Jan. 11, 1949. H. F. FRUTH ET AL. 2,458,987

PIEZOELECTRIC CRYSTAL UNIT

Filed July 18, 1945 2 Sheets-Sheet 1

Fig. 1.

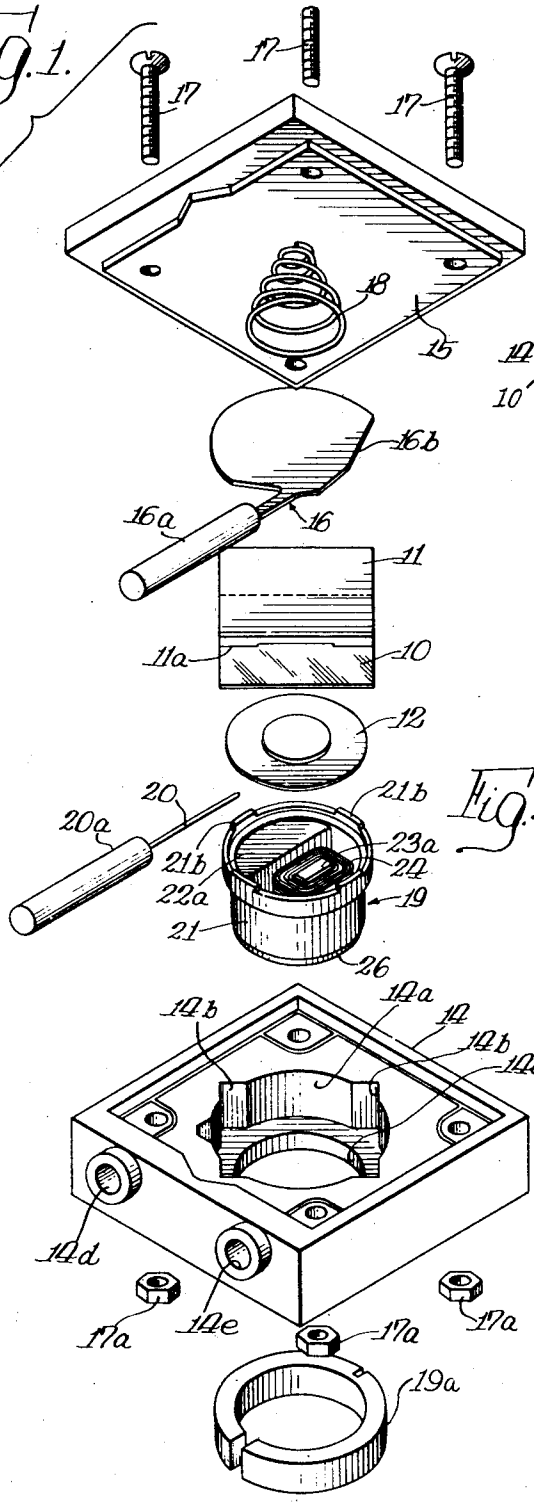


Fig. 2.

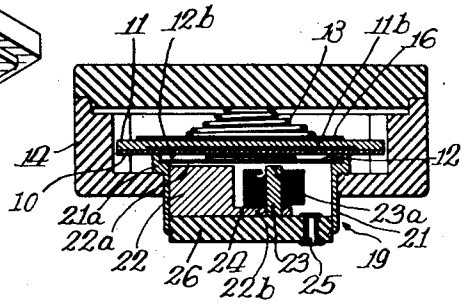
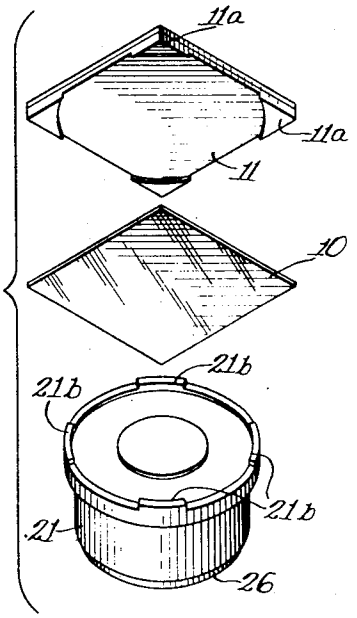


Fig. 3.



