

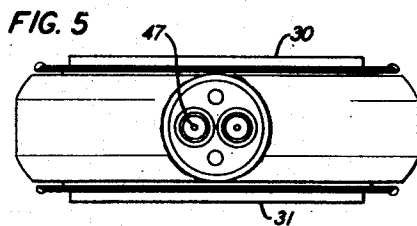
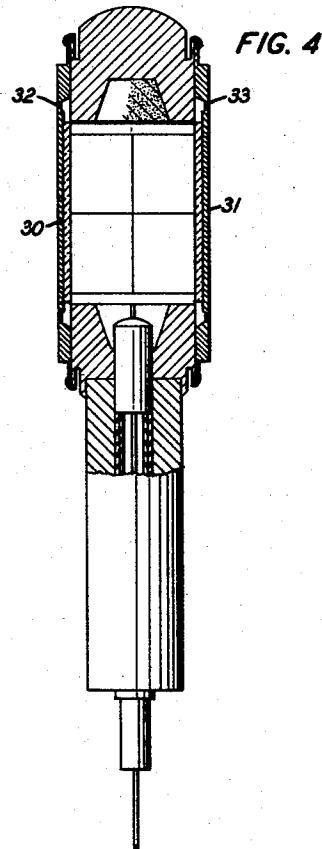
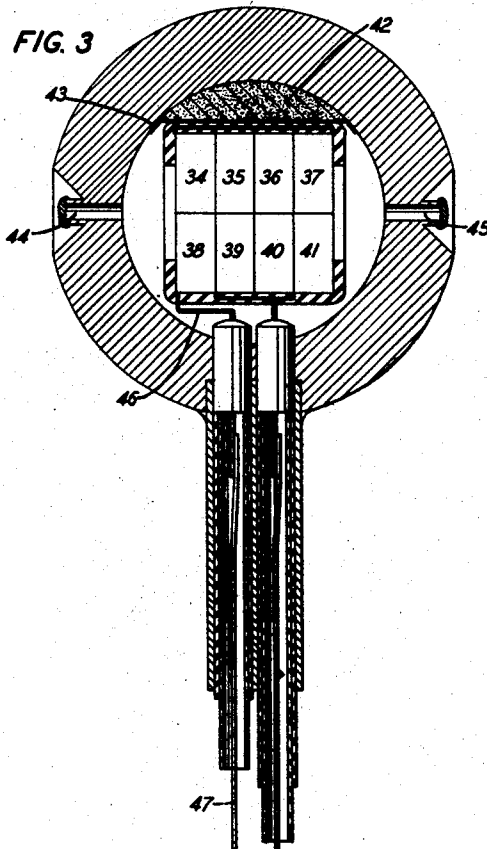
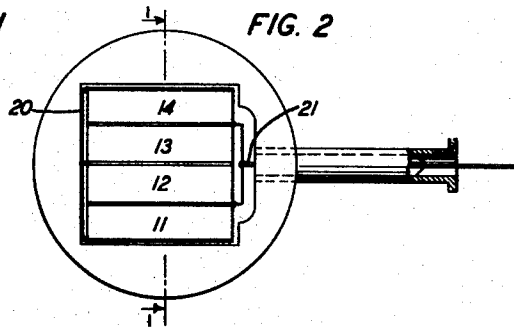
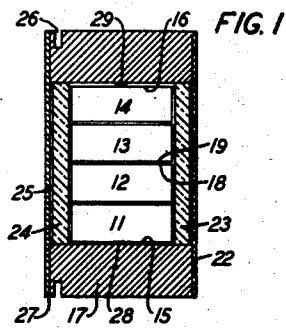
Dec. 30, 1947.

W. P. MASON ET AL

2,433,383

CRYSTAL MICROPHONE

Filed June 24, 1942



INVENTORS **W. P. MASON**
H. J. MCSKIMIN
BY *G. H. Neidt.*
ATTORNEY

UNITED STATES PATENT OFFICE

2,433,383

CRYSTAL MICROPHONE

Warren P. Mason, West Orange, and Herbert J. McSkimin, Lyndhurst, N. J., assignors to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application June 24, 1942, Serial No. 448,230

6 Claims. (Cl. 177-386)

1

This invention relates to microphones and particularly to piezoelectric crystal microphones for submarine signaling applications.

The object of the invention is a device of this type which is capable of efficient response over a wide range of audio and supersonic frequencies.

