Dec. 27, 1966 B. BRIGHTMAN ETAL 3,295,098

SHIFT REGISTER PHASE CONTROL SYSTEM FOR USE IN PRODUCING A VARIABLE DIRECTION BEAM FROM A FIXED TRANSMITTING ARRAY

Filed Nov. 23, 1964 3 Sheets-Sheet 1

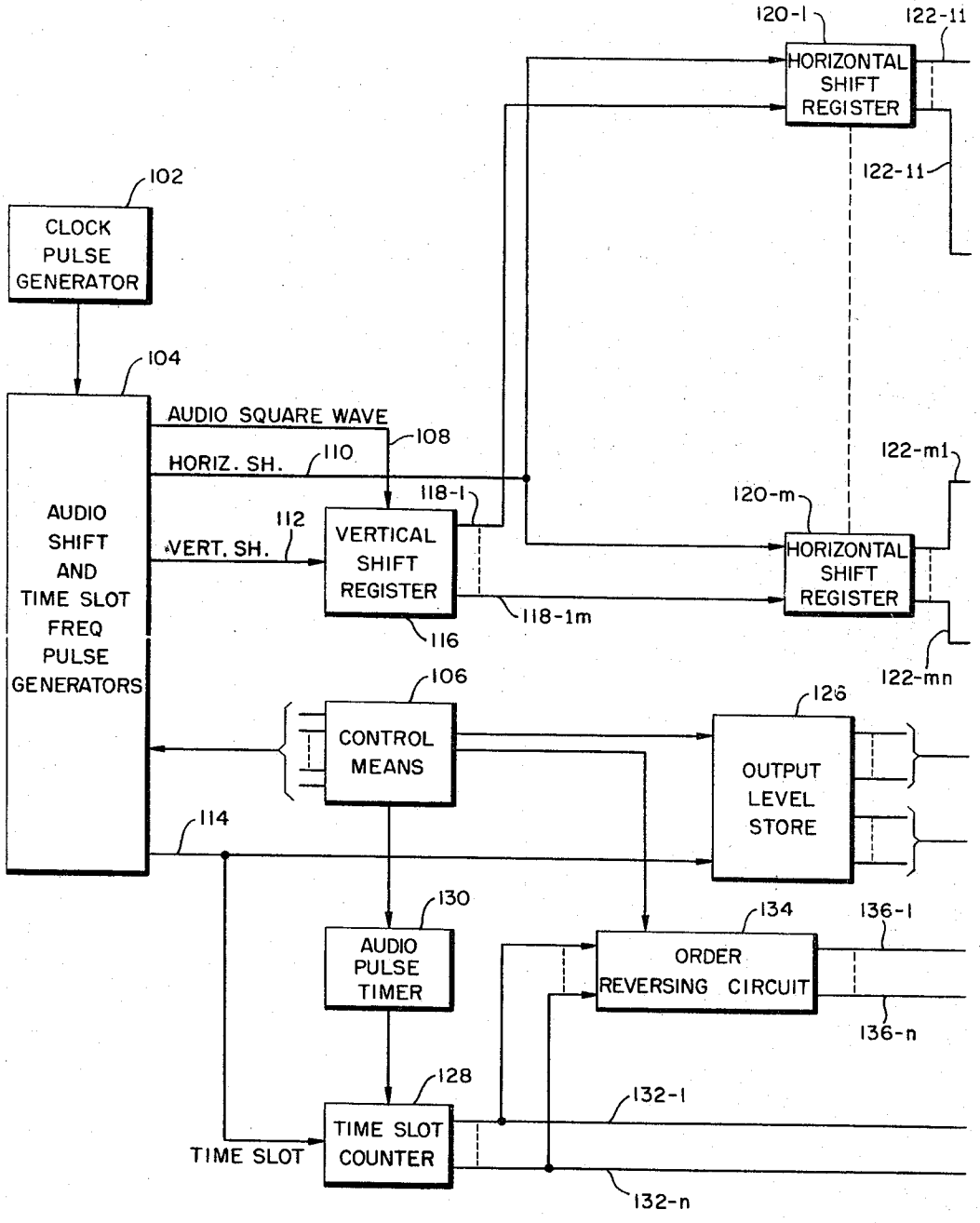


Fig. 1A

FIG. 1A | FIG. 1B

Fig. 1C

Dec. 27, 1966 B. BRIGHTMAN ETAL 3,295,098

SHIFT REGISTER PHASE CONTROL SYSTEM FOR USE IN PRODUCING A VARIABLE DIRECTION BEAM FROM A FIXED TRANSMITTING ARRAY

Filed Nov. 23, 1964 3 Sheets-Sheet 2

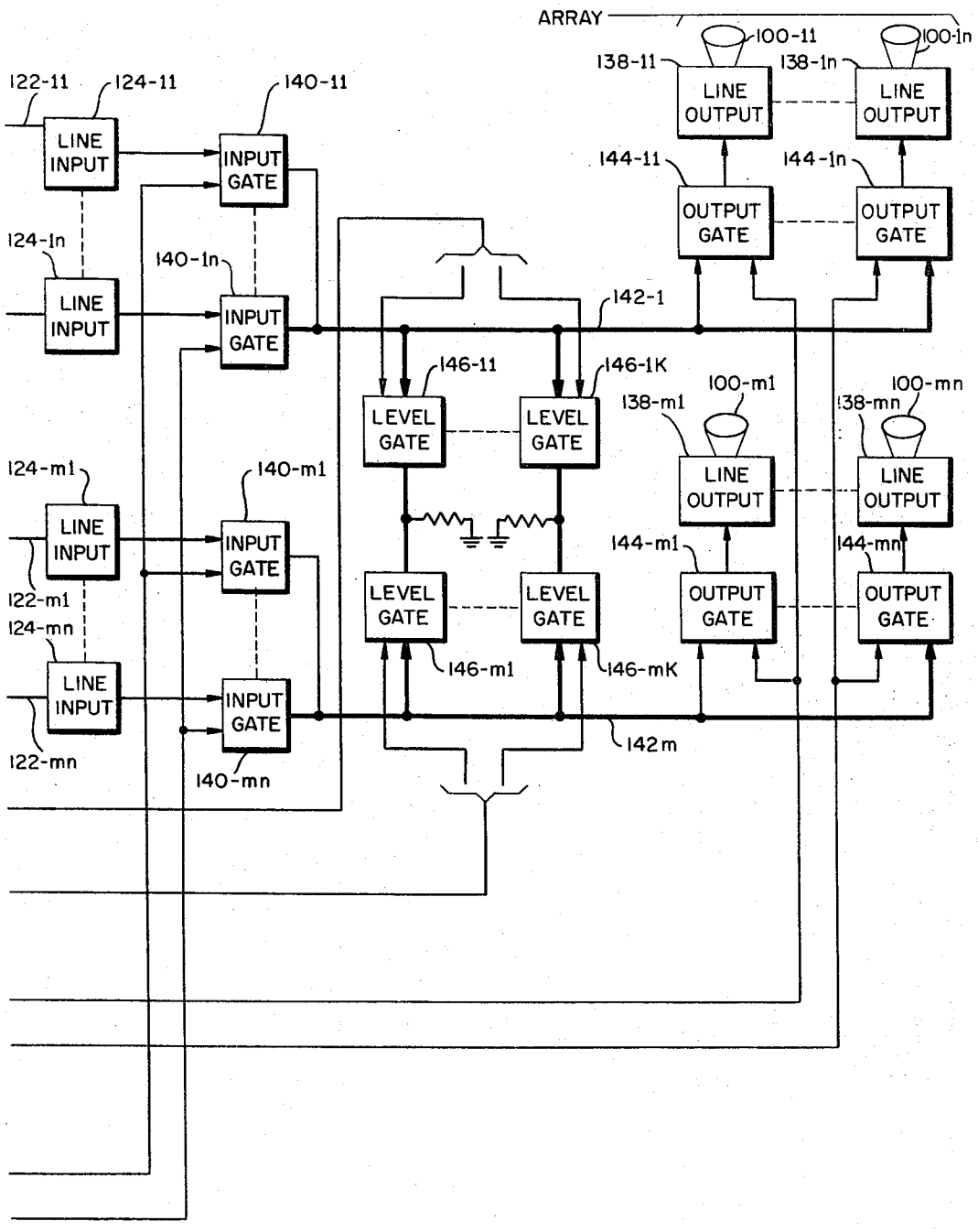


Fig. 1B

Dec. 27, 1966 B. BRIGHTMAN ETAL 3,295,098
SHIFT REGISTER PHASE CONTROL SYSTEM FOR USE IN PRODUCING
A VARIABLE DIRECTION BEAM FROM
A FIXED TRANSMITTING ARRAY
Filed Nov. 23, 1964 3 Sheets-Sheet 3

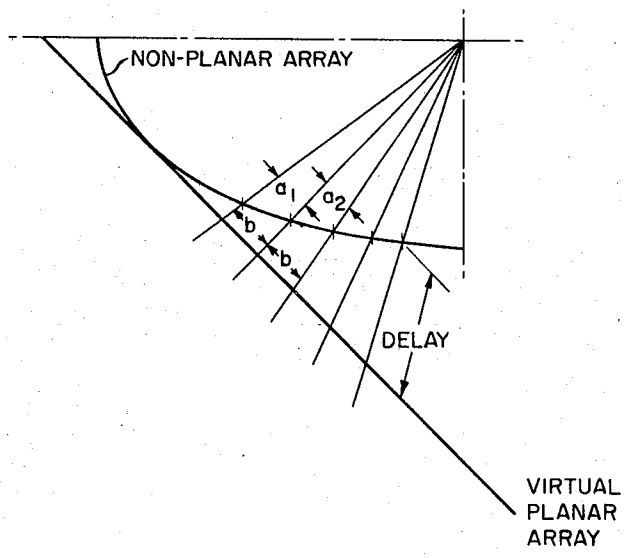


Fig. 2

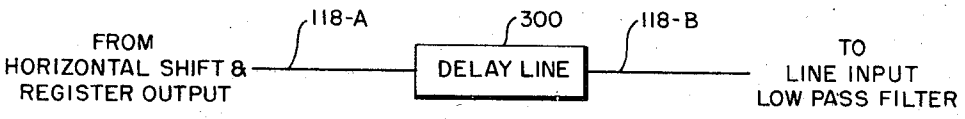


Fig. 3

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SHIFT REGISTER PHASE CONTROL SYSTEM FOR USE IN PRODUCING A VARIABLE DIRECTION BEAM FROM A FIXED TRANSMITTING ARRAY

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9 Claims. (Cl. 340—5)

