Aug. 6, 1946. W. P. MASON 2,405,226

LOW FREQUENCY PROJECTOR OR HYDROPHONE

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FIG. 1.

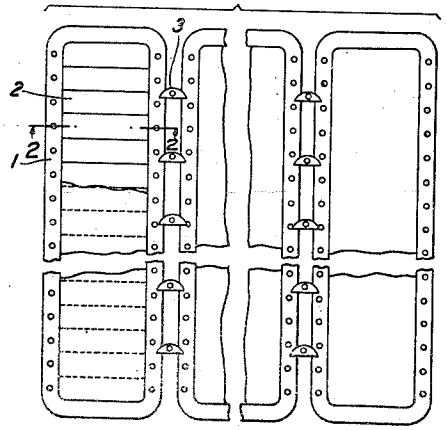


FIG. 4.

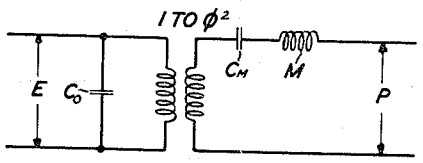


FIG. 5.

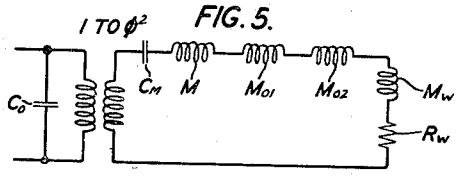


FIG. 2.

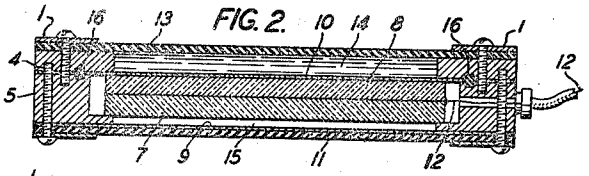


FIG. 6.

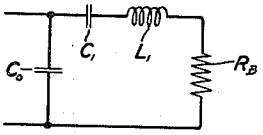


FIG. 3.

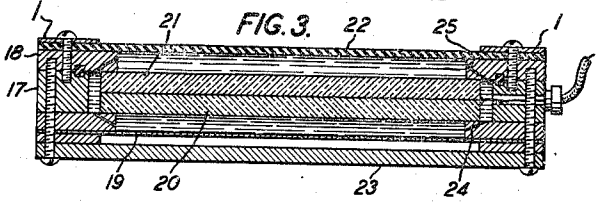


FIG. 7.

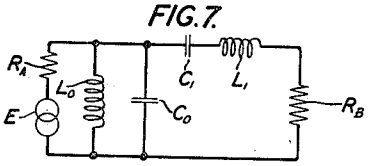


FIG. 8.

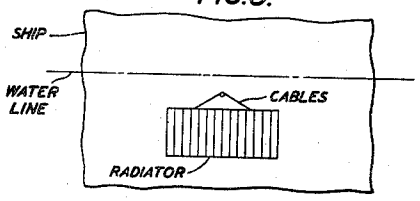


FIG. 9.

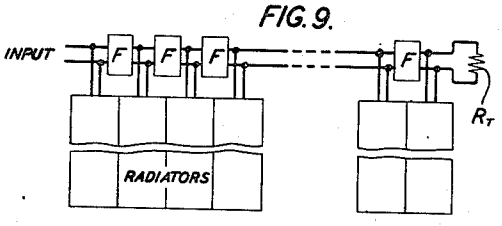


FIG. 10.

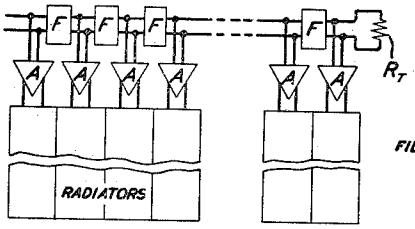
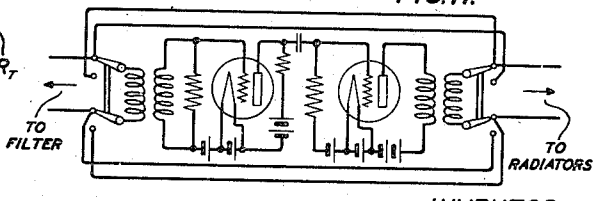


FIG. 11.



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LOW FREQUENCY PROJECTOR OR HYDROPHONE

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FIG. 12.

