

Oct. 11, 1949.

A. C. KELLER

2,484,626

ELECTROMECHANICAL TRANSDUCER

2 Sheets-Sheet 1

Filed July 26, 1946

FIG. 1

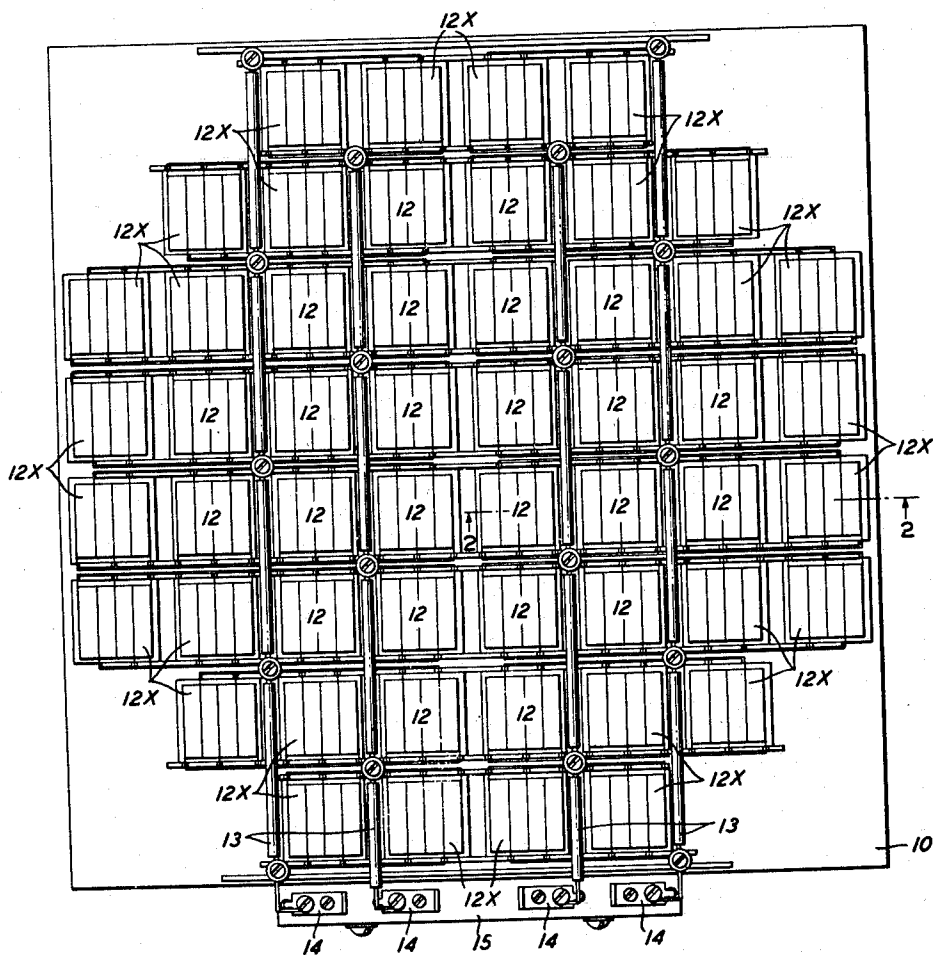


FIG. 2

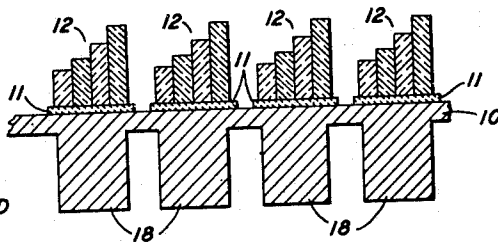
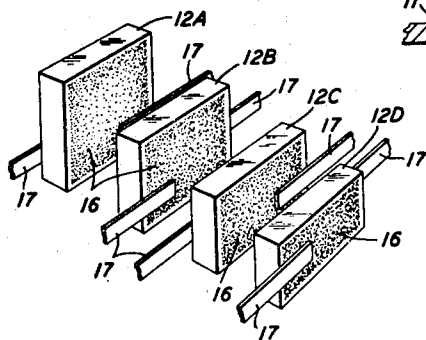


FIG. 3



INVENTOR
A. C. KELLER
BY *A. J. Fleischer*
ATTORNEY

Oct. 11, 1949.

