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Walsh

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[54] **PLURAL BEAM STEERING SYSTEM**

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[73] Assignee: **Raytheon Company**, Lexington, Mass.

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[21] Appl. No.: **323,602**

[52] **U.S. Cl.** .... **340/3 R**

[51] **Int. Cl.** **G01s 9/66**

[58] **Field of Search** .... 340/3 R, 3 FM

[56] **References Cited**

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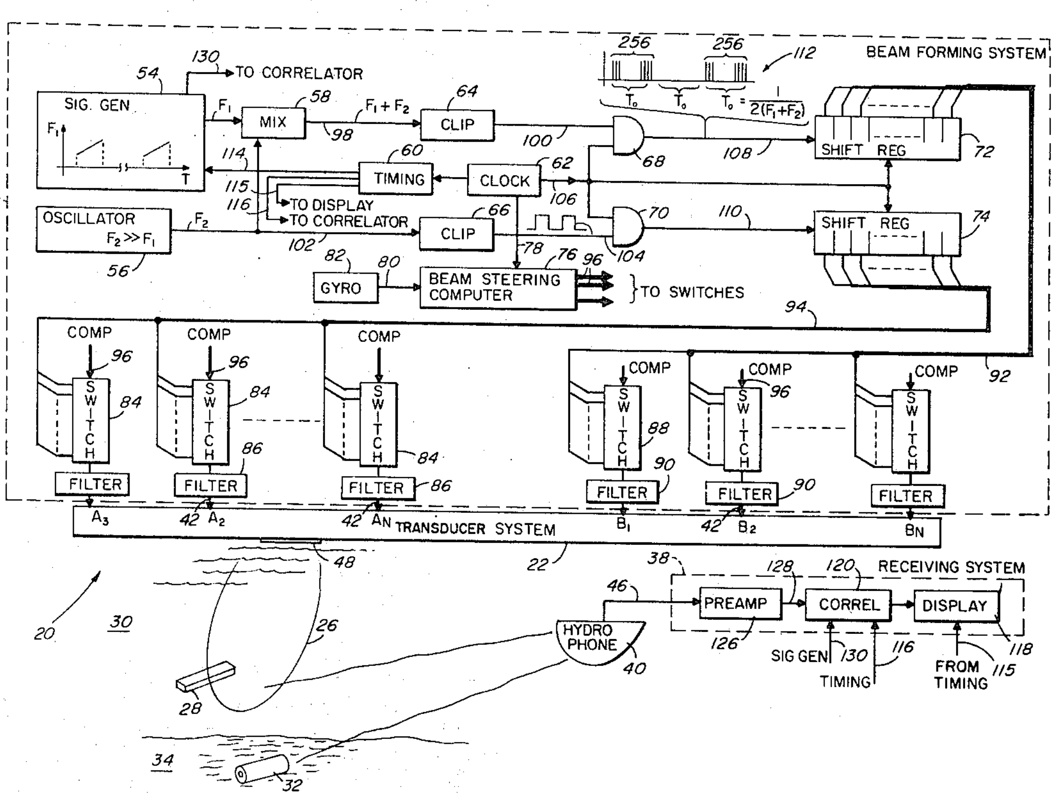
Attorney, Agent, or Firm—M. D. Bartlett; J. D. Pannone; D. M. Warren

[57] **ABSTRACT**

A system for forming and steering beams of radiation at a plurality of frequencies radiated into a medium capable of producing a nonlinear reaction between these beams resulting in a radiant energy signal having a resultant frequency equal to an arithmetic combination of the radiated frequencies. The beam forming is accomplished by an array of radiating elements arranged preferably in a random fashion to produce a directivity pattern having a main lobe while minimizing the magnitudes of side lobes. The steering is accomplished by variable delay lines coupled between a source of signals at the radiated frequencies and the array of radiating elements providing for individual delays to each of these radiating elements so that each of the beams can be steered with individually controllable steering angles. The delays are varied in accordance with command signals from a beam steering computer to direct the main lobes of the radiation patterns through a common region of the medium as the beams are scanned, this resulting in a scanned beam at the resultant frequency. The signal resulting from the nonlinear reaction may be correlated with a replica thereof, the replica being generated in conjunction with the two radiated frequencies.

