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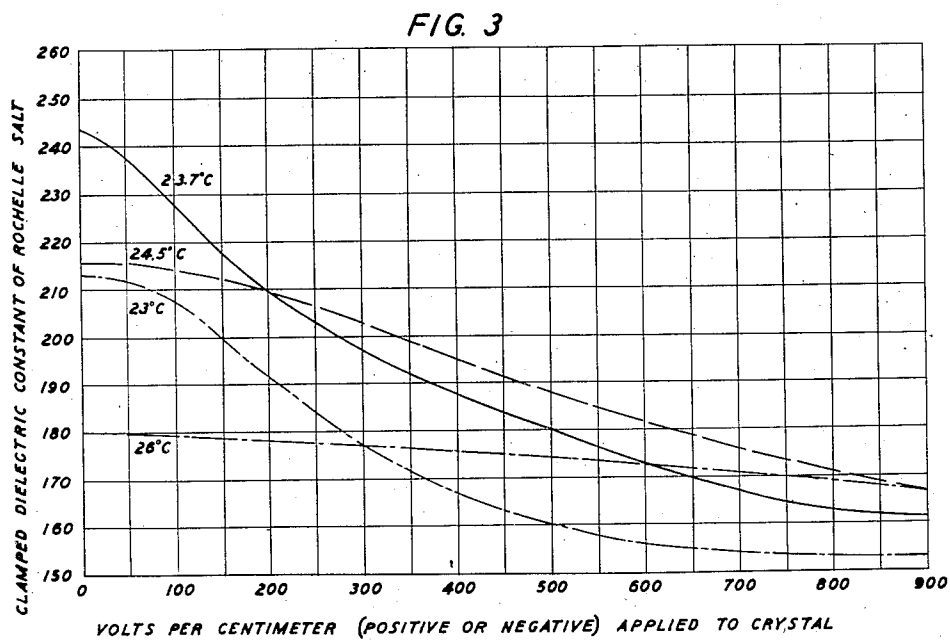
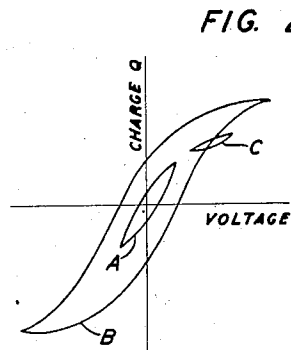
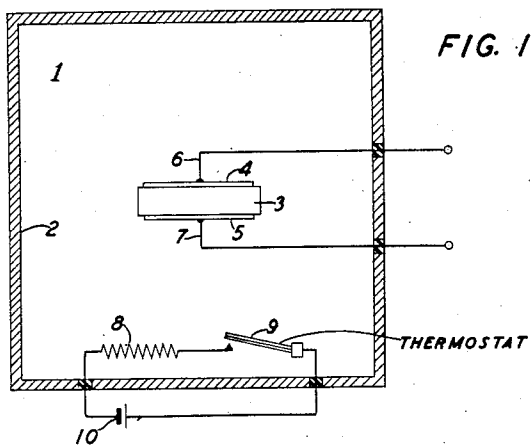
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2,453,243

