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R. J. EHRET ET AL

2,321,285

MODULATION SYSTEM

Original Filed May 22, 1940

FIG. 2.

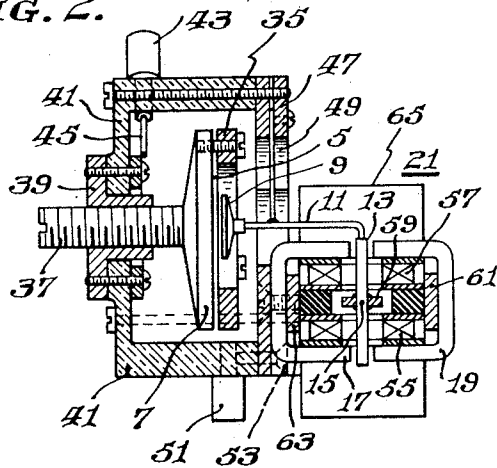


FIG. 1.

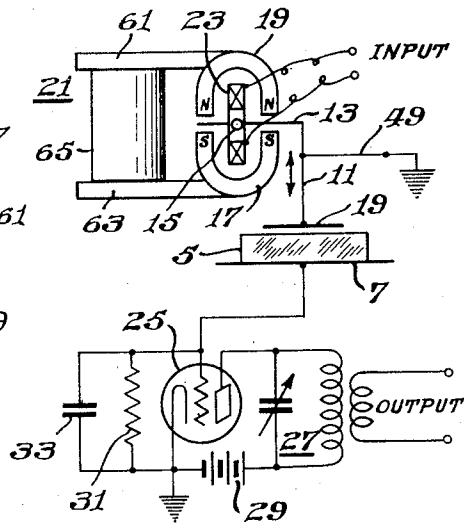


FIG. 3.

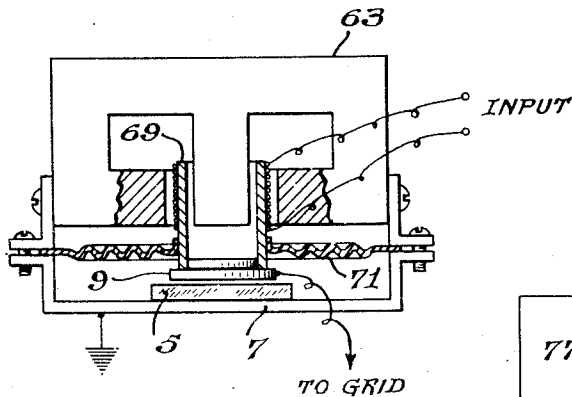
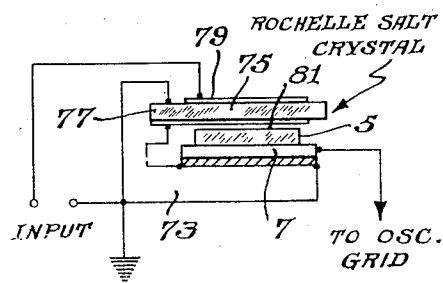


FIG. 4.



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MODULATION SYSTEM

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Original application May 22, 1940, Serial No. 336,550, now Patent No. 2,289,183, dated July 7, 1942. Divided and this application December 10, 1941, Serial No. 422,378

4 Claims. (Cl. 179—171.5)

This is a division of copending application for Modulation system, Serial No. 336,550, filed May 22, 1940, Patent No. 2,289,183, July 7, 1942.

This invention relates to frequency modulation systems, and more particularly to an improved frequency modulator of the type in which the control frequency of a piezo-electric crystal element is varied.

One of the principal problems which confronts the designer of a frequency modulated transmitter is that of providing effective frequency modulation without sacrificing the necessary stability of the average or unmodulated carrier frequency. This is particularly true in the design of high frequency transmitters which utilize a relatively low frequency oscillator and series of frequency multipliers, since undesired changes in the average oscillator frequency are multiplied by the same factor as the desired step-up of the average frequency.