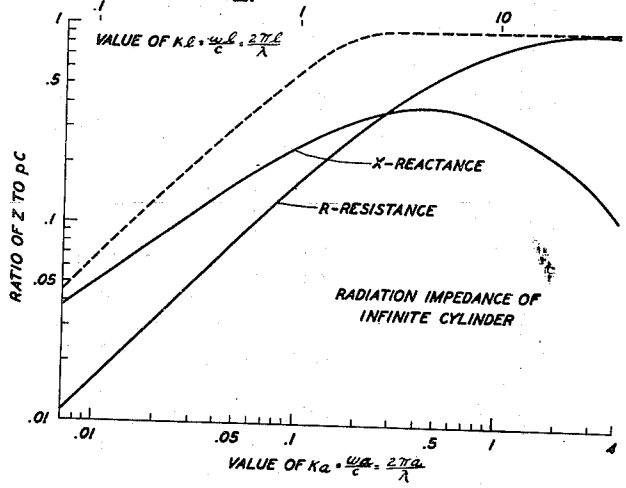


FIG. 13.

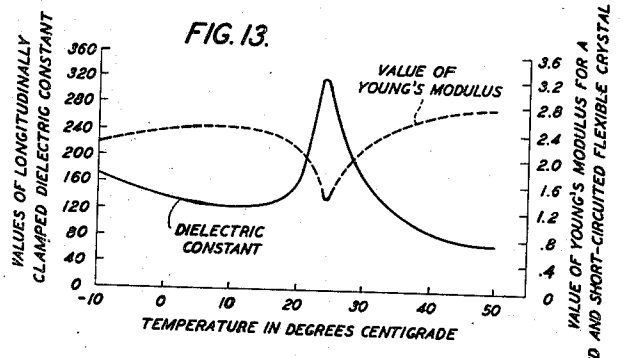
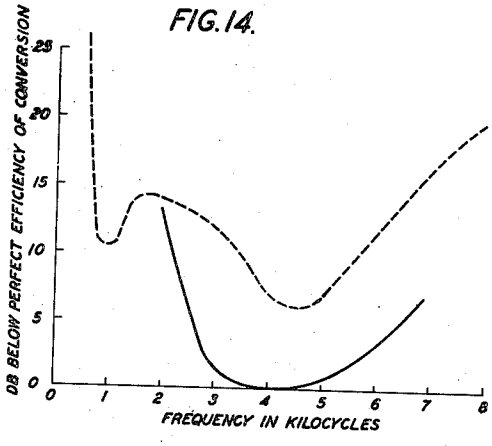


FIG. 14.



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UNITED STATES PATENT OFFICE

2,405,226

LOW FREQUENCY PROJECTOR OR HYDROPHONE

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Application December 28, 1942, Serial No. 470,398

5 Claims. (Cl. 177—386)

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This invention relates to multiunit radiating and receiving devices and to high power compressional wave radiating devices. In the hereinafter described preferred embodiments, illustrative of the principles thereof, it relates particularly to radiating and receiving devices employing a large number of piezoelectric crystals which are capable of radiating high power compressional energy waves and to compressional wave energy radiators and receivers which have "prismatic" properties.

By way of definition, in the present specification a prismatic device, for other than light energy waves, should be understood to be a device which in transmitting a wave comprising energy of numerous frequencies within a particular frequency spectrum will spread the frequency spectrum by imparting a direction, differing for each frequency, to the several frequencies of the spectrum or which in receiving energy will respond to the several frequencies of the spectrum only when they approach the device at particular respective angles, differing for each frequency.

The prismatic characteristics of the devices of the present invention are similar to those of the devices of my copending application entitled "Pipe antennas and prisms," filed March 1, 1941, Serial No. 381,236.

The object of the invention is to provide an efficient low frequency submarine projector or hydrophone which may be used for transmitting and receiving signals in a range where conditions are more favorable than for the ordinary devices used for this purpose.

In accordance with the present invention a submarine projector or hydrophone is formed of a mosaic structure of piezoelectric crystals in the form of a thin blanket of considerable area attached to the hull of a ship. Such a blanket consists of a plurality of narrow vertically disposed units connected in an electrical network by which a prismatic effect may be achieved and including amplifying means adjusted to suppress secondary lobes. By way of example, such a blanket may be of the order of three feet in height, seven and a half feet in length and an inch and a half in thickness.

Each of the said units consists of an array of bimorph crystal structures of a size and shape best suited for the frequency range desired. Such a plurality of crystals are electrically connected in parallel and physically housed in a single container whereby in form each unit effectively consists of a long, narrow and thin strip.

A feature of the invention is a hydrophone consisting of a blanket-like structure comprising a plurality of crystals divided into groups, each group being connected into an electrical network providing means for achieving a prismatic effect

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and the suppression of secondary lobes, the separate crystals being constructed and arranged to respond to frequencies within the audible range.

