

July 22, 1947.

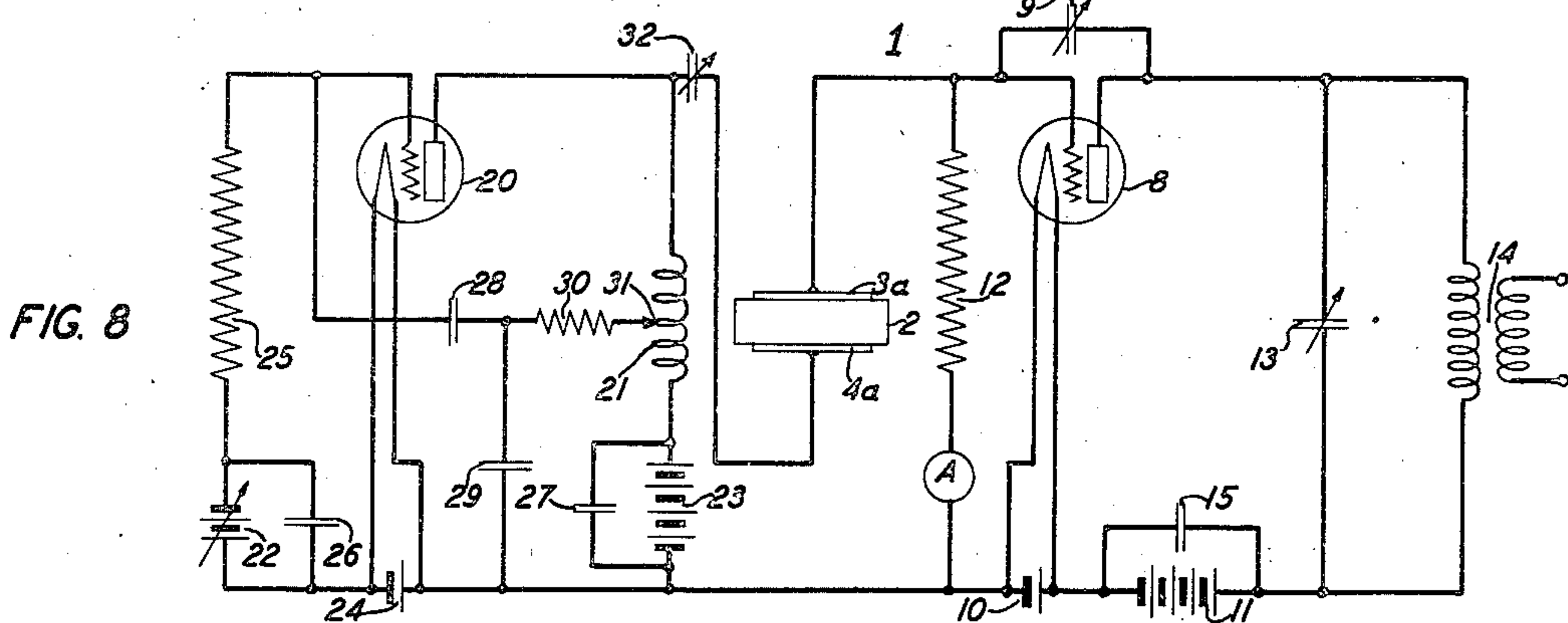
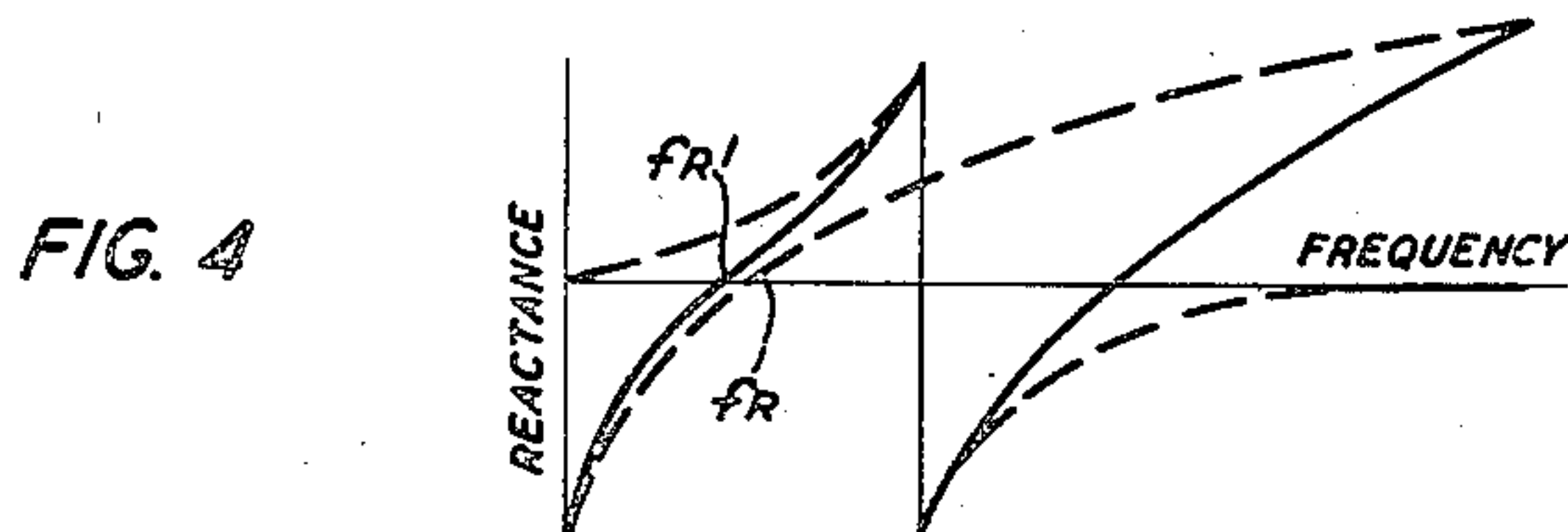
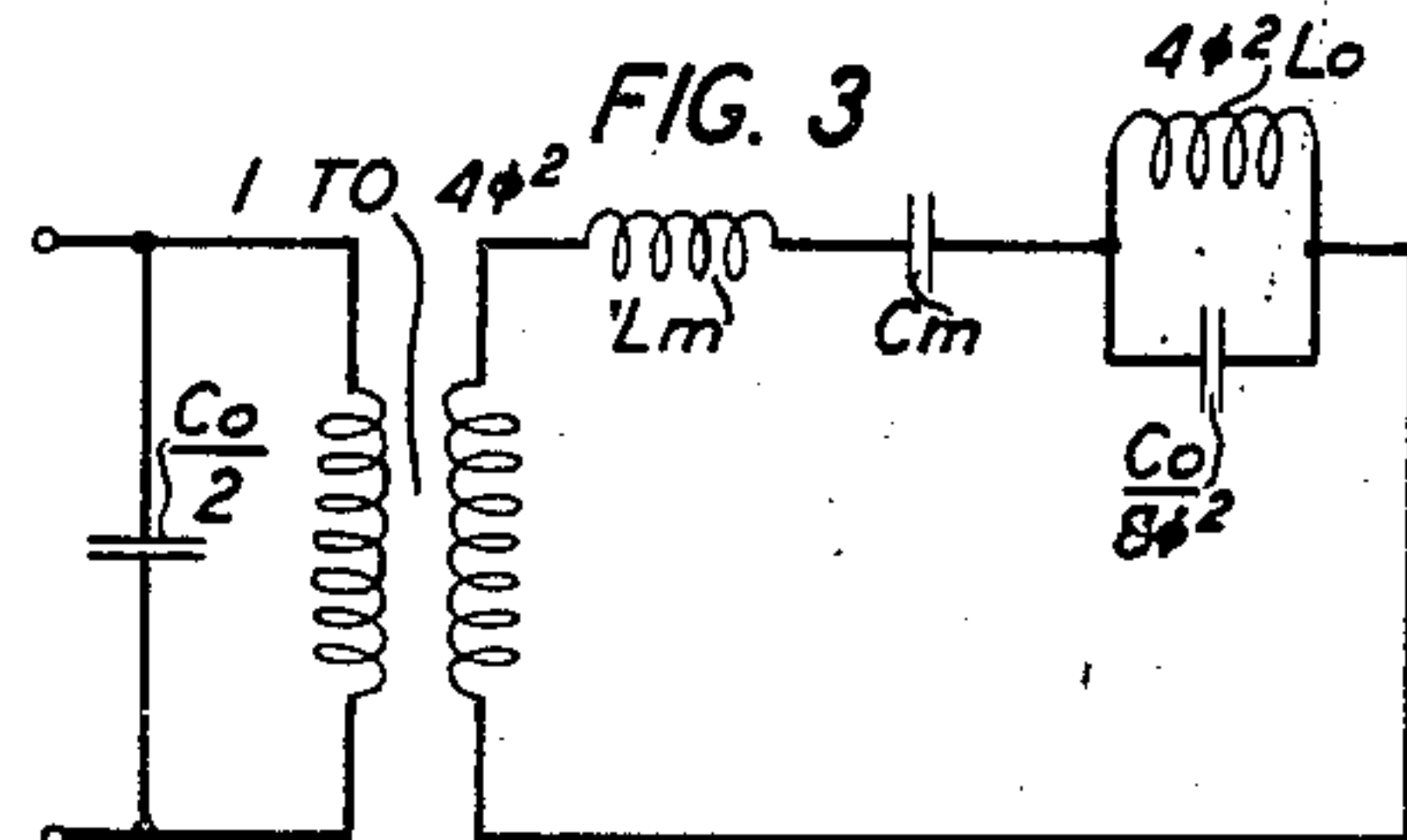
