

Nov. 18, 1969

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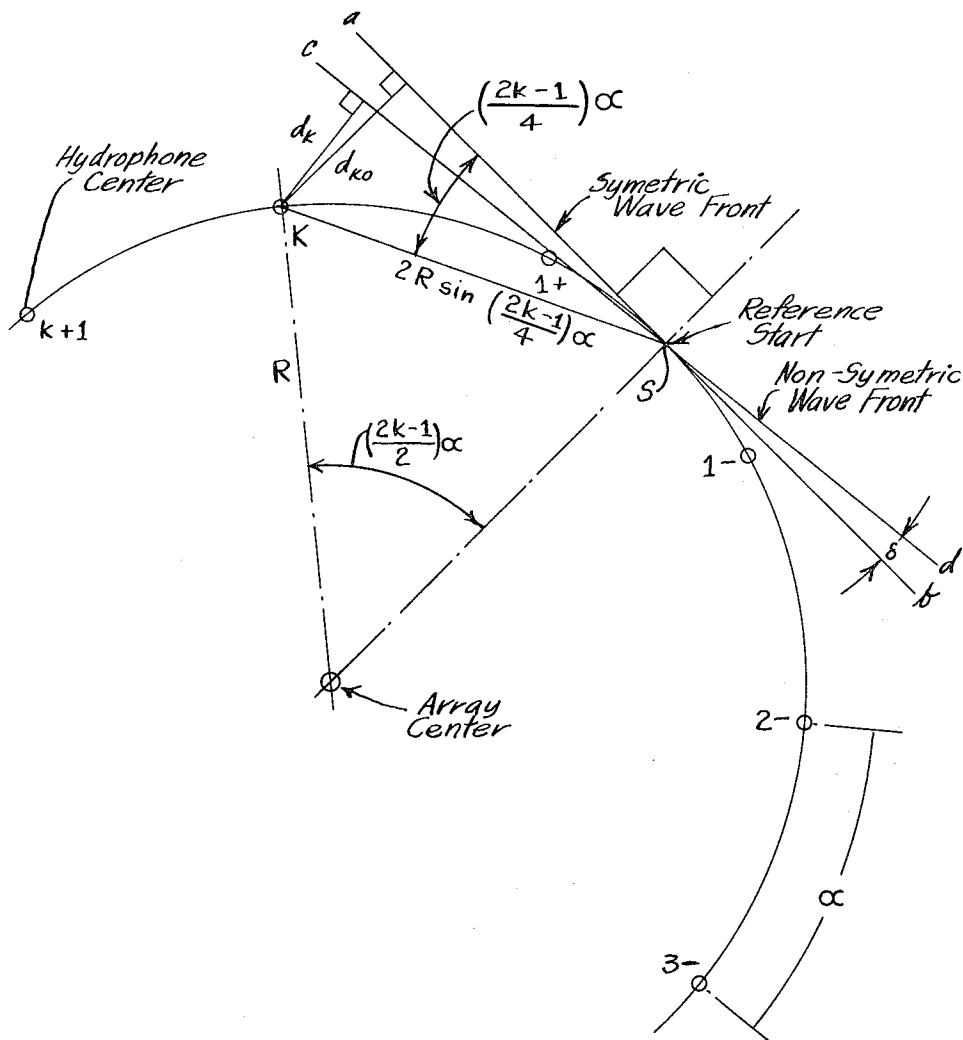
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BEAM FORMING TECHNIQUE AND IMPLEMENTATION FOR SONAR SIMULATION