This invention relates to a phase control system and, more particularly, to such a system for producing a variable direction beam from a fixed transmitting array.

It is well known that a fixed transmitting array, such as an array composed of a plurality of stationary sonar transducers, may be utilized to transmit a directional beam of energy at any transmitting frequency, the direction of the beam being a function of the relative phase difference of the respective signals of the transmitting frequency applied to the respective transducing elements making up the array.

For instance, if signals having the same frequency and phase are applied to each transducer of a planar array of equally spaced transducers arranged in rows and columns, the array will transmit a broadside beam in a direction perpendicular to the planar array. On the other hand, if the phase of the signal applied to the respective transducers of each column is delayed by a time interval with respect to the phase of the signal applied to the respective transducers of the column immediately to its left which time interval is equal to the distance between adjacent transducers in each row divided by the velocity of propagation of the transmitted energy in the medium surrounding the transducers, an end-fire beam substantially parallel to the planar array will be propagated to the right. Similarly, if this time delay is more than zero, but is less than that necessary to produce an end-fire beam, a beam of energy will be propagated at some azimuth angle in the first quadrant which angle is a function of this time delay. In like manner, if the phase of the signal applied to the transducers of each column is delayed by an appropriate time interval with respect to the phase of the signal applied to the transducers of the column immediately to its right, a beam of energy will be propagated at some azimuth angle in the second quadrant. Just as the azimuth angle may be controlled by controlling the relative time delay between adjacent columns of a planar array, the elevation angle may be controlled by controlling the relative time delay between adjacent rows of a planar array.