13 Claims, 6 Drawing Figures



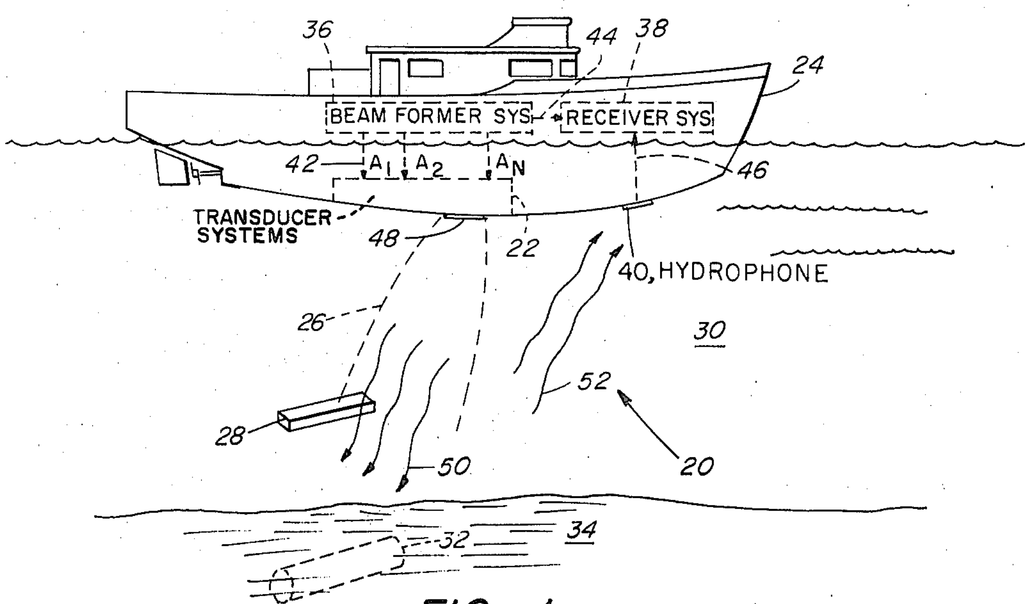


FIG. 1

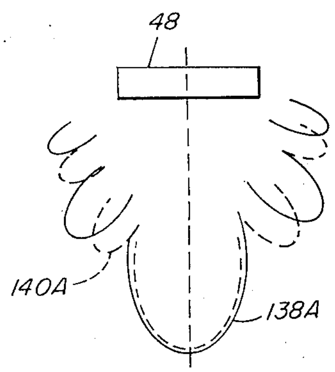


FIG. 5

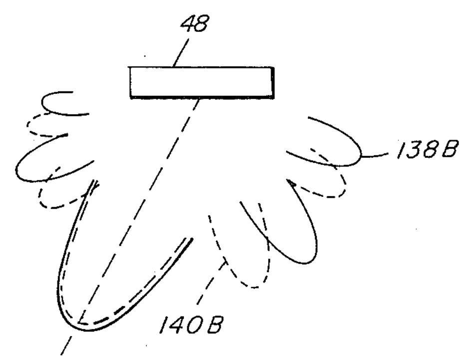


FIG. 6

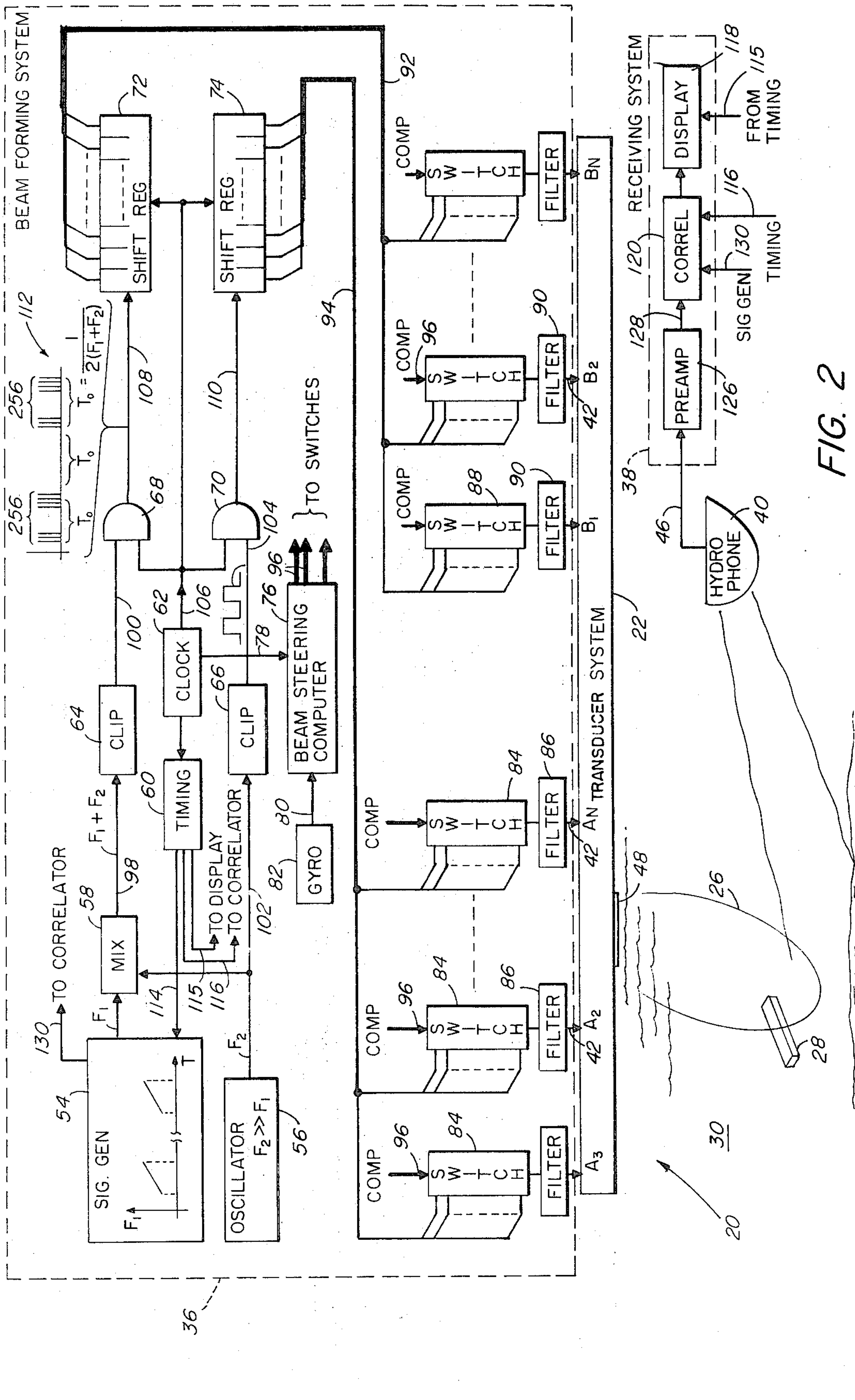

BEAM FORMING SYSTEM
SHIFT REG
SHIFT REG
TO SWITCHES
CLOCK
TIMING
CLIP
CLIP
MIX
SIG. GEN
OSCILLATOR $F_2 >> F_1$
TO CORRELATOR
TO DISPLAY
TO CORRELATOR
BEAM STEERING COMPUTER
GYRO
$F_1 + F_2$
$T_0 = \frac{1}{2(F_1+F_2)}$
COMP
SWITCH
FILTER
TRANSDUCER SYSTEM
RECEIVING SYSTEM
DISPLAY
CORREL
PREAMP
FROM TIMING
TIMING
SIG GEN
HYDRO PHONE