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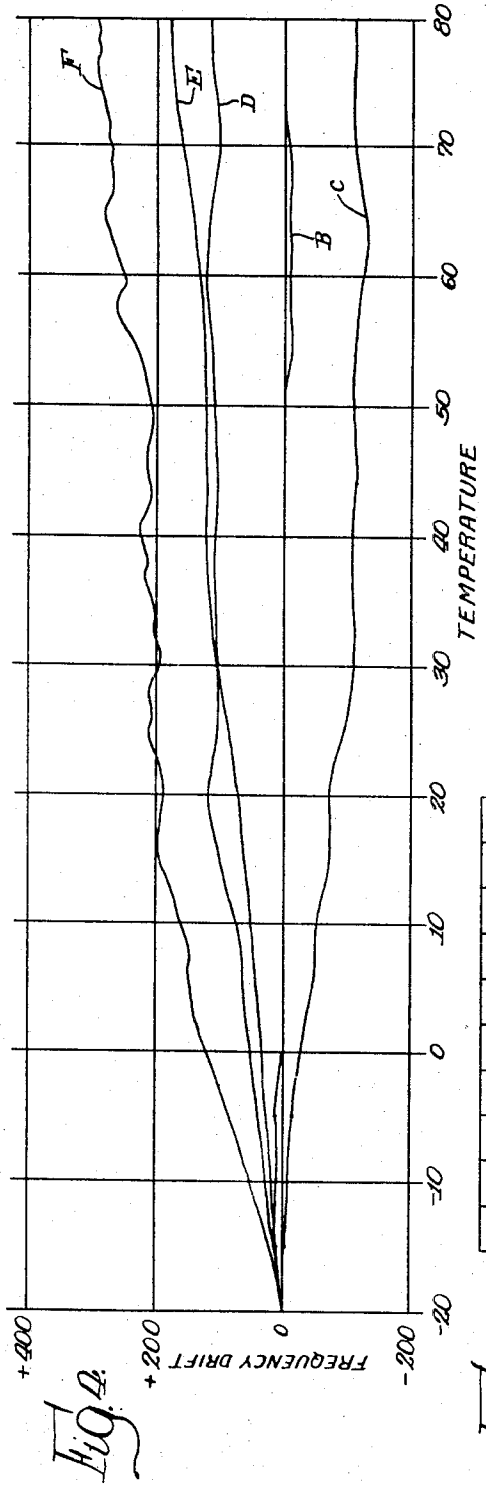


Fig. 4.

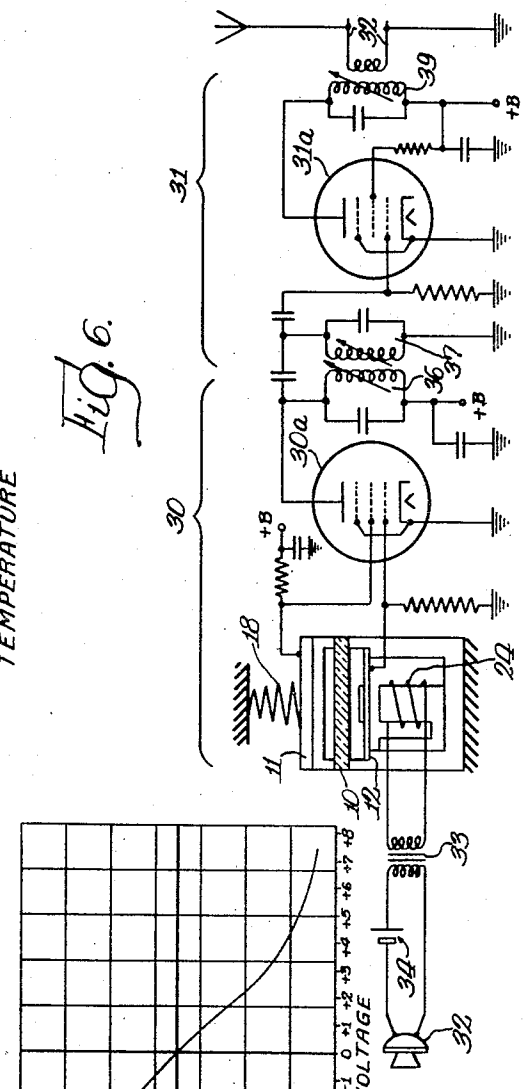


Fig. 6.

