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SHADED ARRAYS OF TRANSDUCER ELEMENTS

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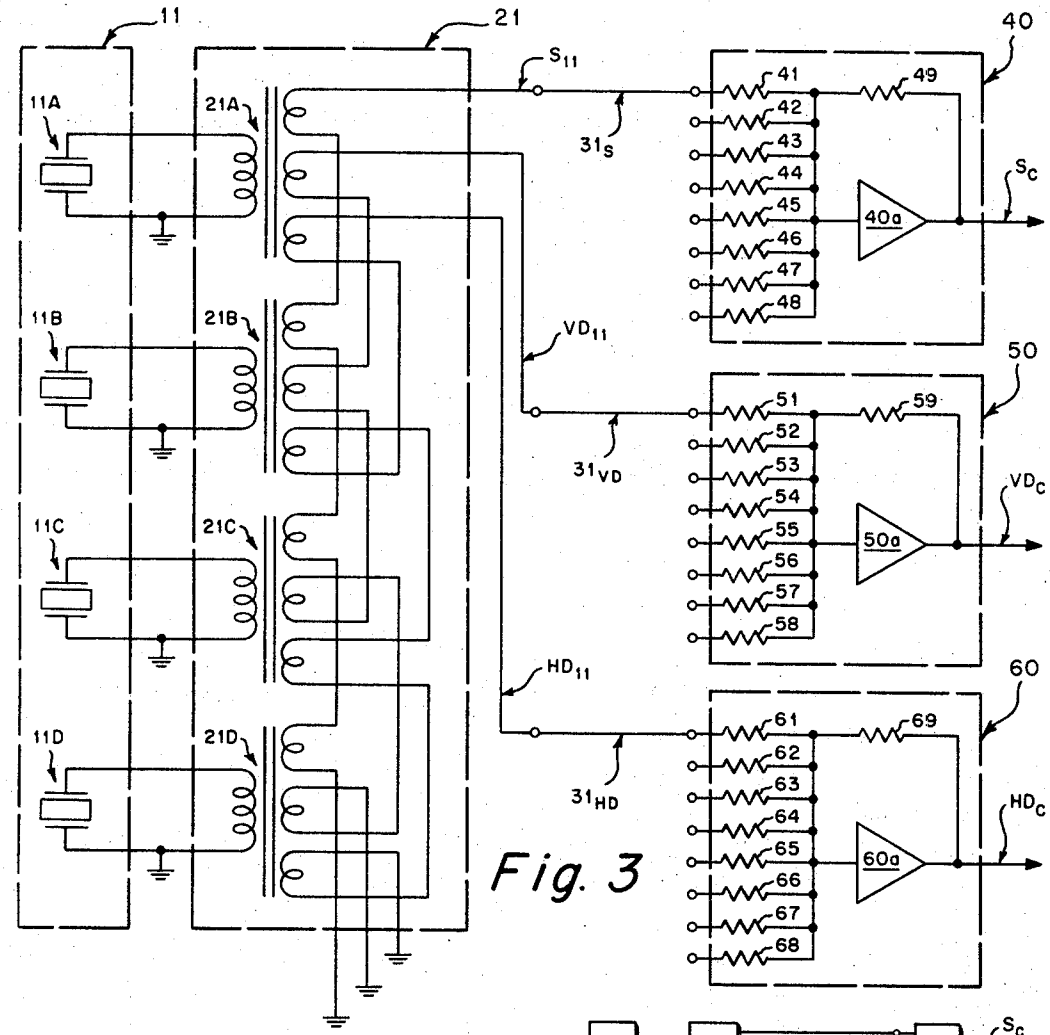


