

[54] **HIGH POWER, LOW FREQUENCY
UNDERWATER TRANSDUCER ARRAY**

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[51] Int. Cl.**H04r 1/40**
[58] Field of Search**310/9.1, 20; 343/854; 340/8,
340/9, 10**

[56] **References Cited**

UNITED STATES PATENTS

3,505,639 4/1970 Chervenak 340/9

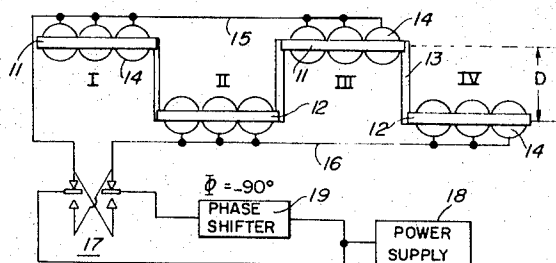
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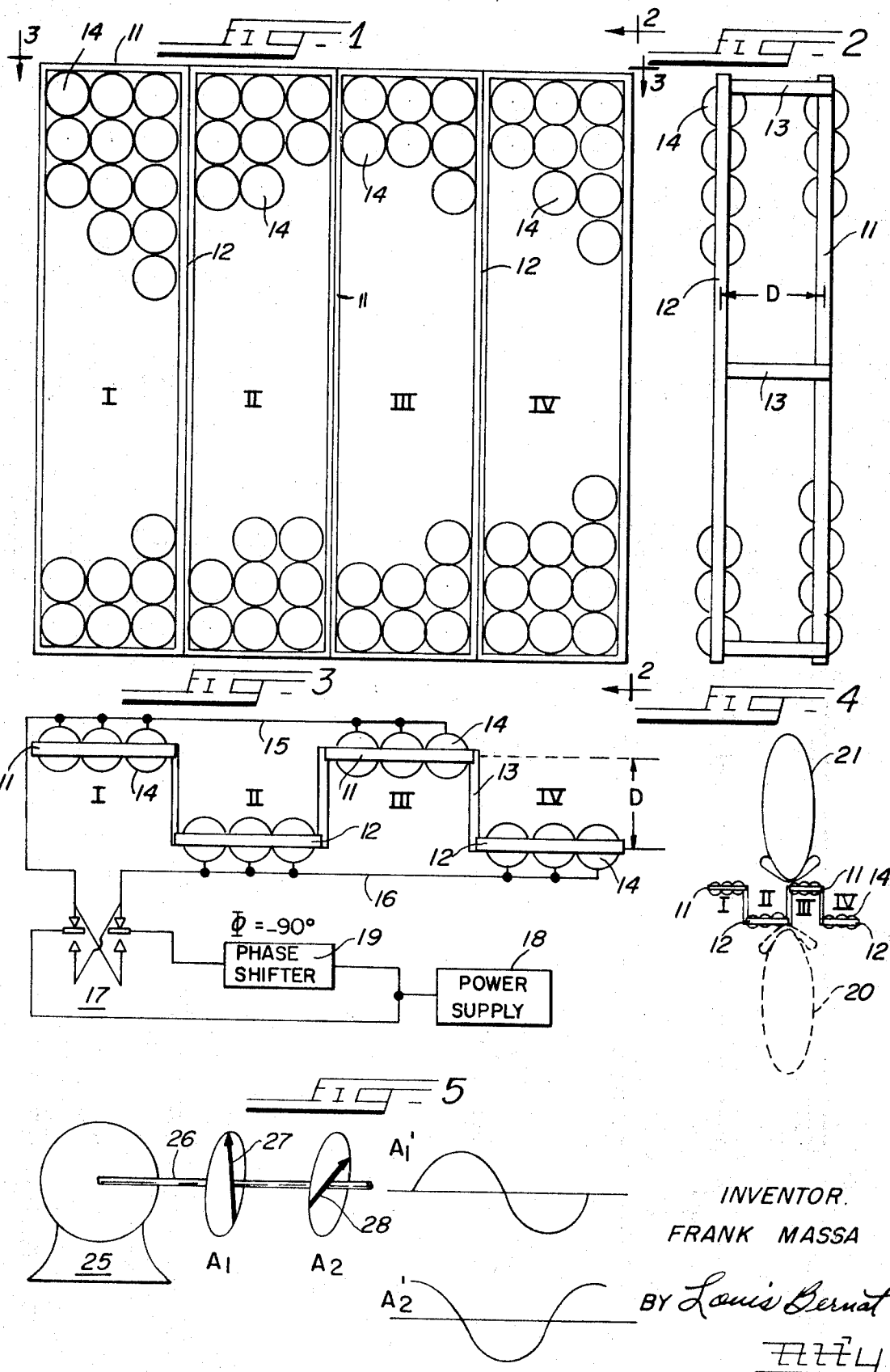
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[57] **ABSTRACT**