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3 Sheets-Sheet 1

Fig. 1



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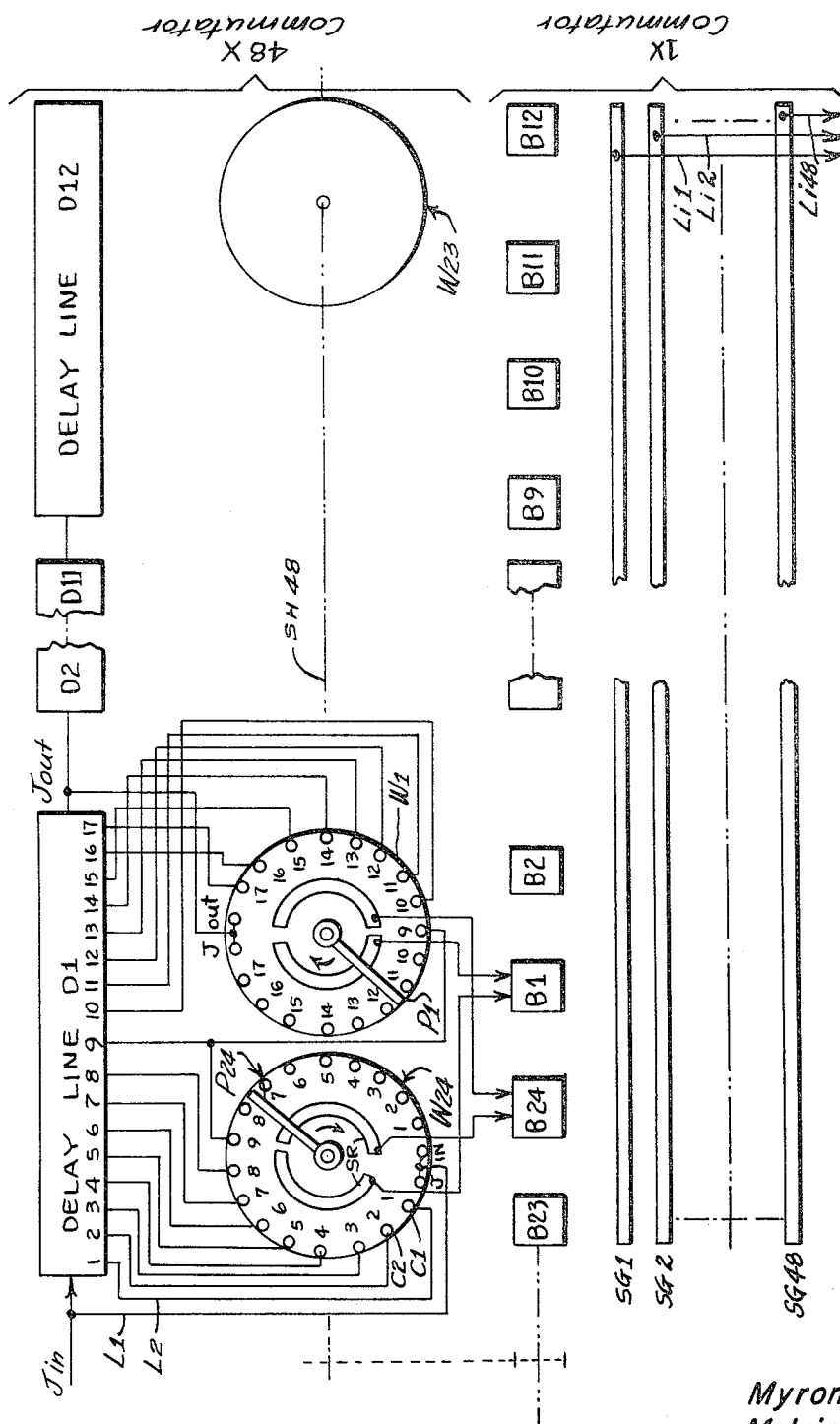