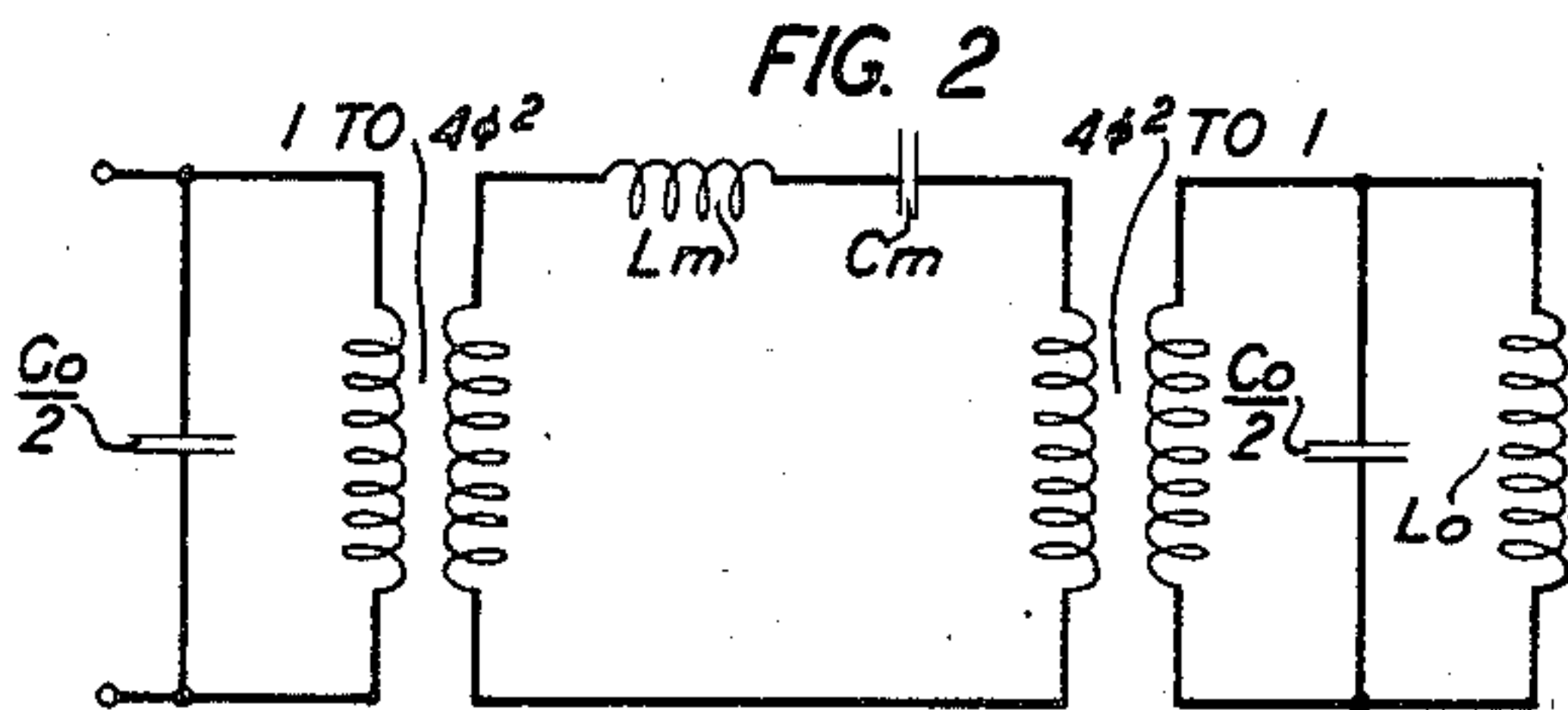
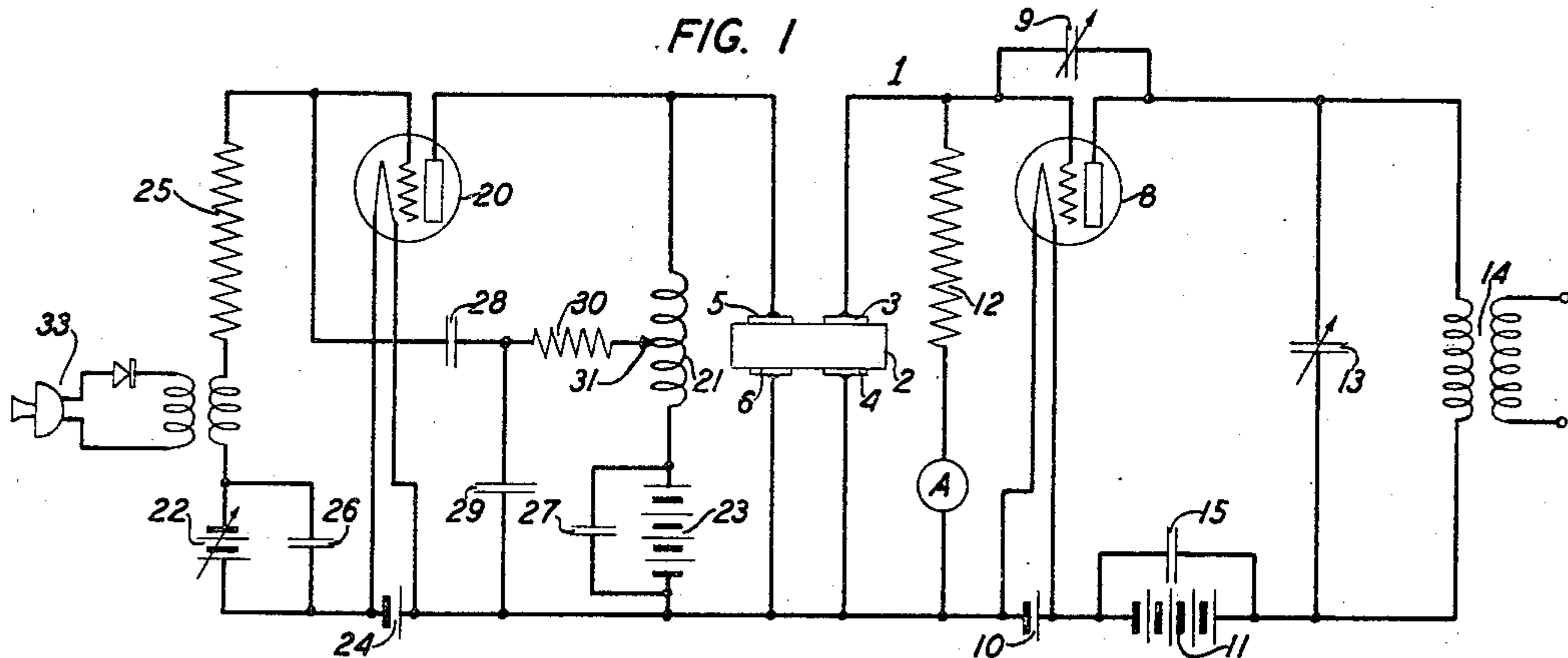
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2,424,246