The reason that a directional beam is produced is that wave energy transmitted by each of the transducers will algebraically add up to re-enforce each other in only a certain direction which depends solely on the positions of the transducers in the array and the relative phase difference existing between signals applied to adjacent transducers. In all other directions, the wave energy transmitted from each of the respective transducers of the array will algebraically add up to cancel each other.

Although in the above discussion it has been assumed that the fixed array is a planar array, this is not necessarily the case. It is possible by properly choosing the positions of the transducers in a non-linear, non-planar array, in a manner to be described in detail below, and by inserting preselected fixed phase delays in the signals applied to the transducers thereof to produce a virtual planar array which is displaced and/or rotated with respect to the actual array. Such a virtual planar array at a predetermined angle with respect to an actual planar array may also be produced by inserting preselected fixed phase delays in the signals applied to the transducers thereof.

Since in most cases it is desirable to produce a directional beam of relatively narrow width, and a beam becomes narrower as the number of transducers in the transmitting array increases, it is often necessary to provide an array consisting of several hundred columns and rows of transducers in order to produce a beam of sufficient directivity. This requires that the minimum phase difference in the signals applied to the transducers of the various columns and rows be quite small, in the order of one degree or less.

It will be appreciated that with ordinary space division techniques it is quite difficult and expensive to provide each one of hundreds of transducers with a sinusoidal signal of a transmitting frequency which is accurately phased to a fraction of one degree for each selected one of a relatively large plurality of different available beam directions. This problem has limited the use of fixed transmitting arrays for producing a variable direction beam.

The present invention contemplates the utilization of time division multiplex techniques and, more particularly, the use of shift registers to produce the multiplicity of needed sinusoidal signals of different phases. Time division techniques may also be used to distribute the sinusoidal signals to the appropriate transducers for forming a beam in any one of a large plurality of different directions. Furthermore, for proper beam forming the relative levels of sinusoidal signals applied to the various transducers must be controlled. Time division multiplex techniques are also utilized for such level control.

It is therefore an object of the present invention to provide an improved phase control system for producing a variable direction beam from a fixed transmitting array.

It is a further object of the present invention to provide such a phase control system utilizing time division multiplex techniques.

It is a still further object of the present invention to provide such a time division multiplex phase control system incorporating shift registers.

These and other objects, features and advantages of the present invention will become more apparent from the following detailed description, taken together with the accompanying drawings, in which:

FIGS. 1A and 1B, when placed next to each other as shown in FIG. 1C, illustrate a block diagram of a preferred embodiment of the present invention;

FIG. 2 illustrates the relationships of a non-planar array with a virtual planar array produced therefrom; and

FIG. 3 illustrates a modification in the embodiment shown in FIGS. 1A and 1B utilized in producing a virtual planar array.

Referring to FIGS. 1A and 1B, there is diagrammatically shown a planar array of sonar transducers arranged in m rows and n columns, namely, transducers **100–11** . . . **100–1***n*; . . . ; **100–***m***1** . . . **100–***mn*. The spacing between adjacent columns of transducers is equal and the spacing between adjacent rows of transducers is equal, but the column spacing and the row spacing are not necessarily equal to each other.

The phase control system for producing a variable direction beam from this planar array of transducers is synchronized by clock pulses having a very high frequency, such as 15 mc., for instance, from clock pulse generator **102**. Audio, shift and time slot frequency pulse generators **104** to which clock pulses are applied may consist of a plurality of clock pulse frequency dividers or a plurality of clock pulse synchronized multivibrators. In any event, control means **106**, which either manually and/or automatically supplies all control information, provides audio, shift and time slot frequency pulse generators **104** with beam direction information as to the desired value of the horizontal shift frequency

and vertical shift frequency as well as audio frequency information. This information is utilized to either control the tuning of the individual clock pulse synchronized multivibrators or the divisor of the individual frequency dividers, as the case may be, in block **104**. In this manner, a variable frequency audio square wave is produced on conductor **108** having a period which is an exact integral multiple of the clock pulse period, variable frequency horizontal shift pulses are produced on conductor **110** which have a pulse repetition period which is an exact integral multiple of the clock pulse repetition period, and variable frequency vertical shift pulses are produced on conductor **112** which have a pulse repetition period which is an exact integral multiple of the clock pulse repetition period. In addition, block **104** includes similar means for producing time slot pulses at some fixed integral multiple of the clock pulse repetition period, such as at a frequency of 1 mc., which appear on conductor **114**.

