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

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2 Sheets-Sheet 1

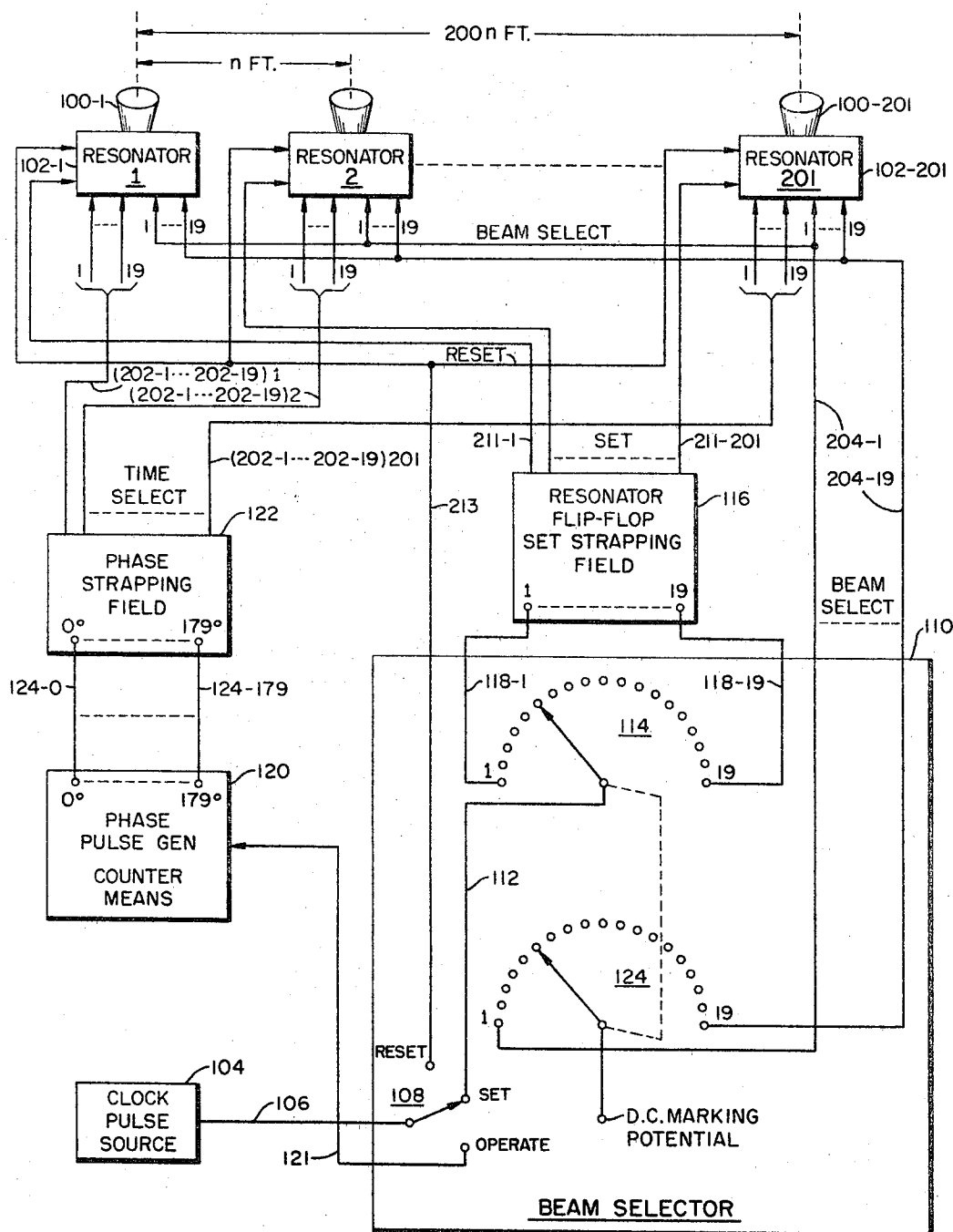


Fig. 1

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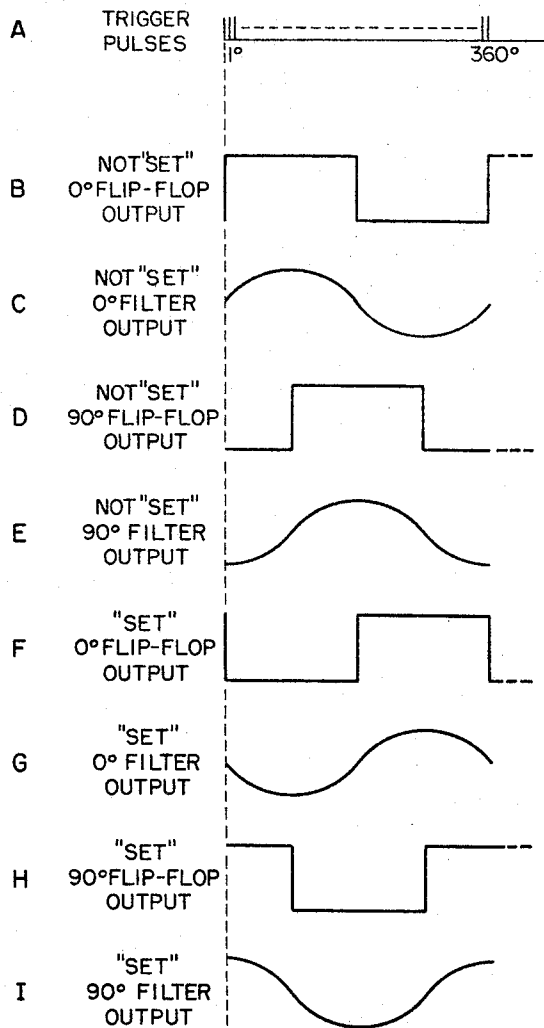
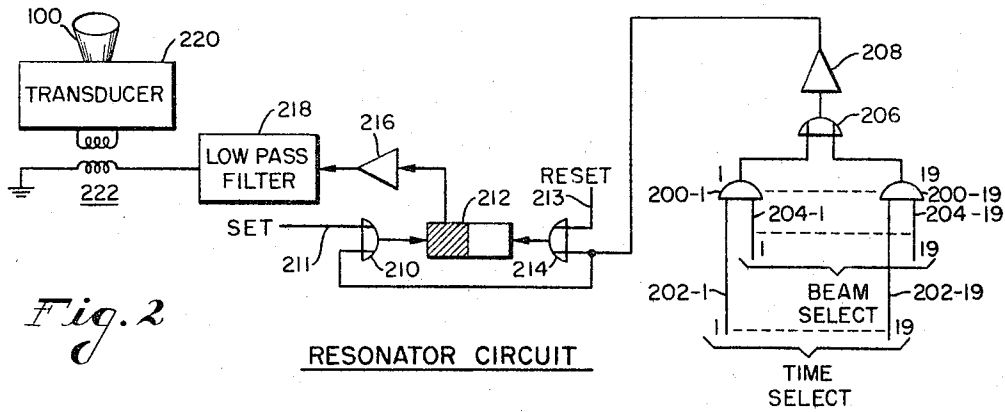


Fig. 3

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

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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 some given transmitting frequency, the direction of the beam being a function of the relative phase difference of the respective signals of the given 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 linear array of a plurality of equally spaced transducers, the array will transmit a broadside beam in a direction perpendicular to the linear array. On the other hand, if the phase of the signal applied to each transducer is delayed by a time interval with respect to the phase of the signal applied to the transducer immediately to its left which is equal to the distance between adjacent transducers divided by the velocity of propagation of the transmitted energy in the medium surrounding the transducers, and end-fire beam parallel to the linear 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 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 each transducer is delayed by an appropriate time interval with respect to the phase of the signal applied to the transducer immediately to its right, a beam of energy will be propagated at some angle in the second quadrant.