A plurality of underwater transducers are physically mounted in two spaced parallel planes, a quarter wavelength apart. The signals driving the transducers in each of the two planes are electrically displaced from each other by a quarter wavelength. In this way, the sound from the transducers adds on one side of the two planes and cancels on the other side, to provide a unidirectional beam of sonic energy.

14 Claims, 5 Drawing Figures





HIGH POWER, LOW FREQUENCY UNDERWATER TRANSDUCER ARRAY

This invention relates to low frequency, high power, underwater sound sources, and more particularly to means for achieving a unidirectional beam of sonic energy in deep water where extremely high hydrostatic pressures preclude the use of conventional pressure release materials.

Although the invention is not limited to any specific type of transducer, it is particularly useful in combination with a large array of inertial type transducers, similar to the transducer illustrated in U.S. Pat. No. 3,319,220, issued May 9, 1967, entitled "Electromagnetic Transducer for Use in Deep Water," Frank Massa, Jr., inventor. An array of these low frequency inertial transducers may be assembled as illustrated in my copending application Ser. No. 61,198, filed Aug. 5, 1970, and entitled "Baffle Structure for Underwater Transducer Array." Both of these inventions and the subject invention are assigned to the same assignee.

If the linear dimensions of the array are large, as compared to the wavelength of the sound being radiated, a beam of sonic energy is radiated from both sides of the array. However, in most underwater sonic applications, it is desirable to have such a radiation from only one side of the array. The sharpness of this beam is a function of the size of the array.

In the past, the radiation of sound on one side of an array has been achieved by providing a low acoustic impedance, pressure release system on the other side of the array. This is because the pressure release material shields and prevents radiation from the other side of the array. For example, the pressure release system could comprise one or more sheets of cell-tite rubber or corprene. It could also comprise a number of flexible walls of air-filled tubes which are mounted behind the array. In all of these systems, the release material is arranged to cover most of the area of the baffle assembly.

The above described pressure release systems can prevent radiation from one side of the array, but only in relatively shallow water (i.e. less than a few thousand feet in depth). In water of greater depth (e.g. several thousand feet and more), the pressure release system is not effective because the air cells are compressed beyond a point where they are operative.

Accordingly, an object of this invention is to provide a very deep water baffle structure for mounting an array of inertial type transducers to generate a single unidirectional beam of sound. Here, an object is to avoid a use of pressure release material.

Another object of this invention is to provide a baffle structure and an assembly of transducer elements which generate a unidirectional beam of sound. In this connection, an object is to radiate sound from the baffle assembly when submerged in water of great depth, in excess of 2,000 ft.

A further object of this invention is to prevent a back beam radiation of sound. Here, the object is accomplished by mounting a group of transducers in a pattern, with an array of the transducers arranged in two parallel planes separated by a quarter wavelength of sound.

In keeping with an aspect of this invention a structural frame-like configuration is provided for mounting deep water transducers. The frame supports a three

dimensional array in which the transducers are symmetrically mounted in two groups which are spaced away from one another by a quarter wavelength in the direction of the sound radiation. Electronic phase shift means are preferably provided for driving each of these two separated groups of transducers with a different electrical power signal which is shifted by a quarter wavelength to relate to the quarter wavelength physical spacing. This combination of physical and electrical spacing provides a unidirectional beam of sound which is radiated from only one side of the array.

