

Aug. 16, 1938.

S. C. HIGHT

2,126,886

ACOUSTIC RECTIFYING DEVICE

Filed Aug. 1, 1935

2 Sheets-Sheet 1

FIG. 1

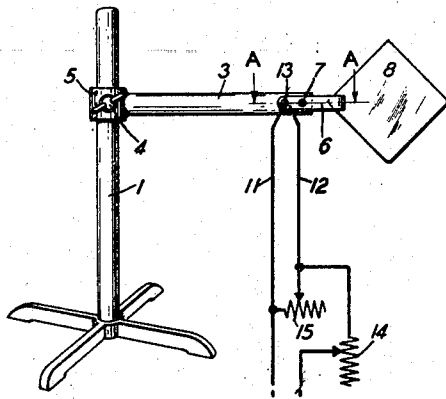


FIG. 2

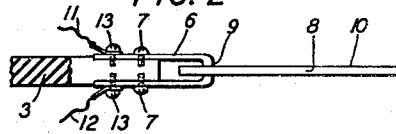


FIG. 4

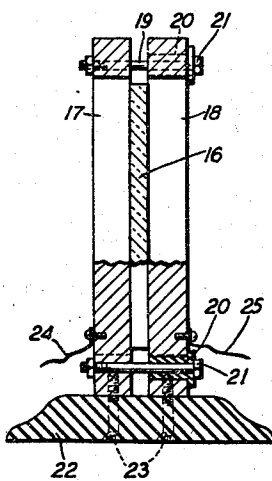
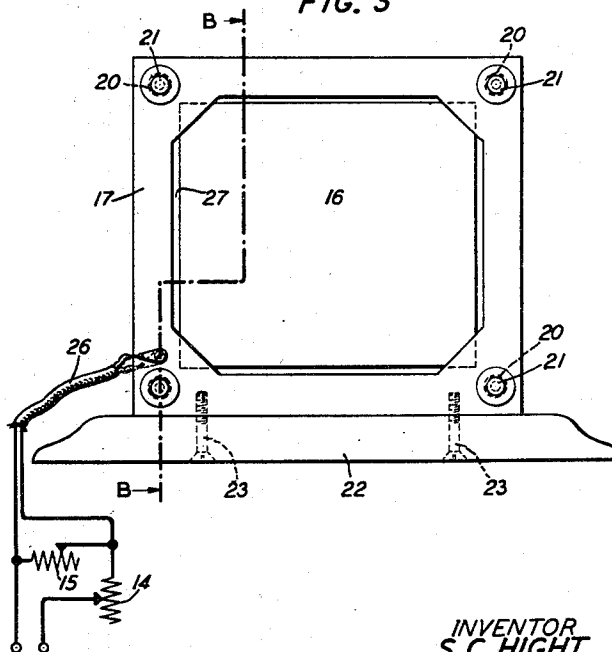