The reason that a directional beam is produced is that with a certain relative phase difference existing between the signals applied to adjacent transducers, the wave energy transmitted by each of the transducers will algebraically add up to reinforce each other in only a certain direction, which depends solely on the given frequency of the signals applied to all the transducers and the certain phase difference between them. 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.

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 a linear array consisting of several hundred transducers in order to produce a beam of sufficient directivity.

This requires that the minimum phase difference in the signals applied to the various transducers be quite small, in the order of 1° or so.

It will be appreciated that with ordinary space division techniques it is quite difficult and expensive to provide each one of several hundred transducers with a sinusoidal signal of a given frequency which is accurately phased to a fraction of 1° 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.

It is an object of the present invention to provide an

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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 techniques.

It is a still further object of the present invention to provide such a system wherein the particular sinusoidal signal applied to each individual one of the transducers is individually generated with a desired phase by circuit means which are in close proximity to that transducer.

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

FIG. 1 is a block diagram of the preferred embodiment of the invention for producing any one of nineteen directional beams at 10° intervals ranging from an end-fire beam directed to the left to an end-fire beam directed to the right;

FIG. 2 is a schematic diagram of the circuit of a preferred circuit of each of the resonators shown in FIG. 1; and

FIG. 3 is a timing chart helpful in understanding the invention.

Referring now to the drawings, shown in FIG. 1 is a linear array of two hundred one sonar radiators 100-1 . . . 100-201, inclusive, adjacent radiators having a spacing therebetween of n feet, so that the separation between radiator 100-1 and radiator 100-201 is $200n$ feet. In intimate association with each sonar radiator is a resonator, such as resonators 102-1 . . . 102-201, as shown. All the resonators are identical in structure and function and the circuit details thereof, discussed below, are shown in FIG. 2. The entire array of hydrophone radiators along with their associated resonators is immersed in the ocean or in some other body of water.

Referring now to FIG. 2, there is shown a typical resonator circuit which includes nineteen AND gates 200-1 . . . 200-19, inclusive. Applied as a first input to each respective one of AND gates 200-1 . . . 200-19 is an individual one of a group of time select conductors, such as conductors 202-1 . . . 202-19. Applied as a second input to each respective one of AND gates 200-1 . . . 200-19 is an individual one of a group of beam select conductors, such as conductors 204-1 . . . 204-19. The respective outputs of AND gates 200-1 . . . 200-19 are applied through OR gate 206 as an input to amplifier 208. The output of amplifier 208 is applied both through OR gate 210 as a first input to flip-flop 212 and through OR gate 214 as a second input to flip-flop 212. In addition, set conductor 211 may apply a set pulse through OR gate 210 as a first input to flip-flop 212 and reset conductor 213 may apply a reset pulse through OR gate 214 as a second input to flip-flop 212. The output of flip-flop 212 is applied as an input to amplifier 216 and the output of amplifier 216 is applied as an input to low-pass filter 218. The output of low-pass filter 218 is applied to the sonar transducer 220 of hydrophone radiator 100 through coupling transformer 222.

Referring back to FIG. 1, clock pulse source 104, which generates trigger pulses at a pulse repetition rate in the order of a megacycle, has its output applied over conductor 106 to the wiper of three-position switch 108 included in beam selector 110. Connected to the first or reset position of switch 108 is conductor 213 which is multiplied to all of the resonators 102-1 . . . 102-201. Conductor 112 connects the second or set position of switch 108 to the wiper of nineteen-position switch 114 included in beam selector 110. Each of the nineteen positions of switch 114 are individually connected as inputs to resonator flip-flop set strapping field 116 over conduc-

tors 118-1 . . . 118-19, as shown. Resonator flip-flop set strapping field 116 connects each individual input thereof to a different unique combination of some of set output conductors 211-1 . . . 211-201 through isolating means which prevent the short-circuiting of the various inputs to resonator flip-flop set strapping field 116. Each of set output conductors 211-1 . . . 211-201 is individually connected to its associated resonator.