FIG. 2

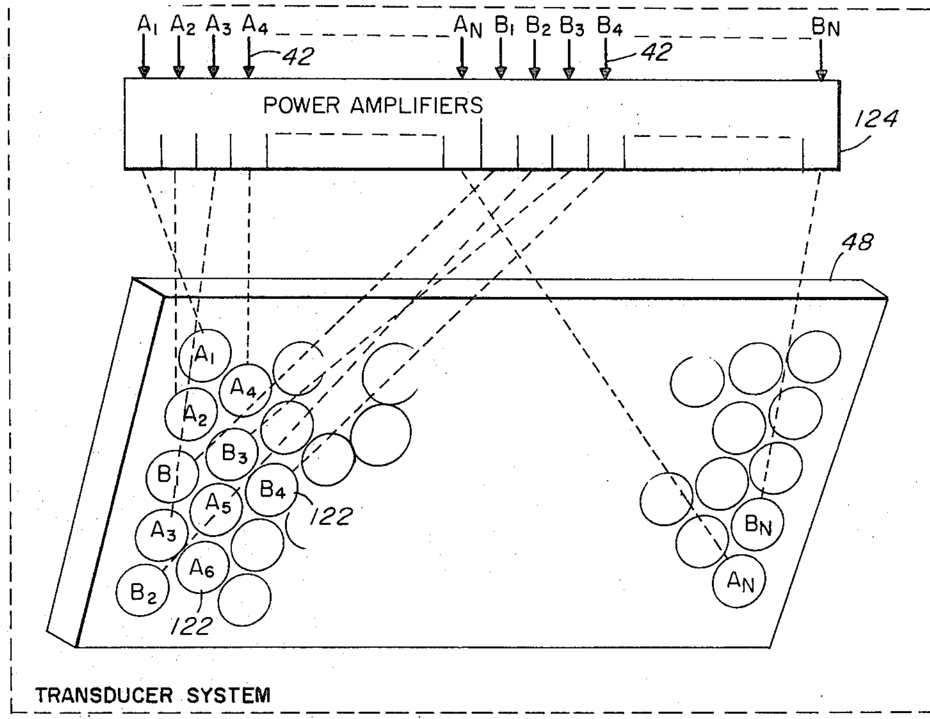

A1 A2 A3 A4 AN B1 B2 B3 B4 BN
42
POWER AMPLIFIERS
124
22
48
A1
A4
A2
B3
B1
A5
B4
122
A3
A6
B2
122
BN
AN
TRANSDUCER SYSTEM