Fig. 2

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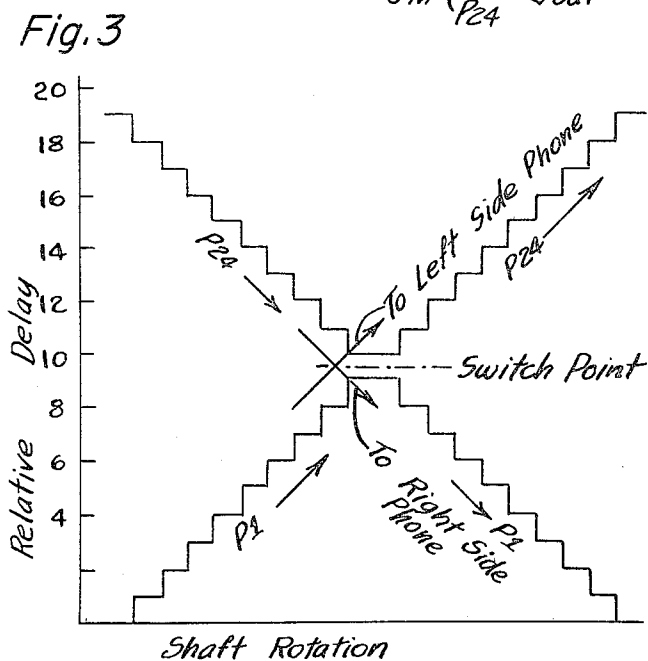
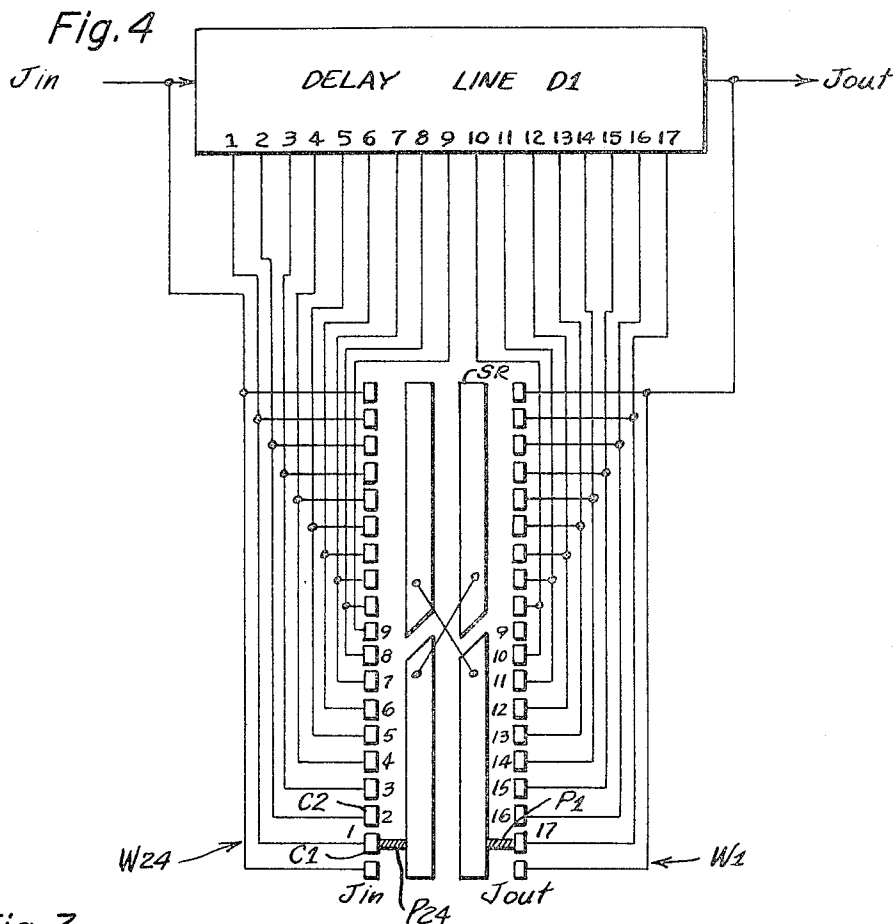
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BEAM FORMING TECHNIQUE AND IMPLEMENTATION FOR SONAR SIMULATION

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4 Claims

ABSTRACT OF THE DISCLOSURE

A technique and apparatus for developing an electrical analog of an underwater sound wave as sensed by a circular array of hydrophones comprising a delay line with multiple taps scanned reversibly by a first higher speed commutator which furnishes an output to a second lower speed commutator, the commutated output of which is said analog.

BACKGROUND OF THE INVENTION

This invention is in the field of simulation, more particularly of sonar device simulators. In the BQS-4 sonar device successive ones of a circular array of hydrophones detect an impinging sound wave at successive time intervals. The bearing of the sound source is determined from the sequence and timing of the signal outputs of the individual hydrophones. Heretofore great difficulty has been experienced in simulating this sonar device because of difficulty experienced in simulating the hydrophone output signals which must be selected and phased with great exactness to indicate the azimuth of a simulated sound source. In the prior art, recorded signals, e.g., on magnetic tape, have been used as inputs to a sonar simulator. However, small relative displacements between the several recorded tracks, uneven tape stretch, tape yaw, and other difficulties have made this expedient unsatisfactory.