The third or operate position of switch 108 is connected as an input to phase pulse generator counter means 120 over conductor 121. Phase pulse generator counter means 120 includes a cyclically-operated counter having a count capacity of one hundred eighty. The counter itself may have one hundred eighty individual outputs or it may be a flip-flop counter. In the case where the counter is a flip-flop counter, the phase pulse generator counter means 120 also includes converter means for producing a mark on any one of one hundred eighty output terminals thereof in accordance with the count of the counter. In any case, the one hundred eighty output terminals of phase pulse generator counter means 120 are individually connected to one hundred eighty input terminals of phase strapping field 122 over conductors 124-0 . . . 124-179, inclusive.

Phase strapping field 122 connects the nineteen time select conductors 202-1 . . . 202-19 of each one of resonators 102-1 . . . 102-201 to a different unique predetermined combination of input terminals of the strapping field 122 through isolating means which prevent short-circuiting of the input terminals thereof.

Beam selector 110 also includes a D.C. marking potential which is applied to the wiper of nineteen-position switch 124, which is ganged with the wiper of nineteen-position switch 114. The nineteen respective positions of switch 124 are individually connected in multiple to beam select conductors 204-1 . . . 204-19 of each of resonators 102-1 . . . 102-201.

Considering now the operation of the present invention, it is assumed that it is desired to transmit any selected one of nineteen directional beams from the transmitting array, the first of these beams being an end-fire beam to the left, the nineteenth of these beams being an end-fire beam to the right, and each of the remaining beams differing in angle from the beams adjacent thereto by 10°.

To begin with, three-position switch 108 is turned to its reset position. This results in trigger pulses from clock pulse source 104 being applied over conductors 106 and 213 to each of resonators 102-1 . . . 102-201, where they are applied through OR gate 214 to the second input of flip-flop 212 of each resonator. In response to the first-trigger pulse applied to the second input of the flip-flop 212 of the various resonators, the flip-flops 212 of each of the resonators which happen to be in a set condition is switched to its reset condition. Additional trigger pulses applied from conductor 213 will have no effect on the condition of flip-flops 212 of the various resonators.

Leaving three-position switch 108 in its reset position, the ganged wipers of nineteen-position switches 114 and 124 are turned to any selected one of the nineteen positions thereof in accordance with the desired direction of the beam to be transmitted. This results in switch 124 applying a D.C. marking potential to the selected one of beam select conductors 204-1 . . . 204-19.

After the ganged wipers of switches 114 and 124 have been turned to the selected position, three-position switch 108 is turned to its set position. This results in trigger pulses from clock pulse source 104 being applied over conductors 106, 112, and the selected one of conductors 118-1 . . . 118-19 to the input terminals of resonator flip-flop set strapping field 116, which in turn forwards these pulses to a unique combination of conductors 211-1 . . . 211-201 connected to resonators 102-1 . . . 102-201, where the trigger pulses are applied through OR gate 210 to the first input flip-flop 212 of only those resonators selected by resonator flip-flop set strapping field 116.

Therefore, the flip-flop 212 of those resonators selected by resonator flip-flop set strapping field 116 will be switched from its reset condition to its set condition by the first applied trigger pulse. Additional trigger pulses will have no effect.

Three-position switch 108 is then turned to its operate position. This results in trigger pulses from clock pulse source 104 being applied over conductors 106 and 122 to the input of phase pulse generator counter means 120, causing the count of the counter of phase pulse counter generator means 120 to be advanced one count in response to each applied trigger pulse. In response to each one hundred eighty successive trigger pulses, a mark will be successively applied to each of conductors 124-0 . . . 124-179.