FIG. 3

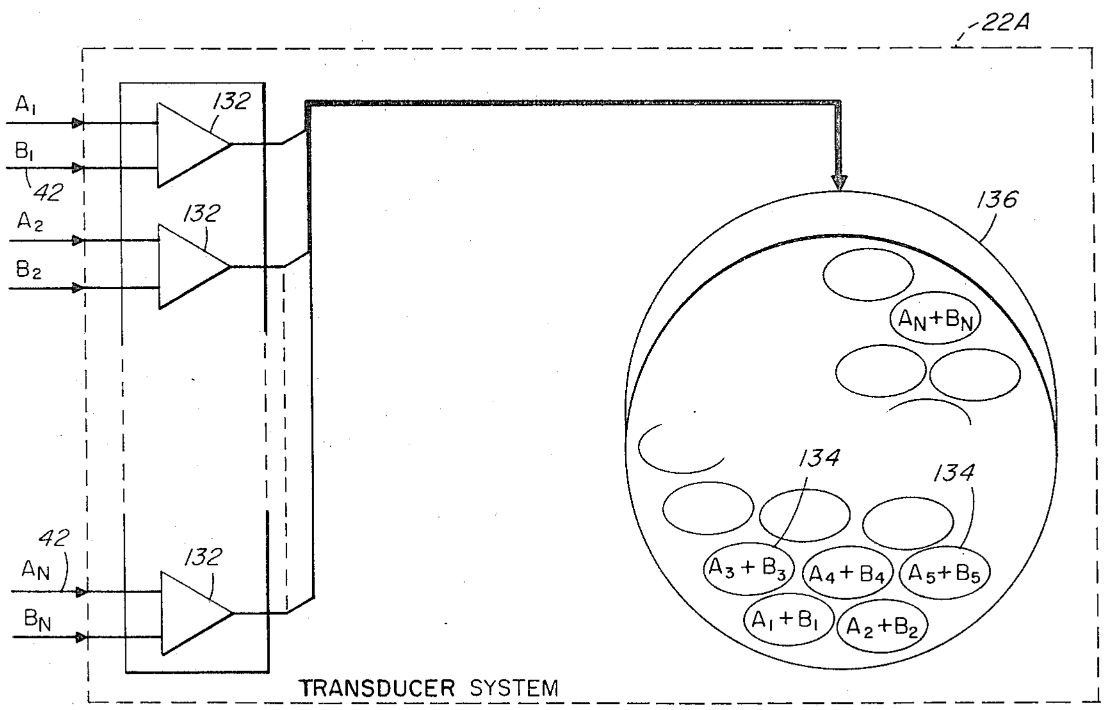

22A
A1
B1
42
132
A2
B2
132
42
AN
BN
132
136
AN+BN
134
134
A3 + B3
A4 + B4
A5+B5
A1 + B1
A2+B2
TRANSDUCER SYSTEM

FIG. 4

PLURAL BEAM STEERING SYSTEM

BACKGROUND OF THE INVENTION

In the past, numerous experiments have been conducted for examining a parametric interaction of two beams of sonic energy which are radiated at two different frequencies through a nonlinear medium, this interaction providing a beam of sonic energy radiated at other frequencies, each of which is equal to an arithmetic combination of the first two frequencies. The other frequencies most commonly examined are the sum and difference frequencies. The difference frequency radiation, as has been disclosed in a copending application for United States patent entitled "System for Low-Frequency Transmission of Radiant Energy," Ser. No 111,218, filed Feb. 1, 1971 by William L. Konrad and Mark A. Chramiec, now abandoned, is particularly useful for providing low frequency transmission in a narrow beam from a relatively small size radiator and furthermore is useful for penetrating material such as the ocean bottom from which higher frequencies tend to be reflected. It is also known that the attenuation of sonic radiations in a fluid medium such as water varies with the frequency of the radiation such that lower frequencies experience less attenuation than higher frequencies. At long ranges from a source of sound where both the high frequencies and the low frequencies are of relatively low intensities due to the attenuation effects of the medium, the intensity of the lower frequency radiation may well be stronger than the intensity of the higher frequency radiations due to the selective attenuation even though, initially, the intensities of the higher frequency radiations were much greater than the intensity of the lower frequency radiation produced by the parametric interaction of the higher frequency radiations. As a practical matter, the intensity of the lower frequency radiation, as reflected off the sand or muck at the bottom of a harbor, is of such low intensity that detection of the low frequency radiation is obtained by correlation techniques in which the reflected signals are compared with a replica generated synthetically

Maximum utilization of the difference frequency radiation requires a capability for steering a beam of this radiation for purposes such as scanning the bottom of a harbor, as well as stabilizing the beam during the rocking of a boat carrying equipment for generating the beam. A problem arises in that, since the beam of radiation at the difference frequency arises from the nonlinear interaction of two beams of radiation at higher frequencies, each of the higher frequency beams must be steered in such a manner that the resultant difference frequency beam can be formed and be steered in a desired direction. It is also apparent that a radiating transducer or projector of sonic energy does not produce a single lobed beam but, rather, produces radiation having a directivity pattern characterized by a main lobe plus a multiplicity of side lobes whose relative amplitudes depend on factors such as the size of the projector and, if the projector consists of an array of radiating elements, upon the spacing of these elements. It is readily apparent that in the steering of the two beams of higher frequency radiation, each of which is characterized by a multiple lobed directivity pattern, that care is required to insure that the side lobes of the respective directivity patterns are so oriented with respect to the projector that there is no substantial overlapping of the side lobes as might result in the parametric interaction of the side lobes to produce a multiplicity of differently oriented beams of radiation at the difference frequency. An additional problem must also be considered, namely, that in any sonar system utilizing a beam of radiation at the difference frequency, it is most probable that some form of signal modulation will be utilized, particularly if correlation techniques are to be employed in the reception of the difference frequency radiation; such modulation must necessarily be present on at least one of the high frequency radiation beams, this presenting the requirement for preserving the temporal relationships of the modulation on one high frequency beam relative to the other high frequency beam as these beams are steered about a projector which may well have a length equal to many wavelengths of the high frequency radiations.

SUMMARY OF THE INVENTION

The aforementioned problems are overcome and other advantages of beam steering are provided by a system, in accordance with the invention, which comprises an array of transducer elements which radiate radiant energy at a first frequency and at a second frequency, the radiating elements being positioned for forming beams of the radiant energy and directing these beams into a nonlinear medium such as sea water, to provide a parametric interaction between these beams of energy. This interaction, which is associated with the wave propagation characteristic often referred to as finite amplitude, produces a resultant beam of energy emanating from a region of the medium which is illuminated simultaneously by the beams of radiation at the first and at the second frequencies, the resultant radiation having frequencies which are equal to arithmetic combinations of the first and the second frequency. Of particular interest herein is the resultant beam having a frequency equal to the difference of the first and the second frequencies. The invention further comprises means for generating signals at the first and the second frequencies having a desired modulation, and means for coupling and selectively delaying each of these signals to each of the transducer elements. In one embodiment of the invention, the delayed signals at the first frequency are coupled to half of the transducer elements while the delayed signals at the second frequency are coupled to the remaining half of the transducer elements, the transducer elements operating at the first frequency being interleaved with the transducer elements operating at the second frequency so that there is a common phase center for the beams of radiation produced by the sets of transducer elements operating at the first and the second frequencies. A receiving system is also disclosed in which provisions are made for generating a replica of the difference frequency signal for correlation with a signal received from the medium at the difference frequency. In an alternative embodiment of the invention, the delayed signals at the first frequency are summed together with the delayed signals at the second frequency and applied to the radiating elements so that each radiating element transmits both a signal at the first frequency and a signal at the second frequency. With either embodiment of the invention, the temporal relationship is retained between the modulation of the signal at the first frequency and the signal at the second frequency at all points along the array of transducer elements by virtue of the variable delays, these delays being provided by a computer in accordance with interferometric principles.