The use of a modulated crystal controlled low frequency oscillator has been proposed, in which the control frequency of a piezo-electric crystal is modulated, by varying the air gap between the crystal element and one of the electrodes. By the term control frequency is herein meant that frequency at which a crystal controlled oscillator normally operates. This variation has heretofore been accomplished by making the top crystal electrode in the form of a stretched diaphragm, similar to that used in microphones, the position of which is varied with respect to the crystal by an electro-magnet adjacent to the diaphragm which is energized by the modulating voltage. The crystal is connected in a conventional oscillator circuit and stabilizes the average frequency of the oscillator in the usual manner. Variations in the air-gap, however, produce variations in the oscillator frequency which can be utilized in accordance with well established practice to energize or excite a transmitter, for example. Such an arrangement is described in Patent No. 1,933,735, issued November 7, 1933 to A. Hund, for example.

It has been found that rather small variations in the oscillator frequency are produced by the systems of the prior art. This may be explained by the fact that the diaphragm does not vibrate as a whole at all frequencies but breaks up into different modes of vibration for different frequencies in a manner which is similar to the production of standing waves on a vibrating string. Thus, when one portion of the diaphragm is moving toward the crystal another portion may be moving away from the crystal, so that the effective change in the gap is minimized.

In addition it is well known that a magnetically operated diaphragm produces double frequency components unless a fixed magnetic flux is employed to pull or bias the diaphragm away from its neutral position. This is, of course, the reason that the electromagnets of all telephone receivers, headphones, and the like, employ a permanent magnet as a core. If such an arrangement be utilized to eliminate frequency doubling in the crystal modulator it will be appreciated that the pull on the diaphragm will give it a curved shape so that the effective air gap at the center is increased. To obtain the maximum frequency variation for a given diaphragm movement, however, it is essential that the spacing between the crystal and the diaphragm be as small as possible. It will be appreciated, therefore, that for a given diaphragm movement it is not possible to obtain as great a change in frequency with the biased magnetic diaphragm as with one which is not so biased, and yet the biasing is necessary to reduce distortion.

Accordingly it is the principal object of this invention to provide a frequency modulated oscillator having a stable average frequency. Other objects include the provision of an improved crystal modulator of the variable air gap; the provision of improved means for driving the movable electrode of a crystal modulator; the provision of a light, economical crystal modulator suitable for use in portable equipment; and the provision of a variable air gap crystal modulator of improved operating characteristics.

In brief, the foregoing objects are accomplished, in accordance with the present invention by providing the crystal with a substantially inflexible spaced electrode which is mounted on an electromagnetic or electrodynamic motor mechanism, the electrode being movable bodily toward and away from the crystal. Such an electrode need not be rigidly supported at the edges, as does a stretched diaphragm, and consequently will present less impedance to the driving mechanism. Its surface will not be distorted by wave patterns, nor is it necessary to distort the electrode to overcome second harmonic generation. As a result the spaced electrode may be smaller than the diaphragm, and the unmodulated or normal air gap may be reduced, thus increasing the modulating range of the device. The present divisional application covers an embodiment of this invention in which the driving mechanism for the spaced electrode is another piezo-electric element of the pick-up type, such as a Rochelle salt crystal, or the like.

This invention will be better understood from the following description when considered in connection with the accompanying drawing, and its scope is indicated by the appended claims. Similar reference numerals refer to similar elements throughout the drawing.

Referring to the drawing, Figure 1 is a schematic drawing of an electromagnetic modulator; Figure 2 is a sectional view of a modulator assembly; Figure 3 is a schematic drawing of an electrodynamic modulator; and Figure 4 is a schematic drawing of a piezo-electric modulator.

Referring to Fig. 1, a quartz crystal 5 is mounted on a base plate 7 which may be any conventional crystal holder. A spaced electrode 9 is positioned adjacent the upper face of the crystal, and is rigidly mounted on and supported by an arm 11 which is, in turn, connected to a soft iron magnetic armature 13, so that movement of the armature produces a like movement of the electrode 9 in a direction perpendicular to the surface of the crystal.