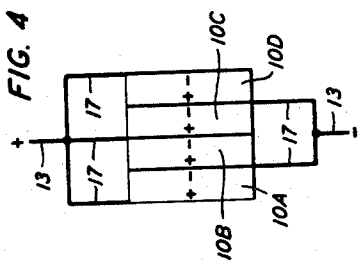
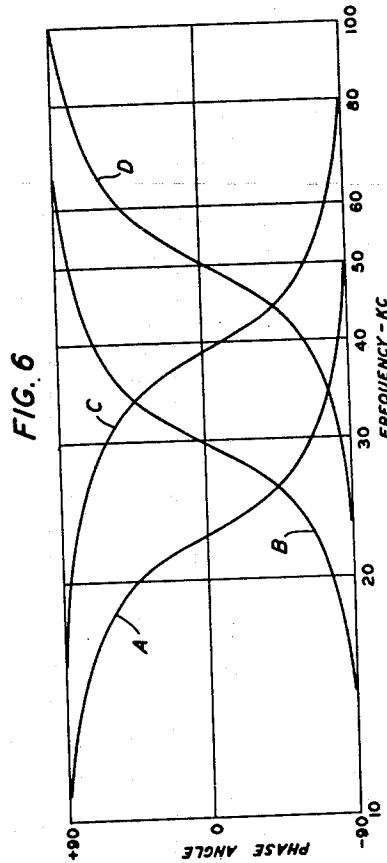
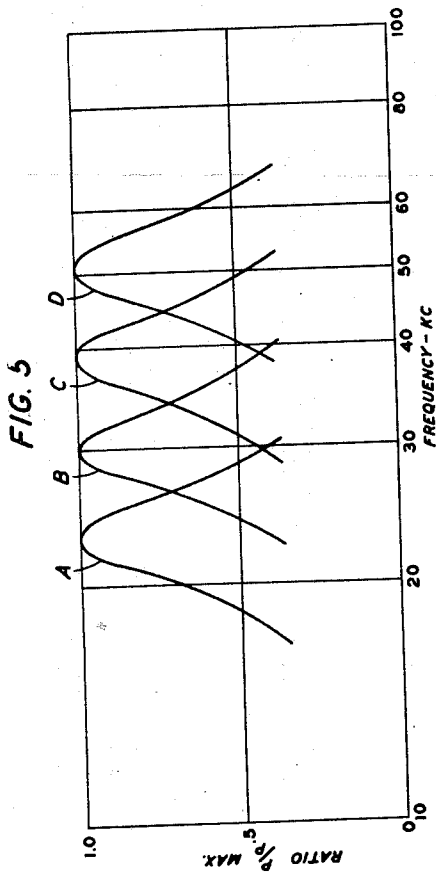
A. C. KELLER

2,484,626

ELECTROMECHANICAL TRANSDUCER

Filed July 26, 1946

2 Sheets-Sheet 2



INVENTOR
A. C. KELLER
BY *[Signature]*
ATTORNEY

UNITED STATES PATENT OFFICE

2,484,626

ELECTROMECHANICAL TRANSDUCER

Arthur C. Keller, Bronxville, N. Y., assignor to
Bell Telephone Laboratories, Incorporated, New
York, N. Y., a corporation of New York

Application July 26, 1946, Serial No. 686,345

8 Claims. (Cl. 177—386)

1

This invention relates to electromechanical transducers and more particularly to piezoelectric transducers especially suitable for use in supersonic submarine signaling devices.

One general object of this invention is to increase the operating frequency band width of electromechanical transducers comprising inherently resonant vibratory members.

More specifically, one object of this invention is to realize substantially uniform response over a wide range of frequencies with a transducer of the piezoelectric type.

In one illustrative embodiment of this invention, a supersonic submarine signaling device comprises a crystal unit composed of a number of crystal blocks and operable to convert electrical signals into supersonic compressional waves or vice versa. In general, such a crystal unit is characterized by a resonance characteristic so that a substantial response can be obtained over only a restricted range of frequencies centered on the resonant frequency.

In accordance with one feature of this invention, the crystal unit is so constructed that a substantially uniform response of large magnitude is obtained over a wide range of frequencies, for example, over a band of substantially 40 kilocycles or more.

More specifically, in accordance with one feature of this invention, the crystal unit comprises a plurality of crystal blocks vibratile in the longitudinal mode, and in face-to-face relation, the several blocks being constructed and arranged so that they have different respective resonant frequencies within the intended operating band and being so associated electrically that at frequencies between the resonance frequencies the responses of each two adjacent blocks are additive.

