Aug. 13, 1946. T. J. POPE 2,405,604

COMPRESSIONAL WAVE TRANSLATING DEVICE

Filed March 13, 1943

FIG. 1

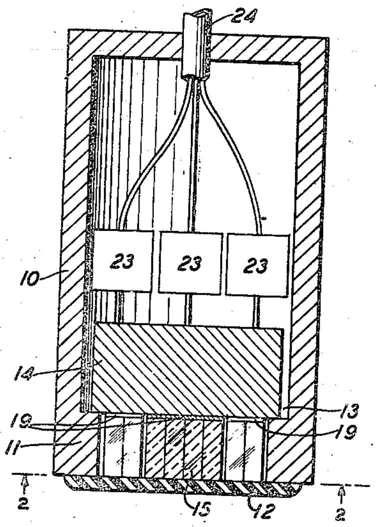
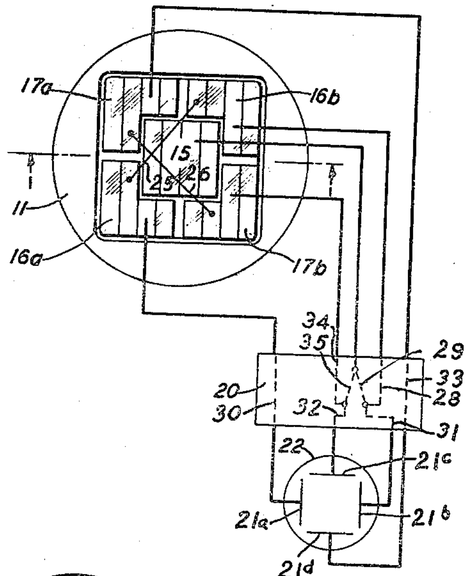


FIG. 2



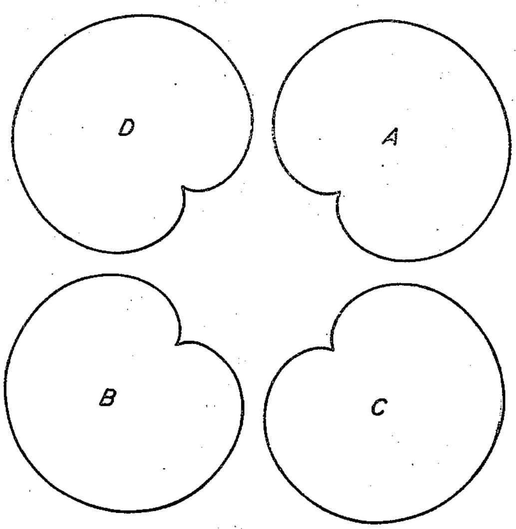
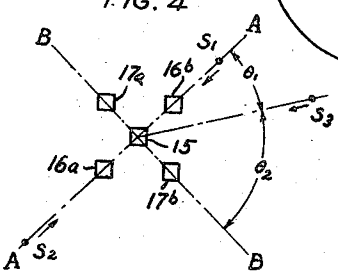


FIG. 3

FIG. 4



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COMPRESSIONAL WAVE TRANSLATING DEVICE

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9 Claims. (Cl. 177—386)

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This invention relates to compressional wave translating devices and more particularly to microphones specially suitable for use in supersonic submarine signaling systems.

One object of this invention is to obtain a predetermined directional characteristic for sonic translating devices. More particularly, one object of this invention is to realize from a supersonic hydrophone an output the directivity pattern of the magnitude of which is accurately indicative of the direction of the source of the supersonic waves with respect to the hydrophone.

In one illustrative embodiment of this invention, a hydrophone comprises a group of compressional wave responsive elements associated with a common diaphragm, the elements individually having predetermined directional response characteristics, and means for combining the outputs of the several elements to produce a desired directional characteristic for the group of elements. In a particular construction, the several elements are formed of multi-slab piezoelectric crystals, the crystal slabs of each element being oriented mechanically and electrically to operate cophasically.

In accordance with one feature of this invention, the group of wave responsive elements comprises a central non-directional element and two two-part bidirectional elements having substantially cosine directivity, the parts of the bidirectional elements being arranged in quadrature about the central element and the two parts of each bidirectional element being diagonally opposite one another. The central element is electrically associated with the bidirectional elements in such manner that the response pattern of the group of elements is composed of four cardioidal lobes orthogonally related.

