HIGH RESOLUTION DIRECT GRAPHIC RECORDING OF UNDERWATER SOUND

by John M. ALDEN and L. A. FARRINGTON

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One of the tasks underwater sound does particularly well is to record and store for future reference closely related depth sounding or underwater distance observations. Electronics has provided underwater sound with extremely sensitive and precise listening and data-collection devices. These devices are capable of collecting vast amounts of information in great detail. There has been, however, great difficulty in providing equally sensitive, accurate underwater sound output devices.

Leading oceanographers have long felt that a direct graphic recording device that could provide extremely accurate time base, operate over a wide range of writing speed and record with great detail the relative strengths of signal returns would provide new insight into the data being generated by underwater sound devices.

Much significant effort has been carried on in this direction. Perhaps the most promising and significant results to date, however, have come out of the work of the scientists at Woods Hole Oceanographic Institution with their development of the Precision Graphic Recorder — a recording and control system for underwater sound systems which now gives promise of narrowing the gap between underwater sound detection equipment and recording or display devices. The PGR gives promise of being the forerunner of many types of echo sounding recorders tailored for specific missions in underwater sound. This paper is presented with the thought that an understanding of the recording principles and their incorporation into the Precision Graphic Recorder for broad underwater sound application may be revealing to those designers and operating personnel concerned with instrumentation for oceanographic research.

The Precision Graphic Recorder

Known as the Precision Graphic Recorder, this recorder is capable of providing precise sweep rates for 12 very useful depth intervals (20 fathoms to 3 000 fathoms) with accuracies of one in 3 000 fathoms. A unique *acoustic keying* control and *recording interval gating* system make it possible to control underwater acoustic equipment so that recordings of any of the 12 selected depth intervals in any depth of water can be picked out for exclusive full-scale presentation as single or dual channel recordings. Recordings are rich brown tone shade markings with a touch of red, on white translucent paper. The broad tone shade response of the paper with tone shade marking proportional to the strength of signal makes it possible to record very weak signal returns as well as strong signal returns, while the ability to select recording line densities from 64 to 384 lines per inch permits integration of the weak signals to intensify their tone shade marking over the general random markings created by very noisy conditions.

Prototype Design

The Precision Graphic Recorder was developed by Mr. S. T. KNOTT and Dr. J. B. HERSEY and his associates at the Woods Hole Oceanographic Institution (*). The first design consideration was the recording paper. One highly sensitive recording medium, the moist starch iodide electrosensitive paper has been extremely successful in recording at higher speeds, and especially in catching the weaker transient signals. Widely used during World War II, this paper had the difficulty of often spoiling in storage before use, and also losing its recording definition after recording. A more popular paper was the plastic coated carbon type with metallic backing which the pen burns in the signal. This proves excellent for many uses, but is limited in tone shades and requires excessive currents and care for high speed operation.

An electrosensitive type paper developed after World War II, called Alfax Type A paper, manufactured by the Alfax Paper and Engineering Co., Inc. was investigated by KNOTT and HERSEY. This paper demonstrates the ability to record over a wide range of writing speeds without excessive current requirements. A moist, electrosensitive paper, it has the sensitivity to provide rich sepia tone shade markings almost directly proportional to current passage (See curves, diagram I). These markings on white translucent paper are in the range of color spectrum most suited for fastest eye-brain interpretation (**). It exhibits no storage probems or deterioration of markings records.

(*) See KNOTT, HERSEY : Interpretation of high-resolution echo-sounding techniques and their use in bathymetry, marine geophysics, and biology : *Deep-Sea Research*, Vol. 4, 1956.

(**) See : *Alfax News*, Vol. I, No. 5, published by Alfax Paper & Engineering Co., Inc., Westboro, Mass., U.S.A.