In a specific and illustrative embodiment of this invention, the crystal unit comprises four blocks the resonant frequencies of which are substantially in the same ratio as the upper and lower frequencies of the band at which, for the particular material, the response is a preassigned value relative to the response at resonance, and adjacent crystals are oriented so that they are in reverse electrical relation, whereby at a frequency intermediate the resonance frequencies of adjacent crystals the responses of adjacent crystals are in phase.

This invention and the above-noted and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawing, in which:

Fig. 1 is a face view of the crystal and resonator assembly in a broad band, supersonic submarine signal transducer illustrative of one embodiment of this invention;

Fig. 2 is a view in cross-section of a portion of

2

the assembly shown in Fig. 1, taken along line 2—2 of Fig. 1;

Fig. 3 is an exploded perspective view of one of the crystal units included in the assembly illustrated in Figs. 1 and 2;

Fig. 4 is a diagram illustrating the relative polarities of the crystal blocks in each unit and of the electrical connections thereto;

Fig. 5 is a graph illustrating the frequency response characteristics of the crystals in each unit, and

Fig. 6 is a graph showing the relative phase of the outputs of the crystals in each unit.

Referring now to the drawing, the assembly illustrated in Fig. 1 comprises a mounting or resonator plate 10, for example of steel, having affixed thereto, as by cementing, a plurality of insulating, for example, ceramic, plates 11 to each of which a piezoelectric crystal unit 12 is secured, also, for example by cementing. As shown in Fig. 1, the several crystal units are arrayed in horizontal and vertical rows which are graded in length, as disclosed, for example, in Patent 2,417,830, granted March 25, 1947, to Arthur C. Keller, so that a highly directional response and propagation pattern for the transducer is attained. The crystal units may be connected electrically, the individual crystal connections being as described hereinafter, by bus wires 13 leading to terminals 14 mounted upon an insulating block 15 carried by the plate 10.

All of the crystal units may be operated in parallel electrically or they may be divided electrically into two equal groups, e. g. to the right and to the left of the vertical median plane in Fig. 1, for side lobe comparison operation.

As shown clearly in Figs. 2 and 3, each of the crystal units 12 comprises a group of crystal blocks of the same width and thickness but of different lengths, the length being the dimension normal to the face of the resonator plate 10. The crystals are cut and mounted for vibration in the longitudinal mode, i. e., for vibration normal to the face of the plate 10, and may be of any one of a number of piezoelectric materials, such as Rochelle salt, ammonium dihydrogen phosphate or potassium dihydrogen phosphate. In a particular construction, 45-degree Z-cut ammonium dihydrogen phosphate (hereinafter referred to as ADP) crystals have been found satisfactory.

In the particular construction illustrated, each crystal unit comprises four crystal blocks 12A, 12B, 12C and 12D, having electrodes 16, for example, of gold, upon the opposite faces thereof, to which metal foil leads 17 are connected. The blocks are in face-to-face relation and have their electrical axes oriented so that the relative polarities of the four crystal blocks are as shown in Fig. 4. Also, the foil leads 17 for each crystal

unit are of the relative polarities indicated in Fig. 4.

As is known, the resonant frequency and the frequency response characteristic of each of the crystal blocks is determined by the block dimensions and where, as in the construction illustrated in the drawing, the blocks are of the same width and thickness, the relation of the resonant frequencies of the several blocks in each unit is determined by the length of the blocks. The length of each block is made substantially equal to one quarter wavelength of a preassigned frequency within the intended operating range for the device and the relative lengths of the several blocks are made such that the several resonant frequencies are such that a substantially uniform response over a preassigned frequency range for the group is realized. The maximum separation between the several resonant frequencies involved, which can be utilized, is determined by the maximum frequency band width over which each crystal will operate with a desired ratio of power to maximum power. For example, for ADP crystals the ratio of the upper and lower frequencies between which the response will be down no more than 3 decibels from the maximum (at resonance) is 1.3. Thus, in a transducer intended to operate over the frequency range from 20 to 57 kilocycles, with the response 3 decibels down at the extreme frequencies, the crystals being 45-degree Z-cut ADP, the lengths of the blocks 12A to 12D were such that the resonant frequencies were 22.8, 29.6, 38.5 and 50.1 kilocycles, respectively. The successive resonant frequencies, it will be noted, are in the ratio of 1.3:1.