The drawings consist of two sheets having fourteen figures, as follows:

Fig. 1 is a fragmentary view of a plurality of radiators showing how they may be mounted on the hull of a ship;

Fig. 2 is a cross-sectional view taken on line 2, 2 of Fig. 1 of a crystal showing how the crystal may be mounted and illustrating the relationship of the oil and air chambers with respect thereto;

Fig. 3 is a similar view showing another form of crystal arranged to be insensitive to longitudinal waves in the metal frame;

Fig. 4 is a fragmentary circuit diagram showing an electrical circuit equivalent to the bimorph crystal;

Fig. 5 is a similar but more detailed circuit;

Fig. 6 is a circuit diagram showing the relationship of the equivalent constants for a crystal of a particular size as derived in the body of the specification;

Fig. 7 is a circuit diagram showing a half section of a confluent type filter illustrating the manner of using the electromechanical driving elements;

Fig. 8 is a fragmentary side view of the hull of a ship showing the placement of the radiator in relation to the water line;

Fig. 9 is a schematic circuit diagram showing how a plurality of radiators are connected in a network with a plurality of filters to produce a prismatic effect;

Fig. 10 is a schematic circuit diagram showing how unidirectional amplifiers may be used in the network of Fig. 9;

Fig. 11 is a circuit diagram showing a circuit arrangement by which the amplifiers may be pointed in one direction or the other as the crystal devices are to be used as radiators or hydrophones;

Fig. 12 is a graph showing the result of calculations of the radiation impedance of an infinite cylinder;

Fig. 13 is a pair of graphs showing fundamental constants of a 45-degree X-cut Rochelle salt crystal vibrating in flexure; and

Fig. 14 is a pair of graphs showing the efficiency of conversion of a bimorph Rochelle salt projector used at low frequencies. The solid line graph shows the projector designed as a filter circuit and the dotted line graph shows an alternative wide band low efficiency design.

This disclosure sets forth a method for obtaining an efficient low frequency projector or hydrophone which uses 45-degree X-cut Rochelle salt crystals in the form of a bimorph unit. Calculations indicate that such a unit will cover a fre-

quency range from 2750 cycles to 6000 cycles with better than a 50 per cent efficiency of conversion. By resonating the static capacity at a lower frequency than the resonant frequency of the crystal, it is possible to cover the frequency range from 700 cycles to 7000 cycles with a 10 per cent efficiency of conversion.

A low frequency radiator of this sort can be used as an element in a prism type projector and receiver for submarine location. Due to the low frequencies possible, the medium will have less attenuation and less refractivity, and hence it is possible to locate a submarine at greater distances and with a greater certainty. Such a projector also has the advantage that on account of the lower frequency a pulse sent out from the searching ship will not be as easily located by a submarine.

In the low frequency range from 1000 to 6000 cycles, it is difficult to obtain a projector or hydrophone which will radiate or pick up sound with a good efficiency. Magnetic projectors made in this range have an efficiency of less than 1 per cent and, furthermore, have a small power handling capacity. The device of the present invention is a projector or pick-up device using bimorph Rochelle salt crystals capable of radiating a wide band of frequencies efficiently and with considerable amounts of power.

In form, the radiator consists of a long strip, by way of example, 7 to 8 centimeters wide, 3 to 4 centimeters thick and several feet long. In the drawings, Fig. 1 illustrates how a plurality of such radiators may be attached to the external surface of the hull of a ship. The same showing is made in Fig. 8 to illustrate the position of the plurality of radiators with respect to the water line. In Fig. 1, each radiator comprises a frame 1 housing a plurality of bimorph crystals 2 indicated by a plurality of horizontal lines. The various units may be secured to the surface of the hull of the ship in any convenient manner, such, for instance, as by a plurality of clamps 3 which may be loosened and rotated to allow the removal and replacement of any one unit at a time.

Such a unit can be used as an efficient pick-up device having a directivity normal to the length thereof but no directivity along other directions. By mounting a number of such radiators side by side, attached directly to the ship's hull and connected to a suitable filter or phase shifter a prism-type projector and hydrophone can be obtained capable of working in the low frequency range. Due to the lower attenuation and refraction of the medium for such frequencies the range of such a device may be larger than for the ultrasonic type of radiator. Furthermore, the position of a ship sending out a low frequency pulse is not as easily located by a submarine unless it also has a large receiver capable of working to low frequencies.

On account of the bimorph type of construction used, such a device mounted in the side of a ship will not pick up the structural noise propagated through the frame of the ship.

