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H. MUELLER

2,306,555

METHOD FOR FREQUENCY CONTROL

Filed May 23, 1940

Fig. 1

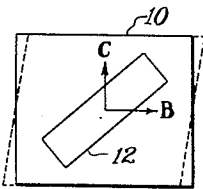
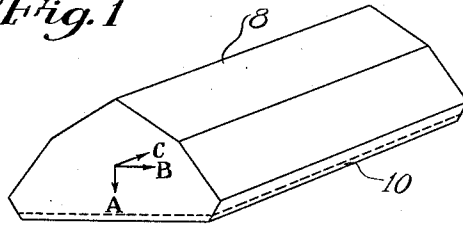


Fig. 2

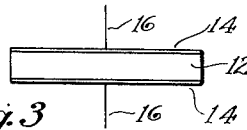


Fig. 3

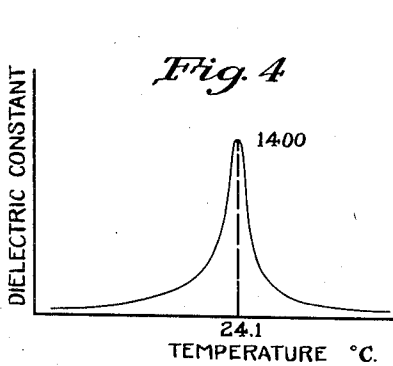


Fig. 4

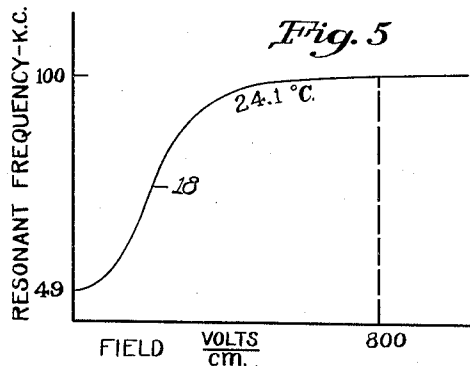


Fig. 5

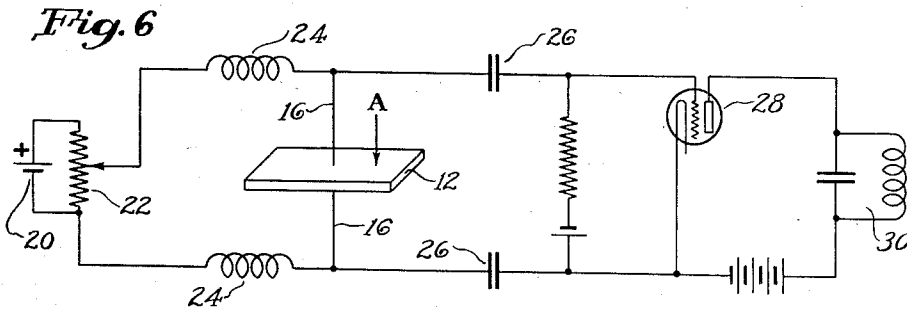


Fig. 6

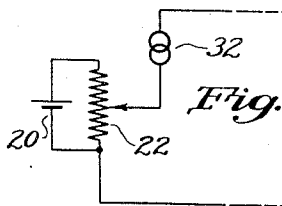


Fig. 7

Witness
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UNITED STATES PATENT OFFICE

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METHOD FOR FREQUENCY CONTROL

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3 Claims. (Cl. 171-327)

The present invention relates to methods and apparatus for frequency control, utilizing crystal units, and useful for precise control of oscillator frequencies, for filter systems and for other applications.

The usual crystal control unit employs a quartz crystal which must be accurately finished to an exact thickness corresponding to the frequency which is to be controlled thereby. Except for some dependence on temperature, the resonant frequency depends only on the thickness of the crystal, and the controlled frequency is not subject to variation or adjustment except by the use of crystals of different thickness.

