

Aug. 27, 1968

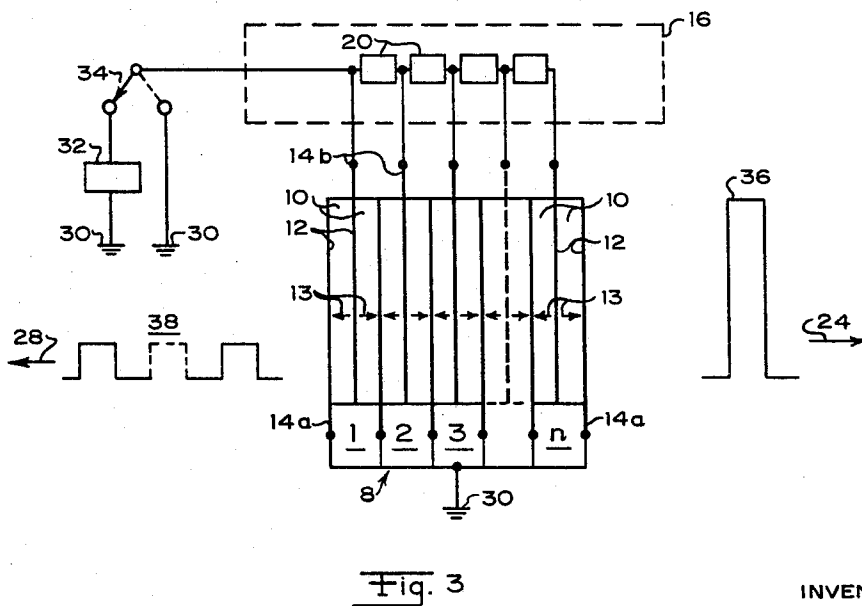
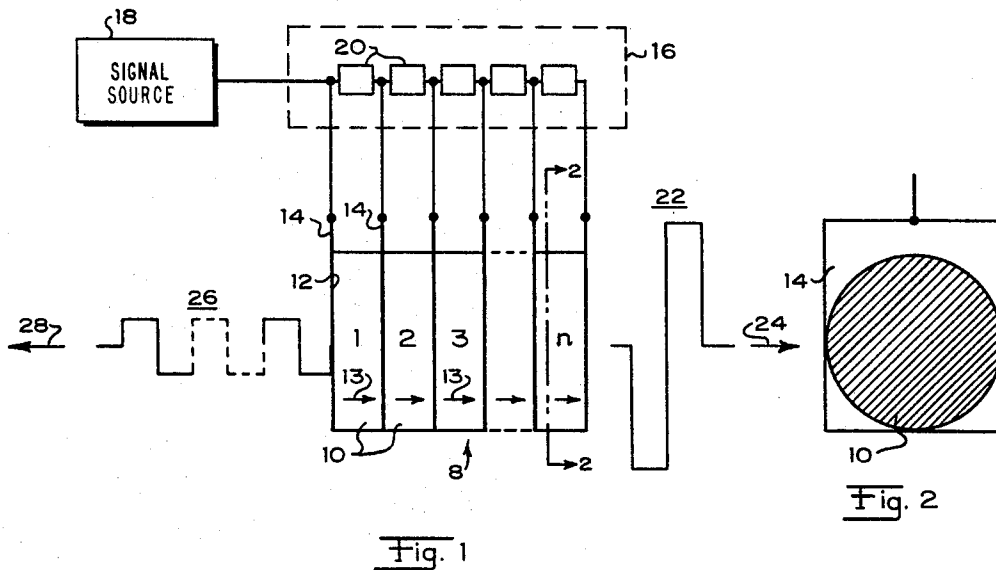
E. H. PHILLIPS