The audio square wave on conductor **108** is applied as a signal input to vertical shift register **116** and the vertical shift pulses on conductor **112** are applied as a shift input to vertical shift register **116**. In accordance with the well-known operation of shift registers, the first or input stage of a shift register registers the then present level of the signal input applied thereto and in response to each shift pulse applied thereto each stage of the shift register beyond the first or input stage thereof registers the level which has already been registered in the preceding stage thereof. It will therefore be seen that the audio square wave applied as a signal input to vertical shift register **116** will be reproduced at each successive state thereof with a time delay of one vertical shift pulse period with respect to the audio square wave reproduced at the preceding stage thereof. This delay may easily be adjusted merely by controlling the repetition rate of the vertical shift pulses.

Vertical shift register **116** has preferably *m* stages, although it may have more, and the output audio square wave appearing, respectively, at each of these *m* stages is individually applied over a separate one of conductors **118–1** . . . **118–*m*** as a signal input to a corresponding one of horizontal shift registers **120–1** . . . **120–*m***, and the horizontal shift pulses on conductor **110** are applied in common as a shift input to all of horizontal shift registers **120–1** . . . **120–*m***. Each of horizontal shift registers **120–1** . . . **120–*m***, in a manner similar to that described for vertical shift register **116**, will reproduce at each successive stage thereof an audio square wave with a time delay of one horizontal shift pulse period with respect to the audio square wave reproduced at the preceding stage thereof. This delay may easily be adjusted merely by controlling the repetition rate of the horizontal shift pulses.

Each of horizontal shift registers **120–1** . . . **120–*m*** has at least *n* stages, although it may have more. The output audio square wave appearing, respectively, at each of these *n* stages of horizontal shift register **120–1** is individually applied over a separate one of conductors **122–11** . . . **122–1*n*** as a signal input to each corresponding one of line inputs **124–11** . . . **124–1*n***. In a similar manner, the output audio square wave appearing, respectively, at each of the *n* stages of each succeeding intermediate horizontal shift register (not shown) is applied to a corresponding line input, and the output audio square wave appearing, respectively, at each of the *n* stages of horizontal shift register **120–*m*** is individually applied over a separate one of conductors **122–*m*1** . . . **122–*mn*** as a signal input to each corresponding one of line inputs **124–*m*1** . . . **124–*mn***. Each of line inputs **124–11** . . . **124–*mn*** includes a low-pass filter for passing only the fundamental frequency square wave input applied thereto for converting the square wave input applied thereto into a sinusoidal wave having the same frequency and phase.

The time slot pulses appearing on conductor **114** are applied as an input to output level store **126** and time slot counter **128**. Audio pulse timer **130**, under the control of control means **106**, permits time slot pulses to be applied to the counter of time slot counter **128** during intermittent transmitting periods, each of which may be in the order of seconds. Each transmitting period, under the control of audio pulse timer **130**, is followed by a receiving period, which also may be in the order of seconds, during which time slot pulses are prevented from being applied to the counter of time slot counter **128**. During each transmitting period, time slot counter **128** acts as a commutator or steering circuit for cyclically forwarding time slot pulses in sequence to each of individual conductors **132–1** . . . **132–*n***. Conductors **132–1** . . . **132*n*** are applied as an input to order reversing circuit **134**, which, under the control of control means **106**, either couples conductors **132–1** . . . **132–*n*** to conductors **136–1** . . . **136–*n*** in the same order, i.e., conductor **132–1** is coupled to conductor **136–1**, conductor **132–2** (not shown) is coupled to conductor **136–2** (not shown) . . . and conductor **132–*n*** is coupled to conductor **136–*n***, or in reversed order, i.e., conductor **132–1** is coupled to conductor **136–*n***, conductor **132–2** (not shown) is coupled to conductor **136–(*n*–1)** (not shown) . . . and conductor **132–*n*** is coupled to conductor **136–1**. Order reversing circuit **134** merely consists of two sets of AND gates, either one of which is opened and the other of which is closed under the control of control means **106**.