I have discovered that certain crystals, of which Rochelle salt may be taken as an example, possess resonant frequency characteristics which are dependent on the initial loading or stressing of the crystal. This property is not exclusive to Rochelle salt, but in general applies to any crystals which exhibit the so-called seignette-electric effect, namely, the property of possessing an extremely high dielectric constant at one or more critical temperatures.

The present invention, which is based on the foregoing discovery, comprises a crystal unit embodying a crystal of the above-mentioned type, together with means for stressing or loading the crystal, preferably by subjecting it to a bias or loading potential to produce an electric field within the crystal. Such a unit is useful in any of the applications where quartz crystals are now employed, and has important advantages, particularly in its ability to vary or adjust the resonant frequency in a simple manner.

Other features of the invention consist of certain arrangements of parts and modes of operation hereinafter described and particularly defined in the claims.

In the accompanying drawing Fig. 1 is a perspective view of a Rochelle salt crystal formed according to common methods; Fig. 2 is a plan view of a slab cut from the crystal of Fig. 1, illustrating the preferred method of forming the control unit according to the present invention; Fig. 3 is an elevation of the crystal control unit; Figs. 4 and 5 are characteristic curves showing the principle upon which the invention operates; Fig. 6 is a diagram of an oscillator circuit embodying the present invention; and Fig. 7 is a diagram of a modified circuit useful for frequency modulation.

In Fig. 1 is shown a crystal 8 of Rochelle salt which is grown according to usual methods. The crystal is of the characteristic orthorhombic hem-

ihedric form which is also exhibited by many other crystals of the same class, examples of which will be given hereinafter. The mutually perpendicular axes A, B and C are indicated in the drawing. As in the manufacture of piezoelectric devices the crystal is cut into thin slabs in planes perpendicular to the "A" axis, illustrated by the dotted line 10 in Fig. 1.

One of the slabs 10, or rather a small square portion cut therefrom, is shown in Fig. 2. When an electric field is applied to the crystal in the direction of the "A" axis, the crystal deforms into a non-rectangular parallelogram as indicated in exaggerated form by the dotted lines in Fig. 2. Conversely, a mechanical shear stress applied in a manner to deform the crystal generates an electric field within the crystal. For purposes of the present invention a piece of the slab 10 may be cut to any desired shape. It is preferable, however, to cut a narrow rectangular piece 12 whose axis is approximately 45 degrees from the B and C axes of the crystal, since for any given applied potential such a shape will have the maximum deformation in relation to its area.

Sheets of conducting foil 14 are then applied to the top and bottom faces of the crystal 12 and are cemented thereto in close electrical contact, in accordance with any suitable procedure. Since the invention is believed to depend upon the high dielectric constant of the crystal, this close contact is necessary in order that the effective dielectric constant between the plates may not be reduced by the presence of an air gap or material of lower dielectric constant. Leads 16 are attached to the foil electrodes 14.

Before describing the application of the crystal to an electrical circuit, certain properties of the crystal may be explained by reference to Figs. 4 and 5. Fig. 4 is a plot of dielectric constant against temperature. At a critical temperature of 24.1° C., Rochelle salt has an extremely high dielectric constant which is in the neighborhood of 1400. At temperatures slightly different from the critical value the dielectric constant drops to a lower value, between 80 and 100. There is another peak of dielectric constant at about -18° C. The properties at the low temperature peak are similar to those at the higher temperature peak, but reference herein will be made to the latter peak only because in practical applications the higher temperature would ordinarily be used. This property of exhibiting an anomalous dielectric constant within a narrow temperature range is the seignette-

electric effect to which reference has previously been made.