The invention and the above noted and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawing in which:

Fig. 1 is an elevational view mainly in section of a supersonic hydrophone illustrative of one embodiment of the invention;

Fig. 2 is in part a sectional view of the hydrophone, taken along plane 2—2 of Fig. 1 and in part a circuit diagram illustrating one manner of utilizing the hydrophone;

Fig. 3 is a diagram showing the directional response characteristic of the hydrophone illustrated in Figs. 1 and 2; and

Fig. 4 is a diagram illustrating the cooperation of the translating elements in the device shown in Figs. 1 and 2 to produce the directional pattern illustrated in Fig. 3.

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Referring now to the drawing, the hydrophone shown in Figs. 1 and 2 comprises a cylindrical housing **10**, for example of metal, having an apertured end portion **11**, the aperture in this portion being closed by a diaphragm **12**, for example of rubber, joined or secured in water tight relation to the housing. Within the housing and seated upon and secured to an internal shoulder **13** is a cylindrical metallic, for example steel or lead, or ceramic support or plate **14** upon which a group of translating units of the hydrophone is mounted.

This group includes, as shown in Fig. 2, a central element **15**, and four similar outer elements **16a**, **16b**, **17a** and **17b** disposed about the central element. The central element **15** is of square form as shown and is composed of a plurality, for example four, of similar piezoelectric crystals such, for example, as 45 degree Y-cut Rochelle salt blocks or slabs, mounted in face to face relation. The several blocks or slabs are physically oriented and electrically interconnected in parallel in known manner so that all respond electrically in the same way in response to pressure variations therein, that is, so that the electromotive force generated in each block or slab when it is subjected to pressure in the direction of the end faces thereof is in the same direction and in phase with that generated in the other blocks or slabs.

Each of the outer elements **16a**, **16b**, **17a** and **17b** is L-shaped and, like the central element, is composed of piezoelectric, e. g., 45 degree Y-cut Rochelle salt, crystal blocks or slabs physically oriented and electrically interconnected in such manner that the blocks or slabs react in the same way to pressure variations therein. Further, diagonally opposite outer elements are connected electrically in series or parallel opposing so that, in effect, the hydrophone comprises two bi-part translating elements, **16a**, **16b** and **17a**, **17b**, orthogonally related and symmetrically arranged with respect to the central element **15**.

The several elements are secured to the plate **14** and insulated therefrom. For example, these elements may be joined to the plate by cementing to a relatively thin ceramic plate indicated at **19**, having a low dielectric constant, this plate being in turn cemented to the plate **14**. As shown in Fig. 1, all of the elements are of the same height, i. e., of the same dimension normal to the face of the plate **14** to which they are secured. The end faces of the elements toward the diaphragm **12** may be in firm engagement with the diaphragm. Alternatively, those faces may be spaced from the diaphragm and the chamber bounded by the diaphragm 12, casing 10 and plate 14 filled with a fluid, for example castor oil, having substantially the same impedance to transmission of supersonic compressional wave energy as sea water. Also in a particularly advantageous construction, the dimension noted and the thickness of the plate 14 are related to the wave-length of the signal to be translated. If the hydrophone is to be operated as a single frequency pick-up device, as for example in echo ranging underwater object locating systems, the dimension of the elements noted and the thickness of the plate 14 are made equal to a quarter wave-length of the signal frequency, for the transmission of this frequency therethrough. Of course, because the velocities of propagation of compressional wave energy through the piezoelectric crystals and the metal plate 14 are different, the absolute magnitude of the height of the crystal blocks or slabs and of the thickness of the plate 14 will be different. The quarter wave-length dimensioning of the elements and plate 14 provides a vibrational antinode at the plane of joinder between the translating elements and the plate 14 and thus assures efficient conversion by the translating elements of compressional wave energy conveyed thereto by the diaphragm 12. If the hydrophone is intended for use as a band frequency device, the crystal height and plate thickness advantageously are made equal to a quarter wave-length of the mean frequency in the band to be translated.

The diagonally opposite elements 16*a*, 16*b* and 17*a*, 17*b* are spaced, center to center, a distance substantially equal to one-half wave-length of the operating frequency, if single frequency operation is intended, or to one-half wave-length of the mean frequency in the band to be translated where band frequency operation is intended.

The central translating element 15, it will be appreciated, is essentially non-directional about the axis normal to the ends thereof; that is, this element is equally sensitive to compressional waves impinging upon the diaphragm substantially irrespective of the angular location of the source of the waves with respect to this element. Each of the bi-part elements 16*a*, 16*b* and 17*a*, 17*b*, however, because of the half wave-length spacing of the parts thereof and inasmuch as the two parts of each element are in series or parallel opposing relation is markedly directional, and has substantially cosine directivity. That is, when the source of the compressional waves is along the normal bisector to the diagonal connecting the two parts, the pick-ups of the two parts are substantially equal and inasmuch as these parts are in series or parallel opposing the net pick-up of the two parts is zero; when the source of the compressional waves is along the diagonal between the two parts in either direction along this diagonal, the net pick-up of the two parts is a maximum; when the source is along a line at an angle to the diagonal, the net pick-up of the two parts is proportional to the cosine of the angle between this line and the diagonal.