FREQUENCY MODULATING AND HARMONIC PRODUCER APPARATUS

Filed Oct. 21, 1943

2 Sheets-Sheet 1



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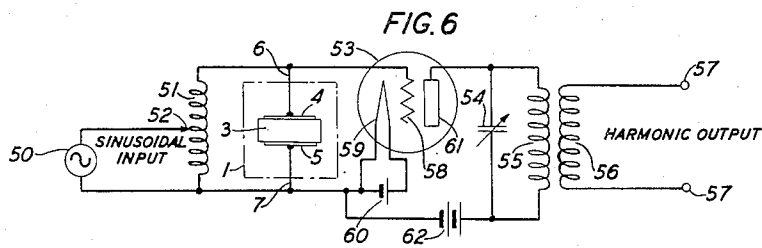
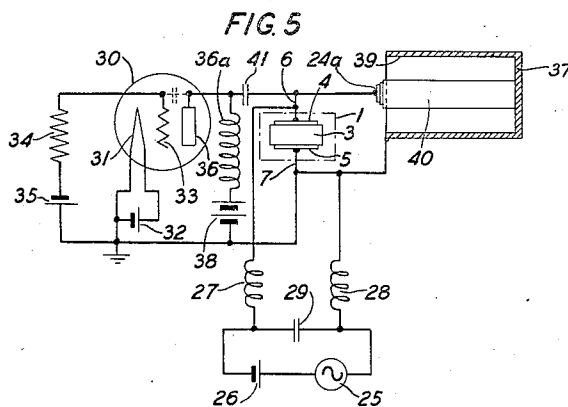
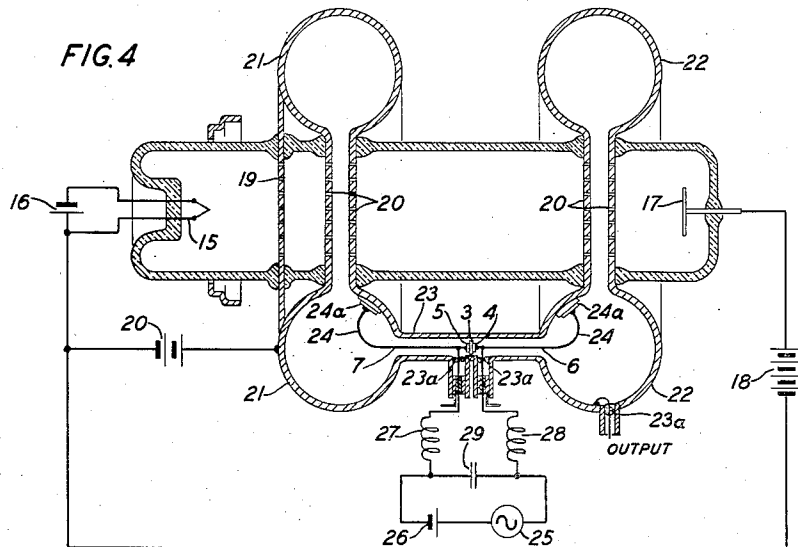
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FREQUENCY MODULATING AND HARMONIC PRODUCER APPARATUS

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2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE

2,453,243

FREQUENCY MODULATING AND HARMONIC
PRODUCER APPARATUS

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Application October 21, 1943, Serial No. 507,130

11 Claims. (Cl. 250—36)

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This invention relates to frequency modulating apparatus and particularly to variable capacitance modulators for changing the circuit frequency in oscillation generator systems, filter systems, harmonic producing systems and other systems.

One of the objects of this invention is to utilize the hysteresis and capacitative properties of non-resonant piezoelectric type crystals in high frequency systems generally.

Other objects of this invention are to produce a fast-acting variable capacitance condenser, and to provide a modulator which may be worked to very high frequencies.

More specific objects of this invention are to frequency modulate an oscillation generator, and to provide for the production of harmonics from an alternating current source of sinusoidal waves.

Certain piezoelectric crystals of which Rochelle salt is an example may be made to possess effective variable capacitance and hysteresis loop characteristics which are dependent on a variable bias or loading potential applied to the crystal. These characteristics in general may apply to any crystal which exhibits a relatively high dielectric constant at one or more critical temperatures called the Curie point temperatures. Such a crystal when held at a substantially constant temperature corresponding to its critical or Curie point temperature and when made non-resonant with respect to the frequency of the circuit in which it is connected may be utilized as a fast-acting modulator in high frequency systems generally.

The temperature-controlled, non-resonant Rochelle salt crystal or other suitable crystal element may be connected in circuit relation with a high frequency system and utilized as a fast-acting variable capacitance condenser, the capacitance of which is controlled by and varies as a function of either the direct current bias voltage or the alternating current bias voltage that may be applied thereto. This effect is a consequence of the hysteresis loop that the crystal goes through when its temperature is held constant at or near its Curie point temperature. In the case of the so-called standard or ordinary type of Rochelle salt crystal, the Curie point temperature thereof occurs at a temperature of about 24° C. In the case of the heavy water type of Rochelle salt crystal, the Curie point temperature comes at about 35° C. or 95° F. at which temperature a simple form of temperature control will suffice to hold the temperature constant.

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The static capacitance of such non-resonant crystal elements may be effectively changed by a change in the value of the positive or negative bias voltage applied thereto, and the effect is a maximum at the Curie point temperature and may be utilized to vary or modulate the frequency of a fixed or constant frequency quartz crystal-controlled oscillation generator or an ultra-short wave coil or cavity-controlled type of oscillation generator, or to shift the frequency band of a filter system to frequency modulate a quartz crystal-controlled oscillator for example, or to replace the motor driven capacitor of a broadcast frequency modulator transmitter, or to produce harmonics and modulation products up to a very high frequency and into the centimeter range if desired.