One form of the low frequency projector is shown in Fig. 2. It consists of a steel framework comprising the elements 4 and 5 which, when assembled in any convenient manner, securely hold the bimorph crystal. This crystal consists of two slabs of crystals 7 and 8, plated on their surfaces with conducting material. The conducting surfaces of the outer faces of the crystal are connected together and form one electrical terminal of the device and the plating of the inner surfaces are connected together and connected to conductor 12 which forms the other terminal of the device. As shown, the outer surfaces are electrically connected to the frame but it will be understood that the device may easily be completely insulated from the frame. In the complete unit consisting of a plurality of crystals the electrical connections of such terminals are in multiple, so that each radiator will have two terminals.

On the radiating or upper side, the chamber between the crystal and the rubber diaphragm 13 is filled with castor oil 14, which conducts the vibrations from the crystal to the rubber diaphragm, which in turn conducts the vibrations to the sea water. On the other side of the crystal is an air chamber 15 which introduces a low impedance on the crystal. Since the two sides of the chamber are in series in the equivalent electrical circuit, all of the energy will be transferred to the sea water side and none to the air side. When the radiator is lowered into the water, the air chamber is compressed but maintains an equalizing pressure on the crystal surface and prevents the crystal from being bent.

In order to prevent the leakage of air through the rubber diaphragm 11, a thin metal diaphragm 9 is soldered to the metal frame 5 on both sides of the chamber. In order to prevent the leakage of castor oil to the crystal a similar thin metal diaphragm 10 is soldered to the frame part 4. In assembling the unit the crystal is first glued to the lower steel frame part 5. The upper part 4 is then screwed down to the lower part 5 and glued to the upper surface of the crystal. The chamber is then filled with castor oil and the upper rubber diaphragm is screwed in place. It will be noted that a thin strip of rubber 16 between the upper and lower metal frame parts 4 and 5 prevents sea water from coming into the crystal chamber. This is crushed down until a metal-to-metal contact is made between the two parts 4 and 5 of the frame.

When it is desired to have the pick-up insensitive to longitudinal waves in the metal frame, as would be the case if the projector is mounted in the ship's frame, the construction shown in Fig. 3 may be used. For this case the crystal is surrounded on both sides by oil chambers which have small interconnecting holes which allow the oil to flow at a slow rate from one chamber to the other. In this construction there is a bottom frame member 17 and an upper frame member 18. A thin metal diaphragm 19 is soldered to the lower frame member 17 and the crystal of two slabs 20 and 21 is clamped between the frame members. The chambers between the rubber diaphragm 22 and the crystal 21 and the crystal 20 and the metal diaphragm 19 are filled with castor oil. An air chamber is provided between the metal diaphragm 19 and the metal backing plate 23. Small by-pass holes 24 and 25 are provided to allow communication between the two chambers filled with castor oil. At very rapid frequencies these small openings act like choke coils and do not allow a rapid interchange of oil from one chamber to the other. At a high water pressure, the rubber diaphragm is pressed in and more oil flows to the back oil chamber causing the air chamber to compress. In this way no static pressure acts on the crystal. When a longitudinal vibration actuates the frame of the projector approximately equal pressures are generated in the two oil chambers on each side

of the bimorph crystal. As a result, since the crystal is responsive only to unbalanced pressures, no voltage will be generated by such a vibration.

Calculation of radiation efficiencies

The equivalent circuit of a bimorph crystal of this type has been worked out for a unit which is supported on the two ends but is free to bend. This corresponds closely to the case considered here since the glue will prevent the ends from moving but is not stiff enough to keep them from bending. The equivalent circuit as shown in Fig. 4 relates the input voltage and current into the crystal to the average pressure and volume velocity over the surface of the crystal. In this equivalence C_0 is the static capacity of the crystal, C_M the acoustic compliance of the crystal electrically short-circuited, i. e., the ratio between the average pressure over the surface to the time rate of displacement of the crystal surface, and M is the effective inertance of the crystal. In centimeter-gram-second electrostatic units these quantities have the values,

$$C_0=\frac{ll_wK}{l_t}$$

$$C_M=\frac{l^5l_w}{10l_t^3Y_0'}$$

$$M=\frac{1.23\rho l_t}{ll_w}$$

$$\phi=5\frac{(DK)l_t}{(4\pi)l^2} \qquad (1)$$

where l, l_w and l_t are respectively the lengths, width and total thickness of the bimorph crystal, K is the longitudinally clamped dielectric constant of the crystal, Y_0' the value of Young's modulus of the short-circuited plated crystal, ρ the density of the crystal and D a function of the piezoelectric moduli.