The frequency response characteristics of the four crystal blocks are as illustrated in Fig. 5, wherein the response (ordinates) is expressed in terms of the ratio of power P to the maximum power P_{max} and the several curves are identified by the letters A, B, C or D, of the correspondingly lettered crystal block. The maximum response for each crystal block, it will be noted, is at the respective resonant frequency above set forth. Also, as will be noted, the response characteristics of adjacent blocks overlap. The phase of the output of each block relative to an applied voltage and with respect to frequency is illustrated in Fig. 6 wherein, as in Fig. 5, each curve is identified by the letter of the corresponding crystal block.

It will be seen from Fig. 5 that, for each crystal block, below the resonant frequency the output increases as the frequency rises and that above resonance, the output falls as the frequency increases. Also, as is apparent from Fig. 6, the phase of the crystal output relative to the applied voltage is dependent upon the frequency. For example, as illustrated by curve A of Fig. 6, for the crystal block 10A, below the resonant frequency the output leads the applied voltage, at this frequency the output is in phase with the voltage and above this frequency the output lags behind the voltage.

Consider now the outputs of the crystal blocks 10A and 10B. As illustrated in Fig. 5, above the resonant frequency (22.8 kilocycles) of the block 10A, the output decreases. Below the resonant frequency (29.6 kilocycles) of the block 10B, its output is increasing. At an intermediate frequency, i. e., substantially 26 kilocycles, the outputs of the two blocks are substantially equal. If, at this intermediate frequency, the outputs of the two crystal blocks are in phase the two will

add and at this frequency the output of the crystal unit will be the sum of the outputs of the two blocks 10A and 10B and by proper design may be made substantially equal to the output at the resonant frequencies. In order that the outputs of the two crystal blocks will be in phase at the intermediate frequency, it is necessary that the polarity of one of the blocks be reversed relative to the other. As shown in Fig. 4, the crystal block 10B is reversed relative to the crystal block 10A by the indicated connection of the foil leads 17, whereby the phase of output versus applied voltage relative to frequency for the crystal blocks 10A and 10B is as illustrated in Fig. 6.

A similar reversal is provided between crystal blocks 10B and 10C and between the latter and the crystal block 10D so that at the cross-over frequency for each two adjacent blocks the outputs of the two are in phase. At frequencies to either side of the cross-over frequency and between the resonant frequencies, as is illustrated in Fig. 6, although the outputs of adjacent crystal blocks are not exactly in phase they are in such relation as to add. Consequently, over the frequency range of interest, e. g., 20 to 57 kilocycles in the specific construction described, a substantially uniform output is realized.

Although the operation of the device has been explained hereinabove with reference to use of the device as a projector, i. e., wherein the crystals are driven by an applied voltage to convert electrical energy into supersonic energy, it will be understood that the device may be utilized as a transducer of sonic into electrical energy, with similar uniform response over the desired frequency range.

As shown in Fig. 2, the plate 10 is provided with a plurality of resonator blocks 18, one for each of the crystal units 12 and in alignment therewith. Although these resonators are not essential to the method of operation, they increase the efficiency of energy conversion in most cases. These resonator blocks, which may be made integral with the plate 10 or separately therefrom and affixed thereto, are of a length substantially equal to a quarter wavelength of the geometric mean frequency in the operating band of the device, e. g., 33.8 kilocycles in the specific embodiment heretofore described.

The crystal and resonator plate assembly may be mounted in a castor oil filled housing having a sonically transparent window opposite the crystals, in a submarine signal transducer such as disclosed in the application of Arthur C. Keller identified hereinabove.

In order to realize a lobe reduction, a grading of the crystal units as to power, as in the manner disclosed in the patent hereinabove identified, may be employed. For example, the crystal units designated 12x in Fig. 1 may be operated at half the amplitude of the other crystal units. Also pairs of crystal blocks in the individual units may be operated in series electrically to provide a power grading for lobe reduction.

Although in the construction described the blocks constituting each crystal unit are of the same piezoelectric material, they may be of different materials. For example, blocks of the same length but of different materials, such as ADP and Rochelle salt, could be utilized. Because of the difference in the materials, blocks of the same length will operate at different frequencies. For example, one four-block unit may comprise two adjacent ADP and two adjacent Rochelle salt

crystals. Alternatively such a unit may comprise alternate ADP and Rochelle salt blocks.