Phase strapping field 122 connects each one of the time select conductors emanating therefrom to some one of the input terminals thereof in accordance with the predetermined phase differences needed to produce each of the nineteen directional beams. Of course, in some cases, more than one of the time select conductors will be connected to one input terminal.

Referring now to FIG. 2, it will be seen that only a selected one of AND gates 200-1 . . . 200-19 will have a D.C. marking potential forwarded thereto over beam select conductors 204-1 . . . 204-19. This selected AND gate 200-1 . . . 200-19 will have a trigger pulse forwarded thereto only once during each complete cycle of phase pulse generator counter means 120 through phase strapping field 122 over a selected one of time select conductors 202-1 . . . 202-19 of that resonator circuit. The relative time of occurrence of this applied trigger pulse will depend solely on the particular one of the input terminals of phase strapping field 122 to which this particular time select conductor is strapped.

The selected one of AND gates 200-1 . . . 200-19 will therefore forward this particular trigger pulse through OR gate 206, amplifier 208, and OR gates 210 and 214 to both the first and second inputs of flip-flops 212. If flip-flop 212 of this resonator circuit is originally in its reset condition, the first trigger pulse applied thereto will switch it to its set condition, the second trigger pulse applied thereto will switch it back to its reset condition, and in a similar manner each additional trigger pulse applied thereto will continue to switch flip-flop 212 of that resonator circuit back and then forth between its set condition and reset condition. However, if flip-flop 212 of a resonator circuit has already been switched to its set condition by a pulse applied thereto over conductor 211, the first trigger pulse applied thereto from amplifier 208 will switch the flip-flop 212 from its set condition to its reset condition, the second trigger pulse applied thereto will switch flip-flop 212 back to its set condition, and in a similar manner each additional trigger pulse applied thereto will continue to switch flip-flop 212 of that resonator circuit back and then forth between its reset condition and set condition. Thus, flip-flop 212 of each resonator circuit will produce a square-wave output having a period three hundred sixty times as long as the period of the trigger pulses from clock pulse source 104, since flip-flop 212 produces one cycle of its square-wave output in response to two complete cycles of phase pulse generator counter means 120, i.e., in response to the application of three hundred sixty trigger pulses from clock pulse source 106 to phase pulse generator counter means 120.

The relative phase of the square-wave output produced by flip-flop 212 of each resonator circuit depends both on the particular input terminal of phase strapping field 122 from which the trigger pulses applied thereto emanate and whether flip-flop 212 of this resonator circuit is originally in its reset or set condition when the first of these trigger pulses applied thereto is applied. Since phase strapping field 122 has one hundred eighty input terminals, the square-wave output of flip-flop 212 of a resonator circuit will have one of three hundred sixty possible phases.

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The square-wave output of flip-flop 212 of each resonator circuit is applied through amplifier 216 thereof as an input to low-pass filter 218, which passes only the fundamental frequency of the square wave applied thereto. Therefore, the output of low-pass filter 218 is a sinusoidal wave having the same period and phase as the square wave from which it is generated. The output of low-pass filter 218, which is applied through output transformer 222 to transducer 220, causes a sonic signal of the same frequency and phase to be radiated into the surrounding medium by radiator 100.

It will be seen that, with the embodiment of the present invention disclosed herein, it is possible to accurately develop a large plurality of sinusoidal waves having the same frequency, but which may differ in phase from each other by any integral multiple of 1° .