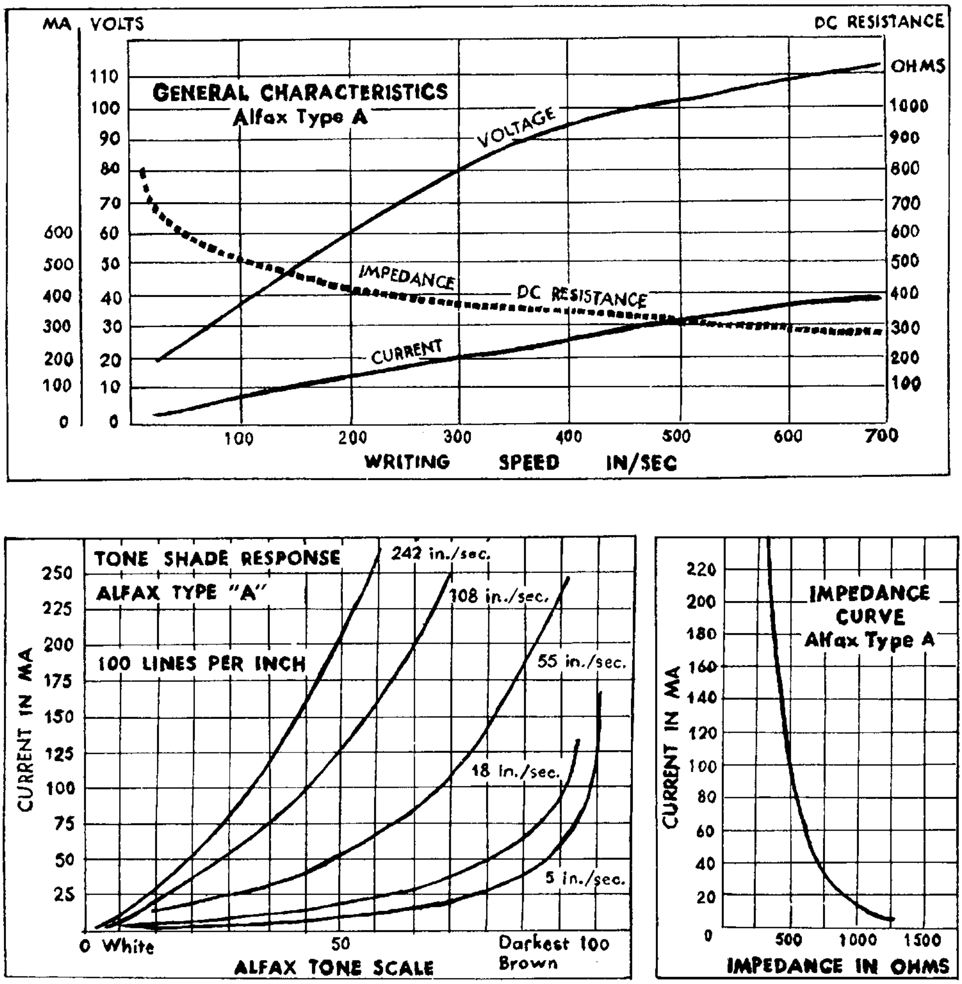


DIAGRAM I. — The above curves were derived using an Alden 305 Helix recorder having a $4\text{-}\frac{7}{8}''$ writing width utilizing the Alden recording technique with the .018″ thickness loop electrode and resilient Helix. Signal input was flat DC. Tone shades are plotted against the Alfax Brown Scale.

High speed recording techniques for the use of Alfax Paper had been worked out for high speed facsimile communication equipment (*). Component recorders known as the Alden *flying spot* helix recorders were available in all sizes. Investigation of the recorder techniques demonstrated that it was capable of operating over a wide range of writing speeds so that writing rates could be selected according to the depths being observed. It was decided to utilize the Alden helix recording technique.

The Alden Recording Techniques involve the use of a moving endless loop electrode, or blade, and a resilient helix as the two electrodes as illustrated in diagram II.

(*) See : Some of the Aspects of High Speed Facsimile. M. ALDEN, 23 January 1952, A.I.E.E. Winter General Meeting, New York City.

A negative signal is carried to the blade by the helix and the intersection of the two elements creates a spot of electricity. As the spot moves it writes a line — with electricity — across the electrosentive paper, with the line length being equal to the lead of the helix. The negative signal on the helix causes instant electro-deposition of ions on to the Alfax electrosensitive paper from the blade.

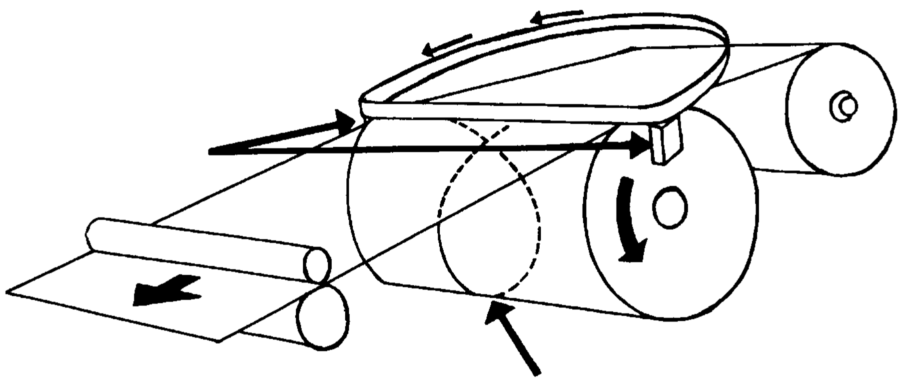


DIAGRAM II. — The Alden " Flying Spot " Helix recording technique. A moving endless loop electrode is positioned down against stops over a resilient helix with a loop electrode also acting as a seal for the paper chamber.