FREQUENCY-MODULATED CRYSTAL OSCILLATOR

Filed Sept. 16, 1943

2 Sheets-Sheet 1



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FREQUENCY-MODULATED CRYSTAL OSCILLATOR

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2 Sheets-Sheet 2

FIG. 5

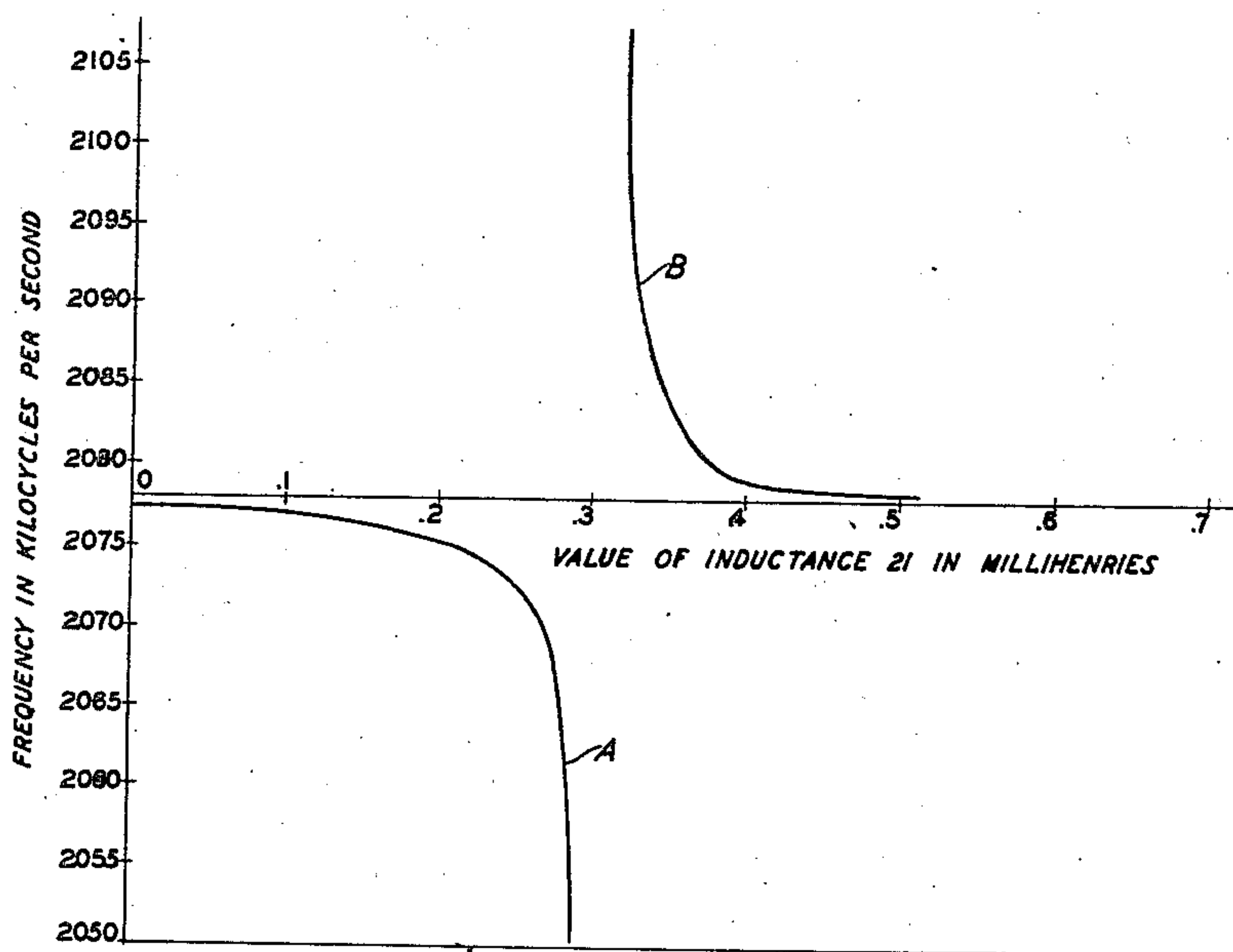


FIG. 6

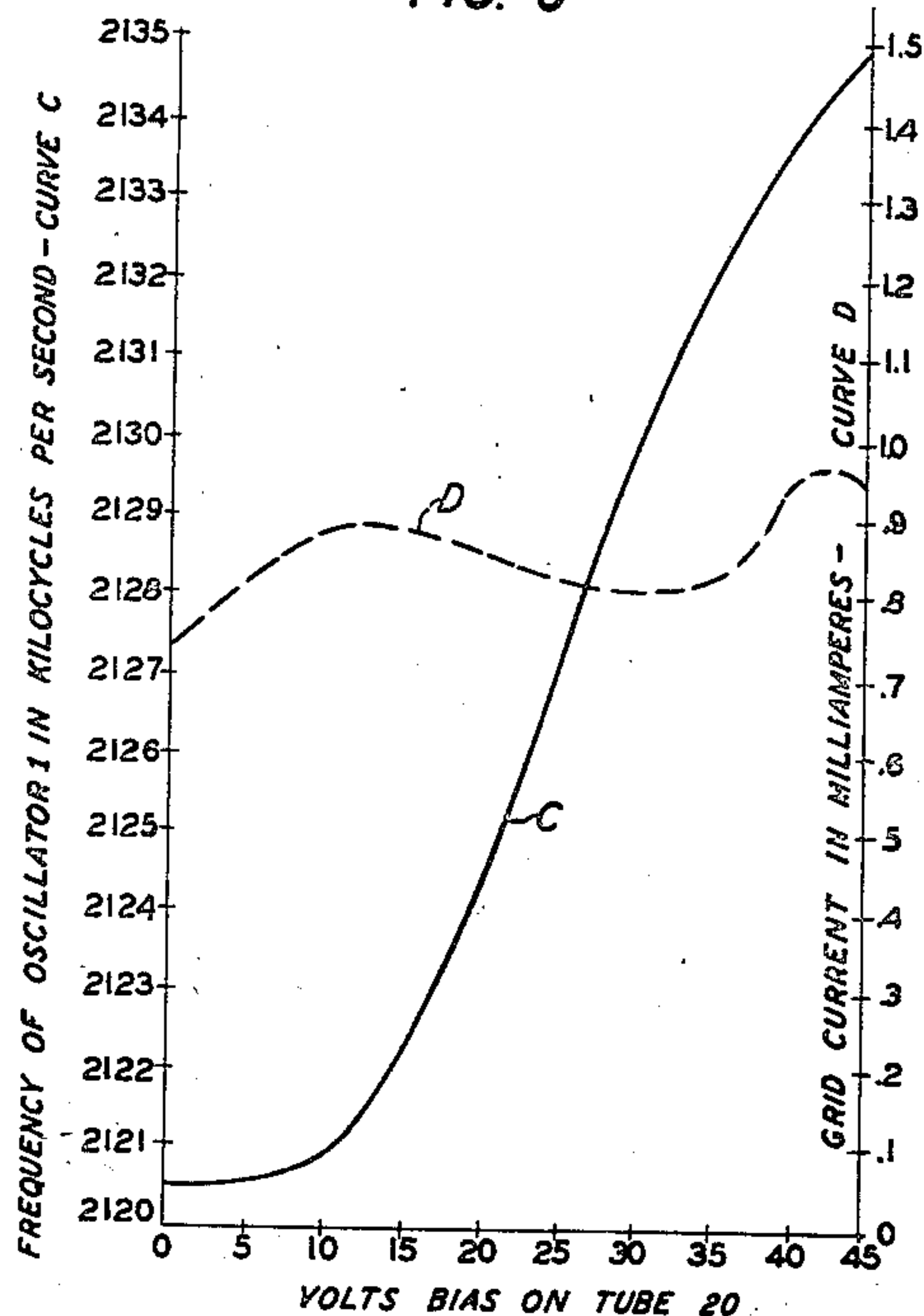
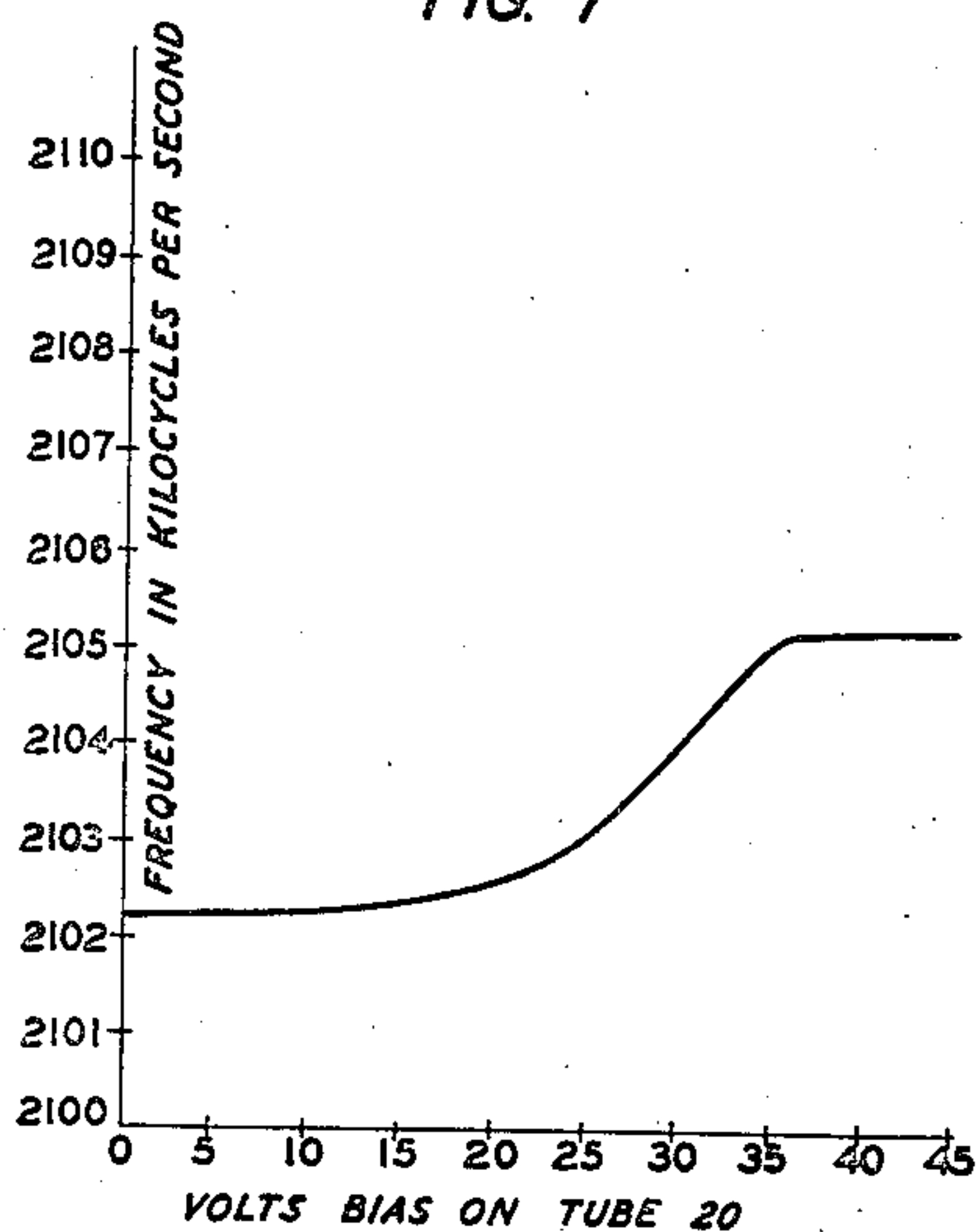


FIG. 7



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FREQUENCY-MODULATED CRYSTAL
OSCILLATOR

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Application September 16, 1943, Serial No. 502,560

4 Claims. (Cl. 179—171.5)

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This invention relates to frequency-modulating systems and particularly to frequency-modulating systems and apparatus that may be utilized for varying or modulating the frequency of quartz or other crystal-controlled oscillation generators, for example, or of other types of crystal-controlled frequency-modulated circuits.