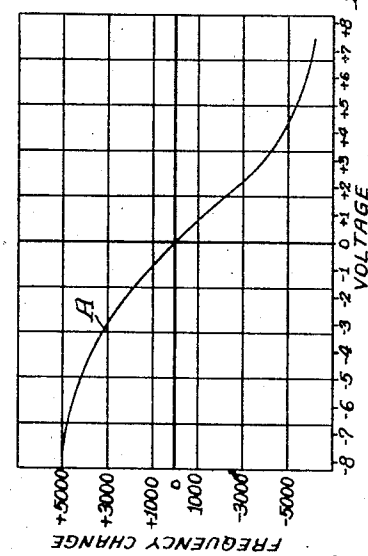


Fig. 5.

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PIEZOELECTRIC CRYSTAL UNIT

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Application July 18, 1945, Serial No. 605,762

13 Claims. (Cl. 171—327)

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The present invention relates to piezoelectric crystal units of the character employed for frequency control purposes in high frequency circuits and more particularly to an improved variable frequency piezoelectric crystal unit.

In certain applications, such, for example, as frequency modulation transmitters, it is necessary to vary the output frequency of an oscillator in accordance with an impressed signal or control voltage. Usually this is accomplished either by reactance tube control of a conventional tuned circuit oscillator or by providing separate modulator and crystal controlled oscillator stages and effecting the desired signal modulation of the oscillator output frequency in the modulator stage. Systems of the latter type, while possessing the frequency stability inherent in crystal controlled systems, are relatively costly due to the amount of apparatus involved. Systems of the first type are subject to objectionable and uncontrolled drift in the output center or carrier frequency of the signal modulated carrier.

It is an object of the present invention, therefore, to obviate the above difficulties by providing an improved piezoelectric crystal unit, the output frequency of which may be directly and accurately controlled in accordance with a variable voltage impressed thereon.

It is another object of the invention to provide an improved variable frequency piezoelectric crystal unit having an output frequency which is not appreciably affected by ambient temperature changes.

It is a further object of the invention to provide improved and exceedingly simple facilities for varying the output frequency of a piezoelectric crystal.

More generally, it is an object of the invention to provide a variable frequency piezoelectric crystal unit which is of small, rugged and low cost construction, and when combined with the usual circuit elements of a piezoelectric oscillator, will reliably function as an oscillator-modulator having great center frequency stability.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification taken in connection with the accompanying drawings, in which:

Fig. 1 is an explosion view illustrating the components of an improved variable frequency piezoelectric crystal unit characterized by the features of the present invention;

Fig. 2 is a side view in full section illustrating

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the unit when the parts thereof are completely assembled;

Fig. 3 is a top view in perspective of the diaphragm subassembly embodied in the unit;

Figs. 4 and 5 are graphs illustrating certain operating characteristics of the unit; and

Fig. 6 is a view schematically illustrating the unit as an oscillator-modulator in a frequency modulation wave transmission system.

Referring now to the drawings and more particularly to Figs. 1, 2 and 3 thereof, the present improved crystal unit is there illustrated as comprising a piezoelectric quartz crystal 10 of rectangular configuration and having a thickness determined by the particular frequency at which the crystal is designed to oscillate. In accordance with the present invention this crystal is clampingly supported between a thermally deformable bimetallic electrode 11, having the function of compensating the crystal output frequency against drift occasioned by ambient temperature changes, and a deformable magnetic diaphragm electrode 12 which is variably deformable under the control of electro-responsive means indicated generally at 19 to vary the output frequency of the crystal in accordance with an applied control or signal voltage. The electrode 11, together with the crystal 10 and the diaphragm driving unit 19, are adapted to be received within an open cavity 14a formed within an insulating housing member 14 which is preferably comprised of a suitable plastic or ceramic material. Along one edge thereof, this housing member is provided with a pair of holes 14d and 14e within which the connecting pins 16a and 20a of conductive terminals 16 and 20 are respectively disposed. Preferably these pins, which are adapted for mating engagement with the contacts of a suitable socket, are embedded or otherwise sealed into the openings 14d and 14e through which they respectively extend. At its inner end, the conductor 16 terminates in a flat plate 16b which is adapted to be pressed into engagement with the upper surface of the electrode 11. The wire extension of the conductor 20 is adapted for soldered connection with a conductive non-magnetic housing 21 which supports the parts of the diaphragm driving unit 19. This housing is of tubular configuration and is adapted to extend through an opening 14c formed in the bottom wall of the holder centrally of the cavity 14a. It is provided with a radially displaced rim portion 21a which seats against the bottom of the cavity 14a and carries an internal ledge seating the periphery of the diaphragm 12. Thus the

housing member 21 functions as a holder for the diaphragm 12. A split ring 19a clampingly embracing the housing member 21 externally of the housing 14 is employed to maintain the unit 19 assembled with the housing 14.