Fig. 3

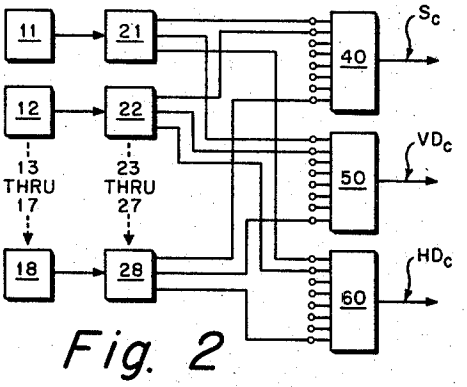


Fig. 2

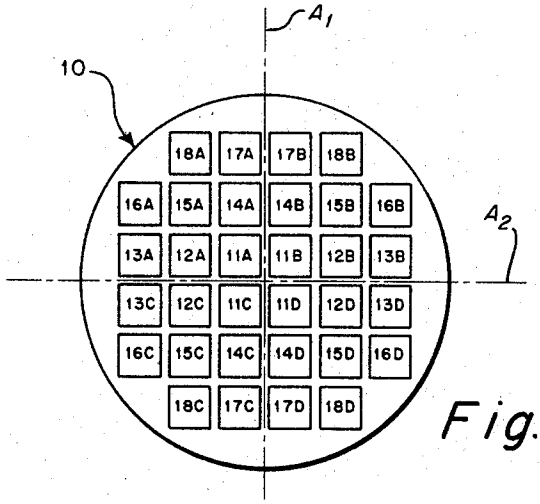


Fig. 1

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SHADED ARRAYS OF TRANSDUCER ELEMENTS

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The present invention relates generally to apparatus for sensing and locating a source of wave energy and more particularly to a new and improved amplitude shaded transducer array useful as a directional hydrophone.

Multi-element arrays of magnetostrictive elements conventionally are constructed to provide a composite directivity pattern output by serially interconnecting a winding from each element, amplitude shading of the various element outputs to achieve a selected array directivity pattern being accomplished by utilizing for each element a winding which has a certain relative number of turns. Multi-element arrays of piezoelectric elements are conventionally constructed by connecting each element in series with the primary winding of a corresponding transformer and serially interconnecting secondary windings from each transformer in the same manner as are connected the magneto-strictive windings. Amplitude shading in this type of array is also accomplished by utilizing secondary windings each having a certain relative number of turns to achieve the desired array directivity pattern therefor. To achieve adequate shading in both types, the numbers of turns in the windings are quite high; and the windings, thereby, introduce undesirable phase shifts because of the increased capacitance of the windings to each other and to ground. Additionally, utilizing serially connected windings having respective selected numbers of turns to accomplish the desired degree of amplitude shading renders selective adustment of the shading of a particular element in the array practically unfeasible in that either the particular element winding or the particular associated transformer secondary winding must be disassembled for increasing or decreasing the number of turns a desired amount or additional circuit means must be provided for achieving the same result.

The general purpose of this invention is to provide an improved amplitude shaded transducer array for hydrophones and other sensing devices which embraces all the advantages of known amplitude shaded arrays and possesses none of the aforedescribed disadvantages. To attain this, the present invention contemplates amplitude shading by the use of summing amplifiers.

An object of the present invention is the provision of an improved amplitude shaded transducer array wherein problems introduced by phase shifts of the various outputs of the elements in the array are mitigated to insignificant levels.

Another object is the provision of an amplitude shaded transducer array wherein the particular shading of a particular element may be easily and quickly changed.

A further object is to provide an improved multiple pattern amplitude shaded array which may be more easily and less expensively fabricated than are the known amplitude shaded transducer arrays.

Still another object is the provision of an amplitude shaded array of transducer elements useful for experimental confirmation of predicted directivity patterns.

Other objects and advantages of the invention will hereinafter become more fully apparent from the following description of the annexed drawing which illustrates a preferred embodiment and wherein:

FIG. 1 represents one view of a planar array of transducer elements as applied to the invention;

FIG. 2 is a block diagram of a circuit according to the invention for amplitude shading of the transducer array of FIG. 1; and

FIG. 3 is a partial schematic of the block diagram of FIG. 2.