The present invention depends on the fact that Rochelle salt, as well as any crystal which exhibits the seignette-electric effect, also has a resonant frequency in the region of the same critical temperature. This resonant-frequency effect differs from that of the familiar quartz crystal in several respects. First, it does not depend in any way upon the thickness of the crystal but rather on its area and shape in a manner to be later described; and, second, it depends on the electric field or voltage gradient applied to the crystal. This dependence of resonant frequency on electric field is illustrated in Fig. 5. This is for a Rochelle salt crystal of the narrow rectangular shape shown at 12 in Fig. 2 and approximately two centimeters long, at the critical temperature of 24.1° C. At zero potential the crystal has a resonant frequency of approximately 49 kilocycles. If a potential difference is applied to the electrodes 14 the resonant frequency increases as shown in Fig. 5. The curve has a portion of upward curvature near the bottom, an approximately linear portion 18, and an upper portion which becomes flat or nearly so. The upper flat portion represents a region of saturation in which a change of voltage produces only a slight change in resonant frequency. For Rochelle salt saturation is reached at a field strength of about 800 volts per centimeter of thickness, and the resonant frequency for the crystal mentioned reaches a maximum of approximately 100 kilocycles. For such a crystal, the resonant frequency for any voltage is approximately inversely proportional to the length; thus a narrow crystal one centimeter long would have a similar characteristic but with ordinates twice as high.

For crystals of other shapes, the characteristic curves are in general similar to Fig. 5. A crystal 3 x 5 centimeters with sides parallel to the B and C axes also has a frequency characteristic with the same numerical values indicated by Fig. 5. In such a crystal, however, or in any crystal which is not fairly long in comparison with its width, there may be more than one resonant frequency for each applied voltage, that is, the complete plot of resonant frequency against voltage would comprise a family of separated curves, all of the same general shape as Fig. 5. This is because of the complex internal stresses and deformations in the crystal, as distinguished from the narrow-cut crystal 12 wherein the deformation is substantially one of simple elongation. In such complex cases, there is no simple relation between frequency and crystal size, although in general the frequency increases with decreasing area.

At temperatures other than the critical, the variation of resonant frequency with changes of voltage gradient is not so pronounced. For example, at 30° C. the resonant frequency is nearly constant regardless of the applied voltage. At 23° C. and lower temperatures the material exhibits hysteresis effects, that is, the resonant frequency for any given value of field strength depends on whether the field was established by increasing from a lower value or decreasing from a higher value; however, no uncertainty is introduced as long as the manner of field establishment is taken into account. The crystal is preferably held within close limits, at or near the critical temperature. This presents no difficulty, since the surroundings may be easily held by

standard temperature control methods to 0.1 C., and the crystal itself, because of its low heat conductivity, will not usually vary more than 0.01° C.

An oscillator circuit embodying the invention is illustrated in Fig. 6. The crystal 12 is subjected to a constant but adjustable direct-current potential from a battery 20 connected through a potentiometer 22 or other adjusting device and choke coils 24 to the leads 16 which are attached to the foil surfaces of the crystal unit. The leads 16 are connected through condensers 26 to the input of an oscillator 28 of conventional form, the output circuit of which includes a tuning circuit 30. As in other frequency-control systems, the oscillator is tuned by the circuit 30 to the desired frequency. Since the tuning circuit has a broad peak, reliance is placed on the crystal control to limit the output to a sharp peak. The resonant frequency may be closely adjusted to the desired value by the potentiometer 22. The temperature should be maintained to the critical value by any suitable control means.

In operation of an oscillator circuit where a sharp frequency control is desired, it is preferred to work at or near saturation on the curve of Fig. 5. In the particular example given herein, saturation is attained when the potentiometer 22 is adjusted to apply a field of 800 volts per centimeter to the crystal. If the loading voltage were lower, so that the operation occurred on the linear portion 18 of the characteristic, for example, the output would be less sharp; this is necessarily true, because the alternating field applied to the crystal by reason of its connection to the oscillator causes a slight variation of resonant frequency.

Operation at a loading potential below saturation is useful for many purposes. Here the resonant frequency is dependent on the loading potential. In the oscillator circuit of Fig. 6, this affords an opportunity of adjusting the resonant frequency, even though the output may be somewhat broader than if the operation occurred on the flat portion of the curve. The amount of broadening may, however, be kept within narrow limits. It has been explained that the reduction of sharpness is due to slight changes of frequency brought about by the application to the crystal of the alternating potential generated by the oscillator, and this effect may be reduced by using an oscillator of low output and a crystal of sufficient thickness so that the alternating field in the crystal is negligibly small.