3,399,314

ULTRASONIC SIGNAL APPARATUS

Filed Nov. 12, 1965

2 Sheets-Sheet 1



INVENTOR
EDWARD H. PHILLIPS

BY *A. C. Smith*
ATTORNEY

Aug. 27, 1968

E. H. PHILLIPS

3,399,314

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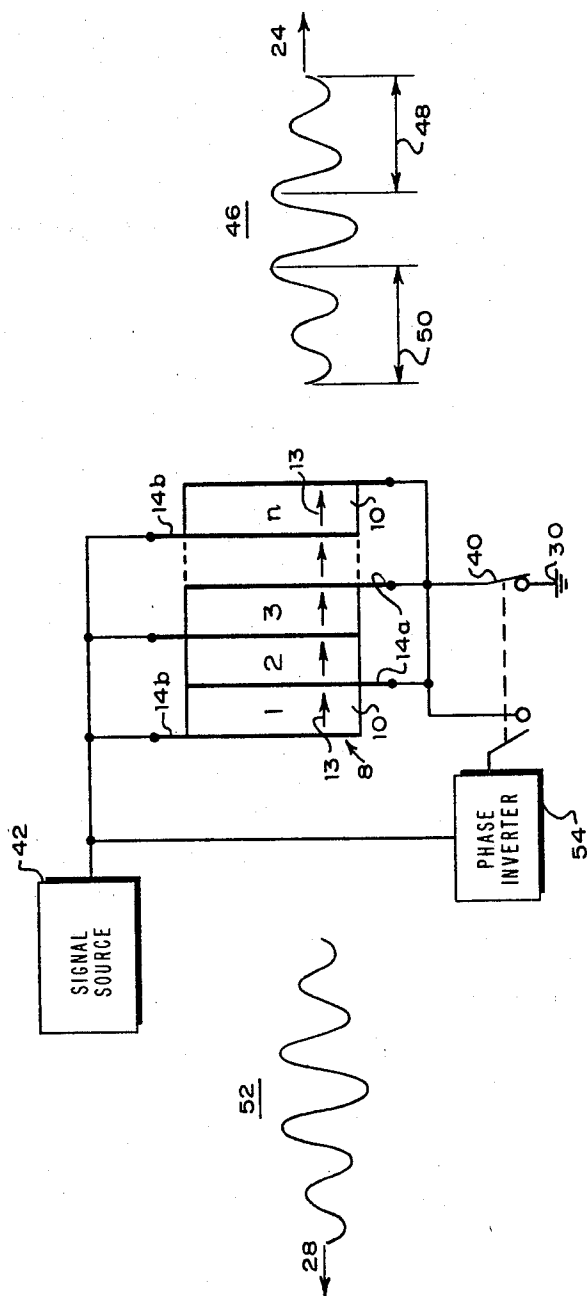


Fig. 4

INVENTOR
EDWARD H. PHILLIPS

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3,399,314

ULTRASONIC SIGNAL APPARATUS

Edward H. Phillips, Los Altos, Calif., assignor to Hewlett-Packard Company, Palo Alto, Calif., a corporation of California

Filed Nov. 12, 1965, Ser. No. 507,500

4 Claims. (Cl. 310-8.2)

ABSTRACT OF THE DISCLOSURE

A plurality of piezoelectric crystals are acoustically coupled in a body. Apparatus is provided for altering the stress conditions of the crystals in a manner to reinforce an acoustical signal as it travels through the body. This apparatus may comprise a timing circuit for sequentially delaying application of an electrical signal to selected ones of the crystals by time intervals corresponding to the transit times required for an acoustical signal generated by one of the crystals and travelling through the body to reach the selected crystals. The timing circuit may be connected directly to a source of electrical energizing pulses, or it may be connected by means of a switch first to a source of electrical energizing potential for setting the crystals to an initial stressed condition and then to a source of electrical reference potential for resetting the crystals to an unstressed condition. Alternatively, this apparatus may comprise a source of electrical energizing signal connected to selected ones of the crystals and operated in a continuous wave mode. A phase inverter may also be connected between this source and selected ones of the crystals to effectively double the amplitude of the acoustical signal produced by the crystals.