For a clearer understanding of the nature of this invention and the additional advantages, features and objects thereof, reference is made to the following description taken in connection with the accompanying drawings, in which like reference characters represent like or similar parts, and in which:

Fig. 1 is a schematic view illustrating a constant temperature-controlled non-resonant Rochelle salt crystal element in accordance with this invention;

Fig. 2 is a graph illustrating typical hysteresis loop characteristics of a temperature-controlled non-resonant Rochelle salt crystal element;

Fig. 3 is a graph illustrating typical variations in the dielectric constant of standard or ordinary Rochelle salt crystals as a function of variable bias voltage applied thereto;

Figs. 4 and 5 are circuit diagrams illustrating frequency-modulated oscillation generators of the cavity-controlled and the coaxial line-controlled types respectively; and

Fig. 6 is a circuit diagram illustrating a frequency multiplier or harmonic producer system.

Referring to the drawing, Fig. 1 is a view illustrating schematically a temperature-controlled crystal unit 1 comprising an enclosing container 2 of any suitable type for enclosing a non-resonant crystal element 3 cut from piezoelectric Rochelle salt or other suitable crystalline material, grown or obtained according to any suitable method. The orientation of the Rochelle salt crystal element 3 may be X-cut, Y-cut or any other suitable piezoelectric cut, and may be made of any suitable shape, such as a relatively thin slab or plate 3 of Rochelle salt having rectangular-shaped or square-shaped major faces for example.

Electrodes 4 and 5 constructed of any suitable conductive material, such as for example metal plates, metallic foils, evaporated or sprayed gold or silver may be provided in contact with the whole or a part of the opposite major faces of the crystal element 3 in order to provide an electric field therefor, and conductive leads 6 and 7 may be attached to the crystal electrodes 4 and 5 for establishing suitable external electrical connections and also, if desired, for supporting the crystal element.

The crystal element 3 may be any suitable piezoelectric crystal element such as for example a Rochelle salt crystal element of either the standard type or the heavy water type, held at or near its critical or Curie point temperature by any suitable means such as a heating resistance 8 controlled by a thermostat 9 and energized by a supply source 10.

Standard or ordinary Rochelle salt is a well-known double tartrate of potassium and sodium ($\text{NaKC}_4\text{H}_4\text{O}_6 \cdot 4\text{H}_2\text{O}$) belongs to the orthorhombic bisphenoidal class of crystals, and has a Curie point temperature of about 24° C. Heavy water Rochelle salt is Rochelle salt crystallized from heavy water (deuterium oxide) as disclosed, for example, in United States Patent 2,188,154 issued January 23, 1940, to S. O. Morgan, and United States Patent 2,227,268 issued December 31, 1940, to W. P. Mason, and has a Curie point temperature of about 35° C. Either the standard type or the heavy water type of Rochelle salt crystal element 3 may be used to obtain an effective variable capacitance, the capacitance of which may be controlled by an applied variable voltage bias in order to obtain a frequency modulator which may be worked at very high frequencies, if desired.

While the crystal element 3 is particularly described herein as being composed of Rochelle salt (sodium potassium tartrate) of either the standard type or the heavy water type, it may be composed of other forms of crystalline material which exhibit effective variable capacitance and hysteresis properties at a critical temperature, such as, for example, sodium rubidium tartrate, sodium thallium tartrate, ammonium dihydrogen phosphate, potassium dihydrogen phosphate and the corresponding arsenates or mixtures thereof.

The crystal element 3 may be cut to any dimension and shape which avoids a natural or resonant frequency therefor that would correspond to the frequency of the circuit in which it is to be directly connected. Where the crystal element 3 is connected in circuit with a high or an ultra-high frequency system, its principal natural frequency will ordinarily be of much lower value than that of the circuit frequency in which it may be connected and accordingly it may function as a non-resonant crystal element 3.