FIG. 3



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FIG. 5

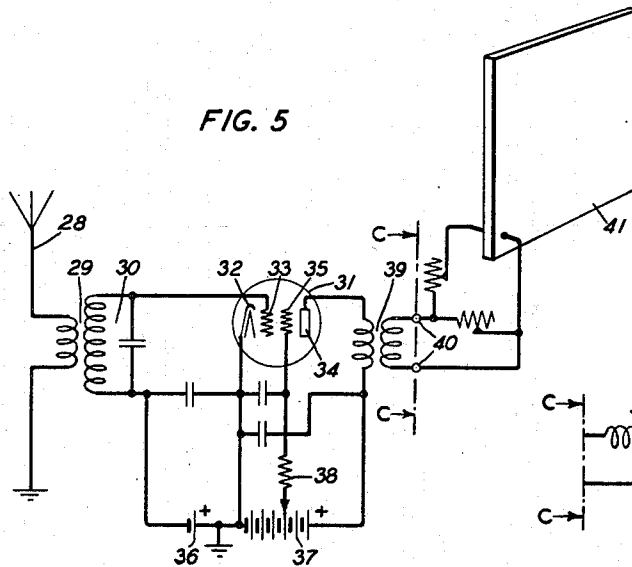


FIG. 7

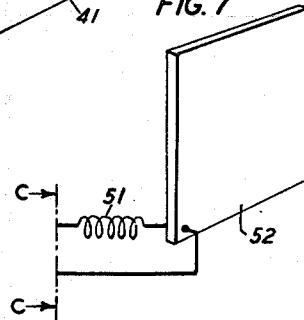
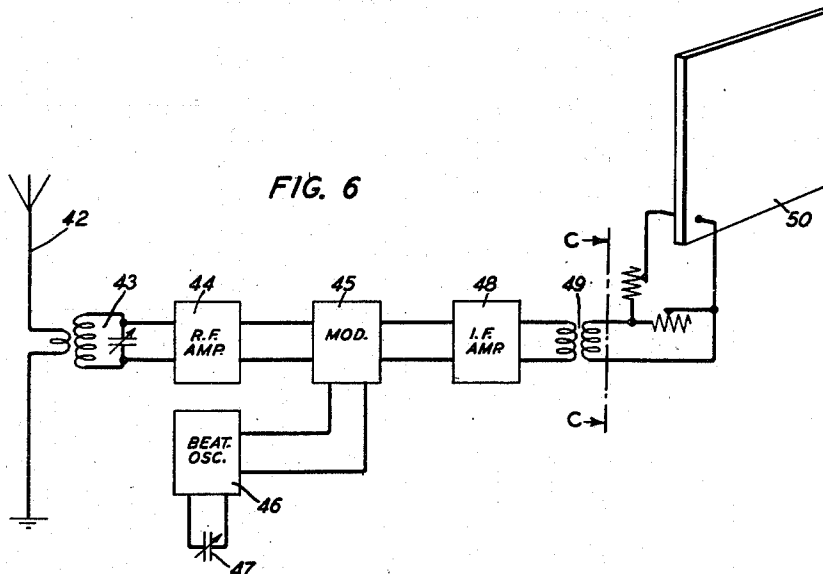


FIG. 6



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## UNITED STATES PATENT OFFICE

2,126,886

## ACOUSTIC RECTIFYING DEVICE

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Application August 1, 1935, Serial No. 34,122

9 Claims. (Cl. 250—21)

This invention relates to acoustic rectifying devices and more particularly to apparatus for translating modulated high frequency electrical waves into low frequency sound waves.

Radio telephony and carrier line telephony are ordinarily effected by imparting to a high frequency electrical carrier wave an amplitude or other type of modulation which corresponds to the simultaneously occurring wave form or intensity and frequency characteristics of a speech wave. After transmission to the remote receiving point the carrier wave may be demodulated to yield an audio frequency electrical current which represents the original speech modulating wave. This audio frequency current is then caused to actuate a telephone receiver or a loud-speaker to reproduce the speech sound waves.

According to the present invention a modulated electrical carrier wave is converted to a mechanical vibration having a corresponding carrier frequency and modulation and the modulated high frequency vibration, in effecting motion of the surrounding air, is rectified to reproduce sound waves in the air. Moreover, the conversion to high frequency vibrational energy and the rectification of the high frequency mechanical wave energy are simultaneously accomplished by a single instrumentality, viz., a piezoelectric plate which is capable of executing high frequency vibrations selectively in response to impressed high frequency electrical electromotive forces of the carrier frequency to which the plate is tuned and of impelling unidirectional currents of air having pulsations or intensity variations corresponding to the modulations or envelope of the high frequency electrical oscillations which excite the vibrations of the piezoelectric plate.

The various aspects and features of the invention may be readily understood upon consideration of the following description in connection with the accompanying drawings in which:

Fig. 1 illustrates a piezoelectric acoustic rectifying apparatus;

Fig. 2 a cross-section of a detail of Fig. 1 on line A—A;

Fig. 3 a modified form of acoustic rectifier;

Fig. 4 a section of Fig. 3 along line B—B;

Fig. 5 shows schematically an acoustic rectifier operating in a tuned radio frequency receiving circuit;

Fig. 6 is a similar diagram of a superheterodyne circuit employing an acoustic rectifier; and

Fig. 7 is a modification of that portion of Figs. 5 and 6 to the right of line C—C.