As shown in FIG. 1B, the relatively phase delayed sinusoidal audio signals appearing at the respective outputs of line inputs **124–11** . . . **124–*mn*** are transmitted by time division multiplex techniques to line outputs **138–11** . . . **138–*mn***. More particularly, the respective sinusoidal audio waves appearing on the output of the respective line inputs **124–11** . . . **124–*m*1** are simultaneously sampled by respective input gates **140–11** . . . **140–*m*1** once during each time frame of time slot counter **128** in the time slot appearing on conductor **132–1**. In a similar manner, the sinusoidal audio waves appearing at the outputs of the other line inputs are sampled during successive time slots of each time frame, the sinusoidal audio waves appearing at the output of respective line inputs **124–1*n*** . . . **124–*mn*** being simultaneously sampled by respective input gates **140–1*n*** . . . **140–*mn*** once during each time frame of time slot counter **128** in the time slot appearing on conductor **132–*n***.

As shown, the output of input gates **140–11** . . . **140–1*n***, associated with the top row, are coupled in common over transmission highway **142–1**, which is coupled as an input to output gates **144–11** . . . **144–1*n***, associated with the top row. An individual common transmission highway is provided for each of the other rows in a similar manner, the output of input gates **140–*m*1** . . . **140–*mn***, associated with the bottom row, being coupled in common over transmission highway **142–*m***, which is coupled as an input to output gates **144–*m*1** . . . **144–*mn***, associated with the bottom row. Each of the output gates, which are normally closed, is opened once during each time frame in accordance with the time slot pulses appearing on that one of conductors **136–1** . . . **136–*n*** connected thereto. This results in applying a sample of a sinusoidal audio wave from a different selected one of the respective line inputs to each separate one of the line outputs during each successive time frame. Each line output includes a low-pass filter for integrating the samples applied thereto to reconstruct a sinusoidal wave of the same frequency and phase as that present at the output of the line input to which that line output is coupled. Further included in each line output is a power amplifier for amplifying the reconstructed sinusoidal audio wave and a transducer forming part of the transducer corresponding to that line output for converting the sinusoidal audio wave from electrical energy to sonic energy.

When a beam direction in the first quadrant is selected by control means **106**, order reversing circuit **134** couples conductors **132–1** to **136–1** . . . **132–*n*** to **136–*n***, respectively. In this case, it will be seen that corresponding input gates are opened simultaneously, i.e., in the top row, input gate **140–11** and output gate **144–11** are opened simultaneously during the first time slot of each time frame to thereby transmit information from line input **124–11** to line output **138–11** over common ransmission highway **142–1**, while input gate **140–1*n*** and output gate **144–1*n*** are opened simultaneously during the last time slot of each time frame to thereby transmit information from line input **124–1*n*** to line output **138–1*n*** over common transmission highway **142–1**. In a similar manner, communication takes place between corresponding line inputs and corresponding line outputs of each of the other rows.

However, in the case where a beam direction in the second quadrant is selected by control means **106**, order reversing circuit **134** couples conductors **132–1** to **136–*n*** . . . **132–*n*** to **136–1**, respectively. In this case, the input and output gates of the top row will be opened in such manner as to provide communication between line input **124–11** and line output **138–1*n*** . . . , and communication between line input **124–1*n*** and line output **138–11**, all over common transmission highway **142–1**. In a similar manner, the line inputs of each of the other rows are placed in communication with, in reversed order, the line outputs of that row over the common transmission highway of that row.

From the above discussion, it is clear that the sinusoidal audio waves applied to the transducers of any row will have a time delay between adjacent transducers which is equal to the period of the horizontal shift pulses on conductor **110**, and it is clear that the sinusoidal audio waves applied to the transducers of any column will have a time delay between adjacent hydrophones which is equal to the period of the vertical shift pulses on conductor **112**. Therefore, the direction of the beam may be changed or adjusted to compensate for pitch, roll or yaw of the vessel to which the array is attached merely by appropriately altering the pulse repetition rate of the horizontal and vertical shift pulses under the control of control means **106**.