At or near the critical or Curie point temperature, which is about 24° C. for the standard type Rochelle salt crystal 3, high values of dielectric constant and static capacitance and effective values of hysteresis loop characteristics may be obtained. The thickness dimension and the major face dimensions of the crystal element 3 may be adjusted to values that result in a desired value for the static capacitance at the Curie point temperature, and the temperature of crystal element 3 being held constant at or near the Curie point temperature thereof, the static capacitance of the crystal element 3 may be varied by a variation in the value of the voltage applied

thereto. At temperatures other than the Curie point temperature, the variations of the static capacitance are relatively small except for relatively high values of applied electric fields. The temperature of the crystal element 3 may be held within close limits at or near the Curie point temperature by any suitable temperature control means. It is desirable or necessary to control the temperature of the crystal element 3 fairly accurately at a constant value of temperature in order that the hysteresis and capacitance effects of the crystal element 3 may be reproducible. The temperature at which these effects are a maximum is the Curie temperature which is about 24° C. for the standard or ordinary type of Rochelle salt and about 35° C. or 95° F. for the heavy water type of Rochelle salt. Similar hysteresis and capacitance effects occur for the heavy water Rochelle salt and for the ordinary Rochelle salt; but due to its higher and more convenient Curie point temperature of about 95° F., the heavy water Rochelle salt crystal element 3 may be more advantageous since a very simple form of temperature control will ordinarily suffice to hold the temperature at a value of about 95° F.

Fig. 2 is a graph illustrating typical hysteresis loop characteristics that occur in temperature-controlled non-resonant Rochelle salt crystal elements 3 as a function of variable bias voltage that may be applied thereto by the crystal electrodes 4 and 5 of Fig. 1. As illustrated by the hysteresis loop curves shown in Fig. 2 the change in static capacitance or charge of the crystal element 3 of Fig. 1 as a result of variation in the voltage bias applied thereto is caused by the hysteresis effects in the crystal element 3. If the applied bias voltage is taken over a relatively small loop, the simple curve A of Fig. 2 results and the capacitance of the crystal element 3 will be the average of that given by the hysteresis loop represented by the curve A of Fig. 2. The energy loss per cycle is proportional to the area of the hysteresis loop A of Fig. 2, while the power loss is that energy loss per cycle multiplied by the frequency f expressed in cycles per second. The series resistance R required to represent this loss will have a power loss P given by:

$$P = R i_m^2 = 4\pi^2 R f^2 Q_m^2 = \text{area times } f \quad (1)$$

where i_m is the maximum current and Q_m is the maximum charge applied to the crystal condenser consisting of the crystal 3 and its electrode plates 4 and 5.

The resistance R is equal to:

$$R = \frac{\text{area}}{4\pi^2 f Q_m^2} \quad (2)$$

As shown by Equation 2, the resistance R is inversely proportional to the frequency f and thus maintains a constant q or ratio of resistance to capacitative reactance for the capacitance with which it is associated. Measurements made over a 30 to 1 range for small values of the maximum charge Q_m , show that the hysteresis resistance R does not vary appreciably. Hence the area is roughly proportional to the square of Q_m , resulting in a Rochelle salt modulating device 3 of Fig. 1, the efficiency of which does not change much with variations in the applied amplitude of voltage and current.

Curve B of Fig. 2 illustrates a typical hysteresis loop curve for a relatively larger amplitude of alternating current voltage applied to a Rochelle salt crystal unit 3 of Fig. 1.

Curve C of Fig. 2 illustrates a typical hysteresis loop curve when a steady direct current voltage bias is placed on the Rochelle salt crystal unit 3 together with a small alternating current voltage superimposed thereon. The value of the capacitance that is equivalent to the hysteresis loop C of Fig. 2 is considerably lower than that for the large loop B of Fig. 2 or for the small loop A of Fig. 2, and results in an effective capacitance that is smaller than the capacitance that is obtained when no steady bias voltage is applied thereto.

Fig. 3 is a graph illustrating typical variations in the value of the clamped dielectric constant of a standard Rochelle salt crystal element 3, as a function of the applied bias voltage, positive or negative. The voltage is expressed in volts per centimeter of the thickness or thin dimension, as applied to the crystal element 3 of Fig. 1. The curve labeled "23.7° C." in Fig. 3 represents the approximate Curie point temperature of this ordinary or standard type of Rochelle salt crystal material and indicates that at this Curie point temperature the maximum variation in the clamped dielectric constant is obtained. At the relatively higher values of frequency, it is the clamped dielectric constant of the crystal element 3 that will be effective.

