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2,483,438

FREQUENCY MODULATION SYSTEM

Filed June 9, 1945

2 Sheets-Sheet 1

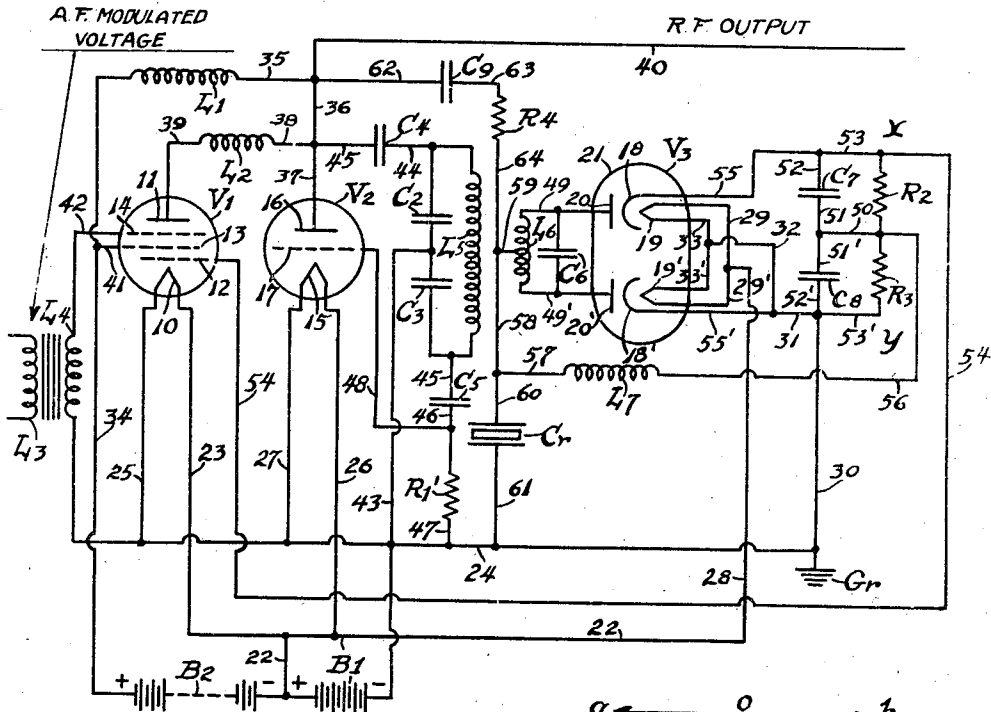


Fig. 1.

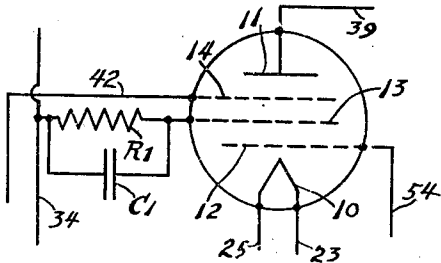


Fig. 2.

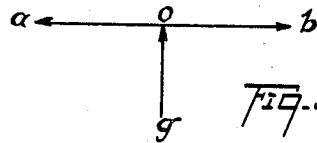


Fig. 3.

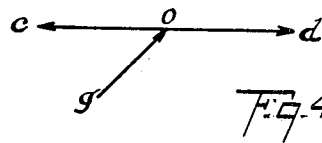


Fig. 4.

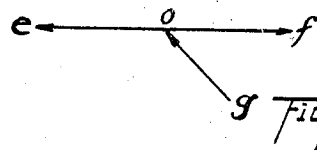


Fig. 5.