Specifically, referring to Fig. 4, if the sound source is at the point S_1, i. e., along the diagonal A—A, which is the normal bisector of the diagonal B—B, the compressional waves will arrive at the parts 17*a* and 17*b* of the element defined by these parts at the same time so that the voltages generated in these two parts are equal and in phase. Inasmuch as these parts are connected

electrically in opposition, as pointed out heretofore, the net voltage obtained from these two parts is zero. Inasmuch as the parts 16*a* and 16*b* are spaced one-half wave-length apart, the compressional waves will reach the part 16*a* one-half cycle after they arrive at the part 16*b*. Thus, the voltage obtained from the bidirectional element 16*a*, 16*b* is a maximum. Similarly, if the sound source is at a point S_2 on the diagonal A—A, the net voltage obtained from the parts 17*a* and 17*b* is zero and that obtained from the bidirectional element 16*a*, 16*b* is a maximum. If the sound source is along the diagonal B—B, the response of the element 16*a*, 16*b* is zero and that of the element 17*a*, 17*b* is a maximum.

If the sound source is at a point S_3 along a line making an angle of θ_1 with the diagonal A—A, the voltage obtained from the bidirectional element 17*a*, 17*b* will be directly proportional to $\cos \theta_2$. Similarly, the voltage obtained from the bidirectional element 16*a*, 16*b* will be proportional to $\cos \theta_1$.

As noted heretofore, the element 15 is substantially equally responsive to compressional waves incident upon the diaphragm 12 at any angle so that the voltage obtained from this element is independent of the direction of the sound source with respect to the hydrophone. This voltage may be represented as E. The voltage obtained from the bidirectional elements, then, are proportional to $E \cos \theta_1$ and $E \cos \theta_2$, respectively. Hence, when the voltage obtained from the non-directional element is combined with that obtained from each bidirectional element, each of the resultants is of the form $E\ (1+\cos \theta)$ and the directional pattern of each bidirectional element in combination with the non-directional element comprises two cardioids symmetrically located on opposite sides of the axis normal to the wave receiving face of the diaphragm 12 and along the diagonal A—A or B—B for the respective bidirectional element. Thus, the group of elements is equivalent to four hydrophones with cardioid directional patterns, the four patterns being in space quadrature. The directional pattern of the hydrophone as a whole is illustrated in Fig. 3 wherein the four cardioidal lobes represent the response, in relation to direction of the source of the wave picked up with respect to the hydrophone, of the group of translating elements. Specifically, in Fig. 3, the lobe A represents the response of the non-directional element 15 plus that of the bi-directional element 16*a*, 16*b*, lobe B that of the element 15 minus element 16*a*, 16*b*, lobe C that of the element 15 plus element 17*a*, 17*b* and lobe D that of element 15 minus element 17*a*, 17*b*. In each such addition a shift of phase of the response of the non-directional element relative to that of the bidirectional element is involved.

The outputs of the several elements can be combined, therefore, to produce an indication of the directional location of the source of the wave with respect to the hydrophone. For example, the translating elements may be connected by way of a resolving circuit, indicated at 20 in Fig. 2, to the deflector plates 21 of a cathode ray oscillograph device 22 so that the combined output of the elements is resolved into two crossed deflecting fields between the pairs of deflector plates, the fields being related in magnitude to produce a resultant effective to deflect the electron beam of the device in the same direction as the wave source bears with respect to the hydrophone whereby the trace or spot produced upon the screen of the oscillograph is a visual indication of the direction of the wave source with respect to the hydrophone.

The general cooperative electrical association of the elements is illustrated in Fig. 2. As noted heretofore, the parts of each bi-directional translating element are connected in parallel or series opposing relation, as by conductors **25** and **26**. The output of the non-directional element is combined with that of each bi-directional element and the two resulting voltages are supplied to the deflector plates **21**. Specifically, the output of the non-directional element **15** is combined with that of the bidirectional elements **16***a*, **16***b* by way of the connections **28** and **29** and the resultant voltage is impressed between the deflector plates **21***a* and **21***b* by way of the connections **30** and **31**. Similarly, the voltage impressed across the deflector plates **21***c* and **21***d* by way of the connections **32** and **33** is the resultant of the outputs of element **15** and elements **17***a*, **17***b* combined by way of the connections **34** and **35**.