Ideally, such a device to be efficient should have a high ratio of generated voltage to applied pressure, a high ratio of static to distributed stray capacity and a static crystal capacity which is large as compared with the input capacity of the associated amplifier. In general, this would require a crystal unit of large dimensions. However, in order to have a uniform response, the resonant frequency of the crystal must be outside the operating range and yet none of its dimensions should be much larger than the half wavelength in water of the highest frequency of interest. At 50,000 cycles per second the half wavelength dimension is only 1.5 centimeters so that a microphone which must respond uniformly up to frequencies of this order is necessarily quite small.

The design of these devices is further complicated by the fact that only one pair of opposed crystal faces must be subjected to hydrostatic pressure variations, since any pressures applied to other faces of the crystal reduce the generated output voltage. In certain prior microphones of this general type the crystal is disposed within a protective housing with opposed faces of the crystal secured to diaphragms which seal opposite sides of the housing. It is found, however, that under alternating pressure conditions a crystal totally enclosed in this manner is nevertheless sensitive to pressure variations in one or more modes in addition to those normal to the diaphragms.

According to this invention a large ratio of voltage to pressure is obtained by means of Rochelle salt crystals which are used in the longitudinal manner in order to obtain the high resonant frequency required for supersonic applications. A plurality of small crystals used in parallel provide a unit which gives a higher generated voltage and has a larger crystal capacity than a single crystal of the same dimensions thereby avoiding excessive losses in coupling the device to an amplifier and at the same time keeping the over-all dimen-

2

sions small as required for operation over a very wide frequency range.

In the preferred structure according to the invention, the crystals are 45-degree Y cut to obtain the highest ratio of voltage to pressure. A thin, porous ceramic piece is interposed between the crystal assembly and each diaphragm and each ceramic piece is secured to the crystals and to the diaphragm by a layer of cement which has a high modulus of elasticity under compression and a very low modulus in shear. The layer of ceramic material greatly reduces the stray capacity between the crystal assembly and the enclosing housing and the layers of cement give good transmission of pressures to the crystals in the desired mode and at the same time dampen out any lateral vibrations which would set up undesirable strains in the crystal.

A further important feature of the invention consists in proportioning the dimensions of the crystal units and assembly to give maximum voltage for pressures applied longitudinally and minimum voltage for pressures applied laterally thereby further increasing the efficiency of the microphone and reducing any tendency for it to respond to vibrations of the casing.

While the crystals may be either 45-degree X cut or 45-degree Y cut, the latter type has been found to be slightly more efficient and to have the further advantage of less variation in capacity over extreme ranges of temperature.

These and other features of the invention will be more clearly understood from the following detailed description and the accompanying drawing, in which:

Fig. 1 is a cross section of a microphone according to the invention;

Fig. 2 is a plan view of the microphone;

Fig. 3 is a plan of a modified form of the invention; and

Figs. 4 and 5 are sectional and side views, respectively, of the microphone of Fig. 3.

The bimorph types of crystal, which are used extensively for audio frequency applications, resonate at comparatively low frequencies and are therefore not suited for devices which must give uniform response up to frequencies of the order of 50 kilocycles. Very high resonant frequencies are readily obtained, however, with a longitudinally vibrating crystal which may be of

either the 45-degree X cut or 45-degree Y cut types.

The theoretical sensitivity of microphones using crystals of these types may be calculated as follows:

In "The location of hysteresis phenomena in Rochelle salt crystals," Physical Review, vol. 58, No. 8, October 15, 1940, it has been shown that the voltage generated on open circuit for a 45-degree X cut Rochelle salt crystal is in electrostatic units

$$E = \frac{f_{14} l y_y}{2c_{44}s_{22}} \quad (1)$$

where

f_{14} =piezoelectric modulus for Rochelle salt= 7.2×10^4 for X cut

l =thickness of crystal in centimeters

c_{44} =shearing modulus around X axis= 12.52×10^{10}

s_{22} =inverse of Young's modulus along the direction of vibration

y_y =strain along length of crystal

$$\text{Since } y_y = p s_{22} \quad (2)$$

where

p is the pressure this reduces to

$$E = \frac{f_{14} l p}{2c_{44}} \quad (3)$$

Since one electrostatic unit of voltage is 300 volts, the numerical ratio of volts to bars pressure becomes

$$\frac{E}{p} = .865 \times 10^{-4} l, \text{ volts per bar} \quad (4)$$

For the 45-degree Y cut crystal the equation equivalent to (3) becomes

$$E = \frac{f_{25} l p}{2c_{55}} \quad (5)$$

where

f_{25} =piezoelectric modulus for Y cut= 45.17×10^4

c_{55} =shearing modulus around Y axis= 3.04×10^{10}

Hence

$$\frac{E}{p} = 2.54 \times 10^{-4} l, \text{ volts per bar} \quad (6)$$

From Equations 4 and 6 it is seen that on open circuit the 45-degree Y cut crystal will generate nearly three times the voltage of a 45-degree X cut crystal of the same thickness.