BRIEF DESCRIPTION OF THE DRAWINGS

The aforementioned aspects and other features of the invention are explained in the following description taken in connection with the accompanying drawings wherein:

FIG. **1** is a pictorial view of a boat carrying a scanning sonar system of the invention for scanning the ocean bottom;

FIG. **2** is a block diagram of the scanning sonar system in FIG. **1**;

FIG. **3** shows a diagram of one embodiment of an transducer system comprising an array of radiating elements for use in the system of FIG. **2**;

FIG. **4** is a diagram of an alternative embodiment of the transducer system of FIG. **3**;

FIGS. **5** and **6** show respectively the directivity patterns of radiant energy directed straight away from a projector and at an angle relative to the projector, a pair of directivity patterns being shown for radiant energy at a first and at a second frequency.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. **1**, there is shown a system **20** comprising an transducer system **22** positioned at the bottom of a ship **24** for forming a beam **26** of radiant acoustic energy and for directing the beam **26** towards an object such as driftwood **28** submerged in the ocean **30** and towards an object such as a pipe **32** buried in the sand **34** beneath the ocean **30**. The system **20** further comprises a beam forming system **36**, a receiving system **38** and a hydrophone **40**, the transducer system **22** being coupled to the beam forming system **36** via electrical conductors indicated by lines **42**, individual ones of these lines **42** being labeled A_1—A_n and B_1—B_n, as will be more fully explained in FIG. **2**. Timing signals are provided by the beam forming system **36** along line **44** to the receiving system **38**, and signals from the hydrophone **40** are transmitted along line **46** to the receiving system **38**.

As will be disclosed subsequently, the transducer system **22** comprises a projector array **48** which forms two coincident beams of radiant sonic energy, the frequencies of these radiations differing slightly. The amplitudes of these radiations are sufficiently high to generate the aforesaid beam **26** which is at a frequency equal to the difference between the two frequencies of the radiations emanating from the projector array **48**, the beam **26** arising through a nonlinear interaction, involving the finite amplitude effect, of the two beams emanating from the projector array **48** with the waters of the ocean **30**. The widths of the beams of energy radiating from the projector array **48** differ slightly because of their differing frequencies but are approximately equal to the width of the low frequency beam **26**. The low frequency radiations are indicated by waves **50** and **52** which are respectively incident upon and reflected by the driftwood **28** and the pipe **32**. The beam **26** is made to scan the sand **34** at the bottom of the ocean **30** in a novel manner, to be described hereinafter, by means of the beam forming system **36** and the transducer system **22** so that data relative to submerged objects in the ocean **30** are communicated via the waves **52** to the hydrophone **40**.

Referring now to FIG. **2**, there is presented a block diagram of the system **20** which shows the transducer system **22**, the hydrophone **40**, the beam forming system **36** and the receiving system **38** previously seen in FIG. **1**. The beam forming system **36** provides a signal modulation suitable for sonar operations, two high frequency signals suitable for transmission from the projector array **48**, and means for coupling the signals to each element of the projector array **48** to form the beam **26**. The beam forming system **36** comprises a signal generator **54**, an oscillator **56**, a mixer **58**, a timing unit **60**, a clock **62**, two clippers **64** and **66**, two AND gates **68** and **70**, two shift registers **72** and **74**, and a computer **76** responsive to clock pulse signals on line **78** from the clock **62** and ship orientation signals on line **80** from the ship's gyrocompass indicated as gyro **82** in the figure. The beam forming system **36** also comprises a set of switches **84** which are coupled to the transducer system **22** by filters **86**, and switches **88** which are coupled to the transducer system **22** via filters **90**. Each of the switches **84** and **88** are digital multiplexing switches which, in response to a multibit command signal from the computer **76**, couple selected outputs from respectively the shift registers **74** and **72** via the filters **86** and **90** to the transducer system **22**. The outputs from the shift registers **72** and **74** are seen coupled to the switches **84** and **88** via cables **92** and **94**. Each of the cables carrying the multibit command signals from the computer **76** to the switches **84** and **88** comprise a set of parallel lines which are shown in the figure by a heavy line and identified by the numeral **96**, it being understood that each of the cables **96** are usually carrying different command signals to respective ones of the switches **84** and **88**.

The signal generator **54** may be of any well-known form for providing a signal modulation suitable for sonar operations, and is shown by way of example as a swept frequency oscillator for producing a frequency modulation. A graphical representation of the signal is shown in the block representing the signal generator **54**. The signal generator **54** provides a pulsed sinusoid in which the frequency of the sinusoid is seen to vary during each pulse with a pattern that repeats from pulse to pulse. The frequency of the signal is represented by the symbol F_1, this symbol also serving to identify the line coupling this signal from the signal generator **54** to the mixer **58**.

The oscillator **56** provides a continuous sinusoidal wave signal to the mixer **58** and the clipper **66**, this signal being identified by the symbol F_2 and having a frequency F_2 which is very much greater than the frequency F_1. The mixer **58** combines the two signals having the frequencies F_1 and F_2 to provide an output signal on line **98** having the frequency F_1+F_2, it being understood that the mixer **58** is of conventional design and includes a suitable band-pass filter for insuring that only the signal having the frequency F_1+F_2 is coupled to the clipper **64**.

The clipper **64** converts the sinusoidal signal appearing on line **98** to a signal having a substantially square waveform on line **100**, the square waveform having a repetition frequency equal to $F_1 + F_2$. Similarly, the clipper **66** converts the signal on line **102** to a square wave signal on line **104**. The signals on lines **100** and

104 are applied respectively to AND gates 68 and 70.