As shown in Fig. 1, pre-amplifiers **23** for the several translating elements may be mounted within the housing **10** and provided with a cable **24** leading from the housing through a watertight seal, not shown.

Although a specific embodiment of the invention has been shown and described, it will be understood that it is but illustrative and that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. A compressional wave translating device comprising a central electromechanical translating element having a substantially non-directional response characteristic, two similar electromechanical translating elements having substantially cosine directivity, each of said two elements including two similar parts and the four parts of said two elements being arranged in alternate relation and space quadrature about said central element, means for electrically coupling said central element to said two elements, and a diaphragm operatively associated with said central and two translating elements.

2. A compressional wave translating device comprising two similar bi-directional electromechanical translating elements having substantially coplanar active faces and similar cosine directional patterns orthogonally related in space, a substantially non-directional electromechanical translating element having its active face substantially coplanar with said active faces, means for electrically coupling said non-directional element to said bi-directional elements so that the response pattern of said bi-directional and non-directional elements in combination includes four cardioidal lobes in space quadrature, and a diaphragm coupled to said active faces of said non-directional and bi-directional elements.

3. A compressional wave translating device, two similar electromechanical translating elements each composed of two parts spaced a distance substantially equal to one-half wave-length of a preassigned frequency, the four parts of said elements being in space quadrature and the two parts of each element being diagonally opposite, a substantially non-directional electromechanical translating element centrally located with respect to said four parts, means for electrically coupling said last element to said two elements, and a diaphragm cooperatively associated with said two elements and said non-directional element.

4. A compressional wave translating device comprising two bi-directional electromechanical translating elements having predetermined similar directional characteristics, each of said elements including two L-shaped parts and the four parts of said elements being arranged to bound a square space, the two parts of each element being diagonally opposite, a central substantially non-directional electromechanical translating element centrally located in said square space, means for electrically coupling said non-directional element to said bi-directional elements, and a diaphragm cooperatively associated with said non-directional and bi-directional elements.

5. A compressional wave translating device comprising two similar bi-directional electromechanical translating elements each of which includes two L-shaped parts spaced a distance substantially equal to one-half wave-length of a preassigned frequency, the four L-shaped parts being mounted in space quadrature with the arms of said L-shaped parts bounding a square space and the parts of each element diagonally opposite and electrically in opposition, a substantially non-directional electromechanical translating element mounted centrally in said space, means for electrically connecting said non-directional element with each of said bi-directional elements to combine the outputs thereof, and means for driving all of said elements mechanically in common.

6. A compressional wave translating device comprising support means, a piezoelectric crystal mounted on said support means and having a substantially non-directional response characteristic, a pair of bi-directional electromechanical translating elements each including two similar piezoelectric crystal parts mounted on said support means, the four parts of said elements being arranged symmetrically in space quadrature about said first crystal and the parts of each of said elements being opposite and electrically in series opposition, means for electrically connecting said first crystal to each of said elements, and a vibratory member operatively coupled to said first crystal and said elements.

7. A compressional wave translating device comprising a support, an electromechanical translating element mounted on said support and having a substantially non-directional response characteristic, a plurality of piezoelectric crystals mounted on said support in symmetrical relation about said element and defining a pair of bi-directional translating elements having substantially cosine directivity, with the directional patterns of said two elements orthogonally related in space, means for mechanically driving said first element and crystals in common, and means electrically coupling said first element and each of said bi-directional elements to combine the electrical outputs thereof.

8. A compressional wave translating device comprising a support, a piezoelectric crystal mounted on said support and having a substantially non-directional response characteristic, two similar pairs of opposite similar piezoelectric crystals mounted on said support in quadrature about said first crystal, the crystals of each pair being spaced a distance substantially equal to one-half wave-length of a preassigned frequency and being connected electrically in opposition, means for mechanically driving all of said crystals in common, and means for electrically con-

necting said first crystal to each of said pairs of crystals to combine the electrical outputs thereof.

9. A supersonic hydrophone comprising a support, a substantially square piezoelectric crystal mounted on said support and having a substantially non-directional response characteristic, four L-shaped piezoelectric crystals mounted on said support about said first crystal, each L-shaped crystal being opposite a corresponding corner of said first crystal and having its arms parallel to the adjacent sides of said first crystal, diagonally opposite L-shaped crystals being spaced a distance substantially equal to one-half wave-length of a preassigned frequency and being electrically in series opposition, a diaphragm operatively coupled to all of said crystals, and means for combining the electrical output of said first crystal with that of each diagonally opposite pair of L-shaped crystals.

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