SUMMARY OF THE INVENTION

The invention concerns a technique and apparatus for developing time delays in an electrical signal to simulate the signal generated by a circular array of hydrophones intercepting an underwater sound wave. The delays are developed with a plurality of interconnected multiple tap delay lines and an associated commutator switching means which scans the taps to develop the required signal. A primary object of the invention, i.e., to eliminate the inaccuracy caused by the prior art recorded signals is attained by dispensing with the recordings. An additional object of the invention, increased efficiency and reliability, is attained by the resulting simplification of the simulator apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates the mathematical basis for deriving the time delays generated by the apparatus.

FIG. 2 is a schematic drawing of the delay lines and switch means for generating and selecting time delays in an electrical signal.

FIG. 3 is a graph of relative delay picked off of delay line section D1 of FIG. 2 by poles P24 and P1 of wafers

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W24 and W1 plotted against shaft rotation of the 48X commutator of FIG. 2.

FIG. 4 shows the internal taps of the delay line D1 of FIG. 2 connected to the contacts of switch wafers W24 and W1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The BQS-4 sonar system has a transducer arrangement wherein forty-eight hydrophones are equally spaced around a sixty-eight inch diameter circle. An impinging sound wave front will excite the forty-eight hydrophones in a certain time sequence or phase relation depending on the direction of the velocity of the impinging wave front, the geometry of the system, and the speed of sound transmission. To simulate the detection of a sound producing object in the water it is necessary to excite each of twenty-four hydrophones with an electrical signal. Each of the twenty-four signals is delayed for a period corresponding to one of the time delays experienced by the sound wave in water (only the twenty-four hydrophones facing the impinging sound wave need be excited because a compensating switch in an actual sonar is arranged to restrict signal transmission to those phones). As the bearing of the sound producing object relative to the hydrophone array is changed, all of the delays must change in a predetermined fashion. This delay, as a function of relative bearing, is implemented by a two speed commutator switching arrangement wherein a first commutator is driven directly by a relative bearing shaft of the sonar system and a second commutator is geared up forty-eight times from the first commutator. Twenty-four delayed signal outputs from the commutator arrangement are fed as inputs into the front end of the BQS-4 sonar. These inputs are the direct electrical analog of a complex sound signal as it impinges on the circular hydrophone array.

With reference to FIG. 1, sounds emanating from a point source remote from a hydrophone array comprising hydrophones 1-, 2-, 1, k, k-, etc., arrive with an approximately straight wave run shown as line a, b. Less than the actual number of hydrophones in the apparatus are shown in FIG. 1 in order to better illustrate the principles involved by accentuating angular displacements. The first hydrophone to be energized by the sound wave reaching the array is dependent on the bearing of the sound producing object. The hydrophones in the array are energized in sequence from the sound reaching the array. At any one time only a 180° portion of the array consisting of twenty-four adjacent hydrophones facing the sound source is connected to the BQS-4 compensating circuitry. Because of the circular arrangement of the hydrophones it may be shown that the delay of the sound reaching successive phones is proportional to the cosine of the angle between phones for the symmetrical case shown in FIG. 1 (symmetry is defined as a target bearing such that the line drawn between the focal point of the hydrophones and the sound producing source bisects the line connecting two adjacent phones). Referring all distances to a reference start point S, indicated, and noting that the time delay of signals reaching the particular hydrophones referenced to this start point is proportional to the distance shown for the symmetric case, the distance d_{k0} from a hydro-

phone k to the symmetric wave front passing through point S may be shown to be equal to

$$d_{ko} = R \left[1 - \cos \left(\frac{2k-1}{2} \alpha \right) \right]$$

where $k=1, 2, n$, etc., R is the radius of the hydrophone array, and α is the angle between two adjacent hydrophones. For the non-symmetric case where a waveform shown as line c, d , is moved by an angle δ from wavefront a, b , the distance from the wavefront c, d , passing through S to any of the hydrophones may be shown to be equal to d_k where,

$$d_k = R \left[\cos \delta - \cos \left(\frac{2k-1}{2} \alpha \pm \delta \right) \right]$$

It may be shown that for δ angles equal to less than $\pm 3.75^\circ$, the time delay is linearly variable with δ for any of the particular hydrophones. Knowing the speed of sound in water d_{ko} and d_k are converted to time delay.