As an example taken from and shown by the curve labeled "23.7° C." in Fig. 3, if a voltage bias of about 300 volts per centimeter is placed on the Rochelle salt crystal element 3 of Fig. 1 held at a constant temperature of about 23.7° C., the dielectric constant thereof may be changed from about 218 to about 184, which represents a change of about 18 per cent, as obtained with an alternating voltage change of ± 150 volts per centimeter placed on the crystal element 3. For a crystal 3 having a thickness dimension between its electrode faces of about one-half millimeter, for example, which may be an illustrative example of a convenient thickness to use in practice, the corresponding voltage for the 300 volt bias voltage referred to is 15 volts and for the alternating voltage of ± 150 volts referred to above is ± 7.5 volts. Such a variable crystal capacitance 3 used as the principal controlling capacitance in a circuit connected therewith may be used to produce a frequency variation of some ± 4.5 per cent in the frequency of the circuit.

While the curves illustrated in Fig. 3 pertain particularly to Rochelle salt crystals 3 of the standard or ordinary composition, similar curves may be obtained using the heavy water type of Rochelle salt operated at its Curie point temperature around 35° C.

Fig. 4 is a circuit diagram illustrating an oscillation generator wherein a temperature-controlled non-resonant modulator crystal unit 3 of the type shown in Fig. 1 is used as a variable capacitance condenser for changing the tuning and for frequency modulating an ultra-short wave cavity-controlled type of oscillation generator which in the example shown in Fig. 4 is of a type disclosed in my copending application, Serial No. 382,180 filed March 7, 1941, now United States Patent No. 2,379,818 dated July 3, 1945. As shown in Fig. 4, the particular cavity-controlled oscillator includes a cathode 15 energized by a cathode supply source 16, an anode 17 energized by an anode supply source 18, a grid electrode 19 energized by a voltage source 20, and additional grid electrodes that may be interposed between the cathode 15 and the anode 17 and between the cavity resonators of the input and output resonators 21 and 22, respectively.

The resonators 21 and 22 may be interconnected by a coupling line 23 and may be utilized to fix or determine the frequency of the oscillations generated. In order to frequency modulate such a constant or fixed frequency cavity-controlled oscillator, the variable capacitance crystal unit 3, 4, 5 of Fig. 1 may be mounted inside the copper coupling line 23 and connected by means of the inner conductor wires 6 and 7, loops 24 and condensers 24a with the input and output cavity resonators 21 and 22, in order to change the tuning thereof in accordance with the amplitude of the variations in the signal currents that may be applied to the crystal element 3 from a voice or other low frequency signal modulating source 25. The conductors 6 and 7 in Fig. 4 may form the inner conductor of the high frequency coaxial transmission line 23 which interconnects and couples the input and output resonators 21 and 22. The signal source 25 may be connected with the crystal 3 through a voltage source 26, choke coils 27 and 28 and a condenser 29. The choke coils 27 and 28 and the condenser 29 disposed therebetween may together function as a low-pass or band-pass filter when placed between the signal source 25 and the crystal unit 3, as illustrated in Fig. 4.

The low frequency signal voltage wires leading from the coils 27 and 28 to the crystal element 3 may be connected as close to the crystal element 3 as is possible, and may be brought through the wall of the evacuated copper cylindrical coupling tube 23 by means of copper-to-glass seals 23a which function to hold the vacuum inside the coupling line 23 and also to electrically insulate the signal voltage wires referred to from the copper tube 23 whereby the low frequency signal modulated voltages from the source 25 may be applied to the crystal electrodes 4 and 5 in order to frequency modulate the high frequency oscillation system. The condensers 24a may be placed in the high frequency system and serve to prevent short circuiting of the low frequency signal voltages by the copper cylinder 23 while freely transmitting the high frequency system oscillations. The condensers 24a may have a capacitance value of the order of 10 to 100 micromicrofarads or other suitable capacitance value that offers a negligible impedance to the transmission of the high frequency system oscillations and a very high impedance to the transmission of the low frequency signal voltages applied to the wires 6 and 7 from the signal source 25. For this purpose, the condensers 24a may be conveniently placed between the loops 24 and the shields or walls 21 and 22 of the cavity resonators, and as illustrated in Fig. 4 may consist of mica dielectric condensers 24a placed in contact with the inner walls of the cavity resonators 21 and 22. While mica condensers 24a have been particularly illustrated in Fig. 4, it will be understood that any other suitable means may be employed for the same purpose.