The novel features which are characteristic of the invention are set forth with particularity in the appended claims. However, the invention itself, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following description when taken in conjunction with the accompanying drawings in which:

FIG. 1 is a schematic plan view showing a transmission side of an array of underwater transducers mounted in a physical configuration incorporating one embodiment of this invention;

FIG. 2 is a side view of the structure illustrated in FIG. 1 taken along line 2—2 thereof and looking in the direction of the arrows;

FIG. 3 is a top view of the structure illustrated in FIG. 1 taken along line 3—3 thereof and looking in the direction of the arrows;

FIG. 4 is a schematic illustration of the unidirectional acoustic radiation patterns (solid curve or dotted curve) which may be transmitted from the transducer array of FIG. 1; and

FIG. 5 schematically shows a pair of alternators which are arranged to produce signals that are displaced from each other by 90°.

In FIGS. 1, 2 and 3, several rigid rectangular frame structures 11 and 12 are arranged, alternately, in two parallel planes which are spaced apart by a distance D. The several frames are held in a desired, spaced apart relationship by structural members 13 which are welded between the frames 11 and 12 to form the assembly into a rigid structure. Additional struts, not shown, may be welded diagonally across the spaces separating these parallel mounted frames in order to form a lattice of welded triangular braces. These struts secure the entire assembly into a lightweight acoustically transparent rigid structure.

In these figures, there are four rectangular frames I, II, III, and IV. However, the assembly could be arranged to have any desired number of frames. Preferably, the separated groups of structures 11 and 12 are arranged into symmetrical pairs with equal areas.

Each of the frame structures I-IV is filled with transducers 14 such as the spherical electromagnetic underwater transducers described in U.S. Pat. No. 3,319,220. These transducers may be mounted by a flexible suspension means such as the structure described in my copending application Ser. No. 60,258, filed Aug. 3, 1970, entitled "Mounting Structure for Spherical Shaped Underwater Transducer," and assigned to the assignee of this invention. For convenience of expression, the transducers mounted within any given frame 11 or 12 may be described as a

"a single plane" of transducers. However, the term is not to be construed as going beyond the disclosure in the drawing.

The frame structures 11 and 12 surround and support a rigid assembly of tubular sleeves which are contiguously positioned in an adjacent side-by-side configuration with their axes parallel to each other. These sleeves are positioned as schematically illustrated in the plan view of FIG. 1. The details of a suitable mounting structure are shown in my copending application Ser. No. 61,198, filed Aug. 5, 1970, referred to above.

Preferably, the widths of the array frames 11 and 12 (FIG. 1) are at least equal to approximately a quarter wavelength of the sound generated by the assembly at the frequency of operation. If the individual frames have a width which is much less than a quarter wavelength of the radiated sound, the acoustic loading on the individual sections decreases rapidly and the efficiency of the sound generating capability falls off appreciably. Also, it is preferable for the widths of the individual frame structures 11, 12 not to exceed approximately one wavelength of sound at the frequency of operation. If the widths of the individual frame structures are increased significantly beyond one wavelength, it is difficult to achieve unidirectionality in the radiated beam.

FIG. 3 schematically illustrates how the frame structures 11 and 12 are displaced in alternately parallel planes and are electrically interconnected. The radiation of sound pressure wave fronts takes place from the alternating groups of transducers. Thus, these wave fronts are separated by a distance D which is equal to the transducer spacings.

All of the transducers assembled in the array frames 11 of one plane are electrically connected together by the cable 15. All the transducers mounted in the frame structures 12 of the other plane are electrically connected together by the cable 16. Thus, the transducers are grouped together and associated as sound radiators both in space and electrically.

A phase shift is introduced into either bank of transducers by a reversing switch included in the circuit diagram of FIG. 3. More particularly, a phase reversing switch 17 is shown in an upper position as illustrated in FIG. 3. Here, the cable 15 is connected directly to a power supply 18, and the cable 16 is connected via a phase shifter 19 to the power supply 18. The phase shifter 19 might include an electronic phase shift network which is a part of the electronic power supply system 18. The electronic system design does not, per se, form a part of this invention. Therefore, its specific details are not shown.

Between the groups of transducers 11 and 12, the spacing D is made equal to a quarter wavelength of the sound at the frequency of operation. Also, the phase shifter 19 introduces a phase delay of 90° (a quarter wavelength) in the electrical signal at the frequency of operation. Therefore, the sound wave radiated in the downward direction (as viewed in FIG. 3) is in phase for both groups of radiating transducers 11 and 12. The sound wave radiated in the opposite or upward direction (as view in FIG. 3) is 180° out of phase for both groups of transducers 11 and 12. Hence, the radiation in the upward direction is nearly zero. Therefore, for the described electrical connection, the radiation

pattern from the complete array is that shown by the dotted line directional characteristic curve 20 (FIG. 4).