The complete equivalent circuit for the crystal used on a radiator is shown in Fig. 5. The impedances on the two sides of the crystal are effectively in series. On the non-radiating side the impedance will consists of the inertance of the oil chamber in series with the compliance of the air chamber. This compliance is so large compared to the compliance of the crystal that it can be neglected. On the radiating side the elements consist of the inertance of the oil chamber and the radiation resistance and inertance of the medium. For a circular source the resistance for small apertures increases proportional to the square of the frequency, but for a long thin source it is to be expected that the resistance would vary more nearly proportional to the frequency. This has been confirmed by calculations on the radiation resistance of infinite and finite cylinders vibrating radially. Such calculations show that if the length of the cylinder is greater than half a wave-length at all frequencies concerned, the resistance and reactance of a radiating cylinder vary as shown in Fig. 12. The dotted line shows the multiplying factor plotted as a function of $\omega R/c$, to correct the radiation resistance for the effect of finite length, where $\omega=2\pi f$; a=radius of cylinder; l=length of cylinder; λ= wave-length; ρ=density of water; and C=velocity of sound in water.

We are interested primarily in the radiation resistance and reactance of a pulsating rectangle in an infinite baffle. However, comparison between radiating spheres and radiating pistons in baffles shows that if the ratio of the diameter to the wave-length is less than two tenths, the

radiation resistance and reactance for the sphere and piston do not differ appreciably. Hence, we are justified in assuming that the radiation resistance and reactance of a rectangle a half wave-length long or greater over the frequencies of interest will have the same resistance and reactance as a cylinder having the same diameter as the rectangle is wide. This results in a radiation resistance of the right order of magnitude to work well with the impedance of a bimorph Rochelle salt crystal.

The most advantageous type of crystal for this use is a 45-degree X-cut Rochelle salt crystal. Although it cannot radiate as much power as a 45-degree Y-cut crystal, it has a higher electromechanical coupling which results in a considerably wider frequency range than can be radiated efficiently with a 45-degree Y-cut crystal. Furthermore, on account of the increased area of such a radiator, the amount of power radiated per square centimeter can be less. In a bimorph type of crystal, the properties do not vary as much as for a longitudinal crystal and hence the temperature effect will not be as large. For these reasons the 45-degree X-cut crystal is here employed.

With this crystal the values of the constants in centimeter-gram-second units are:

$$\rho=1.775$$
$$D=9.70\times10^4 \qquad (2)$$
$$Y_0=3.16\times10^{11}$$

when Y_0 is the value of Young's modulus for an unplated crystal. Y_0', the value for the plated and short-circuited crystal, is given by

$$Y_0'=\left[1-\tfrac{3}{4}\frac{(D^2K)}{(4\pi Y_0}\right] \qquad (3)$$

when K, the clamped dielectric constant, is as shown in Fig. 13. With this value of K the effective Young's modulus for a plated crystal is as shown in Fig. 13 as a function of temperature. Since most of the projectors are worked below 18° C., we can take as rough values

$$Y_0'=2.2\times10^{11};\ K=150 \qquad (4)$$

By way of example, let it be assumed that it is wished to radiate a band of frequencies centered around 4000 cycles. It is assumed that 6 centimeters is about the longest 45-degree X-cut crystal that is commercially feasible. The resonant frequency of the crystal in air will be

$$f=\frac{1}{2\pi\sqrt{MC_M}}=\frac{.455l_t}{l^2}\sqrt{\frac{Y_0'}{\rho}} \qquad (5)$$

In water, however, we add masses due to the water load and the weight of the oil in the chambers. If we make these chambers a total thickness of .5 centimeter on a side or l_t=1.0 centimeter, the added inertance due to the oil will be

$$M_0=\left(\frac{l_tl_0}{ll_w}\right)_{\text{oil}}=\frac{1}{ll_w} \qquad (6)$$

The added inertance of the water as determined from Fig. 12 will be

$$\frac{1}{ll_w}\left(\frac{.4\rho v}{2\pi\times4000}\right)=\frac{2.38}{ll_w} \qquad (7)$$

Actually an allowance of $3/ll_w$ is made since the piston type usually has more added mass than the cylinder type. Hence, the total inertance added to the inertance of the crystal should be

$$M_w=\frac{4}{ll_w} \qquad (8)$$

The resonant frequency will then be

$$f_R=\frac{1}{2\pi\sqrt{(M+M_w)C_M}}=\frac{.455l_t}{l^2}\sqrt{\frac{Y_0'}{\rho}}\sqrt{\frac{1}{1+\frac{3.25}{\rho l_t}}} \quad (9)$$