For the purpose of preventing relative rotary movement between the two elements 10 and 11 and the housing 14, the cylindrical cavity 14a is provided with corner receiving recesses 14b within which the corner portions of the two named elements are receivable. In order to displace the opposite faces of the crystal 10 from the electrode 11 and the diaphragm 12, the electrode 11 is provided with downwardly depending corner parts or feet 11a which bear against the corner portions of the upper crystal face, and the upper edge of the housing member 21 is cut away to form four equal angularly displaced feet 21b which bear against the lower crystal face. For the purpose of urging the electrode 11 toward the housing member 21, thereby to clamp the corner portions of the crystal 10 between the feet 11a and 21b, a helical coil spring 18 is provided which, during the assembly of the unit, is compressed between the upper terminal plate 16 and an insulating cover 15 which is utilized to close the open side of the housing 14. Assembly screws 17 and nuts 17a extending through registering openings in the housing 14 and the cover 15 are employed to maintain the two named parts in assembled relationship.

As best shown in Fig. 2 of the drawings, the driving unit 19 comprises a magnetic field structure which may be variably excited to distort the diaphragm 12 toward and away from the lower crystal face for the purpose of changing the output frequency of the unit. In brief, this field structure comprises a permanent field magnet 22 having a pole face end 22a adjacent the under surface of the diaphragm and having a laterally extending part 22b which carries a center pole piece 23 having a pole face end 23a disposed adjacent the under surface of the diaphragm 12 in the exact center thereof. Preferably, the permanent magnet 22 is formed of Alnico or the like and, in cooperation with the pole piece 23, serves normally to bias or distort the diaphragm 12 to its normal setting thereof relative to the lower face of the crystal 10. In order to increase or decrease this bias, a driving coil or winding 24 is provided which embraces the center pole piece 23 and is adapted for energization from a connected control or signal voltage source. The components of the described field structure are supported within the housing member 21 upon an end closure plate 26 which is formed of Bakelite or another suitable insulating material and is rigidly interconnected with the lower end of the member 21 in any desired manner. This closure plate carries a pair of terminals 25 which are connected to the terminal ends of the winding 24 and through which connections may be made to a control or signal voltage source.

In the assembly of the described components of the unit, the housing 14 and terminals 16 and 20 are preassembled as a separate subassembly. Similarly the components of the diaphragm driving unit 19 are preassembled as a separate subassembly. These two assemblies are brought together by inserting the tubular housing member 21 through the opening 14c at the bottom of the cavity 14a and telescoping the split ring 19a over the housing member 21. The next step is that of soldering the terminal conductor 20 to the rim of the housing member 21 to provide an electrical connection between the socket pin 20a and the

diaphragm 12. With the driving unit 19 thus assembled with the housing 14, the crystal 10 is matched with a bimetallic electrode 11 in the manner more fully described below, following which the matched crystal and electrode are inserted beneath the conductor plate 16 for support by the feet 21b of the housing member 21. The spring 18 is next placed in position over the terminal plate 16 and the cover pressed down against this spring until its edges are in meeting engagement with the edges of the housing 14. The assembly screws 17 and nuts 17a may now be employed to secure the cover 15 and housing 14 together, thus completing the assembly of the unit.

From the preceding explanation it will be apparent that the crystal 10 is positively restrained against lateral motion relative to the electrode 11 and the diaphragm 12 by virtue of the spring developed clamping pressure exerted upon the corner portions thereof by the parts 11a and 21b between which the crystal is held. Further, the seating engagement of the crystal and electrode corner parts with the sides of the recesses 14b precludes any appreciable rotary movement of the crystal relative to the electrodes. In this regard it will be noted that only a very small portion of the crystal face area is held under compression between the parts 11a and 21b, thus minimizing the decrease in crystal activity resulting from the restraining force exerted through the thickness of the crystal. With this construction, and as best shown in Fig. 2 of the drawings, an air gap 11b is provided between the lower surface of the bimetallic electrode 11 and the upper face of the crystal. A similar air gap 12b is provided between the lower crystal face and the diaphragm 12. These two air gaps, due to the deformable characteristics of the electrodes 11 and 12 are each variable to determine the output frequency of the crystal unit.