The essential difference between the Alden technique and earlier helix recording techniques is the use of a moving *endless loop electrode* positioned down against stops over a *resilient helix*. The resilient helix has very low inertia so it is able to compensate for any slight paper thickness or blade variations and maintain a consistant pressure over a wide range of writing speeds. Since ions are deposited from a *blade* in the recording process by making it an endless loop and slowly moving the electrode, the wear from ion deposit is evenly distributed through the blade. This constant freshening of the blade's surface through the endless loop electrode technique provides a constantly freshened electrode surface — which is always in perfect straight line alignment with the paper and helix over thousands of feet of recording.

Interchangeable Recording Speeds

With the recording paper and technique determined, combinations of recording speeds that would best embrace the scope of underwater sound research studies were tried out. A series of motor drives were used to operate the recording drum of Alden 8" and 19" helix recorders at a number of different speeds. The wider presentation seemed preferable to provide optimum resolution in oceanographic observations. Twelve different speeds were selected. The table below lists the 12 speeds and shows the corresponding full-scale depth ranges and recording sweep intervals that these speeds provide.

Speed	RPM	Full-scale range in fathoms	Yards	Metres	Sweep interval in seconds
1	1 200	20	40	36.7	1/20
2	600	40	80	73.4	1/10
3	480	50	100	91.8	1/8
4	240	100	200	183.6	1/4
5	160	150	300	275.4	3/8
6	120	200	400	367.2	1/2
7	80	300	600	550.8	3/4
8	60	400	800	734.4	1
9	48	500	1 000	918.0	1-1/4
10	24	1 000	2 000	1 836.0	2-1/2
11	16	1 500	3 000	2 754.0	3-3/4
12	8	3 000	6 000	5 508.0	7-1/2

Key and Record Gating

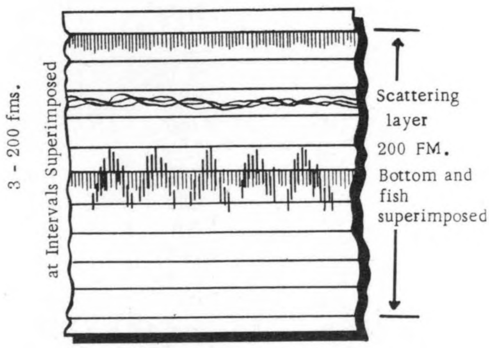
With the basic problems of depth interval selection solved by the range of recording speeds that Alfax Paper and the Alden *flying spot* helix techniques permitted, it was possible to invest the new recorder with still more versatility by making it capable of dividing any one of the 12 full-scale depth ranges into 12 equal depth divisions that could be independently and discretely observed and recorded. This was achieved through a basically simple programming technique to control, in various desired patterns, both the triggering of the out-going sonar pulse and the gating in the desired recording interval relative to returns from these pulses. A 12 segment electromechanical commutator coupled to the helix drive unit of the recorder operates at *one twelfth* the speed of a complete helix sweep (one helix drum revolution). There are two rows of 12 equally spaced segments on the commutator. One row of segments controls sonar pulse triggering; the other controls recording gate intervals. Because of the 1/12 speed ratio, the interval between any two segments in the same row corresponds to one complete revolution or helix sweep interval are related, as shown in the preceding table, it is possible to program the keying of sonar pulses and select the recording intervals in any combination of 12 sweeps or drum revolutions.

This programming is accomplished through toggle switches and other front panel controls which engage the segments on the commutator so that keying and recording occur in various desired patterns. When a segment on the keying row is not engaged, the sonar pulse generated for corresponding sweep is inhibited; when a segment on the recording row is not engaged, signal return occurring during that interval is gated out.

Programming

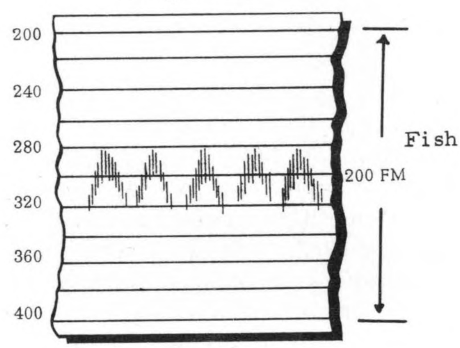
Diagram III illustrates the unique programming possible with the Precision Graphic Recorder. Sample program 1 shows the programming