Referring to Fig. 1, a supporting standard 1 is provided with a laterally extending arm 3 of suitable insulating material as, for example, hard rubber slidably arranged on the upright member of standard 1 and fixed in position thereon by means of set screw 4 extending through the

sleeve extension 5 of member 3. A pair of resilient clips 6 of copper or other conducting material are attached at its opposite sides to member 3 by screws 7 in such fashion as to clamp and correspondingly support a piezoelectric plate 8 between their outer end projections 9. The piezoelectric plate 8 may be of any suitable piezoelectric material. In a form of the apparatus which has been successfully employed it comprises a quartz plate having the curie or X cut so that its principal or large lateral faces are perpendicular to the electric axis of the crystalline material. The plate 8 carries on each of its principal faces a coating 10 of silver applied by the process used in making mirrors. In lieu of the silver coating a thin film of platinum or other metal may be applied by the process of sputtering or evaporation in a vacuum. If a coating of silver is used, it may be protected from deterioration by an additional platinum coating on the silver. These thin conducting metallic films or coatings are very light and flexible and, adhering to the crystal, move with the surface of the crystal in vibrating. In order to apply an electric field to the piezoelectric plate 8, conductors 11 and 12 are provided and terminate in electrical connections 13 on the spring clips 6 which are in contact at their outer ends with the conducting coatings 10 on the opposite faces of the plate 8. In the specific example to which reference has been made the plate was 3.8 centimeters square and 0.28 centimeters thick. An electric field applied to the plate in the direction of the thickness causes an extension or contraction along the direction of the thickness. If the field is alternating and of a frequency corresponding to the natural period of the plate, vibration of the plate takes place. For longitudinal waves in the direction of the thickness of the plate, mechanical resonance occurs at a definite ordinary room temperature at a frequency given by the formula

$$\text{frequency} = \frac{2.86 \times 10^6}{\text{thickness}}$$

where the frequency is given in cycles per second and the thickness in millimeters. The natural frequency of the plate 8 vibrating in this manner and given a thickness of 2.86 millimeters is accordingly approximately one million cycles per second.

When the plate 8 is vibrating in the manner which has been described, the thickness of the plate is periodically varying, so that the principal plane surfaces are alternately moving apart and toward each other. The motion of each of these principal surfaces is analogous to that of a piston of very large area and very small stroke. Experimental measurement of the amplitude of the motion for the particular apparatus described indicated that each surface moved approximate-

ly  $8 \times 10^{-5}$  centimeters. From the area of the plate and the amplitude of the motion, it may be readily calculated that each stroke of the surface considered as a piston displaces approximately one cubic millimeter of air. At a million strokes per second, the total displacement, if accumulative, would be considerably more than a liter displacement each second for each surface of the vibrating plate. The earth's atmosphere approximates a mixture of gas including about 77 per cent of nitrogen and 21 per cent of oxygen with a residuum of other gases. The effective molecular diameters of the two principal gases are respectively 3.39 Angstrom units for oxygen and 3.5 Angstrom units for nitrogen. The mean free path of nitrogen may be approximately 900 Angstrom units and for oxygen approximately 1,000 Angstrom units. With an amplitude of motion of  $8 \times 10^{-5}$  centimeters or 8,000 Angstrom units for the surface of the plate 8 and conceiving the atmosphere as made up of layers of molecules with a spacing between layers of the order of 1,000 Angstrom units, it will be apparent that a surface of the plate 8 at each outward stroke sweeps through a space equivalent to ten layers of molecules and impels these molecules outwardly. During the outward stroke of the crystal surface the random motion of gas molecules in the vicinity of the surface is given a direction normal to the surface and at the completion of the stroke most of the molecules immediately adjacent to the surface have their momentum directed away from that surface. The motion of the gas molecules around the periphery of the plate 8 is still random, hence, when the surface of the crystal moves rapidly inward there is a tendency for the molecules of the random motion type to enter the space through which the vibrating surface has receded. In actual practice, it is found that the air moves inward toward the edges of the piezoelectric slab and is forced outward from each of the large vibrating surfaces in a stream perpendicular to that surface. Moreover, as the amplitude of vibration of the piezoelectric surface corresponds to the amplitude of the impressed high frequency electromotive force by which the vibrations are excited, the vibrations will increase in magnitude with increase in the amplitude of the impressed electrical oscillations and will correspondingly decrease with decrease of the impressed oscillations. The result is that the air impelled outwardly from a vibrating surface of the plate 8 will carry amplitude pulsations corresponding to the modulations of the impressed electrical oscillations. If these modulations correspond to speech waves, the resulting pulsations in the unidirectional air current proceeding from the surface of the plate 8 will, likewise, correspond to speech waves or, in other words, will be sound waves corresponding to the speech modulations. Accordingly, the plate 8 operates to transform the energy of high frequency electrical oscillations into corresponding high frequency mechanical vibrations and, at the same time, to effectively rectify these mechanical vibrations in their effect in imparting motion to the adjacent air.