If the phase reversing switch 17 is moved to the lower contact position (as shown in FIG. 3), the phase shifter 19 is connected to the cable 15. The cable 16 is then connected directly to the power supply. In this electrical condition, the sound radiated from the two displaced groups of transducers is in phase for the upward direction (as viewed in FIG. 3), and the out of phase sound wave is in the downward direction (as viewed in FIG. 3). Here, a unidirectional beam pattern is achieved, for the entire array, as illustrated by the solid line curve 21 of FIG. 4.

Thus, the electrical phase relationship combined with the physically spaced configuration of the symmetrical groups of transducers provides a desired radiation pattern. The waves combine to achieve a unidirectional radiation of sound on one side, and they neutralize each other to preclude undesirable radiation from the rear of the transducer array.

It is not necessary to employ any pressure release systems. Therefore, the teachings of this invention achieve the twin objects of (1) providing unidirectional radiation from an array of bidirectional radiating sources and (2) operating satisfactorily at great water depths where the high hydrostatic pressure does not permit the use of conventional pressure release materials.

The sharpness of the desired beam angle determines the number of frame sections 11 and 12 which are used to establish the total width of the complete array. Sharper beam angles result from width total combined widths of the assembled frame structures. The desired vertical beam angle of the complete array establishes the height of the individual frames (as illustrated by the vertical dimension in FIGS. 1 and 2).

Although FIGS. 1 and 2 illustrate an individual frame section in a single plane for the complete vertical structure, it is obvious that the vertical distance may also be broken up into multiple subsections. Among other things, this subdivision makes it convenient to handle individual assemblies during production. This is especially attractive when the array is very large and the total length and weight of the frames are excessive for single frame assemblies. This occurs in the lower audio frequencies where, for example, operation is in the frequency region of a few hundred cycles. The diameter of each individual spherical transducer 14 might then be in the order of 2 feet and its weight might be in the vicinity of 1,000 lbs.

A second embodiment of the electrical apparatus is attractive for certain applications (e.g. where the array is used for echo ranging purposes). Here, tone bursts of short duration are sent out into the water, and essentially sinusoidal electrical wave shape is required. To provide this wave shape, a rotating power supply, consisting of two alternators A1, A2, (FIG. 5) is driven from a single motor 25. The alternators are connected to a common drive shaft 26. The rotor 27 on one alternator A1 is displaced with respect to the other rotor 28 so that the electrical signal A2' from one alternator is delayed by 90° with respect to the electrical signal A1' from the second alternator.

If the tone bursts are to be of very short duration, with very high power intensity (in the vicinity of megawatts), relatively smaller alternators may be employed if a massive fly wheel is attached to the drive shaft. The fly wheel serves as an inertial energy storage system for increasing the short time power output of the alternators when used on an intermittent basis.

While several specific illustrative embodiments of the present invention have been shown and described, it should be understood that various modifications and alternative constructions may be made without departing from the true spirit and scope of the invention. Therefore, the appended claims are intended to cover all equivalent structures as fall within their true spirit and scope.

I claim:

1. An array of underwater transducers which radiate oppositely directed sound waves, said array comprising a plurality of rigid planar frame structures, each frame defining a surface, means for holding said frames in spaced parallel side-by-side relationship with adjacent ones of said frames being placed in pairs, one member of each of said pairs being positioned in front of the other member of said pair by a distance of approximately a quarter wavelength at the operating frequency, a plurality of said transducers mounted within each of said frame structures with all of the transducers in any of said frames having their radiating surfaces aligned in a single plane and generating sound waves parallel to the surface of said frame, said holding means comprising means for rigidly holding alternate non-adjacent ones of said plurality of said frame structures in spaced parallel planar relationship and for holding non-adjacent frames intermediate said alternate frame structures in a second spaced parallel planar relationship, thereby forming two planar groups of non-adjacent frames displaced from each other by said quarter wavelength at the operating frequency.