Program 1



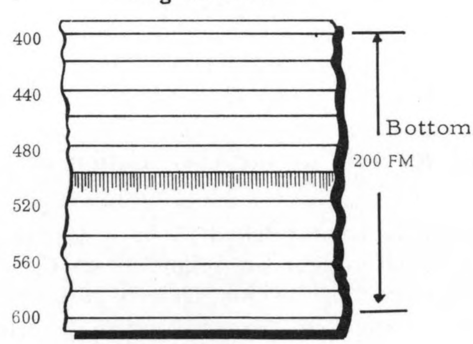
All intervals superimposed

Program II



200 to 400 fathom interval only

Program III



400 to 600 interval only

DIAGRAM III. — Gating and keying programming of the Precision Graphic Recorder.

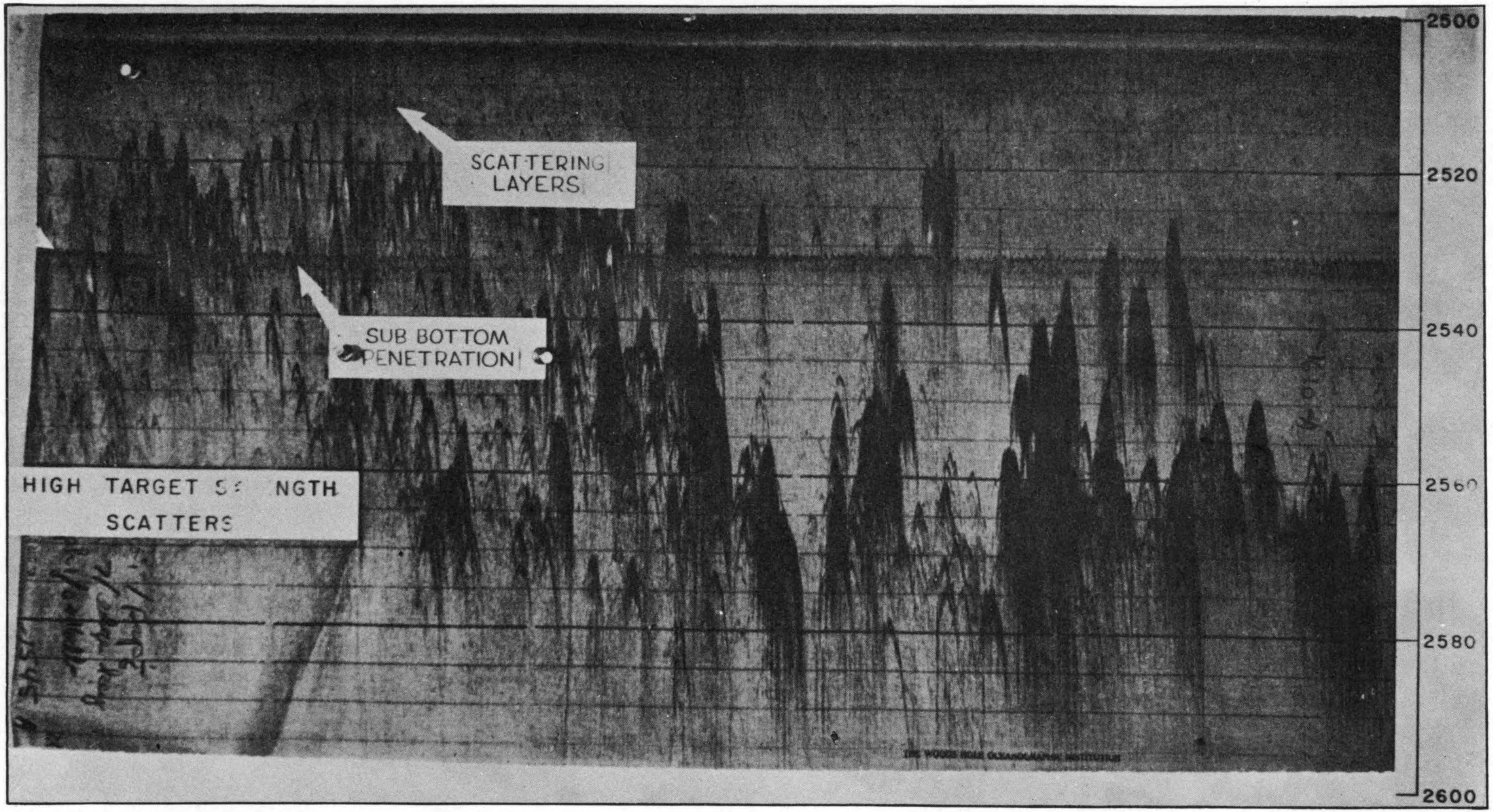


FIG. 1. — This photograph of a recording made with a PGR and Alfax Paper by Woods Hole Oceanographic Institute, dramatically shows several 100 fathom sound intervals superimposed. Noted on the recording are the phenomena " captured " in a " sound picture ". Refer to " Description Alden 419 Precision Graphic Recorder " as to the ability of the recording program to separate discreetly the various information now recorded as superimposed. (Photo about ¼ actual size of recording.)