The magnetic armature 13 is pivotally mounted at a point 15 intermediate its ends between the opposed faces of a pair of U-shaped pole pieces 17 and 19 which are oppositely magnetized by a permanent or electromagnet 21. A deflecting coil 23, shown in cross-section between the pole pieces 17 and 19, produces a magnetic field which coincides with the armature axis so that the armature is magnetized by currents flowing through the coil. It will be appreciated that the effect of the two similar poles of the two pole pieces will have a cumulative pull on the magnetized armature to cause it to rotate in one direction or the other, depending on the direction of the current in the deflecting coil. The pivotal mounting 15 is sufficiently stiff to prevent excessive movement of the armature. Consequently, the spaced electrode 9 will vibrate at a frequency corresponding to the frequency of the energizing current applied to the "input" terminals.

The spaced electrode 9 is grounded and the base plate 7 connected to the grid of a thermionic oscillator tube 25, or the connections may be reversed, if desired. The anode of the oscillator tube 25 is connected to an oscillatory circuit 27 and a source of anode potential 29 in the conventional manner. A grid leak 31 supplies operating bias for the tube.

It has been found that increased frequency modulation will result from a given spacing and movement of the top electrode when the crystal is connected in parallel with a fixed capacitor 33. This result is apparently contrary to that which would normally be expected, since the effective change of capacity is reduced by the shunt capacity. The value of this capacitor may be as high as several hundred micro-microfarads for a crystal operating on a fundamental of 7 m. c., but its actual value for maximum frequency shift will depend upon the particular oscillator circuit.

In an actual case, a 6000 kc. crystal was tested. A series of curves were plotted representing the frequency versus air gap characteristic of the crystal. For the first curve no shunt capacity was used. With 35 $\mu\text{mf.}$ shunt capacity the slope of the curve increased substantially. Increasing the shunt capacity to 50 and then 100 $\mu\text{mf.}$ brought successive increases in the slopes of the curves. Beyond 100 $\mu\text{mf.}$, however, the slope of the curve decreased again, indicating that for that particular circuit a shunt capacity of the order of

100 $\mu\text{mf.}$ gave the maximum change of frequency for a given movement of the movable electrode.

The cross-sectional drawing of a crystal modulator unit illustrated in Fig. 2 shows the constructional details of an actual device corresponding to the schematic illustration of the preceding figure. The crystal 5 is mounted on a base plate 7 and clamped at the edges by means of a retaining ring 35. By the term "base plate" is herein meant the fixed electrode of the crystal, which may comprise a conductive mounting plate which is also an electrode, or a conductive material placed on the crystal which is then mounted on a non-conductive support. The base plate 7 is mounted on an adjusting screw 37 for setting the air gap between the crystal and the spaced electrode 9. The screw 37 is threaded into a collar 39 which is mounted in the bottom of a cup-like porcelain container 41 which forms the main body of the crystal holder. Electrical connection to the fixed electrode is made by means of a pin 43 set in the porcelain, and connected to the collar 39 by means of a lead 45.

The top of the porcelain cup is covered by an apertured plate 47, through which extends the driving member 11 which connects the magnetic armature 13 to the spaced electrode 9. The driving member is held in position by a stiff wire 49, one end of which is connected at right angles to the driving member 11 at or near the electrode, the other end being connected to the top plate 47. The wire 49 functions to maintain the electrode parallel to the crystal, throughout its range of movement. In the absence of such a guiding wire the electrode 9, arm 11 and armature 13 would tend to rotate about the axis 15 and the electrode would not remain parallel to the crystal, which is an undesirable condition. This lead or wire 49 also provides an electrical connection to the spaced electrode of the crystal. A mounting pin 51 is electrically connected to the top plate 47 by a screw 53. Various materials may be used in the construction of these posts, but preferably materials having a low temperature coefficient should be used. Metals of differing coefficients may also be utilized to compensate for undesired expansion of the elements due to changes in temperature.

The top plate of the crystal holder is fixedly connected to the U-shaped pole piece 17 of the driving mechanism. For convenience, the deflecting coil is wound in two serially connected sections 55 and 57 separated by insulation to provide a space for the armature pivot which is, for example, a resilient spring strip 59, the lateral cross section of which is shown. The pole pieces 17 and 19 are mounted on supporting members 61 and 63 which are fastened to the ends of a highly magnetized permanent magnet 65.