For the manifestation of acoustical rectification it is not necessary that the lateral dimensions be large compared to the thickness. For low frequencies, as for example, below 500 kilocycles, it may not be convenient to obtain such large ratios of dimensions because the thickness is large and the size of crystal plates available is

limited. It is desirable, however, to have as large an area as possible for the reason that greater sound energy will be produced. In the event that more sound energy is desired than can be obtained from one piezoelectric plate several such plates may be operated in parallel. In general, this would necessitate the use of a more powerful amplifier to supply the increased energy.

As is well known, the mechanical resonance characteristic of a vibrating piezoelectric plate is such that the device is highly selective. Accordingly, in order to operate the apparatus most effectively the impressed electrical oscillations must correspond to the natural frequency of the piezoelectric device. Where the frequency of the modulating wave is relatively low the selective characteristic of the piezoelectric device may transmit the resulting side-bands effectively. If, on the contrary, modulating waves have effective frequencies extending over a considerable band as in the case of speech or music, the apparatus will discriminate against the side-band frequencies representing the higher frequency elements of the speech or music and the resulting sound wave will be correspondingly distorted. In order to prevent or minimize such distortion the selective characteristic of the piezoelectric apparatus may be effectively broadened by the introduction of either mechanical damping or electrical damping or both. In the apparatus of Fig. 1, some degree of mechanical damping may be introduced by the clamping effect of the spring clips 6 and the relative positioning of the gripping surface of these clips with respect to the periphery of the plate 8. Electrical damping may be introduced in conjunction with the mechanical damping by means of variable series resistance 14 and shunt resistance 15. In actual practice in connection with the apparatus of Fig. 1, series resistance 14 may be of the order of 500 to 5,000 ohms. The shunt resistance 15 may be of the order of 1,000 ohms and in general of a magnitude lower than 1,000 ohms.

Fig. 3 discloses a modified form of acoustic rectifier in which a piezoelectric plate 16 of rectangular form is clamped at its corners between metallic frame members 17 and 18 of suitable conducting material by means of bolts 19 extending through the members 17 and 18 and provided with insulating sleeves 20 and clamping nuts 21. Members 17 and 18 are supported in vertical position on a base member 22 of insulating material to which they are respectively connected by screws 23. Plate 16 is provided with conducting coatings similar to those described in connection with the plate 8 of Fig. 1 and electrical connection is established with the coatings through the adjacent frame members 17 and 18 to which are electrically connected the terminals 24 and 25 of cord 26. A suitable degree of mechanical damping may be introduced by proper design of the members 17 and 18 in accordance with the extent of the periphery of plate 16 which the frame members 17 and 18 engage. As in the apparatus of Fig. 1, the mechanical damping may be supplemented, if desired, by electrical damping introduced by resistance members 14 and 15.

It will be appreciated that in operation, air is drawn in laterally from beyond the periphery of plate 16 through the slot extending between members 17 and 18 and through the marginal space 27 between the periphery of plate 16 and the frame members. A certain amount of air will also be drawn in over the outside of the

frame members 17 and 18. The air is impelled outwardly from each side of the plate 16 in a direction perpendicular to the face of the plate.

Although, as has previously been explained, the frequency of the exciting electrical oscillation or the central frequency of the band of oscillations, if a band is impressed, should correspond to the resonance frequency of the piezoelectric element, the acoustic rectifying property is found to be nearly independent of the frequency of vibration. Apparatus employing suitable quartz plates has been used in different vibrating systems at various frequencies over a range extending from 50 kilocycles to 14 megacycles per second, it being understood that in each instance the apparatus was designed to be resonant at the carrier frequency of the impressed oscillations.

Although the devices described have comprised piezoelectric elements consisting of quartz other piezoelectric materials may be employed. In particular, at frequencies in the range lower than 50 kilocycles Rochelle salt may be employed. It should be remembered, however, that the orientation of the piezoelectric plate with respect to the crystalline material from which it is cut and the mode of excitation and the frequency of the impressed electrical oscillations should, in each instance, be such as to excite extensional or longitudinal oscillations in the thickness direction of the piezoelectric plate whereby the principal faces of the piezoelectric element are caused to alternately approach and recede from each other.