The AND gates 68 and 70 are utilized as sampling circuits for providing a succession of samples for each period of the square wave on line 100 and the square wave on line 104. The clock 62 provides clock pulses on line 106 to the AND gates 68 and 70. The AND gate 68 in response to the coincidence of a clock pulse on line 106 and a positive portion of the square wave on line 100, this corresponding to a logic state of 1, provides a pulse having a logic state of 1 on line 108. Similarly, the AND gate 70 provides a pulse on line 110 corresponding to the coincidence of the clock pulse on line 106 and the positive portion of the square wave on line 104. Since the repetition frequency of the clock pulses on line 106 is very much greater than that of either the square wave on line 100 or the square wave on line 104, for example, approximately 512 clock pulses may be provided for each period of the square wave on line 100, the sequence of pulses appearing on line 108 has the form shown in the graph 112 in which a sequence of 256 pulses appears over an interval of time equal to one-half the period of the square wave on line 100, this being followed by an interval of time equal to one-half the period of that square wave in which no pulses are seen on line 108, thereafter this pattern repeating itself. Clock pulses from the clock 62 are also sent to the timing unit 60 which comprises suitable countdown circuitry to provide synchronizing pulses on lines 114, 115 and 116 to synchronize the operation of the signal generator 54 with the sampling by the AND gates 68 and 70, the operation of the computer 76, and the operation of a display 118 and a correlator 120 which will be described subsequently.

The shift registers 72 and 74 are clocked by the clock pulses on line 106 to admit successive pulses in the train of pulses appearing on the lines 108 and 110, respectively. Since the repetition frequencies of the pulses on the lines 100 and 104 are unequal, the repetition frequencies of the pulses appearing on the lines 108 and 110 are unequal. It is furthermore noted that the frequency of the pulses on line 108 varies in accordance with the modulation provided by the signal generator 54, and that these pulses disappear completely in the intervals between the pulses of the F_1 sinusoid appearing at the output of the signal generator 54. Due to the lack of synchronism between the clock pulses on line 106 and the square wave on line 100, the number of pulses appearing on line 108 for each half cycle of the square wave varies slightly from period to period of this square wave. Similar comments apply to the relationship between the pulses on line 110 and the pulses on line 104. The pulses on line 108 advance through the shift register 72 and are dropped when they reach the end of the shift register 72; similarly, the pulses on line 110 advance through the shift register 74 and are dropped when the reach the end thereof.

It is apparent that the waveform appearing at any one cell of the shift register 72 is identical to the waveform appearing on line 108 except that it is delayed in time, different delays being provided by each cell of the shift register 72. In a similar way, delayed replicas of the pulse train on line 110 appear at successive cells of the shift register 74.

Referring momentarily to FIG. 3, there is seen a diagrammatic view of one embodiment of the transducer system 22 in which the projector array 48 is seen comprising transducer elements 122. The transducer system 22 also comprises a set of power amplifiers 124 of which individual amplifiers couple respective ones of the lines 42 to the transducer elements 122. The transducer elements 122 are further labeled A_l—A_n and B_l—B_n, these labels corresponding to the labeling of the lines 42 which couple the beam forming system 36 to the transducer system 22 as seen in FIGS. 1 and 2. It is noted that the transducer elements 122 labeled A_l—A_n are interleaved in a random manner among the transducer elements 122 labeled B_l—B_n, as described hereinafter.

Referring now to both FIGS. 2 and 3, it is seen that the outputs of the switches 84 are coupled via filters 86 along respective ones of the lines 42 labeled A_l—A_n through respective ones of the power amplifiers 124 to the transducer elements 122 labeled respectively A_l—A_n. Similarly, the outputs of the switches 88 are coupled via filters 90 via respective ones of the lines 42 labeled B_l—B_n through respective ones of the power amplifiers 124 to the transducer elements 122 labeled respectively B_1—B_n. In response to signals on respective ones of the lines 96, each of the switches 84 couple replicas of the signal on line 110 to the respective filters 86, the amount of delay in the replica of the signal on line 110 being determined by the particular cell of the shift register 74 that has been selected by the switch 84. Similarly, the switches 88 select delayed replicas of the signal on line 108 and apply them to the filters 90. The filter 86 has a band-pass characteristic suitable for filtering out frequencies associated with the sampling frequency or, equivalently, the repetition frequency of the clock pulses on line 106. For example, each filter 86 may be a band-pass filter centered about the frequency F_2 with an upper frequency cutoff which is well below a harmonic of the square wave signal on line 104 and also well below the frequency of the clock pulses on line 106. In this way, each of the signals appearing on the lines 42 labeled A_l—A_n are sinusoids having the frequency F_2 but are delayed from the signal appearing on line 110. In a similar manner, the filters 90 are provided with a band-pass characteristic which passes the frequency $F_1 + F_2$ but excludes frequencies of a harmonic of the square wave signal appearing on line 100 and excludes the repetition frequency of the clock pulses on line 106. Thus, the signals appearing on the lines 42 labeled B_l—B_n are sinusoids having the frequency $F_1 + F_2$ are delayed from the signal appearing on line 108. Thus, the transducer elements 122 labeled A_l—A_n are energized with a sinusoid of frequency F_2 while the transducer elements 122 labeled B_l—B_n are energized with a sinusoid having a frequency of $F_1 + F_2$. If desired, the filters 86 and 90 may be eliminated in those cases where it is desired to use a narrow band-pass filter characteristic of the transducer elements 122 for filtering out the higher frequency components of the signal appearing in the outputs of the switches 84 and 88. For example, transducer elements of a well-known piezoelectric characteristic such as transducer elements of barium titanate have a narrow band filter characteristic which may be utilized in lieu of the filters 86 and 90. However, the filters 86 and 90 are preferred in that they minimize the chance of any intermodulation distortion in the set of power amplifiers 124.