Referring now to FIG. 1, a vertically disposed planar array of thirty-two substantially identical piezoelectric transducer elements, 11A through 18D, is shown. Elements 11A through 18D are positioned within the upper left hand quadrant relative to acoustic axes A_1 and A_2 in the same manner as are the similarly enumerated elements 11B through 18B, 11C through 18C and 11D through 18D in their respective quadrants. Elements which have the same enumeration, such as elements 11A, 11B, 11C and 11D are also grouped into an element group, such as 11, because, in accordance with each of the selected directivity patterns, for the array hereinafter set forth, the outputs of each of these elements is to receive the same degree of amplitude shading. In symmetrical arrays, the outputs from those elements in each of the four quadrants which have the same position relative to the acoustic axes of the array receive the same degree of amplitude shading in order to achieve a symmetrical directivity pattern. Of course, it will become apparent from this disclosure that other symmetrical and asymmetrical directivity arrays are contemplated without departing from the principle and scope of the present invention.

As shown in FIG. 2 each element group 11 through 18 provides element output signals to a corresponding transformer group 21 through 28. Each transformer group responsively provides three selected combinations of element outputs which are fed to corresponding summing amplifiers 40, 50 and 60.

Referring now to FIG. 3, the electrical output of each transducer element, such as 11A of representative element group 11, is fed to the primary winding of a corresponding transformer, such as 21A. The transformers are similarly grouped to correspond to a particular respective group of elements. For example, transformer group 21 includes transformers 21A, 21B, 21C and 21D which each respectively receive the corresponding output from elements 11A, 11B, 11C and 11D of element group 11. The interconnection of the elements of element groups 12 through 18 with their respective transformers, not schematically shown, is the same as that shown in FIG. 3 for the elements of element group 11 and their corresponding transformers of group 21.

Each of the transformers, such as 21A, includes three secondary windings, there being a secondary winding for each directivity pattern desired to be obtained from the same array of transducer elements. Each of the secondary windings preferably includes the same number of turns to avoid introducing undesirable phase shift as between the signals corresponding to the various outputs of the transducer elements.

In the disclosed embodiment, three basic combination signals S_{11}, VD_{11} and HD_{11} (sum, vertical difference and horizontal difference directivity patterns) from which may be obtained composite directivity pattern outputs have been selected for each group of elements 11 through 18 to illustrate the invention; and the groups of selectively connected secondary windings of the corresponding transformer groups respectively provide combination output signals which are symbolically represented for element group 11 as follows, those for groups 12 through 18 being identical:

$$S_{11}=A+B+C+D$$
$$VD_{11}A+B-C-D$$

and

$$HD_{11}=A-B+C-D$$

A, B, C and D are the electrical signals proportional to

the respective output signals of each of the elements 11A, 11B, 11C and 11D in group 11 which are taken at each secondary winding of the respective transformers 21A, 21B, 21C and 21D.

A more detailed discussion of composite array directivity patterns and how they are employed for rendering a hydrophone directionally responsive may be found in Albers, Vernon M., Underwater Acoustic Handbook—II, University Park, Pennsylvania, Pennsylvania State University Press, 1965.

Referring again to FIG. 3, S_{11} is obtained from those secondary windings of each of transformers 21A, B, C and D which are electrically serially interconnected in aiding (+) relationship. VD_{11} and HD_{11} are similarly obtained by selectively serially connecting the other secondary windings of each of the transformers in electrically aiding (+) or opposing (−) relationship to form those appropriate groups of serially interconnected windings. The secondary windings of the other transformer groups 22 through 28 are similarly interconnected.

Where magnetostrictive transducer elements are used instead of piezoelectric elements, it is contemplated that the secondary windings of transformers 21A et seq. would then comprise the output windings of the elements.