One of the objects of this invention is to control the operating mechanical characteristics of a vibratory piezoelectric crystal element, such as a quartz or other type of piezoelectric crystal element.

Another object of this invention is to utilize a piezoelectric crystal element for varying or modulating the frequency of the circuit in which it may be connected.

Another object of this invention is to provide a simple method for frequency modulating a crystal oscillator without losing its inherent frequency controlling stability.

In accordance with this invention variable positive reactance means, such as a variable reactance tube and an inductance coil of suitable reactance values, may be connected with and utilized in combination with a vibratory piezoelectric crystal element such as a quartz or other type of piezoelectric crystal element. The reactance of the reactance means and the reactance of the crystal element may be made of suitable related values with respect to one another in order to effectively control the operating characteristics and the frequency of the crystal element which may in turn be utilized to control the frequency of an oscillation generator or any other circuit the frequency of which is to be controlled by the crystal element.

The crystal element and the variable positive reactance tube means may be utilized as a frequency-modulation system for any type of crystal-controlled oscillation generator, and the same crystal element may be utilized not only for controlling the frequency of the oscillation generator but also for modulating the frequency thereof in accordance with rectified voice or other signal currents, the reactance tube means being utilized to produce a positive reactance that is controlled and varied by the amplitude of the signal currents applied thereto in order to correspondingly change the reactance characteristics of the crystal element, thereby causing the frequency of the crystal element and the oscillator generator associated therewith to change in accordance with the amplitude of the signal currents that may be applied to the input or grid circuit of the reactance tube means.

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The frequency-modulation system provided in accordance with this invention may be utilized to vary or modulate the frequency of a crystal-controlled oscillation generator over relatively wide frequency limits, without losing the inherent frequency stability of the crystal element. In a particular frequency-modulated crystal oscillator using a split plating form of electroded quartz crystal element with applied voltage bias on the grid of the reactance tube, a crystal frequency variation was obtained of about 15.3 kilocycles per second in a crystal element of about 2,100 kilocycles per second, corresponding to a crystal frequency variation of about 0.73 per cent. Using another setting in the same crystal oscillator gave about a 3 kilocycle per second crystal frequency variation with a more stable output.

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 circuit diagram illustrating a frequency-modulated crystal oscillator system embodying this invention;

Figs. 2, 3 and 4 are diagrams illustrating characteristics of crystal elements and reactance means utilized in this invention;

Figs. 5, 6 and 7 are graphs illustrating some experimental results obtained in operating a particular frequency-modulated crystal oscillator of the type shown in Fig. 1; and

Fig. 8 is a circuit diagram illustrating a modification of the system shown in Fig. 1.

Referring to the drawing, Fig. 1 is a circuit diagram illustrating an embodiment of the invention as applied to a crystal-controlled oscillation generator 1 the frequency of which is controlled by a piezoelectric crystal element 2 which may be of any suitable type. As illustrated in Fig. 1, the crystal element 2 may be provided with two effective pairs or sets of oppositely disposed electrodes or coatings 3, 4, 5 and 6, one set of electrodes consisting of the opposite electrodes 3 and 4 being utilized to control the frequency of the oscillation generator 1, as shown in Fig. 1. The particular illustrative example given in Fig. 1 for the oscillator generator 1 comprises a triode oscillator tube 8, a coupling condenser 9, suitable voltage supply sources 10 and 11 for the cathode and plate electrodes of the vacuum tube 8, a grid-cathode resistance 12, a tuned output circuit which may consist of a parallel-connected con-

condenser 13 and output transformer 14. The condenser 15 is a by-pass condenser. The connections of the component elements of the oscillation generator 1 are conventional, the crystal element 2 and the grid resistance 12 being connected in the grid-cathode or input circuit of the electron tube 8, and the parallel-connected tuning condenser 13 and inductor 14 being connected in the plate-cathode or output circuit of the oscillator tube 8. The by-pass condenser 15 is shunted across the plate supply battery source 11. It will be understood that the oscillation generator circuit 1 of Fig. 1 may be any suitable oscillator circuit the frequency of which is to be controlled by the piezoelectric crystal element 2 connected therewith in any suitable manner, the particular oscillation generator circuit 1 shown in Fig. 1 being an illustrative example only.

The piezoelectric crystal element 2 may be any suitable quartz crystal element or may be any other type of piezoelectric crystal element such as a crystal element of tourmaline, Rochelle salt, or ammonium dihydrogen phosphate, for example. The frequency of the crystal element 2 may be made of any desired value, and may be determined either by the thickness dimension thereof or by the large or face dimensions thereof according to the particular crystal element selected. As an example for a relatively low frequency face-mode quartz crystal element, the crystal element 2 may be a GT cut crystal element of the type disclosed, for example, in W. P. Mason Patent 2,204,762, dated June 18, 1940. As an example for a relatively high frequency thickness-mode quartz crystal element, the crystal element 2 may be an AT or BT cut crystal element of the type disclosed for example in Lack et al. Patent 2,218,200, dated October 15, 1940, and R. A. Sykes Patent 2,306,909, dated December 29, 1942. The GT cut quartz crystal element as disclosed in W. P. Mason Patent 2,204,762, dated June 18, 1940, may be utilized when a relatively low, frequency crystal element is desired, and has the advantage of very high temperature-frequency stability. The AT or BT cut crystal elements are low temperature-frequency coefficient crystal elements which may be utilized where a higher frequency crystal element is desired. It will be understood, however, that the crystal element 2 of Fig. 1 may be any suitable piezoelectric crystal element.

As illustrated in Fig. 1, the crystal element 2 is provided with two sets of oppositely disposed electrodes 3, 4, 5 and 6, which may be formed integral with the quartz or other crystal body 2 and which may be composed of any suitable conductive material such as evaporated gold or silver, for example. The two lower electrodes 4 and 6, instead of being divided or split along the center line of the major face of the crystal element 2 as illustrated in Fig. 1 may be united into a single electrode coating and used with the two separated top electrodes 3 and 5 to form the two effective sets of electrodes for the crystal element 2.