Referring to Fig. 5, a radio receiving system comprises the usual antenna 28, coupling transformer 29 and tuned circuit 30 tuned to the frequency of the waves to be received. Oscillations of the desired carrier frequency received by the antenna and impressed on the tuned circuit are amplified by the pentode amplifying device 31 having the usual cathode 32, control grid 33, anode 34 and screen grid 35. Control grid 33 is biased in well-known manner by the source 36. Anode 34 is connected to the positive terminal of source 37 to an intermediate point of which screen grid 35 is connected through a path including high resistance 38. The amplified oscillations are impressed by means of a transformer 39, the primary winding of which is included in the output circuit of the amplifying device 31 and the secondary circuit of which is connected to the terminals 40 of the acoustic rectifying device 41. The device 41 may be constructed in accordance with either Fig. 1 or with Fig. 3 as desired. In operation, modulated incoming carrier waves corresponding in carrier frequency to the frequency of the tuned circuit 30 and the resonance frequency of rectifying device 41 are received and after amplification by the amplifying device 31 are impressed upon the acoustic rectifier 41 to reproduce sound waves corresponding to the tone, speech, or music by which the incoming carrier wave is modulated. In this manner a high degree of selectivity is attained inasmuch as underside oscillations are discriminated against both by the tuned circuit 30 and by the acoustic rectifying device 41. The sharpness of response of the device 41 may be regulated as desired by suitable adjustment of the elements 14 and 15 as described in connection with the operation of the device of Figs. 1 and 3.

Fig. 6 discloses a superheterodyne receiving system in which an antenna 42 is coupled to the tuned circuit 43 of a radio frequency amplifier

44 from which amplified received modulated oscillations are impressed upon a modulator 45 together with locally produced oscillations from a beat frequency oscillation generator 46 in well-known fashion. The beat frequency oscillator is provided with a tuning device as, for example, variable condenser 47 so that the modulated intermediate frequency oscillations produced as a result of interaction of the incoming oscillations and the locally produced oscillations will fall within a band of frequencies for which intermediate frequency amplifier 48 is selective. Associated by means of a transformer 49 with the output circuit of intermediate frequency amplifier 48 is an acoustic rectifying device 50, the natural vibration frequency of which corresponds to the intermediate carrier frequency. It transpires that the natural selectivity of the acoustic rectifying device 50 supplements the selective characteristics of the intermediate frequency amplifier 48 in aiding to select the oscillations of the desired intermediate frequency from extraneous oscillations of other frequencies which may be present or be produced in the output circuit of the modulator 45. This circuit enables the use of piezoelectric apparatus of lower natural resonance frequencies. It also enables a particular acoustic rectifying device 50 to be used for a considerable range of incoming carrier frequency oscillations by virtue of the fact that the local oscillator frequency and the tuning of the input circuit 43 may be varied independently or simultaneously in accordance with the well-known superheterodyne practice to select any of a number of different frequency carrier waves. There is an additional advantage in the use of this circuit in that it enables the precise frequency of the intermediate frequency oscillations impressed upon the acoustic rectifier to be nicely controlled to accord with the natural mechanical resonance frequency of the acoustic rectifying device thus simplifying the design of the acoustic rectifier and permitting greater tolerance in its characteristics.

As is disclosed in U. S. Patent 1,921,035 granted August 8, 1933 to W. P. Mason the effect of the introduction of a series inductance in a path including a quartz piezoelectric crystal element is electrically to increase the separation between the resonance and anti-resonance points of the path. This effect has been investigated in the development of apparatus according to the present invention and it has been found that the band of frequencies at which the crystal will actually vibrate is materially increased by the insertion of the inductance. Fig. 7 shows such a circuit which may be substituted as indicated for the portion of the circuits of Fig. 5 and Fig. 6 to the right of line C—C or for the corresponding portions of the circuits of Figs. 1 and 3. In Fig. 7, inductance 51 is preferably given such a magnitude as to resonate with the simple electrostatic capacity between the electrodes of piezoelectric element 52 at a frequency equal to the anti-resonant frequency of the crystal. In the nomenclature of Figs. 2 and 3 of Mason Patent 1,921,035 the inductance 51 should have a reactance numerically equal to that of capacity  $C_0$  at frequency  $f_0$ . The width of the response band of the piezoelectric element can thus be made as great as 10 percent of the resonant frequency of the crystal. This method of broadening the band introduces less loss than the mechanical and electrical damping methods previously described.

What is claimed is:

1. A sound producing device comprising a flat plate of crystalline quartz having its thickness in the direction of an electrical axis of the virgin material, means for supporting the plate at its periphery to permit it to vibrate and to permit air to move in laterally from beyond its periphery, and means to cause the plate to vibrate in the direction of its thickness in accordance with modulated high frequency oscillations whereby air is impelled outwardly from the flat face of the plate to produce sounds corresponding to the modulations of the high frequency oscillations.