Apparatus for simulating this time delay is shown in FIG. 2. Here, twelve lumped delay line sections D1, D2 . . . D12, are connected in tandem and activated by inputs to D1 appropriate to the sonar operating mode. Each section is divided into a number of sub-sections, not illustrated. Each subsection has an output tap and the section input and output are each considered a subsection and tapped. See Table 1 which lists the number of subsections, number of taps, sub-section delay, and section delay, for each of the twelve sections.

All of the subsection delays in a given section are of equal length. The total delay line (all twelve sections connected in tandem) has a flat amplitude response of 150 to 15,000 cycles/second and a total delay of 577.36 microseconds. The time delay from center to center of each adjacent delay line section is equivalent to the time delay from hydrophone No. 1 to No. 2, to No. 3, etc. for the symmetric case. Consequently, each of the twelve sections corresponds to twelve hydrophones located on each side of a reference start point. Since the hydrophones are spaced by 7.5° , the seventy-five internal taps per section in the last eight sections correspond to a resolution of $.1^\circ$. It may be shown that the total delay for maximum δ of 3.75° between the hydrophones closest to the reference start point is small compared to the delay between hydrophones spaced approximately 90° from the reference start point. Consequently, the major contribution of the composite hydrophone phase shift as related to the bearing change is due to the higher numbered phones (i.e. those farthest away from the reference start point). Therefore, as noted in FIG. 2 and Table 1, the first four delay line sections have fewer internal taps than the last eight delay line sections.

Each subsection of the multiple tap delay line sections is connected by a line such as L1, L2, to a respective contact C1, C2, of a wafer W24, W1 . . . W23 of a twenty-four pole twenty-four wafer rotary switch labeled 48X commutator. Each wafer has a number of contacts C, equal to the number of associated delay line taps and a pole such as P24 of wafer W24. Each of these twenty-four poles is fixed on the single shaft SH48 of the 48X commutator which is coupled to the bearing angle shaft of the sonar system through 48:1 gearing so that a bearing angle change of 7.5° corresponds to a complete rotation of the 48X commutator. The first half of the taps of each of the delay lines are connected to the contacts of one wafer such as W24 and the second half are connected to the contacts of a second wafer such as W1, as shown.

Each of the poles sequentially connects its associated contacts through respective slip rings SR to a brush such as B24, B1, B2 . . . B23, of a twenty-four brush, forty-eight segment commutator switch labeled the 1X commutator which is driven in synchronism with the relative bearing shaft of the sonar apparatus. Twenty-four slip rings, not shown, are associated with this commutator since brushes B1 . . . B24 actually rotate with the rela-

tive bearing shaft inside a circular array of the forty-eight commutator segments SG1 . . . SG48. The showing of FIG. 2 is merely schematic to better illustrate the interrelationships of the several elements. The output of each of the commutator segments is routed through output lines such as LI1, LI2, LI48, to a summer, not shown, which sums like segments for the other sound producing sources.

Commutator switching is accomplished in two stages to effectively move the sonar signal in azimuth.

The 1X commutator is, essentially, a twenty-four brush forty-eight position sequential switch which simulates the shadow effect of the rearward side of the hydrophone head. In operation, the twenty-four brushes are symmetrically arranged about the echo return center line (drawn through point S in FIG. 1) and are alternately break-before-make and make-before-break contacts. The break-before-make and make-before-break configuration is necessary to avoid shorting out the delay line while maintaining an accurate beam. The brushes are formed by a fan shaped assembly of contact springs rotating on a shaft. Stationary commutator segments SG represent the individual hydrophones, and are equally spaced at 7.5° intervals around a circle. Moving brushes cover the forward side of the hydrophone array only.

The 48X commutator is a complex twenty-four section switch, with wafers containing from 19 to 77 contacts and split slip-ring switching. The purpose of the 48X commutator is simulate vernier sonar target motion between azimuth radials through the hydrophones of the array. This requires that the acoustic delay to one of a pair of hydrophones located on opposite sides of an azimuth radial intersecting the sound source (No. 1 left—No. 1 right, No. 2 left—No. 2 right, No. 3 left—No. 3 right, etc.) increases gradually while the delay to the other of the pair decreases at the same rate. Therefore, the 48X commutator switches from sub-section tap to adjacent subsection tap scanning outwards and then inwards on each side of the center tap of each section. Slip ring switching provides the mechanical means for performing the opposite direction scanning motion and crossover of complementary brushes.