The system may be used for frequency modulation. If a low-frequency alternating source 32 is connected in series with the source of direct current loading potential as shown in Fig. 7, the oscillator output will be frequency-modulated in accordance with the alternating input.

The crystal unit also finds application in filter circuits, notably in filter circuits for intermediate-frequency amplifiers of radio receivers. When extreme sharpness is required, as in code reception, the unit may be loaded to saturation, but when a greater band width is desired, as in telephone reception, the unit may be loaded to a point where the frequency is dependent on the voltage.

Although the invention has been thus far described as employing Rochelle salt crystals (sodium potassium tartrate), the invention is equally applicable to other crystals, the only necessary characteristic of which is that they possess the seignette-electric effect heretofore described.

Examples of other crystals of the same class are sodium rubidium tartrate and sodium thallium tartrate, as well as crystals grown from a mixture of any of the foregoing materials in any proportions. Crystals formed from the pure materials or any mixtures thereof have the same properties although the critical temperatures differ somewhat from the values herein given for Rochelle salt. In general, these materials will show a peak of dielectric constant between 15° and 30° C. and another peak between -15° and -30° C.

Crystals may also be grown from a mixture of any of the foregoing with sodium ammonium tartrate. While the latter shows no appreciable seignette-electric effect itself, it may be used up to about thirty percent in mixture with any of the previously described materials.

All of the foregoing crystals are of the orthorhombic hemihedric form. Crystals of other forms which also exhibit the seignette-electric effect may be used. For example, crystals of di-hydrogen potassium phosphate, di-hydrogen potassium arsenate, di-hydrogen ammonium phosphate, and di-hydrogen ammonium arsenate show the same effects and may likewise be used. All of these latter materials form crystals of tetragonal shape. These materials have an extremely high dielectric constant in the neighborhood of -150° C. While they may be used so long as temperature control may be maintained, the crystals previously described will ordinarily be preferred because of the greater convenience in maintaining temperature control under conditions which are not too greatly different from room temperature.

The present invention depends upon the use of crystals which exhibit the seignette-electric effect. While the seignette-electric effect, namely, the anomalous increase of dielectric constant at critical temperatures, has been known, it is a new discovery, so far as I am aware, that materials possessing this property also possess the characteristic of dependence of resonant frequency on applied stress. The invention differs from the quartz crystal control in which the dielectric constant is relatively small and invariable. Furthermore, the actual apparatus is necessarily different from the apparatus involving

the use of quartz crystals. In my invention the electrodes are attached to the crystal unit in close contact therewith, in order to take advantage of the high dielectric properties, whereas in the quartz unit the crystal is separated from one of the electrodes by an air gap. Furthermore, as previously described, the resonant frequency is not dependent upon thickness but upon the area and shape of the crystal unit, since the deformation shown in Fig. 2 is in shear rather than in compression.

The invention in its broader aspects contemplates the loading or initial stressing of a seignette-crystal by any means, although only the preferred method of electrically stressing the crystal is herein described. In other respects, also, the invention is not to be considered as limited to the precise embodiments herein described, but may be modified within the purview of the appended claims.

Having thus described the invention, I claim:

1. A method of frequency control which consists in initially stressing a crystal possessing seignette-electric properties by applying a loading potential thereto, applying thereto an alternating electrical potential, and maintaining the crystal close to a critical temperature at which it has an extremely high dielectric constant.

2. A method of frequency control which consists in subjecting a crystal possessing seignette-electric effects to a uniform electric field along its A axis, applying thereto an alternating potential at the frequency to be controlled, and maintaining the crystal substantially at a critical temperature at which it has an extremely high dielectric constant.

3. A method of frequency control which consists in shear-stressing a crystal possessing seignette-electric properties by subjecting the crystal to a biasing electric field of sufficient strength to render the crystal sharply resonant to a certain frequency dependent on the shape and size of the crystal and substantially independent of small variations of electric field in the crystal, maintaining the crystal at a temperature at which it has an extremely high dielectric constant, and applying an alternating potential to the faces of the crystal.

HANS MUELLER.