As illustrated in Fig. 1, one set of the crystal electrodes comprising the set of opposite electrodes 3 and 4 is connected with the grid and cathode electrodes of the oscillator tube 8 and functions to control the frequency of oscillations generated in the oscillation generator 1. A variable reactance tube 20 and an inductance coil 21 are connected with the second set of crystal electrodes 5 and 6 and function to control and modulate the resonant frequency of the crystal element 2, the resonant frequency of which may be conven-

iently varied by some 0.5 per cent or more as described more fully hereinafter. In order to maintain the non-modulated frequency of the crystal element 2 constant to around some five parts in a million, the grid bias of the reactance tube 20 may be held constant to about one part in a thousand by means of a stable source of substantially constant voltage 22.

The reactance tube 20 may be provided with a suitable plate supply voltage from a source 23, and with cathode current from a supply source 24. A grid resistance 25 is connected with the grid of the reactance tube 20. Condensers 26 and 27 are by-pass condensers connected in shunt circuit relation with the voltage supply sources 22 and 23 respectively. Condensers 28 and 29 and a resistance 30 are also provided. The resistance 30 may be connected to a tap 31 on the coil 21. The condenser 28 functions to prevent the direct current voltage of the source 23 from being applied to the grid of the tube 20. The resistance 30 and condenser 29 function to produce the correct phase on the grid of the tube 20. The connections of the component elements involved in the input and the output circuits of the reactance tube 20 are as follows: The set of crystal electrodes 5 and 6 are connected across the plate-cathode or output circuit of the reactance tube 20. The inductance coil 21 connected in series circuit relation with the by-pass condenser 27 is connected across the output circuit of the reactance tube 20, and, as particularly illustrated in Fig. 1, is disposed in shunt relation with the set of electrodes 5 and 6 of the crystal body 2. The resistor 30 is connected at one of its ends to the tap connection 31 on the inductance coil 21 and at its other end the resistor 30 is connected to the condensers 28 and 29, the condenser 28 being connected between the resistance 30 and the control grid or input electrode of the reactance tube 20 and the condenser 29 being connected at one of its ends to the cathode of the reactance tube 20 and at its other end to the condenser 28 and the resistance 30. The grid-cathode or input circuit of the reactance tube 20 comprises the grid resistor 25 connected in series circuit relation with the parallel-connected voltage source 22 and by-pass condenser 26. Currents from a signal source 33 may be impressed across the input circuit of the reactance tube 20 in any conventional manner, as by means of a series-connected transformer therein for example.

As an illustrative example, the circuit elements of a particular frequency-modulated crystal oscillator constructed in accordance with the circuit of Fig. 1 may have values roughly as follows: The tubes 8 and 20 may be type 205-D vacuum tubes or other suitable thermionic tubes. The plate supply sources 11 and 23 may be of 120 volts direct current or of other suitable plate supply voltage for the tubes 8 and 20. The crystal element 2 may be an AT cut thickness shear mode crystal element having a thickness-mode frequency of about 2,100 kilocycles per second, for example. The condenser 13 and inductance windings 14 may be of any suitable values to provide a tuned output circuit for the oscillation generator 1. The grid resistance 12 for the oscillator tube 8 may be about 100,000 ohms or other suitable value. The grid resistance 25 for the reactance tube 20 may have a resistance value of about one megohm, and the source 22 may be of about 45 volts direct current. The resistance 30 may have a resistance value of about 100,000 ohms, and the condenser 28 may have a capac-

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itance of about .005 microfarad or other suitable value to keep direct current voltage from the source 23 off the grid of the reactance tube 20. The condenser 29 may have a capacitance of about 5 micromicrofarads or other suitable value. The values of the reactances of the inductance coil 21 and of the reactance tube 20 are adjusted to suit the reactance of the static capacitance of the crystal element 2, as more fully described elsewhere in this specification.

The reactance tube 20 may be any suitable vacuum tube which taken with the inductance coil 21 has a positive reactance value which is near to or in the neighborhood of the reactance value of the static capacitance of the crystal element 2 and hence may operate as a modulating reactance to vary the resonant frequency of the crystal element 2 by changing the mechanical properties of the crystal element 2. By the term "positive reactance," is meant that the reactance value of the tube 20 and coil 21 as measured from terminal 31 to ground exhibits a positive reactance similar to that measured for an inductance coil.

The change in the mechanical properties of the split-plated crystal element 2 is due to its termination in positive reactances 20 and 21 of a definite control value. The reactance tube 20 may be used for producing the control value of the reactance and for varying the reactance of the inductance coil 21 in such a way that the mechanical properties of the crystal element 2 are changed, thereby causing the frequency of the oscillation generator 1 to change correspondingly. The modulated reactances 20 and 21 are placed across one set of the opposite crystal electrode coatings 5 and 6 and being a variable reactance of suitable value with respect to the static reactance of the crystal element 2, the resonance frequency of the crystal element 2 is changed correspondingly.

Fig. 2 is a diagram illustrating the equivalent circuit of the piezoelectric crystal element 2 of Fig. 1 that has two sets of opposite crystal electrodes 3, 4, 5 and 6, one set of which, such as the electrodes 5 and 6, is connected across or in parallel circuit relation with an inductance winding which may be the inductance coil 21 of Fig. 1 and which is designated L_0 in Fig. 2. The equivalent circuit shown in Fig. 2 for the divided plating crystal element 2 of Fig. 1 consists of a capacitance labeled $C_0/2$ in Fig. 2, which is equal to one-half the static capacitance C_0 of the crystal element 2, an electromechanical transformer of ratio 1 to $4\phi^2$ as shown in Fig. 2, a series resonant circuit designated L_M, C_M in Fig. 2 which represents the mechanical elements of the piezoelectric crystal element 2 of Fig. 1, another electromechanical transformer $4\phi^2$ to 1, and a shunt capacitance $C_0/2$ which represents the set of electrode plates 5 and 6 of the crystal element 2 of Fig. 1. For information on the nature of the transposition ratio $4\phi^2$, reference is made to page 205 of the book "Electromechanical Transducers and Wave Filters," D. Van Nostrand, by the applicant (Figs. 6, 7).

As shown in Fig. 2, the electromechanical transformer labeled, $4\phi^2$ to 1 and the shunt capacitance $C_0/2$ representing the crystal circuit for the set of electrodes 5, 6 of the crystal element 2 is terminated in the inductance L_0 . Bringing the inductance L_0 and the capacitance $C_0/2$ of Fig. 2 through the electromechanical transformer $4\phi^2$ to 1 of Fig. 2, the resulting network

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is as shown in Fig. 3. The individual reactance curves of the two elements comprising the crystal element and the inductance L_0 are shown in Fig. 4 by the broken lines, while the reactance curve for the combination crystal element and inductance L_0 is shown by the solid line curve of Fig. 4.