controls set to trigger the sonar pulse and record the return interval every sweep. A sweep speed control is set at 200 fathoms, which means the depth from surface to bottom is divided into three intervals — surface to 200 fathoms, 200 to 400 fathoms, and 400 to 600 fathoms. The record gate control is set in position 1, which means the recording will be delayed one sweep after triggering. Every sweep interval is represented on the diagram by a coded line, which shows that sound returns from each of the three 200 fathom intervals are being recorded simultaneously. In sweep 4 it can be seen that the return from the scattering layer at 50 fathoms is being recorded.

Also being recorded during this sweep are returns from fish in the 200 to 400 fathom depth interval and returns from the ocean bottom in the 400 to 600 fathom interval. The returns from the second and third intervals are delayed one and two sweeps respectively because of the additional distances travelled by the pulse. Thus the pulse return recorded during sweep 4 from the 200 to 400 fathom interval was actually transmitted during sweep 3, and the return from the 400 to 600 fathom interval was transmitted during sweep 2. The resultant recording shows that all returns are superimposed, because all sweeps were recorded. Illustration 1 is a recording of similarly superimposed 100 fathom intervals in water depths of 2 530 fathoms.

To record the fish in interval 2 discretely, the system can be operated as indicated in sample program 2 in the diagram. Here, only every other sweep triggers an outgoing sonar pulse. The active sweep control is set at position 1 of program 2. The record gate control is set at position 2, which means that signal returns during the trigger sweep are gated out and only returns occurring during the sweep interval following active sweep are recorded.

Consequently the returns from the scattering layer in the first interval are not recorded, nor are the returns from the bottom in the third interval, for these returns are results of the previous sweep, sweep 3, at which time recording was gated out. Only the fish from the second interval are recorded, and the resulting record shows the fish graphically represented at the 200 to 400 fathom intervals.

In program 3, every third sweep triggers a sonar pulse (sweeps 1, 4, 7, etc.) by setting the sweep control to position 1 of program 3. The record gate is set to gate out returns from the first two sweeps. Only returns from the third sweep are recorded. In this way the returns from the bottom are discretely recorded. Triggering is effected on sweeps 1, 4, 7, etc. and recording on sweeps 3, 6, 9, etc.

Thereby the only return that is recorded is the signal from the bottom that is generated during sweep 4. The returns from the first two layers are gated out. The resultant recording is consequently a graphic bottom profile. Figure 2 shows a similar bottom profile recorded on the 1 500 fathom scale.

The recording is spread out, but to achieve continuity the returns are recorded as a continuous signal. This is accomplished by slowing the paper feed rate. The paper feed drive unit is coupled to the helix drive unit to provide five different paper feed rates for each different helix recording speed. Thus, if the paper is slowed down, it will result in greater line density in situations where this is desirable, or integration of signal returns through utilization of the high sensitivity of the Alfax paper, or continuity in instances such as illustrated in this example.