The combination output signals S_{11}, VD_{11}, and HD_{11} are respectively fed through conductors 31_S, 31_{VD} and 31_{HD} to input resistors 41, 51 and 61 of summing amplifiers 40, 50 and 60. Similarly, the combination output signals S_{12-18}, VD_{12-18} and HD_{12-18} of the other element groups 12 through 18 are respectively fed to input resistors 42 through 48, 52 through 58, and 62 through 68. The illustrative compositive directivity pattern outputs S_c, VD_c and HD_c each effectively include selected portions of the outputs of each of the elements in the array and may be expressed by the following equations:

$$S_c = K_{41}S_{11} + K_{42}S_{12} + K_{43}S_{13} + \ldots + K_{48}S_{18}$$
$$VD_c = K_{51}S_{11} + \ldots + K_{58}S_{18}$$

and

$$HD_c = K_{61}S_{11} + \ldots + K_{68}S_{18}$$

K_{41-48} equal respective selected coefficients for achieving optimum directivity in the composite sum pattern. Similarly, the coefficients K_{51-58} and K_{61-68} are selected to achieve optimum directivity in the respective vertical difference and horizontal difference patterns.

One technique for selection of the above coefficients K_n is taught in Underwater Acoustic Handbook—II, supra. The following table represents for each of the three aforementioned directivity patterns suitable values of K_n for each of the groups of elements 11 through 18.

SHADING COEFFICIENTS FOR OPTIMUM DIRECTIVITY, Kn

Transducer Element Group	K_{41-48} for Sum Pattern	K_{52-58} for Vertical Difference Pattern	K_{61-68} for Horizontal Difference Pattern
11	1.000	0.571	0.571
12	0.685	0.391	1.000
13	0.298	0.691	0.477
14	0.685	1.000	0.391
15	0.469	0.685	0.685
16	0.204	0.298	0.326
17	0.298	0.477	0.169
18	0.204	0.326	0.298

In order to obtain the composite pattern outputs S_c, VD_c and HD_c from the respective combination signals S_{11} et seq., VD_{11} et seq., and HD_{11} et. seq., the summing amplifiers 40, 50 and 60 of FIG. 2 are provided. The summing amplifiers 40, 50 and 60 shown schematically in FIG. 3 includes a plurality of input resistors 41 through 48, 51 through 58, and 61 through 68 which respectively receive the aforementioned combination signals S_{11} et seq., VD_{11} et seq., and HD_{11} et seq., at one terminal. The other terminals are commonly connected to the input terminal

of a respective differential amplifier 40*a*, 50*a* and 60*a*, preferably having a very high open loop gain. A closed feedback loop including a respective feedback resistor 49, 59 and 69 electrically connects the output and input terminals of each amplifier 40*a*, 50*a* or 60*a*. Summing amplifiers of the type used herein are well known in the art.

It is well known that the output voltage amplitude of a summing amplifier equals the negative of the sum of all the amplitude-modified input voltages, the amplitude of each input voltage received by an input resistor being modified by the ratio of the resistance of the feedback resistor to the resistance of the particular resistor. Consequently, selective amplitude shading of each of the various element output combination signals received from each of the transformer groups 21 through 28 by a given summing amplifier 40, 50 or 60 may be accomplished by appropriately selecting or adjusting the resistance of each of the input resistors thereof relative to the resistance of the feedback resistors thereof. For example, in achieving the shading for the optimum vertical difference pattern, the ratio of the resistance of the feedback resistor 59 to the resistance of the input resistor 51, according to the example above, is to be made equal to the coefficient K_{51} whose value as shown above in the foregoing table is 0.571.

An amplitude shaded array according to the invention can be quite useful for the experimental confirmation of predicted directivity patterns, for the degree of shading of a particular group of elements can be quickly and easily altered to a selected value merely by changing or adjusting the resistance of the corresponding input resistor in order to equate the feedback to input resistance ratio with the desired shading coefficient determined for the predicted directivity pattern.

Of course, the composite outputs S_c, VD_c, and HD_c may be used in accordance with any of the well known methods in the art for ascertaining the bearing of the source of the acoustic wave sensed by the transducer elements.