Also, although a specific embodiment of the invention has been shown and described, it will be understood that it is but illustrative and that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. An electromechanical transducer comprising a group of electromechanical translating members having similar phase angle input-output characteristics and each resonant at a preassigned frequency within a prescribed band of frequencies, said members being mounted side by side for vibration in the same mode, the resonant frequency of adjacent members being different and the frequency response characteristics of adjacent members overlapping, a pair of terminals, and means electrically connecting said members to said terminals with adjacent members in reverse relation, the resonant frequencies of said members being in such ratio that the outputs of each pair of adjacent members are in phase at a frequency substantially midway between the resonant frequencies thereof.

2. An electromechanical transducer for translating a band of frequencies with the response at the extreme frequencies of said band having a preassigned ratio to the maximum response, said transducer comprising a group of electromechanical translating elements mounted side by side in a row and each having a prescribed resonant frequency within said band, the resonant frequency of each element being different from those for the other elements and the resonant frequencies of adjacent elements being in the same relation as the extreme frequencies of the band for which the response of each element will be at least as great as said ratio, and means electrically connecting said elements so that in response to signals applied thereto the outputs of adjacent elements are additive and of like phase angle sign relative to said signals at frequencies between the resonant frequencies thereof.

3. An electromechanical transducer comprising a piezoelectric unit including a group of crystal blocks mounted in face-to-face relation, each of said blocks being resonant at a frequency within a preassigned band and the resonant frequency of each block being different from that of the other blocks, adjacent crystal blocks having overlapping frequency response characteristics, and means electrically associating said blocks such that adjacent blocks are in reverse relation, whereby at a frequency between the resonant frequencies thereof the outputs of adjacent blocks are in phase.

4. An electromechanical transducer comprising a group of piezoelectric crystal blocks mounted in face-to-face relation for vibration in the longitudinal mode, opposing faces of adjacent crystals being of opposite polarity, each of said blocks having a preassigned resonant frequency within a preassigned range and different from that of the other blocks and the frequency response characteristics of adjacent blocks overlapping, and means electrically connecting said blocks so that for signals applied thereto, the outputs of adjacent blocks at frequencies between the resonant frequencies thereof have the same sign of phase angle relative to the applied signals.

5. An electromechanical transducer comprising a group of piezoelectric crystal blocks mounted in

face-to-face relation and vibratile in the longitudinal mode, said blocks being of substantially the same thickness and width but of different lengths such that the resonant frequencies of said blocks are different and the frequency response characteristics of adjacent blocks overlap, and means electrically connecting said blocks such that for applied signals the outputs of adjacent blocks are in phase at a frequency between the resonant frequencies thereof.

6. An electromechanical transducer comprising a group of piezoelectric crystal blocks mounted in face-to-face relation for vibration in the longitudinal mode and with the opposed faces of adjacent blocks of opposite polarity, each of said blocks being resonant at a preassigned frequency within a prescribed band and different from the resonant frequency of the other blocks, the frequency response characteristics of adjacent blocks overlapping, a pair of terminals, and means connecting the opposed faces of adjacent blocks to one of said terminals and the other faces of adjacent blocks to the other of said terminals.

7. An electromechanical transducer comprising a plate, a group of longitudinally vibratile piezoelectric crystals mounted on one face of said plate and in face-to-face relation, each of said crystals being of a length substantially equal to a quarter wavelength of a preassigned frequency within a prescribed band and different from the length of the other crystals, said crystals being constructed and arranged so that the frequency response characteristics of adjacent crystals overlap, means electrically connecting said crystals so that the response of adjacent crystals for applied signals of frequencies intermediate the resonant frequencies thereof is additive, and a resonator member mounted on the other face of said plate, opposite said crystals and of a length substantially equal to a quarter wavelength of the mean frequency in said band.

8. An electromechanical transducer for translating signals within a preassigned band with the response at the extreme frequencies of said band having a prescribed amplitude relative to the maximum response, said transducer comprising a group of piezoelectric crystal blocks mounted in face-to-face relation for vibration in the longitudinal mode, said blocks being of the same thickness and width but of different lengths such that each block is resonant at a respective frequency within said band and the resonant frequencies of adjacent blocks are in the same ratio as the extreme frequencies for each block for which the response will be of said amplitude, and means interconnecting said crystal blocks so that the outputs of adjacent blocks between the resonant frequencies thereof in response to signals applied thereto are of the same phase sign relative to the applied signals.

ARTHUR C. KELLER.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,398,117	Rost et al. _____	Apr. 9, 1946
2,408,028	Batchelder _____	Sept. 24, 1946
2,411,911	Turner _____	Dec. 3, 1946
2,415,832	Mason _____	Feb. 18, 1947
2,417,829	Keller _____	Mar. 25, 1947