In addition to controlling the relative phase of the sinusoidal audio wave transmitted from each transducer in accordance with the desired beam direction, it is necessary also to control the relative level of the audio wave transmitted from each transducer in accordance with the desired beam direction. This is accomplished in the embodiment shown in FIGS. 1A and 1B by providing output level store **126**, which may be a pre-programmed multichannel magnetic drum or core store, for instance, which obtains information as to the desired beam direction from control means **106** and which is synchronized by the time slot pulses on conductor **114**. Output level store **126** in accordance with its program and the beam direction information received thereby provides, during each time slot of each time frame, a control pulse for opening some one of *k* normally closed level gates associated with a common transmission highway individual to each row, i.e., normally closed level gates **146–11** . . . **146–1*k*** are associated with common transmission highway **142–1** and normally closed level gates **146–*m*1** . . . **146–*mk*** are associated with common transmission highway **142–*m***. Each level gate, when opened, connects the common transmission highway with which it is associated to a point of reference potential through a resistance. The respective values of the resistances associated with the separate level gates associated with any row are different from each other. Therefore, a portion of the energy transmitted over any common transmission highway during any time slot will be drained off through that resistance which is effectively coupled to that highway during that time slot by that level gate which is open during that time slot. The magnitude of the drained off energy, of course, depends on which particular level gate is open during that time slot. In this manner, the relative levels of the audio waves transmitted from each of the respective transducers may be controlled in accordance with beam direction information.

Although the embodiment shown in FIGS. 1A and 1B utilizes a single vertical shift register feeding a plurality of horizontal shift registers, it should be clear that one could just as easily utilize a single horizontal shift register feeding a plurality of vertical shift registers. In this case the horizontal shift pulses on conductor **110** would be applied to the single horizontal shift register and the vertical shift pulses on conductor **112** would be applied in common to all of the plurality of the vertical shift registers. In addition, in this case a common transmission highway per column would be utilized, rather than a common transmission highway per row as in the embodiment shown in FIGS. 1A and 1B.

The basic preferred embodiment shown in FIGS. 1A and 1B is for use with a physically planar aray. At times the actual physical array is not planar but has some other shape, such as elliptical, for instance. As shown in FIG. 2, a virtual planar array, wherein the effective distance "*b*" between adjacent transducers on the virtual planar array is equal, may be derived from an actual non-planar array by locating the physical transducers of the non-planar array at unequal distances "a_1, a_2 . . . " from each other and providing an appropriate fixed delay for each hydrophone. More particularly, as shown in FIG. 2, the distances "a_1, α_2 . . . " may be determined by choosing a line in accordance with the desired location of the virtual planar array, laying out equidistant points on this line, the distance between adjacent points being "*b*," drawing straight lines between these points and the origin of the non-planar array, and locating the transducers at the intersection of these straight lines and the non-planar array. The distance between the position of a transducer on the non-planar array and the point corresponding thereto on the virtual planar array manifests a fixed time delay which is equal to this distance divided by time velocity of sound in the surrounding medium.

The embodiment shown in FIGS. 1A and 1B may be easily modified, as shown in FIG. 3, to provide this needed fixed delay for each transducer by inserting as part of each line input an individual delay line **300** of the proper delay between each output of each horizontal shift register and the corresponding line input low-pass filter.

Even when the physical array is planar, under certain conditions it may be desirable to use fixed delays to produce a virtual planar array at some fixed angle, such as 45°, with respect to the physical planar array. This is because steering steps are relatively crude toward end-fire with respect to steering steps closer to broadside of the array. For instance, with a 15 mc. clock, it is possible to obtain steering steps of approximately 0.2° when the angle of the planar array and the direction of the beam is between 30° and 45°; while if this angle is less than 10°, the smallest steering steps obtainable is greater than 0.5°. By providing a virtual array at 45° with respect to the physical array, a substantially end-fire beam makes an angle of close to 45° with respect to the virtual array, rather than the angle of close to 0° which it makes with respect to the physical array.