2. In combination, means for receiving ultra audible oscillations modulated in accordance with low frequency signals, means connected thereto for amplifying the energy of the received oscillations, and means associated with the amplifying means for directly producing audio frequency sound waves in the atmosphere from the amplified oscillations comprising a piezoelectric element in the form of a plate so oriented with respect to the virgin piezoelectric material as to execute vibrations in its thickness direction in the manner of a diaphragm in response to the applied amplified oscillations and having lateral dimensions which are large with respect to its thickness, the thickness of the piezoelectric plate being such that it is resonant for vibrations in its thickness direction at a frequency substantially that of the received ultra audible oscillations whereby the piezoelectric element serves to selectively respond to oscillations of the desired ultra audible frequency while discriminating against oscillations of other frequencies, to demodulate the oscillations to which it is responsive to produce oscillations of low frequencies corresponding to those of the signal with which it is modulated, and to produce sound waves corresponding to the demodulated low frequency signal oscillations.

3. A plate of piezoelectric material having principal faces with lateral dimensions of the order of at least ten times the thickness of the plate, the plate having such orientation with respect to the mother crystal that in response to an alternating electric field applied in its thickness direction the plate executes vibrations of longitudinal mode in its thickness direction, means for so mounting the plate as to support it for vibration while permitting ready ingress of air from the region beyond its periphery to the region of one of its faces and free egress of a stream of air from that face, and means for subjecting the plate to an alternating electrostatic field in the direction of its thickness.

4. A loud-speaking device comprising a plate of piezoelectric material of a thickness such as to make the plate resonant for thickness vibrations at an ultra audible frequency, a pair of electrodes associated with the opposite faces of the plate, terminals connected thereto whereby there may be impressed upon the electrodes an ultra audible frequency electromotive force of the resonance frequency of the plate and modulated in accordance with audible signals, means for mounting the plate to enable it to set up vibrations in the contiguous atmosphere corresponding to the complex motion which it undergoes when subjected to a modulated ultra audible frequency electromotive force and damping means associated with the plate for effectively

broadening its response in order to improve its transmission for the band of frequencies corresponding to the signal modulated sideband of the ultra audible electromotive force to which it is resonant.

5. The combination, according to claim 4, characterized in this that the damping means includes an electrical resistor electrically connected in circuit with the device.

6. The combination, according to claim 4, characterized in this that the damping means includes mechanical clamping elements constituting part of the supporting means for the piezoelectric plate whereby the damping of the plate may be predetermined.

7. In combination, a pair of metallic frame members, a plate of piezoelectric material having conductive coatings on its opposite faces, the plate having such a thickness as to be resonant for vibrations in its thickness direction at an ultra audible frequency, means for clamping said plate between the frame members to expose substantially the entire area of its principal faces to the surrounding atmosphere, an insulating base member on which said frame members are mounted, and means for applying an alternating electromotive force of the vibration frequency to which the plate is resonant between the frame members.

8. A piezoelectric loud-speaker comprising a plate of quartz having lateral dimensions of the order of four centimeters and having its thickness in the direction of an electric axis, the thickness of the plate being such as to make the plate resonant for vibrations in its thickness direction at an ultra audible frequency, means for supporting the plate to freely expose substantially the entire surface of a principal face thereof to the atmosphere, and means for causing said plate to execute vibrations in its thickness direction whereby said plate operates to produce speech sound waves in response to excitation by high frequency electrical oscillations of the ultra audible frequency to which it is resonant modulated in accordance with speech waves.

9. A system for reproducing sound waves comprising a piezoelectric crystal device and a circuit for impressing thereon electrical waves of different frequencies including an ultra audible frequency wave modulated by a band of low frequency waves, said piezoelectric device having two principal faces each possessing large enough superficial area facing in a principal direction of vibration to permit effective coupling with the atmosphere, conductive electrodes closely associated with the two principal faces respectively, said device having such thickness between the principal faces as to inherently respond selectively to the frequencies comprised in said modulated wave and to discriminate against neighboring frequencies, means for broadening the response of said device to include the sideband frequencies of the modulated wave impressed on the electrodes, said device producing directly from said modulated waves atmospheric vibrations corresponding in frequency and in wave form to the electrical oscillations impressed upon the electrodes and also of the audio frequencies corresponding to the band of low frequency waves with which said high frequency wave is modulated.

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