The transducer elements 122 labeled A_l—A_n may be separated by a spacing of one-half wavelength at the frequency F_2 and are interleaved among the transducer elements 122 labeled B_l—B_n which are similarly spaced part by a spacing of one-half wavelength at the frequency $F_1 + F_2$. This interleaving is done in a random fashion to minimize the amplitudes of side lobes appearing in the directivity patterns of radiations at the frequency F_2 and $F_1 + F_2$. In addition, the half wavelength spacing also reduces the magnitude of these side lobes. As is known from antenna theory, these spacings may be made still smaller to further reduce the amplitude of the side lobes. However, it is interesting to note that because of the utilization of the finite amplitude effects, the interelement spacing between the transducer elements 122 labeled A_l—A_n and the interelement spacing between the transducer elements labeled B_l—B_n may be increased up to a full wavelength and even beyond producing multiple lobed directivity patterns in which the intensities of the side lobes are relatively high compared to the main lobe as will be described hereinafter with reference to FIGS. **5** and **6.** The directivity patterns having side lobes of minimal amplitudes are preferred since they place more power in the main lobe where it is more efficiently utilized.

The sonic radiation emanating from the projector array **48** at the frequency F_2 radiates outwardly in a direction normal to the face of the projector array **48** when the switches **84** have selected equal delays for each of the signals on the lines **42** labeled A_l—A_n. When these delays have been selected such that the signals emanating from the transducer elements **122** near one end of the projector array **48** have a greater delay than the signals emanating from the opposite end of the projector array, it being pressumed that there is a uniform delay taper across the face of the array **48** and that the amount of delay experienced by the signal of any one transducer element **122** is proportional to the distance of that transducer element from the end of the array experiencing the minimal delay, then the radiation emanating at the frequency F_2 is directed at an angle away from the normal to the array base. By suitably selecting the delay for each of the transducer elements **122** labeled A_l—A_n, the beam of acoustic energy radiated at the frequency F_2 may be steered about two axes, namely, the roll axis and pitch axis of the ship **24** of FIG. **1.** Similar comments apply to the sonic energy radiated at the frequency $F_1 + F_2$.

As shown in FIG. **2,** the receiving system **38** comprises a preamplifier **126,** the correlator **120** and display **118.** Acoustic energy radiated from the projector array **48** and reflected off the driftwood **28** and pipe **32** is received by the hydrophone **40,** which may be of conventional design, and amplified by the preamplifier **126.** The computer **76** provides beam steering commands simultaneously for both the beams of acoustic energy radiated at the frequencies F_2 and $F_1 + F_2$ so that the main lobes of their respective directivity patterns are directed in the same direction. The acoustic energies at these two frequencies ensonify the water of the ocean **30** with sufficient intensity to induce the nonlinear finite amplitude reaction which results in the generation of acoustic energies at a number of frequencies each of which is equal to an arithmetic combination of the frequencies F_2 and $F_1 + F_2$. The sonic radiation produced at the difference of these two frequencies, namely, F_1, is particularly useful in that it is attenuated far more slowly than the higher frequency radiations and grows in relative amplitude with increasing distance from the projector array **48.** Of particular interest is the fact that this low frequency radiation can penetrate the sand **34** and detect submerged objects such as the pipe **32** more readily than the higher frequency radiations which reflect off the bottom surface of the ocean **30.** The hydrophone **40** is designed with a band-pass characteristic suitable for receiving the sonic energy at the frequency F_1, and the preamplifier **126** has a similar band-pass characteristic for amplifying the signals. The display **118** may comprise a cathode-ray tube, and the output signal of the preamplifier **126** appearing on line **128** may be transmitted directly (not shown in the figures) to the display **118** to be visualized. Since the frequency F_1 is typically in the audio range, the display **118** may comprise a set of earphones (not shown) to permit listening directly to the signals reflected from the driftwood **28** and the pipe **32,** the frequency modulation of the signal aiding in identification thereof. However, at depths normally encountered in harbors and at greater depths, the signals received at the difference frequency F_1 may well be excessively small compared to background noise, this precluding direct displaying of these signals on the display **118.** In these situations, the correlator **120** is utilized and a replica is provided on line **130** from the signal generator **54** for comparison with the signal on line **128.** Typically, digital correlators are utilized in which case timing pulses on line **116** are provided for operating the correlator **120.** The output of the correlator **120** is then applied to the display **118.**

Referring now to FIG. **4,** there is shown an alternative embodiment of the transducer system **22** of FIG. **2,** identified by the legend **22A** in FIG. **4.** Amplifiers **132** are provided for coupling the signals on the lines **42,** seen also in FIG. **2,** to individual transducer elements **134** which collectively compose a projector array **136.** Each of the amplifier **132** sums together the signals on the lines **42** such that the signal on the line A_1 is added to the signal on the line B_1, the signal on line A_2 is added to the signal B_2, and similarly with the remaining lines through A_n and B_n. In this way each of the transducer elements **134** radiate sonic energy at both of the frequencies F_2 and $F_1 + F_2$. The computer **76** provides a set of beam steering commands different from that provided for the projector array **48** of FIG. **3** since the sonic energy is radiated from a different set of locations in the case of the projector array **136.**