Although for illustrative purposes, only certain basic embodiments of the present invention have been shown. It is realized that it is within the skill of the art to add various subsidiary features, such as frequency modulation of the audio square wave by varying the frequency of the audio square wave under the control of control means **106**, amplitude modulation of the audio wave by refinement of output level store **126** so that the output level is not only a function of beam direction but is a function of an applied modulation frequency, any of which may be desirable in a sophisticated sonar system.

Therefore, it is intended that the present invention not be restricted to the specific embodiments disclosed, but that it be limited only by the true spirit and scope of the appended claims.

What is claimed is:

1. A phase control system for a two-dimensional fixed transmitting array composed of a plurality of individual transducers arranged in a first number of rows and a second number of columns, said system comprising a clock pulse source for generating clock pulses at a predetermined pulse repetition period, means synchronized by said clock pulses for generating a signal square wave having a period which is a given integral multiple of said predetermined period, means synchronized by said clock pulses for generating first control pulses at a first preselected repetition period, means synchronized by said clock pulses for generating second control pulses at a second preselected repetition period, each of said first and second preselected repetition periods being an integral multiple of said predetermined period which is less than said given integral multiple, a first shift register including a number of successive stages thereof equal to one of said first and second numbers, means for applying said signal square wave as a signal input to said first shift register and for applying said first control pulses as a shift input to said first shift register, a group of second shift registers corresponding in number to said number of successive stages of said first shift register, means for applying the output of each of said successive stages of said first shift register as a signal input to the corresponding one of said second shift registers, means for applying said second control pulses as a shift input to all of said second shift registers, each of said second shift registers including a number of successive stages thereof equal to the other of said first and second numbers, individual line input means coupled to each successive stage of each second shift register including therein low-pass filter means for passing only the fundamental frequency of said signal square wave for converting said signal square wave into a sinusoidal wave, and time division multiplex means coupling said line input means to said transducers for applying each of said sinusoidal waves to a particular one of said transducers.

2. The system defined in claim 1, including control means for selecting said first and second preselected repetition periods in accordance with the desired angular direction of a beam to be transmitted from said array.

3. The system defined in claim 2, including level determining means coupled to said control means and said time division multiplex means for controlling the relative amplitudes of the respective sinusoidal waves applied to the respective transducers in accordance with said desired angular direction.

4. The system defined in claim 3, wherein said time division multiplex means includes a common transmission highway corresponding to each second shift register, and wherein said level determining means includes a plurality of energy leakage means of different values, separate normally closed level gate means coupling each of said energy leakage means to each common transmission highway, and an output level store controlled by said control means for selectively opening certain of said level gate means coupled to each highway in accordance with said desired angular direction simultaneously with the coupling of each respective line input means to a transducer over each highway.

5. The system defined in claim 2, wherein said time division multiplex means includes order reversing means coupled to said control means for coupling said respective line input means to said respective transducers in a first predetermined order when said desired angular direction lies in the first quadrant and for coupling said respective line input means to said respective transducers in a second predetermined order which is the reverse of said first predetermined order when said desired angular direction lies in the second quadrant.

6. The system defined in claim 1, wherein said array is a planar array with adjacent transducers in each row being equally spaced from each other and with adjacent transducers in each column being equally spaced from each other.

7. The system defined in claim 1, including virtual plane producing means for producing a virtual plane displaced from said array composed of an individual point in said virtual plane corresponding to each transducer in said array wherein adjacent points in each row are equally spaced from each other and adjacent points in each column are equally spaced from each other, said virtual plane producing means comprising an individual delay line in series with the low-pass filter means of each line input means, each individual delay line corresponding to a separate one of said transducers and producing a delay equal to the displacement of the point in said virtual plane corresponding to that separate one of said transducers from the transducer with which it corresponds divided by the velocity of propagation of transmitted energy in the medium surrounding said array.

8. The system defined in claim 7, wherein said array is non-planar and wherein each transducer of said array is positioned at the intersection of said array with a line connecting the point of said virtual plane corresponding to that transducer with a common point on the other side of said array from said virtual plane.

9. The system defined in claim 1, further including an audio pulse timer means coupled to said time division multiplex means to effect the enabling thereof solely during intermittent transmitting time periods, the initiation and length of said transmitting time periods being controlled by said timer means.

No references cited.

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