This invention relates to ultrasonic signal apparatus such as is used in ultrasonic detection systems for transmitting ultrasonic power.

It is the principal object of this invention to provide ultrasonic signal apparatus for increasing the ultrasonic power available for transmission in ultrasonic detection systems.

In accordance with the illustrated embodiments of this invention there is provided a stack of acoustically coupled piezoelectric crystals and means for changing the stress condition of the crystals so as to reinforce an acoustical signal traveling through the stack and thereby provide an acoustical output signal having increased power.

Other and incidental objects of this invention will become apparent from a reading of this specification and an inspection of the accompanying drawing in which:

FIGURE 1 shows ultrasonic signal apparatus for transmitting high power acoustical signals according to one embodiment of this invention;

FIGURE 2 shows a sectional view of the stack of acoustically coupled piezoelectric crystals of FIGURE 1 taken along the line 2-2;

FIGURE 3 shows another embodiment of the invention which is well suited for transmitting high power acoustical pulses; and

FIGURE 4 shows still another embodiment of the invention which is well suited for high power continuous wave applications.

Referring to FIGURES 1 and 2, there is shown a stack 8 of n axially aligned and acoustically coupled piezoelectric crystals 10, each having a pair of opposite and parallel planar surfaces 12. These piezoelectric crystals 10 are oriented so that they are polarized in the same direction, as indicated by the arrows 13. The parallel planar surfaces 12 of the piezoelectric crystals 10 each abut continuously upon one of a plurality of plate-like

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electrodes 14 so as to form continuous air tight junctions over the entire area of the parallel planar surfaces 12. These plate-like electrodes 14 may be thin steel strips since steel is a sufficiently good conductor and is acoustically well matched to the piezoelectric crystals 10. Each of the electrodes 14 is connected to a timing circuit 16 which is responsive to a signal source 18 for sequentially energizing the initially de-energized piezoelectric crystals 10 with an electrical signal at a speed equal to the velocity of sound through the stack 8 of piezoelectric crystals 10. Since an acoustical signal travels through the stack 8 with the velocity of sound, this sequential energization of the piezoelectric crystals 10 has the effect of increasing the power of an acoustical signal as it travels from piezoelectric crystal to piezoelectric crystal toward the output end of the stack 8, thereby providing an output acoustical signal of greater power. Furthermore, since the ability of many piezoelectric crystals to transmit power is heat limited, the stack 8 of piezoelectric crystals 10 provides greater heat dissipation than would a single piezoelectric crystal, thereby permitting greater acoustical power transmission through the stack 8. In addition, this acoustical signal apparatus provides greater control of the phase and amplitude of acoustical signal transmission through and from the output of the stack 8 of piezoelectric crystals 10.

As shown in FIGURE 1, the timing circuit 16 may comprise, for example, a plurality of delay lines 20, each having a delay time equal to the transit time of an acoustical signal through one of the piezoelectric crystals 10. These delay lines 20 are connected in series to the electrical signal source 18 such that a delay line 20 is also connected between each adjacent pair of electrodes 14. Thus, in response to an electrical signal from the signal source 18 the n initially de-energized or unstressed piezoelectric crystals 10 are sequentially, at a speed equal to the velocity of sound through the stack of piezoelectric crystals 10, each first energized or stressed because of a potential difference momentarily created thereacross and then de-energized or unstressed when the potential difference goes to zero. This sequentially reinforces an acoustical signal which is produced by the successive energization and de-energization of the first piezoelectric crystal 10 as the acoustical signal travels through the stack 8 so that a high power acoustical signal 22 is transmitted from the n th piezoelectric crystal 10 in the direction 24. This high power acoustical signal 22 comprises a pair of opposite polarity pulses because of the successive energization and de-energization of each piezoelectric crystal 10. A train 26 of n similar, but comparatively low power, acoustical signals is concomitantly transmitted from the first piezoelectric crystal 10 in the direction 28. This train 26 of low power signals may be absorbed in an acoustical load (not shown) placed in front of the first piezoelectric crystal 10.