Referring now to FIGS. **5** and **6,** thereis seen the directivity patterns of the sonic energy radiated from the projector array **48** of FIG. **2** in which the main lobe is radiated in a direction normal to the array in FIG. **5** and at an angle off the axis, or normal, of the projector array **48** in FIG. **6.** The directivity pattern formed by the solid line identified by the number **138A** in FIG. **5** and **138B** in FIG. **6** represents the radiations at the frequency **F2,** while the directivity patterns formed by the dashed lines identified by the legends **140A** in FIG. **5** and **140B** in FIG. **6** represent the sonic energy radiated at the frequency $F_1 + F_2$. Three directivity patterns have been drawn for the situation wherein the interelement spacing is greater than a wavelength to accentuate the side lobes. Of particular interest here is the fact that while the main lobes overlap in both FIGS. **5** and **6,** the side lobes do not overlap, the directivity patterns differing because of the differenting wavelengths of the two radiations. The finite amplitude effect is significantly reduced for side lobes because their intensity is lower than that of the main lobe. Furthermore, due to the lack of spatial coincidence of the side lobes at one frequency versus the side lobes at the other frequency, there is a still further reduction in the finite amplitude effect produced by the interaction of acoustic energies radiated by the side lobes. Accordingly, a directivity pattern (not shown) drawn for the difference frequency F_1 would show a preponderance of the main lobe over the side lobes even though the directivity patterns of the higher frequency acoustic energies which induce the difference frequency radiation have substantial side lobes. For this reason, a highly directive beam of the difference frequency radiation can be readily steered by the system **20** of FIGS. **1** and **2** while retaining its directivity at steering angles without introducing the familiar grating lobe pattern associated with phased arrays in both sonar and radar systems. It is interesting to note, that this discussion of the finite amplitude effect is equally applicable to the nonlinear effects produced by radiations in media other than water, be it a fluid medium such as air or a solid medium.

It is understood that the above-described embodiments of the invention are illustrative only and that modifications thereof will occur to those skilled in the art. Accordingly, it is desired that this invention is not to be limited to the embodiments disclosed herein but it is to be limited only as defined by the appended claims.

What is claimed is:

1. A scanning sonar system comprising:

means for radiating sonic energy in a first and in a second sonic radiation pattern respectively at a first and a second frequency in a medium capable of producing nonlinear acoustic effects, each of said radiation patterns having a main lobe and side lobes, each of said main lobes being directed through a common region of said medium, the side lobes of said first radiation pattern ensonifying regions of said medium separate from regions of said medium ensonified by side lobes of said second radiation pattern;

means for altering the directions of each of said main lobes and said side lobes relative to said radiating means, each of said altered main lobes being directed through a common region of said medium, the altered side lobes of said first radiation pattern ensonifying regions of said medium separate from regions of said medium ensonified by altered side lobes of said second radiation pattern; and

means coupled to said radiating means for generating said sonic energy at a sufficiently high intensity level for providing a nonlinear reaction in the common region of said medium ensonified by said main lobes wherein radiant acoustic energy is provided at a third frequency equal to an arithmetic combination of said first and said second frequencies.

2. A system according to claim **1** wherein said altering means comprises means for delaying a signal radiated from a portion of said radiating means relative to a signal radiated from another portion of said radiating means.

3. A system according to claim **2** wherein said delaying means comprises a multiply tapped delay medium and a plurality of switches interconnecting respective ones of said taps with respective portions of said radiating means.

4. A system according to claim **3** wherein said delay medium comprises a pair of shift registers.

5. The system according to claim **4** comprising means for generating a generally square shaped waveform at said first frequency and a generally square shaped waveform at said second frequency, and means for sampling said waveform at said first frequency and said waveform at said second frequency at a sampling rate higher than said first frequency and higher than said second frequency, said sampling means being coupled to said shift registers.

6. A system according to claim **5** including oscillator means for providing said waveform at said first frequency, said system further comprising a signal generator and means for combining an output of said signal generator with an output of said oscillator means to provide said waveform at said second frequency.

7. In combination:

a plurality of radiating elements positioned for coupling radiant energy into a medium capable of inducing a nonlinear reaction between waves of such radiant energy propagating through said medium;

first means for energizing a plurality of said radiating elements with a signal at a first frequency;

second means for energizing a plurality of said radiating elements with a signal at a second frequency and an intensity which is sufficiently high to induce said nonlinear reaction in said medium between waves of the energies at said first frequency and said second frequency;

said first energizing means including means coupled to respective ones of said radiating elements for steering a wave front of radiation at said first frequency; and

said second energizing means including means coupled to respective ones of said radiating elements for steering a wave front of radiation at said second frequency in a direction for intercepting a region of said medium illuminated by said radiation at said first frequency for providing said nonlinear reaction in said commonly illuminated region, said nonlinear reaction resulting in a signal radiated at a third frequency different from said first and said second frequency.

8. A combination according to claim **7** wherein said first energizing means includes means for providing a sample of said signal at said third frequency, said sample being suitable for a correlation of said sample with said signal radiated at said third frequency.

9. A combination according to claim **8** wherein said second energizing means includes an oscillator for providing a signal at said second frequency.

10. A combination according to claim **9** wherein said first energizing means includes means for combining said signal of said oscillator with said sample to provide a signal at said second frequency.

11. The combination according to claim **10** wherein said first energizing means and said second energizing means includes means for sampling said signal of said oscillator and said signal of said combining means.

12. A combination according to claim **11** wherein said steering means of said first energizing means includes a delay medium coupled to the sampling means of said first energizing means, said delay medium providing a set of delays of said sampled signal, said steering means of said first energizing means further comprising means for selectively coupling delays of said delay medium to said respective ones of said radiating elements.

13. A combination according to claim **7** wherein said plurality of radiating elements are positioned in an array, said array of radiating elements including radiating elements positioned for coupling radiant energy at said third frequency from said medium for receiving said radiant energy.

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