For illustrative purposes, there is shown in FIG. 3, nine timing charts respectively showing three hundred sixty trigger pulses from clock pulse source 104, adjacent pulses of which are separated by 1° intervals; the square-wave output produced by flip-flop 212 when this flip-flop has not been set by a pulse from resonator flip-flop set strapping field 116 and the time select pulse applied thereto is obtained from the 0° input terminal of phase strapping field 122, and the sinusoidal wave obtained at the output of low-pass filter 218 from such a square wave; the square-wave output produced by flip-flop 212 when this flip-flop has not been set by a pulse from resonator flip-flop set strapping field 116 and the time select pulse applied thereto is obtained from the 90° input terminal of phase strapping field 122 and the sinusoidal wave obtained at the output of low-pass filter 218 from such a square wave; the square-wave output produced by flip-flop 212 when this flip-flop has been set by a pulse from resonator flip-flop set strapping field 116 and the time select pulse applied thereto is obtained from the 0° input terminal of phase strapping field 122 and the sinusoidal wave obtained at the output of low-pass filter 218 from such a square wave; and the square-wave output produced by flip-flop 212 when this flip-flop has been set by a pulse from resonator flip-flop set strapping field 116 and the time select pulse applied thereto is obtained from the 90° input terminal of phase strapping field 122 and the sinusoidal wave obtained at the output of low-pass filter 218 from such a square wave.

Although only one preferred embodiment of the invention has been disclosed, it is realized that modifications can be made therein without departing from the disclosed invention. For instance, although, as disclosed, beam selector 110 consists of manual switches, in practice it may be desirable to utilize a more sophisticated automatic programmed beam selector to perform the same functions of choosing the selected beam, controlling the resetting and setting of the flip-flops, and controlling the application of trigger pulses to the flip-flops. Further, although only a linear array has been disclosed, it is obvious that the present invention may be extended to a two-dimensional array to control the direction of a transmitted beam in both elevation and azimuth by providing the appropriate phase relationships between the sinusoidal signals applied to the various transducers of the two-dimensional array. Therefore, it is not intended that the invention be restricted to the preferred embodiment thereof dis-

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closed herein, but that it be limited only by the true spirit and scope of the appended claims.

What is claimed is:

1. Phase control apparatus for individually generating a given plurality of different sinusoidal signals all having the same frequency but having predetermined phase relationships with respect to each other, said apparatus comprising individual means for each of said signals including a low-pass filter, a bistable device having first and second inputs and an output, said device being switched from a first stable condition thereof to a second stable condition thereof in response to a pulse being applied to the first input thereof and being switched from said second stable condition thereof to said first stable condition thereof in response to a pulse being applied to the second input thereof, the output of said device having a first given signal level when said device is in its first stable condition and having a second given signal level when said device is in its second stable condition, and means for applying the output of said bistable device as an input to said filter; and common control means including a clock pulse source for generating periodic trigger pulses at a given repetition rate, commutator means including a cyclically-operated counter coupled to said clock pulse source for sequentially applying successive trigger pulses from said source to separate ones of a predetermined number of output terminals of said commutator means, and coupling means for connecting both the first and second inputs of each respective bistable device to a respective preselected one of said output terminals in accordance with a predetermined phase pattern, whereby each of said bistable devices produces a square-wave output signal having a fundamental frequency equal to said pulse repetition rate of said clock pulse source divided by twice said predetermined number of said output terminals of said commutator means and having a relative phase which depends on the initial stable condition of that bistable device and on that preselected one of said output terminals of said commutator means to which the first and second input terminals of that device are connected, said low-pass filter of each individual means passing only the fundamental frequency of the square-wave output signal applied as an input thereto.

2. The apparatus defined in claim 1, further including set and reset means for determining the initial stable condition of each respective bistable device in accordance with a predetermined initial condition pattern corresponding to said predetermined phase pattern.

3. The apparatus defined in claim 2, further including selector means coupled to said coupling means and said set and reset means for respectively selecting any desired one of a given plurality of predetermined phase patterns and one of a given plurality of predetermined initial condition patterns which corresponds with said desired one of said given plurality of predetermined phase patterns.

4. The apparatus defined in claim 3, further including a fixed array of spaced sonar transducers, and means for individually applying the filter output of each individual means to a different individual one of said transducers.

No references cited.

CHESTER L. JUSTUS, *Primary Examiner*.

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