In lieu of the delay lines 20, the timing circuit 16 may comprise a plurality of switches connected between the electrical signal source 18 and the electrodes 14 so that initially all of the n piezoelectric crystals 10 are energized or stressed, and thereafter they are sequentially de-energized or unstressed at a speed equal to the velocity of sound through the stack 8 of piezoelectric crystals 10. This provides a high power acoustical signal from the last piezoelectric crystal 10 to be unstressed and concomitantly leaves the stack 8 of piezoelectric crystals 10 in the unstressed condition so that it might also be used as a receiver for acoustical echo signals.

Referring to FIGURE 3, there is shown another embodiment of this invention in which the stack 8 comprises n axially aligned and acoustically coupled pairs of piezoelectric crystals 10. As indicated by the arrows 13, the

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piezoelectric crystals 10 are oriented so that these n pairs are polarized in the same manner and so that the piezoelectric crystals of each pair are polarized in opposite directions. The piezoelectric crystals 10 have opposite and parallel planar surfaces 12 each of which abuts continuously upon one of a plurality of plate-like electrodes 14a and 14b, as described above in connection with FIGURES 1 and 2. The electrodes 14a abut upon the outer surfaces 12 of each of the n pairs and are connected in common to a point of reference potential such as ground 30. Similarly, the electrodes 14b, abut upon the facing inner surfaces 12 of each of the n pairs and are connected to the timing circuit 16. The timing circuit 16 may comprise a plurality of delay lines 20 serially connected such that a delay line 20 is also connected between successive electrodes 14b. The delay lines 20 each have a delay time equal to the transit time of an acoustical signal through one of the n pairs of piezoelectric crystals 10 so that the n pairs may be energized or de-energized sequentially with an electrical signal at a speed equal to the velocity of sound through the stack 8 of piezoelectric crystals 10. A source of electrical potential such as battery 32 is connected by switch 34 between ground 30 and the serially connected delay lines 20 so that the piezoelectric crystals 10 are initially all energized or stressed. When it is desired to transmit a high power acoustical signal, switch 34 is actuated to connect the serially connected delay lines 20 to ground 30, as indicated by the dashed alternate position of the switch 34. This has the effect of sequentially de-energizing or unstressing the first through the n th pairs of piezoelectric crystals 10 and thereby sequentially reinforcing an acoustical signal which is produced by the de-energization of the first pair of piezoelectric crystals 10 as the acoustical signal travels through the stack 8. Thus, a high power acoustical signal 36 is transmitted from the n th pair of piezoelectric crystals 10 in the direction 24. This embodiment of the present invention produces a single high power acoustical pulse 36 of one polarity since the n pairs of piezoelectric crystals 10 are merely de-energized or unstressed from their initial energized or stressed condition. A train 38 of n similar acoustical pulses is concomitantly transmitted in the direction 28 from the first pair of piezoelectric crystals 10, but it is of comparatively low power and can readily be absorbed in an acoustical load (not shown) placed in front of the first pair of piezoelectric crystals 10. The stack 8 of piezoelectric crystals 10 may conveniently be used as a receiver after transmission of the high power acoustical pulse 36 since all of the piezoelectric crystals are then de-energized or unstressed.

Referring now to FIGURE 4 there is shown still another embodiment of this invention which is especially well suited for high power continuous wave applications. The stack 8 of piezoelectric crystals 10 is identical to the one described in detail in connection with FIGURES 1 and 2. Thus, as indicated by the arrows 13, the n piezoelectric crystals 10 are all polarized in the same direction and are each disposed between plate-like electrodes 14a and 14b. The electrodes 14a are connected in common to ground 30 with the ganged switch 40 in the position shown, and the electrodes 14b are connected in common to a signal source 42. Signal source 42 which is operated in a continuous wave mode generates an electrical signal varying sinusoidally and having a period equal to the transit time of an acoustical signal through two of the piezoelectric crystals 10. This sinusoidal electrical signal alternately energizes and de-energizes the n piezoelectric crystals 10 and thereby causes the stack 8 to operate in a continuous wave mode and generate an acoustical signal which is sequentially reinforced as it travels through each of the n piezoelectric crystals 10 of the stack 8. Thus, a high power and continuous wave acoustical signal 46 is transmitted from the n th piezoelectric crystal 10 in the direction 24. This high power acoustical signal 46 has rise and fall times 48 and 50, respectively, equal to the transit time of an acoustical signal through the stack 8. A similar

