. 4 Amplitude-time variations effect.

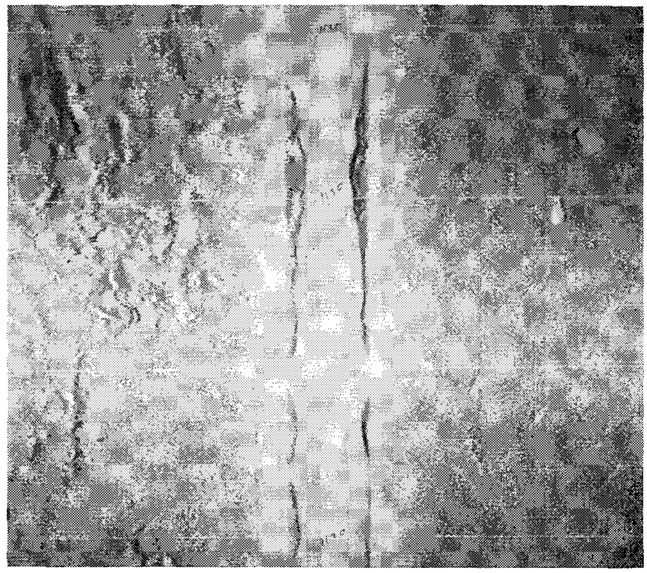

Fig. 5 Photograph of strip map.

geometric spreading loss, attenuation loss, and fall-off in the bottom backscattering strength with decreasing aspect angle. Figure 4 shows this effect, though not in the true scale, since this bottom reverberation decrease from zero to maximum bottom range would be typically 35–45 db. Automatic gain control, with time constants set to pass properly shadow zones, removes unpredictable signal fluctuations as would arise in passing from a sandy to a mud bottom and keeps the receiver output within the dynamic range of the display.

Information contained in the sequential signals received from each transmission are plotted and stored at the display as a line of varying intensity at a line scan rate scaled to the bottom ranges. As the vehicle advances, the vertical display scan, scaled to this advance rate, successively displays the information from each transmission, and a picture of the bottom is built up line by line. Figure 5 is a photograph of sections of a strip map produced by this sonar. Displays for side-looking sonars have so far been of three types: high-contrast, wet paper, facsimile recorders for a combination of real-time read-out and permanent records, direct-view storage tubes for real-time read-out where permanent records are not so important, and cathode-ray-tube film combinations where instant viewing is not important, but the highest quality records are desired.

Figure 6 shows the current transducer design. Behind the neoprene diaphram (shiny material on front) are active

Fig. 6 Current transducer design.

elements of barium titanate, and the unit is oil filled for pressure relief. The titanate element blocks are inserted end to end into a machined slot in the backing stripholder to a total length of 45 in. The ceramic blocks are 0.204 in. wide and 0.430 in. thick. The backing strips are in turn fitted into machined slots in the alumin case, each of which will accommodate two or three transducumers.

In conclusion, the low-altitude, side-looking sonar is an important new instrument useful for detailed observation of the ocean floor and for high-resolution search of bottom areas. The sonar effectively bridges the gap between optical techniques and conventional wide-beam sonars and echo sounders. Both technical feasibility and suitable operational techniques have been clearly demonstrated.