2. The invention in claim 1 and a source of alternating current electrical power, means for shifting the phase of said electrical power, a first group of said transducers mounted in one group of said frame structures, said first group of transducers being connected directly to said source of alternating electrical power and a second group of said transducers being mounted in the other group of said frame structures, said second group of transducers being connected through said phase shifting means to said source of alternating electrical power whereby said two groups of transducers are driven by electrical currents which are displaced in phase with respect to each other.

3. The invention in claim 1, characterized in that said parallel spacing between said two groups of transducers is equal to approximately a quarter wavelength of the frequency at which the transducers are operating, and still further characterized in that said phase shifting means introduces a 90° phase shift in said electrical signal of the frequency at which the transducers are operating.

4. The invention in claim 1 characterized in that said transducers are spherical bidirectional radiators of sound.

5. The invention in claim 4 and a source of alternating current electrical power, means for shifting the phase of said electrical power, a first group of said

transducers mounted in one group of said frame structures, said first group of transducers being connected directly to said source of alternating electrical power and a second group of said transducers being mounted in the other group of said frame structures, said second group of transducers being connected through said phase shifting means to said source of alternating electrical power whereby said two groups of transducers are driven by electrical currents which are displaced in phase with respect to each other.

6. The invention of claim 5 characterized in that said phase shifting means introduces a 90° phase shift in said electrical signal of the frequency at which the transducers are operating.

7. An array of underwater transducers comprising a plurality of rigid planar frame structures arranged in spaced parallel side-by-side paired relationship, each of said frames having a plurality of transducers mounted therein with all transducers in each frame being aligned with their radiating surfaces in a single plane, a first group of said transducers and frame structures including a first member of each pair assembled in side-by-side spaced relationship alternating with a second member of each pair also assembled in side-by-side spaced relationship and arranged so that all transducers within said first member group of alternating frame structures lie in a first plane and all transducers within said second member group of alternating frame structures being assembled to lie in a second plane, said second plane of frame structures being displaced parallel with respect to said first plane of frame structures with said displacement being a distance approximately equal to one quarter wavelength at the operating frequency, and the transducers in said second members being positioned to drive into the spaces between said first member frame structures, said second plane being spaced from and parallel to said first plane.

8. The invention in claim 7 and a source of alternating current electrical power, means for shifting the phase of said electrical power, said first group of transducers mounted within said first group of frame structures being connected directly to said source of electrical power, and the second group of transducers mounted within said second group of frame structures being connected to said source of alternating current electrical power via said phase shifting means.

9. The invention in claim 8 and a reversing switch connected between said source of electrical power and said two spaced parallel groups of transducers whereby the electrical signal phase shifting means may be connected to either of said transducer groups to selectively produce a unidirectional beam of sound from either the front or back of the array assembly.

10. The invention in claim 7 further characterized in that the width of the assembled frame structures lies in the approximate range of one quarter to one wavelength of the sound generated by the transducers at the operating frequency of the array.

11. The invention in claim 10 further characterized in that the individual frames in said groups of frame structures are separated by spaces which are approximately equal to the width of said frames.

12. The invention in claim 7 characterized in that the spacing between said parallel planes is approximately equal to one quarter wavelength of sound of the

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frequency at which the transducers are operating, and phase shifting means connected to the transducers in one frame for introducing a 90° phase shift in an alternating current signal of the frequency at which the transducers in said one frame are operating.

13. The invention in claim 12 and an alternating current electrical power source which includes two alternators connected to a common drive shaft, further characterized in that said phase shifting is accomplished by displacing the rotor of one of said alternators with respect to the rotor of the other alternator so that the phase of a signal generated in one of said alterna-

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tors is displaced by 90° with respect to the phase of a signal generated in the other of said alternators to produce the displaced phase voltages.

14. The invention in claim 13 and a reversing switch connected between said source of electrical power and said two spaced parallel groups of transducers whereby the electrical signal phase shifting means may be connected to either of said transducer groups to selectively produce a unidirectional beam of sound from either the front or back of the array assembly.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,715,711 Dated February 6, 1973

Inventor(s) Frank Massa

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 3, line 65, "view" should read -- viewed --.

Column 4, line 34, "width" should read -- greater --.

Signed and sealed this 19th day of February 1974.

(SEAL)

Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

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