In production, quartz crystals may be so cut that the output frequency of each crystal usually varies directly with temperature, i. e. as the crystal temperature decreases the natural frequency of vibration decreases and vice versa. Another important and well known factor in determining the output frequency of a crystal unit is the mass, density and elasticity of the air between the crystal and the electrodes associated with the two faces thereof. This factor is, of course, determined by the area and length of each of the air gaps 11b and 12b between the crystal faces and the two electrodes. To a lesser extent, the interelectrode capacitance between the electrodes 11 and 12 affects the output frequency of the crystal, which capacitance is varied in response to expansion and contraction of the crystal through the thickness thereof resulting from changing temperature of the crystal. In general, and for an air gap of given area, the two last-mentioned variable factors are changed to produce an increase in the crystal output frequency as the air gap length is increased and vice versa.

Another factor which in part determines the temperature-output frequency characteristic of the illustrated crystal unit is the temperature response of the diaphragm 12 and its associated driving unit 19. For example, the experimentally determined curve B illustrated in Fig. 4 of the drawings, represents the temperature-output frequency characteristic of a substantially perfect crystal as tested using conventional non-temperature responsive electrodes in association therewith. When, however, the diaphragm 12

and associated driving unit 18 were substituted for one of the conventional electrodes, the temperature-output frequency response characteristic C was obtained for the same crystal. This characteristic shows that as the temperature of the unit was increased from a value of −20° C to a value of 80° C., the output frequency was gradually decreased to a value approximately 100 cycles less than the rated frequency value of the crystal. While this modification of the crystal temperature - output frequency characteristic may be attributable to several factors, it is probably in part produced by the changing air gap between the diaphragm armature 12a and the associated pole faces of the magnet 22 and the pole piece 23, occasioned by unequal expansion of the housing member 21 and the named parts of the field structure. Such change in the field structure air gap dimensions produces a decrease in the attractive force exerted upon the diaphragm armature 12a to effect a decrease in the length of the air gap 12b and hence an increase in the crystal output frequency.

In order to reduce the variations in crystal output frequency which are produced in the above described manner in response to ambient temperature changes, the bimetallic thermally deformable electrode 11 is assigned the function of varying the air gap 11b in the correct sense to compensate for the output frequency drift which would otherwise occur, i. e. to render the temperature-output frequency characteristic of the crystal as nearly uniform as possible. To this end, the electrode 11 is arranged so that the center region thereof is cupped toward or away from the upper crystal face to correspondingly reduce the average length of the air gap 11b in response to changing temperature.

The direction of cupping must initially be determined by the type of compensation required. Thus, if it is desired or necessary only to correct the frequency drift represented by the characteristic C in Fig. 4 of the drawings, the high coefficient of expansion side of the electrode 11 is disposed away from the upper crystal face so that as the ambient temperature rises to produce a corresponding rise in the temperature of the crystal 10 and the other parts of the unit, the center region of the electrode 11 is cupped away from the upper crystal face effectively to increase the average length of the air gap 11b. Conversely, as the temperature decreases from the value at which the electrode is not deformed, the center region of the deformable electrode 11 is cupped toward the upper face of the crystal to effectively decrease the average length of the air gap 11b.

The degree of deformation of the electrode 11 thus produced in response to a given change in the ambient temperature is, of course, determined by the amount of departure of the temperature-output frequency characteristic of the crystal and associated diaphragm unit from uniformity. In the case considered above wherein a temperature-output frequency characteristic C is obtained using a non-deformable electrode in association with the upper face of the crystal, the degree of distortion should be such as to produce a temperature-output frequency characteristic D if the particular crystal were clamped between the thermally deformable electrode and a conventional non-temperature responsive electrode. In such case the action of the deformable electrode 11, tending to produce a change in the output frequency of the crystal in one sense, exactly counterbalances the tendency of the diaphragm and associated driving unit to change the output frequency of the crystal in the opposite sense, such that a resilient characteristic of substantial uniformity is obtained.

If, on the other hand, a crystal 10 is used having the more usual temperature-output frequency characteristic F when tested in conjunction with conventional pressure type electrodes, partial compensation is obtained by associating the crystal with the diaphragm 11 and associated driving unit. Thus, by subtracting the values along the curve C from the corresponding values along the curve F, a resultant characteristic curve E may be obtained which is more nearly uniform over the indicated temperature range than the characteristic curve F. To further compensate the combination so that the characteristic is substantially exactly uniform, it is necessary to employ a thermally deformable electrode 11, the action of which is the exact reverse of that described above for a crystal initially having a substantially uniform temperature-output frequency characteristic. Specifically, an electrode 11 is used in which the high coefficient of expansion side thereof is disposed adjacent the upper face of the crystal 10 so that as the ambient temperature rises from the value at which the electrode 11 is undistorted, to produce a corresponding rise in the temperature of the crystal 10 and the other parts of the unit, the center region of the electrode is cupped toward the upper crystal face effectively to reduce the average length of the air gap 11b. Conversely as the temperature decreases from the value at which the electrode 11 is undistorted, the center region of the electrode is cupped away from the upper crystal face to effectively increase the average length of the air gap 11b. Here also, the electrode should be properly designed to effect the degree of deformation required to produce the necessary amount of compensation over the desired temperature range.