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high power acoustical signal 52 is transmitted from the first piezoelectric crystal 10 in the direction 28. If this additional acoustical signal 52 cannot be utilized to advantage in the desired application, it may be attenuated or absorbed in an acoustical load (not shown) positioned in front of the first piezoelectric crystal 10.

The amplitude of the acoustical signals 46 and 52 can be doubled, and hence the power quadrupled, by actuating the ganged switch 40. This connects the commonly connected electrodes 14a to the output of a phase inverter 54 instead of ground 30. The input of the phase inverter 54 is connected to receive the sinusoidally varying electrical signal from the output of signal source 42. When connected in this manner, the stack 8 of piezoelectric crystals 10 generates acoustical signals of four times the power since the maximum potential difference applied across the n piezoelectric crystals 10 during the energization thereof is doubled.

I claim:

1. Ultrasonic signal apparatus comprising:
 - a plurality of piezoelectric crystals, each of said crystals having a pair of oppositely facing surfaces;
 - a plurality of electrodes;
 - said crystals and said electrodes being joined together in a body with each of said oppositely facing surfaces of each of said crystals being continuously coupled to one of said electrodes;
 - a timing circuit connected to selected ones of said electrodes, said timing circuit being operable for delaying application of an electrical signal to selected ones of said crystals by time intervals corresponding to the transit times required for an acoustical signal generated by one of said crystals and travelling through said body to reach said selected crystals;
 - a first source of electrical signal for setting said crystals to a first condition;
 - a second source of electrical signal for setting said crystals to a second condition, the remaining ones of said electrodes being connected to said second source; and
 - a switch for initially connecting said timing circuit to one of said sources, said switch being operable for subsequently connecting said timing circuit to the other of said sources to sequentially change the condition of said crystals at a speed substantially equal to the speed of sound through said crystals and thereby reinforce an acoustical signal as it travels through said body.
2. Ultrasonic signal apparatus as in claim 1 wherein:
 - said plurality of piezoelectric crystals comprises n pairs of adjacent and oppositely polarized crystals, each of said pairs of crystals being polarized in the same manner; and
 - said selected ones of said electrodes are coupled to the adjacent ones of the oppositely facing surfaces of each of said pairs of crystals and said remaining ones of said electrodes are coupled to the others of the oppositely facing surfaces of each of said pairs of crystals.
3. Ultrasonic signal apparatus comprising:
 - a plurality of piezoelectric crystals, each of said crystals having a pair of oppositely facing surfaces;
 - a plurality of electrodes;
 - said crystals and said electrodes being joined together in a body with each of said oppositely facing surfaces of each of said crystals being continuously coupled to one of said electrodes;
 - a source of electrical signal for energizing said crystals, said source being connected to selected ones of said electrodes; and
 - means, including said source, for energizing said crystals to sequentially reinforce an acoustical signal as it travels through said body, said means further including a phase inverter having an input connected

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to said source and an output connected to remaining ones of said electrodes.

4. Ultrasonic signal apparatus as in claim 3 wherein:
 said crystals are all polarized in the same direction;
 said electrodes are alternately connected to said source
 and to the output of said phase inverter; and
 said source is operated in a continuous wave mode to
 provide a periodically varying electrical signal hav-
 ing a period substantially equal to the transit time re-
 quired for an acoustical signal to travel through two
 of said crystals.

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J. D. MILLER, *Primary Examiner*.