Inserting the values

$$Y_0'=2.2\times10^{11};\ \rho=1.775$$

this becomes

$$f_R=\frac{1.6\times10^5 l_t}{l^2}\sqrt{\frac{1}{1+1.83/l_t}} \quad (10)$$

If the band is centered at 4000 cycles, the resonant frequency of the crystal should be 4000 cycles. Assuming l=6. centimeters and solving for l_t, we find

$$l_t=1.34 \text{ cm} \quad (11)$$

This total thickness would be made up of two oppositely poled crystals, each .67 centimeter thick.

With these values, the constants of a crystal bimorph unit 1 centimeter wide, 6 centimeters long and 1.34 centimeters thick will be

C_0=214 c. g. s. units=238 mmf. (12)
$C_M=1.47\times10^{-9}$
M=1.08
$\varphi=2.15\times10^5$ c. g. s. units=.226 in practical units.

The radiation resistance at 4000 cycles, according to Fig. 12, will be about

R=.58 $\rho c=8.7\times10^4$ acoustic ohms per square cm. (13)

In acoustic impedance units we have to divide this by the cross-sectional area which is 6 square centimeters, so

$R=1.45\times10^4$ ohms, acoustic resistance. (14)

If we take these quantities through the electromechanical transformer, we will have electrical quantities as shown on Fig. 6, having the values for a crystal 1 centimeter wide

$$C_0=238 \text{ mmf.}$$
$$C_1=C_M\phi^2=75 \text{ mmf.}$$
$$L_1=M/\phi^2=21.3 \text{ henries} \quad (15)$$
$$R_B=\frac{1.45\times10^4}{\phi^2}=2.84\times10^5 \text{ ohms}$$

The filter-type structure is the most efficient way to utilize electromechanical driving elements, since the filter with matched impedance terminations is the device which will deliver to its output all the energy sent into it over the widest frequency range consistent with the elements of which it is constructed. The widest band filter using the elements of Fig. 6 as part of the filter configuration is one using a series or shunt coil to annul the static reactance of the shunt condenser. For such a wide band it makes little difference which configuration is chosen and so Fig. 7 shows the use of a shunt coil. The filter

is then a half section of a confluent type which has the element values

$$L_0=\frac{(f_2-f_1)Z_0}{2\pi f_1 f_2}$$
$$C_0=\frac{1}{2\pi(f_1-f_2)Z_0}$$
$$L_1=\frac{Z_0}{2\pi(f_2-f_1)} \quad (16)$$
$$C_1=\frac{f_2-f_1}{2\pi f_1 f_2 Z_0}$$

Taking the ratio of C_0 to C_1, and the product L_1C_1, we have

$$\frac{C_0}{C_1}=3.17=\frac{f_1 f_2}{(f_2-f_1)^2}$$
$$L_1C_1=\frac{1}{4\pi^2 f_1 f_2} \quad (17)$$

Solving the first equation, using the value 3.17 for C_0/C_1, we find

$$f_2=1.738f_1 \quad (18)$$

The second equation shows that the crystal resonance occurs at the mean frequency of the pass band which in this case is 4000 cycles. Hence, for this case

$$f_1=3040 \text{ cycles}$$
$$f_2=5270 \text{ cycles} \quad (19)$$

The image impedance at the main frequency should be

$Z_0=2\pi(f_2-f_1)L_1=2.96\times10_5$ ohms per unit length (20)

which agrees well with the radiation resistance as calculated hereinbefore.

The actual loss in conversion from electrical to mechanical energy can be calculated by solving for the current in the output of the network of Fig. 7 and comparing that to what would be obtained by the use of a perfect transformer between the input resistance R_A and the output radiation resistance R_B. This results in the equation

$$\frac{i_2}{i}=\frac{2\sqrt{R_A-R_B}}{\sqrt{\left[R_A+R_B-\frac{R_A}{\omega^2L_0C_1}(1-\omega^2L_1C_1)(1-\omega^2L_0C_0)\right]^2+\left[\frac{1-\omega^2L_1C_1}{\omega C_1}+\frac{R_AR_B(1-\omega L_0C_0)}{\omega L_0}\right]^2}} \quad (21)$$