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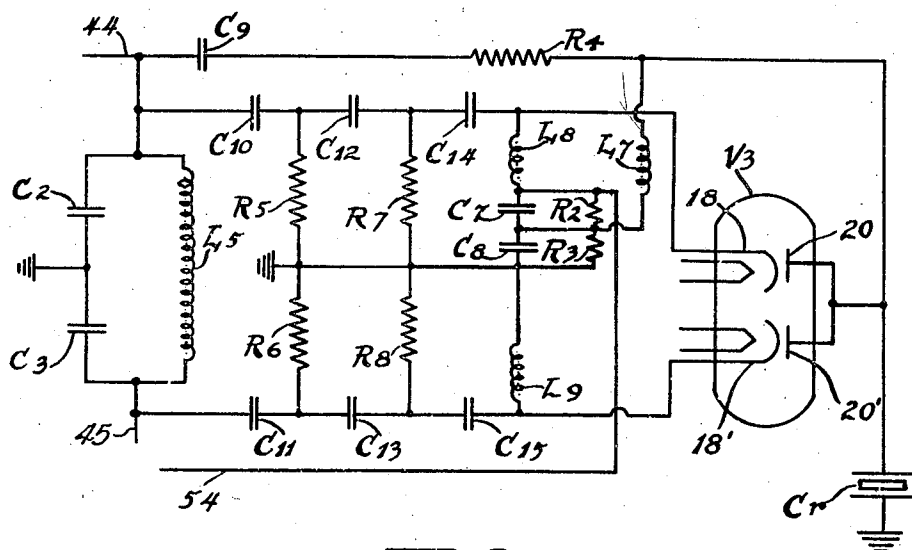
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FREQUENCY MODULATION SYSTEM

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2 Sheets-Sheet 2



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FREQUENCY MODULATION SYSTEM

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7 Claims. (Cl. 332-19)

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This invention relates to means for producing frequency-modulated electrical oscillations, where the frequency modulation has a relatively limited range, as for instance, in frequency modulated telegraph systems.

The advantages of frequency-modulated electrical oscillations are well understood by those skilled in the art, but, unfortunately, it is difficult to maintain the frequency modulations at a predetermined central value. Hence, much attention has been given to the development of apparatus for this purpose, but up to the present time the apparatus heretofore known has necessitated such complex circuit systems and instrumentalities as to introduce difficulties in maintenance of proper operating conditions which largely detract from the merits of the frequency-modulated system.

It is a principal object of the present invention to provide in a system for the production of frequency-modulated electrical oscillations of limited range, a control means which will be relatively simple and free from the disadvantages of the complex apparatus heretofore employed.

With this general object in view and some others which will be apparent to those skilled in the art from the description of the best embodiment of the invention hereinafter given, the invention broadly considered includes, in combination with apparatus for developing frequency-modulated electrical oscillations, a control means which will develop a grid-biasing voltage which is the resultant of two out-of-phase voltages, one of a substantially constant value and the other varying as a direct function of the departure of the frequency modulations from the predetermined average or central value for which the system is adjusted. The grid-biasing voltage is applied to a suitable control grid of the apparatus which produces the frequency-modulated electrical oscillations to thereby compensate for and offset the departure of the frequency modulations from the central value and thereby maintain the required center frequency.

In the embodiment of the invention hereinafter set forth the means for developing the frequency-modulated electrical oscillations includes an oscillator vacuum tube of the triode type, a reactance tube advantageously of the pentode type, means for applying audio frequency modulations to one of the grids, usually the so-called suppressor grid, of the pentode, and connections between the tubes whereby frequency-modulated electrical oscillation will be developed at the plate of the oscillator tube.

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In combination with the above apparatus, the invention comprises an oscillating tank-circuit resonant at a predetermined frequency and energized from the oscillator plate, a connection from the tank-circuit to the grid of the oscillator, means for developing from the tank-circuit an oscillating current 90° out of phase with relation to the current in the tank-circuit, a pair of half wave rectifier devices, such for example as a double diode vacuum tube or full wave rectifier having separate anodes and cathodes which will rectify both the positive and also the negative waves of the current which is 90° out of phase with relation to the current in the tank-circuit, a network in the nature of a double filter system, energized at opposite ends by the separately rectified positive and negative waves, a quartz crystal controller, means for impressing on the crystal controller a voltage direct from the oscillator, means for also impressing on the crystal controller a voltage derived from the full wave rectified current, whereby a suitable reaction is obtained, from the crystal controller means, which, through suitable connections, impresses on a suitable control grid of the apparatus a corrective voltage to prevent too great a departure of the frequency modulations from the central value.