Applicants have also discovered that the magnitude of the voltage generated by a longitudinally vibrating crystal varies with the ratio of width to length and that for maximum voltage this ratio should be about 1.5 or at least lie within the range of 1.75 to 1.25.

A very good compromise between the various requirements outlined above in the case of a microphone for use in water up to about 50,000 cycles per second is obtained by using individual crystals 1.6 centimeters wide, 1.0 centimeter long and .4 centimeter thick. The width dimension (parallel to the planes of the diaphragms) is limited by the wave-length of the highest frequency to which the device is to respond, the length must be limited to about 1 centimeter to keep the resonant frequency high enough when operating in contact with the added mass of the water and the total thickness must be limited to keep the device non-directional in its response. Four such crystals in parallel give a useful capacity of about 15

micromicrofarad if 45-degree Y cut and about 210 micromicrofarad if 45-degree X cut.

For crystals of these dimensions

$$\frac{E}{p} = (45\text{-degree X cut}) = .346 \times 10^{-4} \text{ volts per bar} = -89.5 \text{ decibels below 1 volt per bar}$$

$$\frac{E}{p} = (45\text{-degree Y cut}) = 1.015 \times 10^{-4} \text{ volts per bar} = -80 \text{ decibels below 1 volt per bar}$$

On open circuit both of these voltages will be independent of temperature for low frequencies since the piezoelectric moduli do not vary with temperature.

In an actual microphone the efficiencies given above are reduced by the effects of the distributed capacity of the structure and the wiring necessary for connecting it to an amplifier and a further loss occurs when the wiring is connected to an amplifier.

In the structure of Fig. 1 the insertion of the ceramic pieces between the 45-degree Y cut crystals and the diaphragms reduced the distributed capacity from about 37 micromicrofarad to about 10 micromicrofarad, thereby reducing the loss in efficiency due to this capacity from 11 decibels to about 5 decibels. For a microphone with a 45-degree X cut crystal and the same distributed capacity the loss is only 0.5 decibel. The net open circuit efficiencies are therefore -90 decibels for the 45-degree X cut and -85 decibels for the 45-degree Y cut crystal.

For an amplifier with an input capacitance of only 15 micromicrofarad, which can be realized, the coupling losses are 0.7 and 4.0 decibels, giving final efficiencies of -90.7 and -89 decibel for the X cut and Y cut crystals, respectively. It is therefore seen that the Y cut crystal is 1.7 decibels more efficient than the X cut type. Another reason for preferring the Y cut crystal is that, as pointed out in the article, "Dynamic measurement of Rochelle salt" in the Physical Review for April 1939, the dielectric capacity of a Y cut crystal moreover is not affected by temperature changes whereas the capacity of an X cut crystal may vary sufficiently over an extreme range of temperatures to produce a decibel or more change in the efficiency of a microphone using such a crystal.

In the structure shown in Fig. 1, the four crystals 11, 12, 13, 14 are plated with platinum rhodium .00017 inch thick and disposed with the low potential faces 15 and 16 adjacent the brass casing 17. The middle faces 18, 19 and the two outside faces are connected together with a copper wire 20 and grounded to the casing. The other two pairs of positive faces are connected together and to the lead wire 21 as shown.

In assembling the device the diaphragm 22 which may be of one mil Phosphor bronze is first soldered to the casing and the ceramic pieces 23 and 24 are then cemented to the crystals. The other diaphragm 25 is cemented to one of the ceramic pieces and the other ceramic piece is cemented to the diaphragm 22 which is already in place. In the final operation of soldering the diaphragm 25 to the casing great care must be taken to prevent the whole casing from heating up and destroying the crystals. It has been found that this operation may be performed satisfactorily if the casing is provided with a groove 26, which forms a thin lip 27 to which the diaphragm is soldered, and a heavy copper block is placed against each main face to conduct the heat away

and thereby confine the high temperature to the area immediately adjacent the lip.

The ceramic pieces are about .040 inch thick and are preferably porous to improve the bond provided by the cement. The cement when dry should have a very rubbery consistency such as is obtained by using a cement consisting of a solution of cyclized rubber. Since the layers of cement are to act as the stiffness elements of a mechanical filter for preventing the transmission to the crystals of vibrations which would stress them in other than the longitudinal mode, the thickness of cement required will depend upon various factors, such as the magnitude of the associated masses. In the present structure, however, very good results are obtained with a layer of cement only .0005 inch thick. If in a given case the mass of the crystal assembly and the ceramic pieces resonates with the stiffness of the thin diaphragms this resonance may be eliminated by cementing the sides of the crystal assembly directly to the walls of the casing as indicated at 28 and 29 of Fig. 1.