It should be understood, of course, that the foregoing disclosure relates only to a preferred embodiment of the invention and that modifications or alterations may be made without departing from the spirit and scope of the invention as set forth in the appended claims.

What is claimed is:

1. A shaded array of transducer elements comprising:

a plurality of transducer elements arranged in an array, each element producing a respective electrical output signal in response to sensing acoustic energy;

summing amplifier means including amplifying means having input and output terminals, feedback resistor means operatively coupling the output terminal of said amplifying means with its input terminal, and a plurality of input resistor means with one terminal of each connected to said input terminal of said amplifying means, electrical signals received by each said input resistor means at its other terminal being amplitude shaded in accordance with the selected ratio of the resistances of said feedback resistor means to said input resistor means; and

connecting means operatively connecting selected ones of said elements with the other terminals of corresponding ones of said input resistor means;

whereby said summing amplifier means produces a composite transducer array directivity pattern output corresponding to the sum of the respectively amplitude shaded electrical signals which were received by said input resistor means from said connecting means.

2. A shaded transducer array according to claim 1 wherein said connecting means comprises:

a plurality of transformers each having a primary winding connected to a corresponding transducer element for receiving said electrical output thereof and a sec-

ondary winding electrically connected with a respective selected input resistor means.

3. A shaded transducer array according to claim 2 wherein selected ones of said secondary windings comprise:

means for serially electrically interconnecting said secondary windings to form a group for providing to a respective selected input resistor means an electrical signal corresponding to an electrical combination of the outputs of the corresponding elements thereof, said serially connected group of windings having said electrical connection with said respective input resistor means.

4. A shaded transducer array according to claim 3 wherein certain of said serially connected secondary windings in a group further comprise:

means for serially electrically interconnecting certain of said windings in electrical opposition relative to the remaining ones of said serially connected secondary windings in said group.

5. A shaded transducer array according to claim 3 wherein:

said array of transducer elements comprises a plurality of symmetrical sections each having symmetrically arranged elements, there being the same selected amplitude shading for corresponding elements in each section; and

said secondary windings of said transformers which have their primary windings respectively connected to receive the electrical outputs of said similarly shaded elements further comprise means for serially interconnecting said secondary windings.

6. A shaded transducer array according to claim 2 wherein said plurality of transformers each includes a second secondary winding; said array further comprising:

second summing amplifier means including second amplifying means have input and output terminals, second feedback resistor means operatively coupling the output terminal of said amplifying means with its input terminal, and a plurality of second input resistor means with one terminal of each connected to the input terminal of said amplifying means, electrical signals received by each said second input resistor means at its other terminal being amplitude shaded in accordance with the selected ratio of the resistances of said second feedback resistor means to said second input resistor means; and

means operatively connecting the other terminals of said second input resistor means with selected ones of said second secondary windings for receiving signals therefrom;

whereby said second amplifier means produces a second composite transducer array directivity pattern output corresponding to the sum of the respectively amplitude shaded electrical signals which were received by said input resistor means from said second secondary windings.

7. A shaded transducer array according to claim 6 wherein selected ones of said secondary windings comprise:

means for serially electrically interconnecting said secondary windings to form a group for providing to a respective input resistor means an electrical signal corresponding to an electrical combination of the outputs of the corresponding elements thereof, said serially connected group of windings having said electrical connection with said respective input resistor means.

8. A shaded transducer array according to claim 7 wherein certain of said serially connected secondary windings in a group further comprise:

means for serially electrically interconnecting certain of said windings in electrical opposition relative to the remaining ones of said serially connected secondary windings in said group.

9. A shaded transducer array according to claim 7 wherein:

said array of transducer elements comprises a plurality of symmetrical sections each having symmetrically arranged elements, there being the same selected amplitude shading for corresponding elements in each section; and

said secondary windings of said transformers which have their primary windings respectively connected to receive the electrical outputs of said similarly shaded elements further comprise means for serially interconnecting said secondary windings.

No references cited.

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