FIG. 3 shows the relative delay picked off the taps of delay line section D1 of FIG. 2 by poles P24 and P1 of wafers W24 and W1 plotted against shaft rotation of the shaft in the 48X commutator of FIG. 2. The drawing is self explanatory.

FIG. 4 is another showing of the delay line section D1 tap connections to the contacts C1-C2, etc., of wafers W24 and W1 of the 48X commutator. Note the interconnections between the like numbered contacts. The pole P1 moves upwards in FIG. 4 to successively connect the contacts J_{out}, 17, 16 . . . 9 to a brush B24 of the 1X commutator shown in FIG. 2 through slip ring SR, then continues upward to connect contacts 9, 10, 11 . . . 17, J_{out}, to an adjacent brush B1. Pole P24 connects contacts J_{in}, 1, 2 . . . 9, 8 . . . 2, 1, J_{in}, alternately to brushes B1 and B24.

It may be seen that as the 1X commutator brushes B24 . . . B1 rotate with the sonar apparatus relative bearing shaft to scan the commutator segments SG1-SB48 a signal will be impressed on two adjacent segments representing two adjacent hydrophones. If the simulated sound source is located on an azimuth radial bisecting a line between two adjacent hydrophones (the symmetrical case of FIG. 1), a signal will be impressed on both of the segments simultaneously. If the sound producing object is not so located (the asymmetrical case of FIG. 1) the signal will be impressed on one of two adjacent segments first and on the other slightly later depending on which of the corresponding hydrophones is nearer to the azimuth radial locating the simulated sound producing object. This effect is from the vernier action of the 48X commutator. As the 1X commutator rotates 7.5° corresponding to the spacing between individual hydrophones it is apparent from FIG. 2 that poles P24 and P1 will

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scan delay line D1 from each end tap J_{in} and J_{out} inwards to tap 9 and then out from tap 9 to J_{in} and J_{out}, reversing direction and connections to brushes B24 and B1 by means of slip rings SR to pinpoint the azimuth of a sound source. Eleven succeeding signals will be fed to successive brushes representing successive hydrophones on each side of the sound locating azimuth radial with time delays similar to those caused by an actual sound wave striking succeeding hydrophones of the array.

TABLE 1

Section	No. sub-sections	No. taps	Sub-Section delay (us)	Section delay (us)
1.....	20	19	.2477	4.9544
2.....	38	37	.3881	14.7482
3.....	38	37	.6398	24.3114
4.....	38	37	.8763	33.2986
5.....	76	75	.5534	42.0554
6.....	76	75	.6549	49.7750
7.....	76	75	.7474	56.8034
8.....	76	75	.8274	62.6796
9.....	76	75	.8930	67.8646
10.....	76	75	.9400	71.4364
11.....	76	75	.9748	74.0864
12.....	76	75	.9915	75.3538

577.3672

What is claimed is:

1. In a sonar simulator device, the improvement comprising
- a multiple tap delay line for delaying an electrical signal, and switch means for scanning the taps of said multiple tap delay line to select portions of said delayed signal whereby an electrical analog of an underwater sound wave is developed, said switch means comprising a first multi-pole, multi-wafer, multi-contact commutator switch, and a second multi-brush, multi-segment, commutator switch.

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2. The apparatus of claim 1 wherein said multi-pole switch scans at a greater rate than said multi-brush switch.

3. The apparatus of claim 2 wherein said switch means are connected to scan with the relative bearing scanning means of said sonar simulator device and the signals from said switch means are connected to the inputs of said sonar simulator device.

4. In a sonar simulator device, the improvement comprising:

means for developing an electrical analog of an underwater sound wave including delay means for delaying an electrical signal, and selecting means for selecting portions of said delayed signal, said selected portions comprising said analog, and wherein said delay means comprise a multiple tap delay line comprising a chain of delay line sections and said selecting means comprise switch means for reversibly scanning said multiple taps so that the taps of each said section are scanned outwardly from the center tap to the end taps of said section and are scanned inwardly from the end taps to the center tap of said section.

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