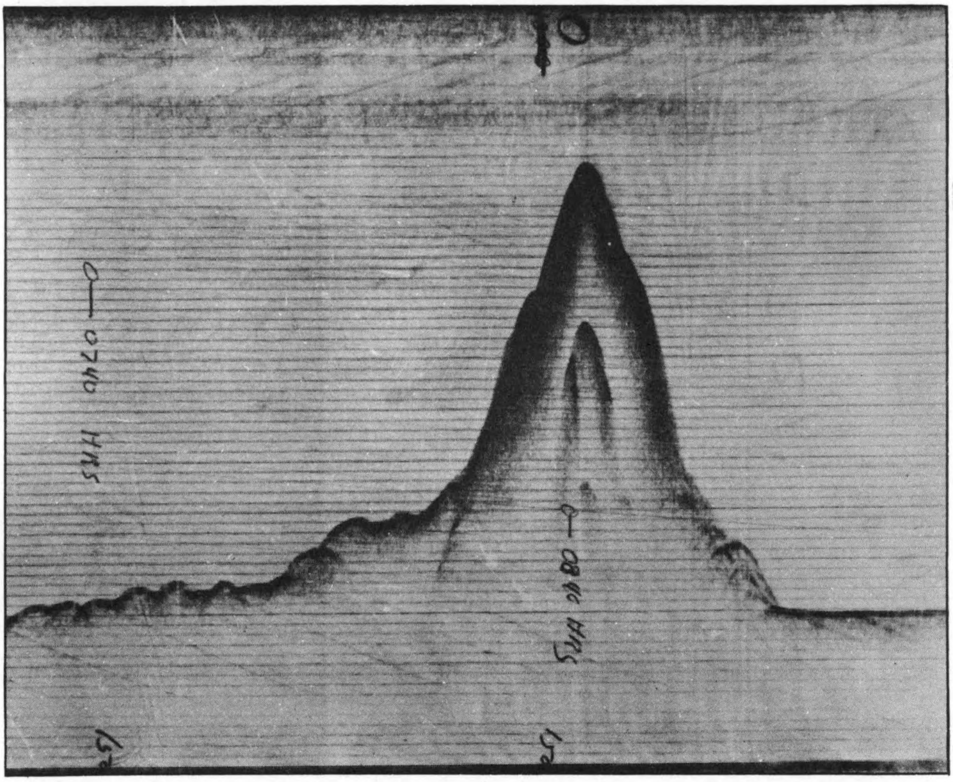


FIG. 2. — This photograph shows a " sea mount " recorded on a PGR by the Woods Hole Oceanographic Institute. Note the tone shades derived from Alfax paper in this instant graphic recording of remarkable underwater topography. (Photo about 1/3 actual size of recording).

Other Features

In addition to the features of wide operating ranges of high-resolution recording made possible through Alfax electrosensitive paper and Alden helix recording techniques, and the unique programming possibilities of the Precision Graphic Recorder, there is the added flexibility of single or dual-channel operation. Changing from single-channel to dual-channel recording operation is performed through simple switching operation, and separate programming can be set up for each channel. Figure 3 shows dual-channel recording where a straight Edo echosounder was used simultaneously with a Spark source sounder.