If we insert the filter relations hereinbefore stated in relation to Fig. 7, and let R_A, the output impedance of the amplifier equal Z_0 for the filter, we have

$$\frac{i_2}{i_T}=\frac{2\sqrt{Z_0R_B}}{\sqrt{\left[Z_0+R_B-\frac{Z_0C_0}{C_1}\left(\frac{\omega_M}{\omega}-\frac{\omega}{\omega_M}\right)^2\right]^2+\left[\left(\frac{\omega_M}{\omega}-\frac{\omega}{\omega_M}\right)\sqrt{\frac{C_0}{C_1}}(Z_0+R_B)\right]^2}} \quad (22)$$

where

$\omega_M=\frac{1}{L_1C_1}=\frac{1}{L_0C_0}$=the mean frequency of the radiator

A plot of this equation with R_B taken from Fig. 12 and

$$\frac{C_0}{C_1}=3.17$$

is then shown in Fig. 14. As can be seen, the efficiency of conversion does not drop below 6 decibles or 25 per cent from 2400 cycles to 6000 cycles.

By separating the resonance of the electrical coil with crystal capacity from the mechanical resonance, a somewhat wider band can be obtained as shown by the dotted line graph of Fig. 14 at some sacrifice of efficiency of conversion. It can be shown that the best efficiency will be obtained by letting the right-hand terms of Equation 21 vanish when $\omega^2=\omega_A\omega_B$ is the resonance of the coil and condenser, and ω_B the mechanical resonance of the crystal and added mass. This results in the relation

$$R_AR_B=\frac{1}{\omega_A\omega_BC_1C_0}=\frac{r}{\omega_A\omega_BC_0^2} \tag{23}$$

where r is the ratio of capacitances

$$\frac{C_0}{C_1}$$

For this case the expression for the efficiency becomes

$$\frac{i_2}{i_T}=\frac{2\sqrt{R_AR_B}}{\sqrt{\left[R_A\left[1-\left(1-\frac{\omega^2}{\omega_B{}^2}\right)\left(\frac{\omega_A{}^2}{\omega^2}-1\right)\frac{C_0}{C_1}\right]+R_B\right]^2+\left[\frac{1}{\omega C_1}\left[\left(1-\frac{\omega^2}{\omega_B{}^2}\right)+\frac{\omega_A}{\omega_B}\left(1-\frac{\omega^2}{\omega_A{}^2}\right)\right]\right]^2}} \tag{24}$$

As an example, let us take $f_A=1000$ cycles, $f_B=4000$ cycles. At the mean frequency of 2000 cycles, R_B the radiation resistance for a crystal 1 centimeter wide is

$$R_B=1.72\times10^5 \text{ electrical ohms} \tag{25}$$

Using the same constants as in the example considered above, the best amplifier impedance is

$$R_A=2.07\times10^6 \text{ electrical ohms per centimeter width of crystal} \tag{26}$$

With these values, and taking R_B from the curve of Fig. 12 the efficiencies of conversion in decibels below perfect efficiency of conversion are shown by the dotted line of Fig. 14. From 700 cycles to 6500 cycles an efficiency of conversion averaging around 10 per cent is obtained with a variation of about ±4 decibels over this region. On account of the large area and relatively high efficiency of conversion such a device would provide a more efficient listening device than has previously been obtained for his frequency range. To work down to 700 cycles a device about 105 centimeters or 3.5 feet long would be required. This would have a receiving area of 630 square centimeters and would be able to deliver 5×10^{-7} watts electrical power to a receiver when a pressure of 100 dynes per square centimeter was acting on it. Since a telephone receiver has a minimum power of about 4×10^{-14} watts to reach audibility, this would represent enough power to operate the receiver without the need of an amplifier. For such a hydrophone, the static capacity of the crystals would be 25000 $\mu\mu f$, so the additional capacity put on by a cable would be small, and could be neglected. The electrical impedance of an amplifier or receiver to work with the unit should be about 20000 ohms.

Use of low frequency projector in a prism type detection system

In order to make full use of the lower attenuation and refractivity of the lower frequency range, a radiator sufficiently large to obtain a good directivity may be used. Such a radiator is too large to turn manually. If, however, it is used in the form of a thin skin attached to the hull of a ship, and the change in direction is obtained by prism methods, the device becomes practical.