As shown by Fig. 4, when the antiresonance frequency of the capacitance $C_0/2$ and the inductance L_0 of Figs. 2 and 3 is above the natural resonance frequency f_R of the crystal element 2, the result will be to lower to f_R' the resonant frequency f_R of the crystal element 2. Moreover, as the antiresonance frequency f_A approaches the resonance frequency f_R of the crystal element 2, the value of f_R' may be made several per cent below the value of f_R . To take advantage of this characteristic, a reactance tube 20 of Fig. 1 may be placed across the electrodes 5 and 6 of the crystal element 2 of Fig. 1 and the reactance constants thereof adjusted so that a positive reactance variation is impressed across the crystal element 2 of Fig. 1. In practice, an inductance coil 21 may be added and shunted across the reactance tube 20 in order to make the reactance variation applied to the crystal element 2 come in the proper reactance range. Then when rectified voice or signal currents from a microphone or other signal source 33 are impressed across the grid input circuit of the reactance tube 20 of Fig. 1, the resonant frequency of the crystal element 2 may be made to change some 0.5 per cent or more in proportion to the amplitude of the voice or other signal currents which may be applied to the input circuit of the reactance tube 20. If the crystal element 2 be one having a low or zero temperature coefficient of frequency, the mechanical elements thereof, designated L_M and C_M in Figs. 2 and 3, will change very little with temperature so that the frequency of the crystal controlled oscillator 1 of Fig. 1 will be nearly independent of temperature. In order to maintain a high constancy for the mean crystal frequency, in the absence of modulation, it is required that the voltage bias from the direct current source 22 of Fig. 1 on the grid electrode of the reactance tube 20 be maintained at nearly constant value, in order to provide a constant reactance across the crystal element 2. As an example, if the total variation of the crystal frequency caused by voltage bias changes on the grid of the reactance tube 20 is to be about 0.5 per cent, then in order to maintain a frequency constancy of about 5 parts in a million, due to voltage bias changes when no modulation is present, the voltage bias from the source 22 may be maintained constant to about one part in a thousand.

Fig. 5 is a graph illustrating the change in frequency of a crystal oscillator of the type illustrated at 1 in Fig. 1, when operated with variable inductance such as may be provided by an inductance coil 21 placed across the secondary electrode platings 5 and 6 of the crystal element 2. More particularly, Fig. 5 illustrates the effect of adding varying values of inductance across one pair of the crystal electrodes 5 and 6 upon the frequency of oscillations generated in a particular crystal-controlled oscillation generator 1 of the type illustrated in Fig. 1. The particular crystal element 2 used in obtaining the data for the example illustrated by the graph in Fig. 5 was a thickness shear mode AT cut type of crystal element 2 having two sets of oppositely disposed electrodes formed integrally with the major faces thereof, one set of electrodes 3 and 4 being

connected with the oscillation generator circuit 1 and the other set of electrodes 5 and 6 being connected across an inductance coil such as the inductance coil 21 of Fig. 1. Using the two sets of crystal electrodes 3, 4, 5 and 6 referred to, the thickness-mode frequency obtained was about 2078 kilocycles per second, which corresponds to the second thickness shear mode of motion excited in such a crystal element 2 by the oscillator 1 when the electrodes 5 and 6 are open-circuited. When the electrode plates 5 and 6 thereof were short-circuited, the crystal frequency dropped slightly to a value of about 2077.115 kilocycles per second. The effect of adding inductance by means of a coil 21 placed across the crystal electrodes 5 and 6 of the crystal element referred to is shown in Fig. 5. Inductances having reactance values that are smaller than the reactance of the static capacitance of the crystal element 2 cause the frequency thereof to decrease with increasing values of inductance, as illustrated by the curve A of Fig. 5. Also, inductances having reactance values that are slightly larger than the reactance of the static capacitance of the crystal element 2 cause the upper resonance frequency thereof to decrease with increasing values of inductance, as illustrated by the curve B of Fig. 5. To obtain a relatively large change of resonant frequency in the crystal element 2, it is necessary to use and vary the reactance of the reactance tube 20 and coil 21 in the neighborhood of the static reactance value of the crystal element 2, since a reactance change therein at any other value will not have very much effect on the resonant frequency of the crystal element 2. Accordingly, to obtain a relatively large change in the resonant frequency in the crystal element 2 of Fig. 1 by means of a change in bias or modulating voltage applied to the input grid circuit of the reactance tube 20 of Fig. 1, the reactance of the tube 20 may be made to have a value such that the plate impedance of the reactance tube 20 is reasonably low so that the reactance component of the reactance tube 20 will then not be too high to affect the shunting reactance coil 21 appreciably. For this reason, the reactance tube 20 may be a low impedance triode 20 or other suitable relatively low impedance tube cooperating with the shunting reactance coil 21, the reactance of which is varied in the neighborhood of the static reactance of the crystal element 2. The static reactance of the crystal element 2, which may have a reactance value of around 4,000 ohms, for example, or other value, will vary according to the particular crystal element selected.

In a particular case, using a particular AT cut crystal element in the circuit arrangement of Fig. 1 provided with a suitable shunting coil 21 and shunting capacitances 28 and 29 for the reactance tube 20, the operating output frequency of the crystal-controlled oscillator followed curve B of Fig. 5. By varying the voltage bias from the source 22 or other rectified source of currents as applied to the grid of the reactance tube 20, the crystal oscillator frequency may be changed as shown in Fig. 6.

Fig. 6 is a graph illustrating the frequency changes and the grid current changes in a particular frequency-modulated crystal oscillator of the type shown in Fig. 1, for varying values of voltage bias applied to the grid circuit of the reactance tube 20. With a fixed voltage bias of about 27.5 volts negative applied to the grid of

the tube 20 from the direct current source of voltage 22 and a variable voltage of about ± 7.5 volts above and below the voltage value of 27.5 volts mentioned, a crystal frequency change of about 9 kilocycles per second was obtained about a means crystal frequency of about 2130 kilocycles per second, as shown by the curve C of Fig. 6. Over this 9 kilocycles per second frequency range, the grid current of the oscillator tube 8 does not change more than about six per cent, as shown by the curve D of Fig. 6 so that the output of the oscillator 1 does not have much amplitude modulation over the modulation frequency range mentioned.

In this method of frequency modulating a crystal oscillator, it will be noted that a relatively wide frequency variation may be obtained in the crystal element 2 by means of a variation in applied voltage bias on the input circuit of the reactance tube 20. As shown in Fig. 6, a crystal element 2 when used in combination with the reactance tube 20 and the shunting reactance coil 21, may have an output circuit frequency variation of some 15.3 kilocycles per second between the crystal frequency values of about 2120 and 2136 kilocycles per second, which represents a crystal frequency variations of some 0.75 per cent as obtained with voltage bias variation applied to the grid circuit of the reactance tube 20. Over about 9 kilocycles of this 15.3 kilocycle per second range shown in Fig. 6, the crystal frequency variation may be quite linear with voltage change, the output being changed but little. This 15.3 kilocycle per second frequency range may be somewhat larger than may be required or desired for many frequency modulation systems and moreover comes at a reactance setting of the reactance tube 20 and reactance coil 21 where the frequency of the crystal element 2 depends to quite an extent upon the reactance value of the shunting reactance coil 21. Accordingly, another value for the reactance setting of the reactance coil 21 may be desirable in order to give a smaller output frequency change and one that may be more linear with bias voltage change such as, for example, a 3 kilocycle per second output frequency change in the crystal frequency of about 2100 kilocycles per second, as illustrated by the particular example given in Fig. 7.