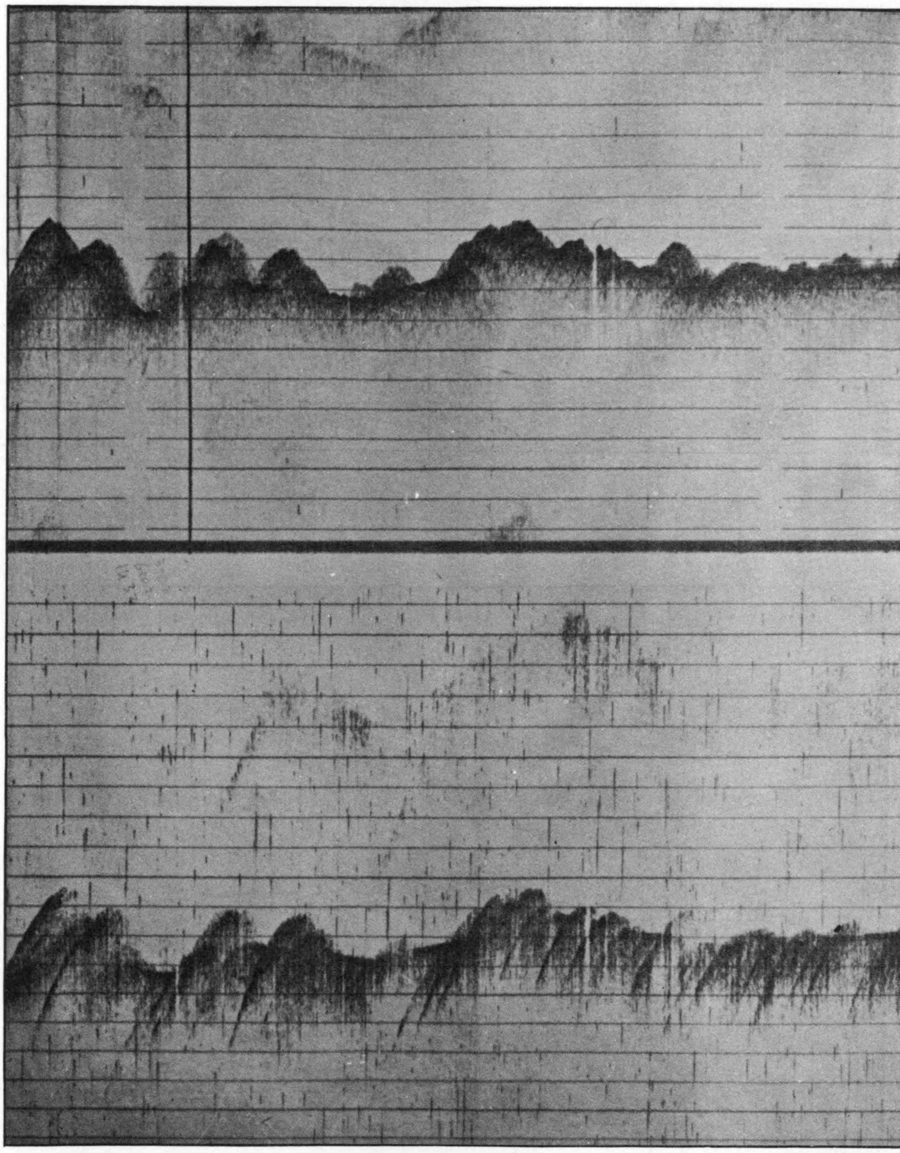


FIG. 3. — Dual channel recording on a 50 fathom scale of a record using conventional. Edo echo sounding equipment. Lower channel received by spark sound source and direction hydrophone.

Flexibility in positioning the recorded interval on the record is provided by optional center keying to trigger the sonar pulse. This triggers the outgoing sonar pulse at exactly the center of the helix sweep and is useful where the recording interval would otherwise be split between the top and bottom of the record (see figure 3). Further flexibility is provided by a differential input shaft control which permits shifting of the recorded interval anywhere desired relative to the paper margins. By recording the outgoing sonar pulse the amount of displacement of the record relative to the margins may always be clearly seen.

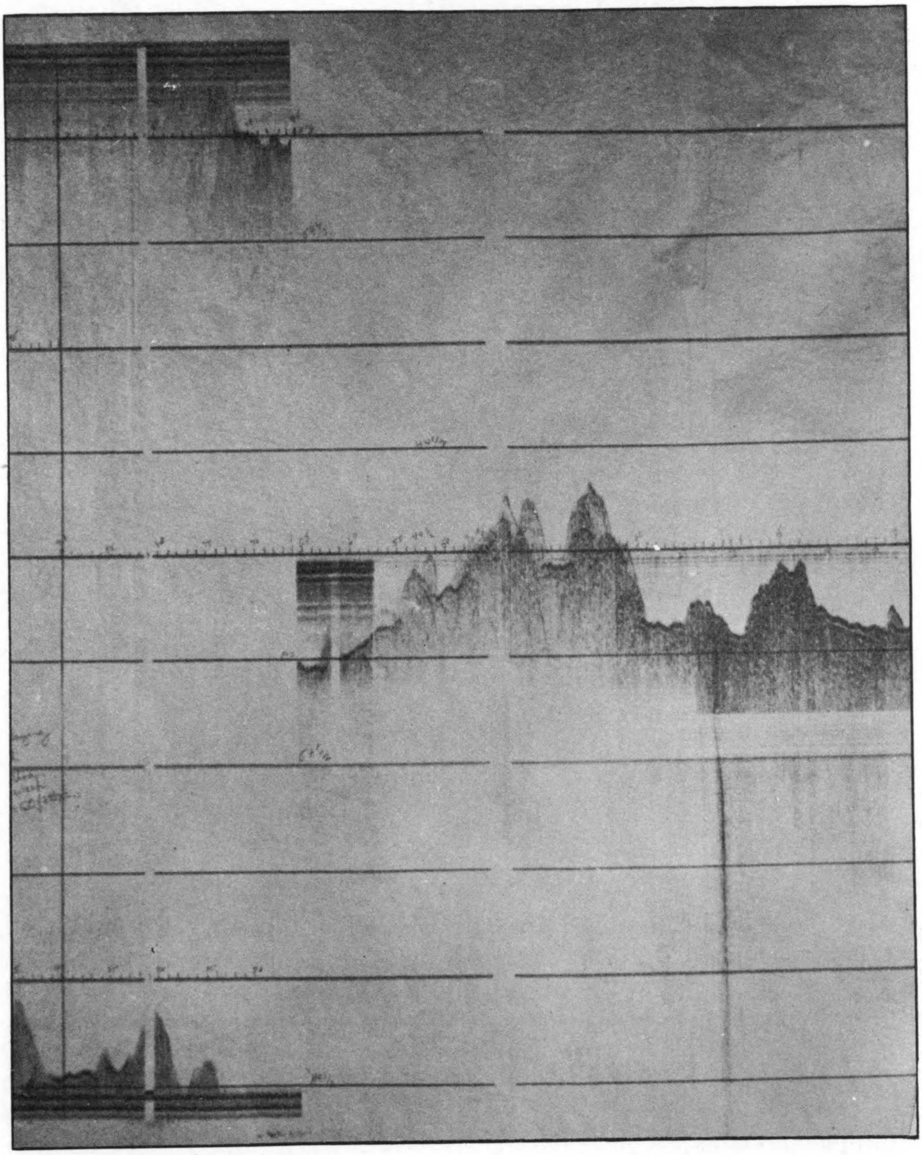


FIG. 4. — Edge keying of PGR recording causing record to split is connected by switching to center keying which brings record to middle of paper. Note in middle of record that keying interval is selectively removed to clarify bottom profile.