From the above explanation, it will be understood that different electrodes, deformable in opposite senses and varying amounts relative to the crystal face in response to like temperature changes, amounts may be required to effect complete compensation of crystal units employing crystals and diaphragm units which together are characterized by different temperature-output frequency characteristics. In this regard it will be understood that in the production of piezoelectric quartz crystals on a volume basis, crystals ground to the same frequency exhibit different temperature-output frequency characteristics. Moreover, manufacturing discrepancies in the production of the diaphragms and their associated driving units may introduce a further variable factor which must be taken into account in accurately compensating the units against frequency drift. Accordingly, in the manufacture of crystal units embodying the present invention on a production basis, it is desirable to provide thermally deformable electrodes 11 having different temperature-deformation characteristics falling in certain predetermined classes. By this expedient matching of the electrodes on an individual basis with selected crystals and diaphragm assemblies may be easily and rapidly accomplished to insure the production of crystal units which are substantially completely compensated against frequency drift. Preferably the electrodes are so designed, classified and matched that they are perfectly flat and unstresed at a

normal temperature of approximately 72° F. and in conjunction with the matched crystal, provide the exact desired output frequency of the unit at this temperature with no voltage applied to the winding 24. As thus designed, the electrodes will be deformed in opposite directions, i. e. toward and away from the upper crystal face in response to departures of the temperature in opposite senses from the predetermined value of 72° F.

As previously indicated, energization of the field structure winding 24 by a voltage of predetermined magnitude and polarity produces corresponding change in the attractive force exerted by the field structure upon the diaphragm 12. Thus, if the winding 24 is energized by current of the proper polarity to increase the flux traversing the field structure and diaphragm, the attractive force acting upon the diaphragm is increased to move the center region of the diaphragm away from the crystal face and thus increase the output frequency of the crystal unit. Conversely, if the winding 24 is energized by current of the proper polarity to decrease the flux traversing the field structure and diaphragm, the force acting upon the diaphragm is partially relieved such that the center region thereof is moved toward the lower crystal face to decrease the output frequency of the unit. In either case, the extent of the frequency change is directly related to the magnitude of the current flow through the winding 24. For example, in a specific embodiment of the present invention, the characteristic curve A was obtained. This curve shows the crystal unit output frequencies obtained when voltages of different values and opposite polarity are applied to the winding terminals 25. As shown by this curve, the application of a variable voltage of one polarity to the terminals 25 resulted in an increase in the output frequency of the unit approaching a limit of 5000 cycles. Conversely, the application of a variable voltage of opposite polarity to the terminals 25 resulted in a corresponding decrease in the output frequency of the unit. Moreover, the characteristic is substantially linear in the region between plus and minus 3000 cycles. This deviation is adequate when multiplied 5 to 6 times for narrow band frequency modulation transmission, such, for example, as in police communication work where deviations of ±15 kc. are commonly employed. Thus, the unit lends itself admirably to the production of an oscillator modulator unit adapted for use in a frequency modulation wave signal transmission system.

A system of this character is illustrated in Fig. 6 of the drawings as comprising an oscillator-modulator stage 30, and a power amplifier stage 31 connected in tandem in the order named and arranged to deliver frequency modulated signal carrier energy to an antenna-ground circuit 22. In the system, the present improved crystal unit is employed in conjunction with an electron discharge tube 30*a* of the pentode type to develop a frequency modulated signal carrier which is transmitted through the compound coupled frequency selective circuits 36 and 37 to a power amplifier tube 31*a* which is utilized to amplify the signal carrier and deliver the same through the selective circuit 39 to the antenna-ground circuit 32 for radiation. Preferably, frequency multiplication is obtained in the coupling system connecting the output electrodes of the tube 30*a* with the input electrodes of the amplifier tube 31*a*. Such multiplication may be easily obtained by

tuning the selective circuits 36 and 37 to a desired harmonic of the output frequency of the crystal 10 and by correspondingly tuning the selective circuit 39 included in the output circuit of the amplifier tube 31*a*. Frequency modulation of the developed signal carrier effected through operation of the described apparatus is obtained by coupling the winding 24 of the crystal unit to the output terminals of a microphone 32. Specifically, this microphone is battery powered by means of a small battery 34 and is coupled to the winding 24 through an audio transformer 33.