In the modification shown in Figs. 3 to 5 more nearly uniform motion over the portions of the diaphragms 30, 31 which are in contact with the crystals is obtained by making the center sections relatively thick and providing the necessary resiliency by means of the annular grooves 32 and 33. In cases where the width crystal dimension of the previous structure proves excessive, this may be reduced by using eight crystals 34 to 41 instead of four each being one-half the width of the crystals of Fig. 2 as shown. This subdivision of the crystals is purely mechanical and the electrical connections to the crystals are the same as before except that in this case the negative conductor 46 is brought through a separate lead 47 instead of using the casing of the positive lead as a conductor as in Fig. 2. In accordance with known practice, a quantity of dehydrated Rochelle salt may be sealed within the casing to maintain the crystals in proper working condition. For this purpose a recess 42 may be provided in the casing and the salt retained therein by means of a silk membrane 43. Vents 44 and 45 in the casing are convenient for circulating air through the device to dry the cement and for testing the seal at the periphery of the diaphragms.

What is claimed is:

1. A vibration translating device comprising a casing, metal diaphragms on opposite sides of the casing, and a plurality of Rochelle salt crystals connected in parallel and secured between the diaphragms for vibration in a longitudinal mode, each crystal having a width parallel to the diaphragms which is between 1.25 and 1.75 times its length normal to the diaphragms to give maximum voltage for longitudinally applied pressures and minimum voltage for laterally applied pressures.

2. A vibration translating device comprising a casing, diaphragms on opposite sides of the casing, and a plurality of Rochelle salt crystal elements connected in parallel and disposed between the diaphragms, said elements being cut for vibration in a longitudinal mode normal to the planes of the diaphragms and having their lengths normal to the diaphragms and widths parallel to the diaphragms proportioned to give a maximum response for longitudinally applied pressure and minimum response for laterally applied pressure.

3. A device according to claim 1 having diaphragms of low stiffness, porous insulating spacers between the crystals and the diaphragms to reduce the distributed capacity of the device, and means for securing the crystals to the casing to prevent the mass of the crystals and spacers from resonating with the stiffness of the diaphragms.

4. A device according to claim 1 in which the casing has a deep groove forming a thin lip to which one of the diaphragms may be soldered without subjecting the crystals to an excessive rise in temperature.

5. A vibration translating device for submarine signaling over a wide frequency range including supersonic frequencies comprising a casing, two diaphragms on opposite sides of the casing, a plurality of piezoelectric Rochelle salt crystals cut for vibration in a longitudinal mode and having a length dimension short enough to keep its resonant frequency above the frequency range of interest and a width dimension short enough to keep the device substantially non-directional at the upper limit of the range, said crystals being electrically connected in parallel and mechanically secured together to form within the casing a longitudinally subdivided crystal assembly having a total thickness small enough to keep the response non-directional at the upper limit of the range, porous ceramic spacers interposed between the ends of the assembly and the diaphragms to reduce the distributed capacity between the assembly and the casing and layers of cement joining the spacers to the diaphragms and to the ends of the assembly and forming therebetween connecting elements of relatively low stiffness in shear for preventing the stressing of the crystals in a lateral mode.

6. A vibration translating device comprising a casing, metal diaphragms on opposite sides of the casing, a 45-degree Y cut Rochelle salt crystal disposed between the diaphragms with its X and Z axes parallel to the planes of the diaphragms for generating a voltage in accordance with pressures normal to the diaphragms, a spacer of porous ceramic material between the ends of the crystal and each diaphragm for reducing the capacity between the crystal and the casing and a layer of material having a relatively high modulus of elasticity under compression and a relatively low modulus in shear interposed between each diaphragm and the crystal for transmitting to the crystal pressures normal to the diaphragms and for reducing the response of the crystal to lateral vibrations.

WARREN P. MASON,
HERBERT J. McSKIMIN.

REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
2,233,992	Wyckoff	Mar. 4, 1941
2,138,036	Kunze	Nov. 29, 1938
1,802,781	Sawyer et al.	Apr. 28, 1931
2,147,712	Mason	Feb. 21, 1939

FOREIGN PATENTS

Number	Country	Date
613,799	France	Sept. 4, 1926