The arrangement illustrated in Fig. 3 utilizes an electrodynamic drive mechanism similar to that employed in loudspeakers. It comprises a permanent magnet 67 and a voice coil 69 mounted in the intense magnetic field of the magnet by means of a flexible spider 71. The usual cone is replaced by a metallic electrode 9 which is adjacent the surface of a piezo-electric crystal element 5. The crystal is mounted on a base plate 7, as before. It is to be understood that the crystal holder may be of the type illustrated in detail in Fig. 2, although, for the sake of simplicity, constructional features well known to those skilled in the art have been omitted. It will be understood that the crystal may be connected to any oscillator to control its average fre-

quency, which frequency will be modulated by a signal voltage applied to the wire coil through the "input" terminals.

A unique driving mechanism is illustrated in Fig. 4, wherein one piezo-electric element is used to control the frequency of an oscillator, while a second piezo-electric element is used to drive the spaced electrode of the first, and thus modulate the oscillator frequency.

The first piezo-electric element 5 is mounted in the usual manner on a base plate 7 which is, for example, insulatingly supported on a member 13. Immediately above the first crystal, a second piezo-electric element 15 is mounted. This element may be of the type commonly used in vibration pickup devices and loudspeakers such as a quartz or a Rochelle salt crystal. It is mounted at one edge 17 on the common supporting member 13. The second or motor piezo-electric element 15 is provided with two foil electrodes 19 and 21, as is well known. The motor element electrode between the adjacent faces of the two elements is grounded, and constitutes an electrode for the frequency controlling element 5. A modulating voltage is applied between the two foil electrodes 19 and 21 with the result that a physical vibration is set up by the motor element which varies the resonant frequency of the frequency controlling element, and thus modulates the oscillator frequency.

While the illustration shows the grounded foil of the motor element functioning as an electrode for the oscillating crystal, it is to be understood that separate elements may be used, if desired. That is, the two crystal elements may be located some distance apart and connected by suitable coupling means, but, for simplicity, the arrangement shown is referred.

The present invention has been described by means of several specific embodiments, but there are, of course, many modifications which may be made without departing from the spirit of this invention. Its scope, therefore, is only limited by the prior art and the spirit of the appended claims.

We claim as our invention:

1. In a piezo-electric device, the combination including a piezo-electric element, an oscillator whose frequency is controlled by said element, a Rochelle salt crystal supported in a position adjacent the surface of said element, a common electrode attached to the surface of said Rochelle salt

crystal and spaced from the adjacent surface of said piezo-electric element, and means for vibrating said crystal in response to a signal voltage to thereby vary the air gap between the piezo-electric element and said common electrode and thus to vary the frequency of said oscillator in accordance with said signal voltage.

2. In a piezo-electric device, the combination of a frequency control piezo-electric element, an oscillator whose frequency is controlled by said element, a motor piezo-electric element for producing vibrations corresponding to signal voltages, a common electrode for said frequency control piezo-electric element and said motor piezo-electric element, said common electrode being movable with said motor element and adjacent the surface of said frequency control element, said common electrode responding to said vibrations for varying the characteristics of said frequency control element in accordance with said signal voltages.

3. In a piezo-electric device, the combination including a first piezo-electric element, means for fixedly supporting said element, a second piezo-electric element mounted adjacent and parallel to the face of said first element, a movable foil electrode covering the surface of said second element and interposed between the adjacent faces of said elements, said foil electrode constituting an electrode for said first element, and means for producing mechanical vibrations in said second element corresponding to signal voltages whereby the position of said foil with respect to said first element, and thus the characteristics of said first element, are varied accordingly.

4. In a piezo-electric device, the combination including first and second piezo-electric elements, electrodes for said elements including one common electrode attached to the surface of the first of said elements and spaced to form an air gap with the second of said elements, an oscillator whose frequency is controlled by said second element, said frequency being determined in part by the air gap spacing between said second element and said common electrode, and means for causing said first element to vibrate in response to modulation frequency voltages whereby said air gap is varied and the frequency of said oscillator changes in accordance with said voltage.

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