With this arrangement, audio voltages developed through operation of the microphone 32 are applied across the terminals of the winding 24 through the transformer 33 to effect movement of the diaphragm electrode 12 relative to the lower face of the crystal 10 in a manner fully apparent from the preceding explanation. Such movement of the diaphragm electrode 12 results in corresponding changes in the output frequency of the oscillator-modulator stage 30. In other words, the signal carrier generated in this stage is frequency modulated in accordance with the audio voltage impressed across the winding 24. Thus, use of the present improved crystal unit in a wave signal transmission system eliminates the necessity for providing separate oscillator and modulator stages. At the same time the rigidity of frequency control inherent in crystal controlled oscillators is retained. Moreover, since the crystal unit is fully compensated to substantially prevent drift in its output frequency occasioned by ambient temperature changes, the center frequency of the generated frequency modulated carrier remains exactly at the desired value under any and all operating conditions normally encountered.

While there has been described what is at present considered to be the preferred embodiment of the invention, it will be understood that various modifications may be made therein which are within the true spirit and scope of the invention as defined in the appended claims.

We claim:

1. A variable frequency piezoelectric crystal unit, comprising a pair of electrodes adapted to have a piezoelectric crystal supported therebetween, one of said electrodes being spaced from one face of said crystal by an air gap and being at least in part movable relative to said crystal in response to ambient temperature variations to control variations in the output frequency of said unit with said ambient temperature variations, the other of said electrodes being spaced from the other face of said crystal by a second air gap and being at least in part movable relative to said crystal to vary the output frequency of said unit, and electro-responsive means for moving said other electrode relative to said crystal.

2. A variable frequency piezoelectric crystal unit comprising a piezoelectric crystal, an electrode associated with one face of said crystal and spaced from said one crystal face by an air gap, electro-responsive means for producing relative movement between said electrode and said crystal to vary the length of said air gap, thereby to vary the output frequency of said unit, said electro-responsive means coacting with said electrode to in part determine the temperature-output frequency characteristic of said unit, and temperature responsive means comprising an electrode associated with the other face of said crystal for minimizing variations in the output frequency of said unit with ambient temperature

variations regardless of the effect of said electro-responsive means and said first-named electrode upon the temperature-output frequency characteristic of said unit.

3. A variable frequency piezoelectric crystal unit comprising a piezoelectric crystal, an electrode associated with one face of said crystal and spaced from said one crystal face by an air gap, electro-responsive means for producing relative movement between said electrode and said crystal, thereby to vary the output frequency of said unit, said electro-responsive means coacting with said electrode to change the temperature-output frequency characteristic of said unit in one sense, and temperature responsive means associated with the other face of said electrode to further change the temperature-output frequency characteristic of said unit in the correct sense to render said characteristic substantially uniform.

4. A variable frequency piezoelectric crystal unit comprising a piezoelectric crystal, an electrode associated with one face of said crystal and spaced from said one crystal face by an air gap, said unit having a non-uniform temperature-output frequency characteristic, and electro-responsive means for producing relative movement between said electrode and said crystal, thereby to vary the output frequency of said unit, said electro-responsive means coacting with said electrode in the correct sense to render said characteristic more nearly uniform.

5. A variable frequency piezoelectric crystal unit comprising a thermally deformable electrode, a deformable diaphragm, a holder for said diaphragm, a piezoelectric crystal spaced from said electrode and diaphragm by air gaps and clamped between said electrode and said holder, said electrode being thermally deformable in the correct sense to reduce variations in the output frequency of said unit with ambient temperature changes, and electro-responsive means supported by said holder for moving said diaphragm relative to said crystal, thereby to vary the output frequency of said unit.

6. A variable frequency piezoelectric crystal unit comprising a thermally deformable electrode, a deformable diaphragm, a holder for said diaphragm, a piezoelectric crystal spaced from said electrode and diaphragm by air gaps and clamped between said electrode and said holder, electro-responsive means supported by said holder for moving said diaphragm relative to said crystal, thereby to vary the output frequency of said unit, said electro-responsive means coacting with said diaphragm to in part determine the temperature-output frequency characteristic of said unit, and said electrode being thermally deformable to change the temperature-output frequency of said unit in the correct sense to render said characteristic more nearly uniform.