Fig. 5 is a circuit diagram illustrating an example of an ultra-short wave coaxial line controlled type of oscillation generator employing the temperature-controlled modulating crystal unit 3 of Fig. 1 for modulating the frequency of the oscillations generated by the oscillator system. The particular oscillator circuit, which is shown in Fig. 5 by way of illustration, may include any suitable oscillator vacuum tube 30 having electrodes such as a cathode 31 energized by a cathode supply source 32, a control grid 33 connected through a grid resistance 34 and a suit-

able biasing source 35 with the cathode 31, and an anode or plate electrode 36 energized through a choke coil 36a by means of a suitable plate supply source 38. A coaxial line type of tuning unit 37 consisting of an outer conductor 39 and an inner conductor 40 functions to fix or determine the frequency of oscillations generated. A blocking condenser 41 is interposed between the choke coil 36a and the crystal unit 3. In order to modulate the frequency of the oscillations generated, the modulating crystal unit 3, 4, 5 may be connected by its terminals 6 and 7 with and across the inner and outer concentric conductors 39 and 40 of the coaxial tuning unit 37 in order to change or modulate the tuning thereof in accordance with corresponding capacitance variations in the modulating crystal unit 3 as caused by variations in the low frequency signal currents which may be applied to the crystal unit 3 from the low frequency voice or other signal source 25. The condenser 24a functions to block the low frequency signal currents while transmitting the high frequency oscillations.

It will be noted that the non-resonant Rochelle salt crystal unit 3 of Figs. 4 and 5 operates as a variable capacitance condenser, rather than as a periodic fixed frequency vibratory or oscillatory crystal, and hence avoids the relatively low stability of operation that obtains when a fixed-frequency vibratory type of Rochelle salt crystal is used to control directly the frequency of an oscillator. While the oscillator circuits shown in Figs. 4 and 5 illustrate particular forms of oscillation generators, it will be understood that the modulating crystal unit 3 of Figs. 1, 4 and 5 may be similarly utilized to modulate the frequency of other types of oscillators which may be controlled by other forms of cavity-type resonators or coaxial line tuners. In general, the oscillation generator may be any suitable circuit that may utilize the non-resonant crystal element 3 as a variable capacitance device.

Fig. 6 is a circuit diagram illustrating a frequency multiplier or harmonic producer system employing the modulator crystal unit 3 of Fig. 1 for producing a high frequency harmonic output from a lower frequency sinusoidal wave input. The input frequency may be applied to the crystal unit 3 from a sinusoidal wave source 50 through a winding 51 having an adjustable tap 52, the output of the winding 51 being connected across the crystal element 3 by means of the connections 6 and 7 and the crystal electrodes 4 and 5. A vacuum tube 53 and a tuned output circuit therefor consisting of an adjustable condenser 54 and transformer windings 55 and 56 may be utilized to derive the harmonic output at terminals 57 from the crystal unit 3. The oscillator tube 53 may comprise any suitable electrodes such as a grid input electrode 58, a cathode 59 energized by a cathode supply source 60, and an anode or plate electrode 61 energized by a suitable anode supply source 62. The input source 50 may produce a single alternating current wave of a given base frequency which after being applied to the crystal element 3 may produce a number of harmonics at the output terminals 57 that may have relatively uniform amplitudes and which may be adjusted over a relatively wide frequency range.

In the harmonic producer system of Fig. 6, the non-rectilinear hysteresis characteristics of the piezoelectric crystal element 3 are utilized to produce the harmonics of the alternating current that may be applied thereto from the input

source 50. Crystals such as Rochelle salt possess this non-linear voltage-current characteristic when operated as a static capacitance held at the critical or Curie point temperature. When an alternating electromotive force is applied across such a crystal element 3 having this property, harmonics of the applied electromotive force may be obtained.

The modulator crystal unit 3 may be worked at high frequencies and may be used to produce harmonics and modulation products to a very high frequency which may be up into the centimeter range. The dielectric constant of the non-resonant crystal element 3 goes through a hysteresis cycle as a result of the variations in the input voltage applied thereto from the constant frequency source 50, and since there are no excessive eddy currents therein to limit the upper frequency range of the crystal unit 3, the crystal unit 3 may be worked at very high frequencies. Small inductance coil modulators working on the hysteresis cycle of iron have been heretofore used to produce harmonics and modulation products up to as high as about 10 megacycles per second, but they cannot be used much above that frequency on account of the excessive eddy currents which shield the magnetic particles. While the dielectric constant of the Rochelle salt crystal element 3 goes through a similar hysteresis cycle, as illustrated in Fig. 2, there is no corresponding excessive eddy current effect to limit its upper frequency range.