Fig. 7 is a graph illustrating an example of a smaller range in the crystal frequency change of the frequency-modulated crystal oscillator circuit of Fig. 1 when provided with a different setting in the reactance values of the variable reactance means used with the same crystal element, as compared with those values that were used in obtaining the curves of Fig. 6. The different setting referred to involves the addition of a slight additional amount of capacity that may be provided by a condenser put in parallel with the inductance coil 21 of Fig. 1 and which moves the operation further up the reactance curve, resulting in a smaller variation of output frequency with applied variable bias voltage, as shown in Fig. 7 where a frequency variation of about 3 kilocycles per second is obtained with a voltage bias of about 27.5 volts on the grid of the tube 20 and about ± 7.5 volts change therein. As shown in Fig. 7, the crystal output frequency change is linear over a range of about 2.5 kilocycles of the three kilocycles per second range referred to, and the average frequency is quite stable with small changes in the reactance of the coil 21, in the bias voltage applied to the

tube 20, and similar small changes in other circuit parameters. To hold the mean frequency within about 100 parts in a million, for example, requires a coil and condenser stability of about 0.25 per cent. Since coil and condenser temperature coefficients are of the order of about 30×10^{-6} per degree centigrade, this would allow about a 100-degree centigrade change. When tubes are changed, it may be desirable to adjust any resulting capacity difference by means of a small variable condenser. The voltage bias applied to the grid of the tube 20 from the direct current battery source 22 should be kept constant to within about $\pm \frac{3}{4}$ of a volt or less for stability in the mean operating frequency of the crystal element 2.

Fig. 8 is a circuit diagram showing a modification of the frequency-modulated crystal controlled oscillation generator illustrated in Fig. 1, modified to provide the crystal element 2 with a single pair of electrodes 3a and 4a which are connected in the grid circuit of the oscillator tube 8 in series with the inductance coil 21 provided with the proper value of reactance. The reactance of the inductance coil 21 of Fig. 8 is varied by means of the reactance tube 20 in the manner heretofore described in connection with Fig. 1. As in the case of the arrangement illustrated in Fig. 1, the reactance of the inductance coil 21 of Fig. 8 is made to have very nearly the same reactance as the static capacitance of the crystal element 2 in order to obtain the optimum effect of frequency variation in the crystal element 2 with variations in the voltage bias applied to the grid of the reactance tube 20 from the source 22. A condenser 32 may be connected in series circuit relation with the crystal element 2 and the inductance coil 21 and may be utilized for the purpose of obtaining a fine adjustment of the mean frequency of the oscillator.

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. Apparatus for varying and controlling the frequency of oscillation of an oscillation generator comprising a piezoelectric crystal body having not more than two effective sets of electrodes, said electrodes comprising the sole effective capacitance producing means directly shunted across said crystal body, and means including said crystal body controlled by positive reactance means having a definite predetermined control value responsive to the amplitude of variable bias potential applied thereto for correspondingly varying the operating frequency of said crystal body and said oscillation generator, said positive reactance means comprising a variable reactance tube having anode, cathode and control grid electrodes, and an inductance coil disposed in circuit relation across said anode and cathode electrodes of said reactance tube and connected in operative circuit relation with said electrodes of said crystal body, said inductance coil having a tap connection thereon, a resistor connected at one of its ends to said tap connection on said inductance coil, and a condenser connected between the other end of said resistor and said cathode electrode of said reactance tube, and another condenser connected between said other end of said resistor and said control grid electrode of said reactance tube, said in-

ductance coil having an inductive reactance substantially greater than the anode circuit impedance of said reactance tube and substantially equal to the static capacitive reactance of said crystal body at said operating frequency of said crystal body, and means including a stable source of constant bias potential disposed in circuit with said control grid and cathode electrodes of said reactance tube for providing a constant mean value for said non-modulated frequency of said crystal body.

2. Apparatus in accordance with claim 1 wherein said crystal body has two effective sets of electrodes, one set of said two sets of electrodes being disposed in shunt circuit relation with said inductance coil and the other set of said two sets of electrodes being disposed in the grid-cathode input circuit of said oscillation generator.

3. Apparatus for varying and controlling the frequency of oscillation of an oscillation generator comprising a piezoelectric crystal body having a single pair of opposite electrodes, said electrodes comprising the sole effective capacitance producing means directly shunted across said crystal body, and means including said crystal body controlled by positive reactance means responsive to the amplitude of variable potential applied thereto for correspondingly varying the operating frequency of said crystal body and said oscillation generator, said positive reactance means comprising a variable reactance tube having anode, cathode and control grid electrodes, and an inductance coil disposed in circuit relation across said anode and cathode electrodes of said reactance tube and connected in series circuit relation with said single pair of electrodes of said crystal body, said inductance coil having a tap connection thereon, a resistor connected at one of its ends to said tap connection on said inductance coil, and a condenser connected between the other end of said resistor and said cathode electrode of said reactance tube, and another condenser connected between said other end of said resistor and said control grid electrode of said reactance tube, said inductance coil having an inductive reactance substantially equal to the static capacitive reactance of said crystal body at said operating frequency of said crystal body, and means including a stable source of constant bias potential disposed in circuit with said control grid and cathode electrodes of said reactance tube for providing a constant mean value for said non-modulated frequency of said crystal body, said single pair of electrodes of said crystal body being connected in series circuit relation with said inductance coil in the control grid-cathode input circuit of said oscillation generator.

4. Apparatus for varying and controlling the frequency of oscillation of an oscillation generator comprising a piezoelectric crystal body having a single pair of opposite electrodes, said electrodes comprising the sole effective capacitance producing means directly shunted across said crystal body, and means including said crystal body controlled by positive reactance means having a definite predetermined control value responsive to the amplitude of variable bias potential applied thereto for correspondingly varying the operating frequency of said crystal body and said oscillation generator, said positive reactance means comprising a variable reactance tube having anode, cathode and control grid electrodes, and an inductance coil disposed in circuit rela-

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tion across said anode and cathode electrodes of said reactance tube and connected in series circuit relation with said single pair of electrodes of said crystal body, said inductance coil having a tap connection thereon, a resistor connected at one of its ends to said tap connection on said inductance coil, and a condenser connected between the other end of said resistor and said cathode electrode of said reactance tube, and another condenser connected between said other end of said resistor and said control grid electrode of said reactance tube, said inductance coil having an inductive reactance substantially greater than the anode circuit impedance of said reactance tube and substantially equal to the static capacitive reactance of said crystal body at said operating frequency of said crystal body, and means including a stable source of constant bias potential disposed in circuit with said control grid and cathode electrodes of said reactance tube for providing a constant mean value for said non-modulated frequency of said crystal body, said single pair of electrodes of said crystal body being connected in series circuit relation with said inductance

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tance coil in the control grid-cathode input circuit of said oscillation generator, and a series-connected condenser in said last-mentioned circuit connected in series circuit relation with said crystal body and said inductance coil for adjusting the mean value of said frequency of said oscillation generator.

WARREN P. MASON.

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