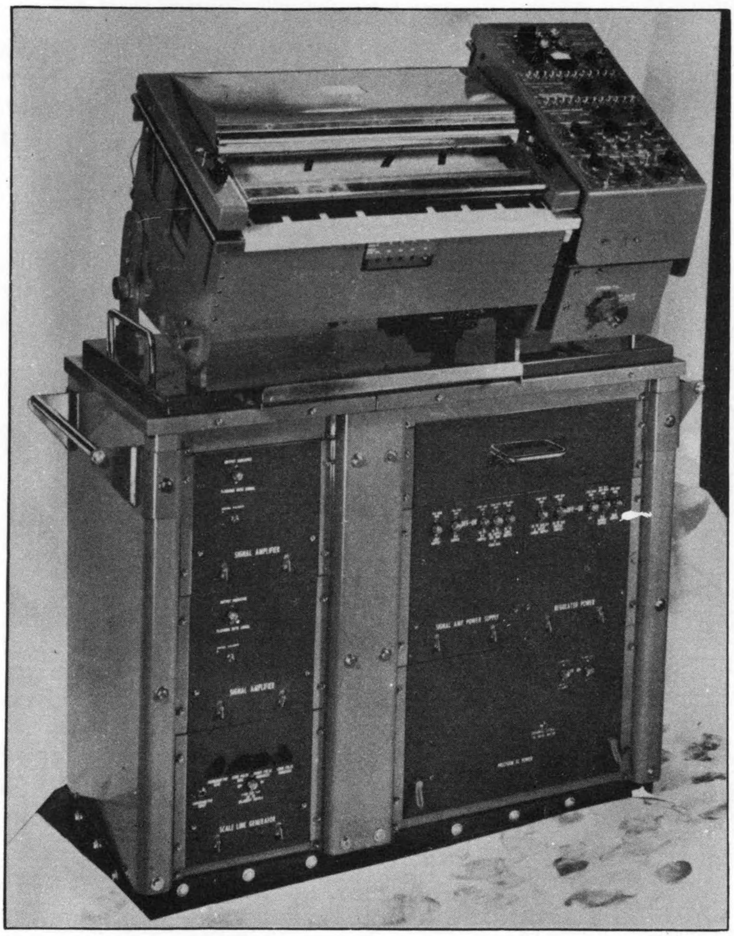


FIG. 5. — Alden 419 Precision Graphic Recorder.

Alden # 419 Precision Graphic Recorder

The Precision Graphic Recorder is now being made available by the Alden Electronic & Impulse Recording Equipment Co., Inc., Westboro, Mass. Packaged with modular electronics and separable recording head for shipboard use, it is known as the Alden #419 Precision Graphic Recorder and is now being supplied research centers in the United States and Canada (figure 4). In addition to being the control and recording element in Sonar systems, the Alden #419 PGR can be the slave unit, operating from external synchronism, to tie in with new underwater acoustic configurations for such applications as :

Continuous seismic profiling
Precise navigation with sonobuoys
Precise tracking of independent sonar pingers
Precise tracking of lowered or towed vehicles
Echo ranging

The PGR can also be utilized as a control and recording device for conventional underwater sound acoustic systems for :

Precision echo sounding
Scattering layer studies
Fish location
Topography mapping
Detection and location of submerged objects
Anti-submarine warfare
Salvage projects

Recorder heads and paper in 2″, 5″, 8-1/2″, 11″, 19″ up to 5′ widths have been successfully employed in other aspects of oceanographic research using techniques of programming similar to those employed in the Precision Graphic Recorders. Specific embodiments of the PGR programming and control may thereby be selected from its operating parameters for special purpose underwater sound instrumentation recording. Notable examples of this are the work of Capt. Jacques COUSTEAU (precision echo sounding), Professor Harold E. EDGERTON (precision tracking of EDGERTON, GERMESHAUSER, and GRIER independent sonar pingers [*]), Dr. William RICHARDSON (continuous temperature profiling [**]), and such companies as Westinghouse Electric, Raytheon, General Electric, and Sperry Rand for classified ASW equipment.

(*) Vol. I, No. 1, *Instant Graphic Recordings*, published at Alden Research Center, Westboro, Mass.
(**) RICHARDSON, HUBBARD : *Deep Sea Journal*, 1960.