As an example for another application of the temperature-controlled non-resonant variable capacitance crystal unit 3 of Fig. 1, the crystal unit 3 may be utilized to replace the present motor driven capacitor of broadcast frequency-modulation transmitters of the type disclosed, for example, in J. F. Morrison Patent 2,250,104 dated July 22, 1941, wherein the difference between the frequency of the quartz crystal oscillator thereof and the frequency of the modulating circuit thereof may be used as a positive and negative bias and placed on Rochelle salt crystal units 3 of the type described in this specification and illustrated in Fig. 1, in order to hold the frequency modulation circuit referred to above in synchronism with the quartz crystal oscillator. Crystal units 3 so utilized have the advantage of being much faster in action than the electrical motor driven capacitor referred to and hence the frequency of the quartz crystal oscillator may be made of the same frequency as that of the frequency-modulating circuit, thus eliminating a number of stages of frequency division.

Although this invention has been described and illustrated in relation to specific arrangements, it is to be understood that it is capable of application in other organizations and is therefore not to be limited to the particular embodiments disclosed.

What is claimed is:

1. A harmonic producer system comprising a source of voltage of variable magnitude, a non-linear type voltage variable capacitive reactance condenser device comprising a solid dielectric material having a curvilinear or non-linear voltage-charge hysteresis characteristic, said device being electro-mechanically non-vibratory or non-resonant with respect to the operating frequencies traversing it, means comprising said device for producing harmonic frequency modulation products therein in response to and dependent upon said magnitude of said variable voltage applied to said device from said voltage source and in

accordance with the effects of said hysteresis characteristic of said device, said hysteresis characteristic being adapted for and of sufficient value for producing said harmonic frequency products in said device, and means connected with said device for deriving or taking off from said device said harmonic frequency products produced in said device by said effects of said hysteresis characteristic.

2. A harmonic producer system comprising a source of voltage of variable magnitude, a non-linear type voltage variable capacitive reactance condenser device comprising a solid dielectric material having a curvilinear or non-linear voltage-charge hysteresis characteristic, said device being electromechanically non-vibratory or non-resonant with respect to the operating frequencies traversing it, and said dielectric material comprising a crystalline substance, means comprising said device for producing harmonic frequency modulation products therein in response to and dependent upon said magnitude of said variable voltage applied to said device from said voltage source and in accordance with the effects of said hysteresis characteristic of said device, said hysteresis characteristic being adapted for and of sufficient value for producing said harmonic frequency products in said device, and means connected with said device for deriving or taking off from said device said harmonic frequency products produced in said device by said effects of said hysteresis characteristic.

3. A frequency changing harmonic producer system comprising a source of base frequency alternating current voltage waves, means including a non-linear type voltage variable capacitive reactance device comprising a solid dielectric material having a curved voltage-charge hysteresis characteristic for distorting said base frequency waves and producing in said device harmonic frequency waves in response to the magnitude of said base frequency waves and in accordance with the effects of said hysteresis characteristic, and means connected with and selecting from said wave distorting means said desired harmonic frequency waves produced in said wave distorting means by said effects of said hysteresis characteristic.

4. A frequency changing harmonic producer system comprising a source of base frequency alternating current voltage waves, means including a non-linear type voltage variable capacitive reactance device comprising a solid dielectric material composed of a non-resonant salt type crystal body having a curved voltage-charge hysteresis characteristic for distorting said base frequency waves and producing in said device harmonic frequency waves in response to the magnitude of said base frequency waves and in accordance with the effects of said hysteresis characteristic, and means connected with and selecting from said wave distorting means said desired harmonic frequency waves produced in said wave distorting means by said effects of said hysteresis characteristic.

5. A frequency changing system comprising an alternating current circuit of predetermined low frequency, and means for changing said low frequency to a higher frequency including a voltage operated variable alternating current capacitance device comprising a Rochelle salt crystal element connected in said circuit and traversed by said current, said crystal element being made non-resonant with respect to said predetermined frequency and having an effective hysteresis char-

acteristic for producing said higher frequency, means for holding said crystal element at a substantially constant temperature corresponding to its Curie point temperature, and another circuit connected with said crystal element and traversed by currents having said higher frequency that differs from said frequency of said first-mentioned circuit, said other circuit including an electron tube having its input circuit connected with said crystal element, and a tunable circuit connected with the output circuit of said electron tube for selecting said higher frequency.