7. A variable frequency piezoelectric crystal unit comprising a thermally deformable electrode, a deformable diaphragm, a cup-shaped holder for said diaphragm, a piezoelectric crystal spaced from said diaphragm and electrode by air gaps and clamped between said electrode and holder, said electrode being thermally deformable in the correct sense to reduce variations in the output frequency of said unit with ambient temperature changes, and electromagnetic means supported within said holder for moving said diaphragm relative to said crystal, thereby to vary the output frequency of said unit.

8. A variable frequency piezoelectric crystal unit comprising a thermally deformable electrode, a deformable diaphragm, a cup-shaped holder for said diaphragm, a piezoelectric crystal spaced from said diaphragm and electrode by air gaps and clamped between said electrode and holder, electromagnetic means supported within said holder for moving said diaphragm relative to said crystal, thereby to vary the output frequency of said unit, said electromagnetic means coacting with said diaphragm to in part determine the temperature-output frequency characteristic of said unit, and said electrode being thermally deformable to change the temperature-output frequency characteristic of said unit in the correct sense to render said characteristic more nearly uniform.

9. A variable frequency piezoelectric crystal unit comprising a thermally deformable electrode having projecting clamping parts, a deformable diaphragm, a cup-shaped holder for said diaphragm having projecting clamping parts around the rim thereof, a piezoelectric crystal clamped between said parts such that air gaps are provided between the faces of said crystal and said electrode and diaphragm, said electrode being thermally deformable in the correct sense to minimize variations in the output frequency of said unit with ambient temperature changes, and electro-responsive means supported by said holder for moving said diaphragm relative to said crystal, thereby to vary the output frequency of said unit.

10. A variable frequency piezoelectric crystal unit comprising a thermally deformable electrode having projecting clamping parts, a deformable diaphragm, a cup-shaped holder for said diaphragm having projecting clamping parts around the rim thereof, a piezoelectric crystal clamped between said parts such that air gaps are provided between the faces of said crystal and said electrode and diaphragm, said electrode being thermally deformable in the correct sense to minimize variations in the output frequency of said unit with ambient temperature changes, and electro-magnetic means supported within said holder for moving said diaphragm relative to said crystal, thereby to vary the output frequency of said unit.

11. A variable frequency piezoelectric crystal unit comprising a thermally deformable electrode having projecting clamping parts, a deformable diaphragm, a cup-shaped holder for said diaphragm having projecting clamping parts around the rim thereof, a piezoelectric crystal clamped between said parts such that air gaps are provided between the faces of said crystal and said electrode and diaphragm, and electro-responsive means supported within said holder for moving said diaphragm relative to said crystal thereby to vary the output frequency of said unit, said electro-responsive means coacting with said diaphragm to in part determine the temperature-output frequency characteristic of said unit, and said electrode being thermally deformable to change the temperature-output frequency of said unit in the correct sense to render said characteristic more nearly uniform.

12. A variable frequency piezoelectric crystal unit comprising a housing having an apertured crystal receiving cavity therein, a tubular holder extending through said aperture and having a shoulder supported upon the bottom of said cavity, a diaphragm supported by said holder within said cavity, a thermally deformable electrode within said cavity, a piezoelectric crystal spaced

from said diaphragm and electrode by air gaps and clamped between said electrode and holder, said electrode being thermally deformable in the correct sense to minimize variations in the output frequency of said unit with ambient temperature changes, and electro-responsive means supported within said holder for moving said diaphragm relative to said holder, thereby to vary the output frequency of said unit.

13. A variable frequency piezoelectric crystal unit comprising a housing having an apertured crystal receiving cavity therein, a tubular holder extending through said aperture and having a shoulder supported upon the bottom of said cavity, a diaphragm supported by said holder within said cavity, a thermally deformable electrode within said cavity, a piezoelectric crystal clamped between said electrode and said holder, said electrode and the diaphragm supporting end of said holder having projecting clamping parts bearing against said crystal which serve to provide air gap spacings between the faces of said crystal

and said electrode and diaphragm, said electrode being thermally deformable in the correct sense to minimize variations in the output frequency of said unit with ambient temperature changes, and electro-responsive means supported within said holder for moving said diaphragm relative to said holder, thereby to vary the output frequency of said unit.

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