As an example let us consider what can be done with a radiator working from 2.75 kilocycles to 6 kilocycles, as calculated previously. To get the same directivity as at ultrasonic frequencies will require a radiator 6 wave-lengths long which at the mean frequency of 4000 cycles will be a length of 225 centimeters or 7.4 feet. If we divide this up into long radiators which are .4 of a wave-length apart at the top frequency of 6000 cycles, this requires twenty-two strips each 10 centimeters wide. The length of the strips is determined by the directivity in a vertical plane. A length of three feet would concentrate most of the power in an angle ±15 degrees from the horizontal. Such a blanket radiator 7.4 feet long, three feet wide and approximately 1.5 inches thick could be attached to the hull on each side of the ship as shown in Fig. 8. On account of the smooth surface, streamlining is obtained and a freedom from turbulent noise. Leads from each radiator connect to a filter or phase shifting network as shown in Fig. 9 for a listening system. On account of the low power carrying capacity of coils and condensers used in filters or phase shifting networks it is desirable to place a power amplifier between each radiator and the filter as shown in Fig. 10. By adjusting the gain of each amplifier it is possible to compensate for the loss in filter or phase shifting network and moreover secondary lobes can be suppressed by driving the middle segments harder than the outer segments. Since amplifiers are one-way devices it is necessary to have the input connected to the phase shifter and the output connected to the radiator when a pulse is sent and reversed when a listening condition is desired. If the input and output impedances of the amplifier are made the same, this can be accomplished by a simple switching arrangement as shown in Fig. 11.

Even if the power radiated by each unit is kept down to the 0.1 watt per square centimeter radiated from other 45-degree X-cut Rochelle salt crystals, the power radiated from each strip will be 150 watts. For all twenty-two strips the total power would be 3.3 kilowatts which is considerably more acoustic energy that has been radiated from ultrasonic projectors. This coupled with the lower attenuation and lower refractivity realizable at the lower frequencies, and the freedom from noise due to streamlining indicates that submarines could be located at farther distances and under more exacting conditions for the low frequency radiator than for the ultrasonic radiator. Such a system also has the advantage that on account of the lower frequency the direction of a pulse sent out from the searching ship will not be as easily located by a submarine.

What is claimed is:

1. A sonic device for use as a submarine projector or hydrophone consisting of a blanket-like array of vertical and horizontal rows of coordinately arranged piezoelectric crystals for placement on the external surface of the hull of a ship, said crystals of each vertical row constituting a unit, an electrical network for connecting said array of crystals to transmitting and re-

ceiving apparatus, said network including phase shifting circuits, each said unit being electrically separated from other of said units by said phase shifting circuits, and each said crystal comprising a bimorph structure constructed and arranged to respond to frequencies within the audible range.

2. A sonic device for use as a submarine projector or hydrophone consisting of a blanket-like array of vertical and horizontal rows of coordinately arranged piezoelectric crystals for placement on the external surface of the hull of a ship, said crystals of each vertical row being connected in multiple, housed in a single container and constituting a unit, an electrical network for connecting said array of crystals to transmitting and receiving apparatus, said network including phase shifting circuits, each said unit being electrically separated from other of said units by said phase shifting circuits whereby a prismatic effect is secured, an amplifier for each said unit, the gains of the amplifiers being higher for the middle units and lower for the end units whereby secondary lobes are suppressed, and each said crystal comprising a bimorph structure constructed and arranged to respond to frequencies within the audible range.

3. A sonic device for use as a submarine projector or hydrophone consisting of a blanket-like array of vertical and horizontal rows of coordinately arranged piezoelectric crystals for placement on the external surface of the hull of a ship, said crystals of each vertical row being connected in multiple, housed in a single container and constituting a unit, an electrical network for connecting said array of crystals to transmitting and receiving apparatus, said network including phase shifting circuits, each said unit being electrically separated from other of

said units by said phase shifting circuits whereby a prismatic effect is secured, an amplifier for each said unit, the gains of the amplifiers being higher for the middle units and lower for the end units whereby secondary lobes are suppressed, means for directively pointing said amplifiers in accordance with the direction of use of said device, and each said crystal comprising a bimorph structure constructed and arranged to respond to frequencies within the audible range.

4. A sonic device for use as a submarine projector or hydrophone consisting of a blanket-like array of piezoelectric crystals in vertical and horizontal rows, the crystals of each vertical row being connected in multiple and acting as a unit, an electrical line including a series of phase shifting networks with a connection to each said vertical row of crystals made to a point in said line between succeeding networks, whereby different frequency currents connected to said line will cause correspondingly different frequency signals to be transmitted in correspondingly different directions or whereby incoming signals may be received from correspondingly different directions in accordance with their frequency.

5. A submarine projector or hydrophone consisting of a plurality of bimorph crystals responsive to frequencies within the audible range, means coordinately arranging said crystals in a sheet of vertical and horizontal rows, means whereby the crystals in each vertical row are connected in parallel and comprise a unit, means whereby the various units are connected to a transmission line and phase shifting networks interposed in said line electrically between each of said units to produce a prismatic effect.

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