6. A harmonic producer or frequency multiplier comprising an electron tube having an input circuit and an output circuit, a tunable circuit connected with said output circuit of said tube, a source of sinusoidal alternating current waves of a given base frequency, a piezoelectric type crystal connected to the output circuit of said source and to said input circuit of said tube, means for maintaining said crystal at a substantially constant temperature corresponding to its Curie point temperature, said crystal having dimensions of a value corresponding to a non-resonant value with respect to said source frequency, said crystal having an effective hysteresis characteristic for producing harmonics therein, and means to take off from said tunable output circuit harmonics of said source frequency produced in said crystal and said output circuit.

7. A harmonic producer or frequency multiplier comprising an electron tube having an input circuit and an output circuit, a tunable circuit connected with said output circuit of said tube, a source of sinusoidal alternating current waves of a given base frequency, a crystal connected with the output circuit of said source and with said input circuit of said tube, means for maintaining said crystal at a substantially constant temperature corresponding to its Curie point temperature, said crystal having dimensions of a value corresponding to a non-resonant value with respect to said source frequency, said crystal having an effective hysteresis characteristic for producing harmonics therein, and means to take off from said tunable output circuit harmonics of said source frequency produced in said crystal and said output circuit, said crystal comprising Rochelle salt.

8. In combination, a source of alternating current waves, and harmonic producer means for changing the frequency of said alternating current to a substantially higher frequency comprising a constant temperature controlled, non-resonant Rochelle salt crystal, the alternating current capacitance and hysteresis characteristics of which are effectively varied as a function of the magnitude of said waves applied thereto for producing said higher frequency harmonics or modulation products therein in response to said source waves, and means including a tunable output circuit for taking off said higher frequency harmonic produced in said crystal.

9. An oscillatory circuit including a source of alternating current potential of predetermined frequency, another circuit, and Rochelle salt crystal element common to both of said circuits, and responsive to said potential from said source, said crystal element being non-resonant with respect to said oscillatory circuit frequency, said crystal element being subjected to a constant temperature near to the Curie point temperature of said crystal element and having an effective hysteresis characteristic for producing harmonic products therein, said other circuit comprising

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a harmonic producer selective means including an electron tube and a tuned output circuit for said electron tube.

10. A frequency changing system comprising an alternating current circuit of predetermined low frequency, and harmonic producer means for changing said low frequency to a higher frequency including a voltage operated variable alternating current capacitance device comprising a piezoelectric type crystal element connected in said circuit and traversed by said current, said crystal element being made non-resonant with respect to said predetermined frequency and having an effective hysteresis characteristic for producing said harmonic higher frequency, means for holding said crystal element at a substantially constant temperature, and another circuit connected with said crystal element and traversed by currents having said higher frequency that differs from said frequency of said first-mentioned circuit, said other circuit including an electron tube having its input circuit connected with said crystal element, and a tunable circuit connected with the output circuit of said electron tube for selecting said higher frequency.

11. A harmonic producer system comprising a wave source of sinusoidal alternating current voltage having a given base frequency, means including an inductance winding having an adjustable tap thereon connected with said wave source for adjusting the magnitude of said voltage in the output circuit of said winding, means including a piezoelectric type crystal element having its electrodes connected with said output circuit of said winding for producing in said crystal element high frequency harmonics from said lower frequency alternating current wave source voltage applied thereto, said last-mentioned

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means including means for holding the temperature of said crystal element at a substantially constant temperature value, said crystal element having dimensions corresponding to natural or resonant frequency values therefor that are substantially different from the frequency values of said source frequency and said harmonic frequencies, said crystal element exhibiting a dielectric constant and a curvilinear hysteresis characteristic sufficient in magnitude to produce said harmonic frequencies therein at said temperature value, means including an electronic tube having an input circuit connected with said electrodes of said crystal element and having a tuned output circuit for selecting one of said harmonic frequencies produced in said crystal element, and said tuned output circuit comprising a transformer having a primary winding shunted by a capacitor and having a secondary winding for supplying said harmonic frequency output.

WARREN P. MASON.

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