The invention further comprises the novel features, details, instrumentalities and combinations which will be apparent to those skilled in the art from the description hereinafter given of the best embodiment of the invention taken in connection with the accompanying drawings.

In the drawings,

Fig. 1 is a diagrammatic view illustrating the invention employing a transformer type of phase-changer;

Fig. 2 is a detailed diagrammatic view showing a slight modification of the connections to the screen grid of the reactance tube, which is of considerable advantage under certain conditions;

Figs. 3, 4 and 5 are diagrammatic views hereinafter referred to, and

Fig. 6 is a diagrammatic view illustrating a modification of the system of Fig. 1 in which a network phase-changer is employed.

Referring to Fig. 1, V₁ is a vacuum tube, in this case of the pentode type, using a heated filament as a cathode, indicated at 10, it being understood that a heater type of tube may be employed if desired. This tube V₁ constitutes a reactance tube having an anode or plate 11, a control grid 12, a screen grid 13 and a suppressor grid 14, employed as a second control grid.

At V₂ is indicated a vacuum tube of the triode

type which serves as an oscillator tube. While its cathode may be of the heater type, it is shown in the drawing as of the heated filament type, as indicated at 15. This oscillator tube has an anode or plate 16, and a control grid 17.

At V₃ is indicated a pair of diode rectifier devices, which in this embodiment of the invention are shown as contained in single envelope, thus constituting together a full wave or double diode rectifier, of the vacuum tube type.

In this double diode rectifier vacuum tube, V₃, the cathodes are indicated at 18 and 18', respectively, and are of the heated cathode type, the respective heating devices being indicated at 19 and 19', respectively.

For each diode a separate anode or plate is employed as indicated at 20 and 20', respectively. The common envelope for the pair of rectifiers is indicated at 21.

The filaments 10 and 15 of the tubes V₁ and V₂ as well as the heating devices 19 and 19' of the respective rectifying diodes of the double tube V₃ are arranged to be electrically heated in any desired way, advantageously by a common source of direct current, in the present case shown as a battery B₁. The filament 10 of the tube V₁ is connected to the battery B₁ by suitable conductors. In the present example, the filament 10 is connected to the positive bus conductor 22 of the battery B₁ by a branch conductor 23 and to a negative bus conductor 24 of the battery B₁ by a branch conductor 25, the negative bus being grounded at G.

The filament 15 of the tube V₂ is connected to the positive bus conductor 22 by a branch conductor 26 and to the negative bus conductor 24 by a branch conductor 27.

The two heating devices 19 and 19' of the double diode tube V₃ are connected in parallel to the positive bus conductor 22 of the battery B₁ over a branch conductor 28, having portions 29 and 29' leading to the respective heating devices 19 and 19'. The other side of each heating device is connected to the negative bus conductor 24 of the battery B₁ in any suitable way, as, for example, over a branch path indicated as comprising conductors 30, 31, 32, the latter having portions 33 and 33' leading to the respective heating devices 19 and 19'.

The anodes or plates 11 and 16 of the tubes V₁, V₂, respectively, have a predetermined positive voltage impressed upon them, as, for example, by a plate current battery B₂. In the present embodiment of the invention, the plate 16 of vacuum tube V₂ is connected to the positive pole of battery B₂ over conductor 34, radio frequency choke coil L₁ and conductors 35, 36 and 37.

The anode or plate 11 of tube V₁ is connected in parallel with the plate 16 of the tube V₂ over an inductance L₂ by conductor 38 (connected to conductor 37) and conductor 39.

A radio frequency output conductor is indicated at 40, this being connected to the plate circuit in a suitable way, as, for example, at the meeting point of conductors 35 to 36.

The screen grid 13 of tube V₁ is also impressed with positive voltage from the battery B₂ in any suitable way, as, for example, by connecting the screen grid 13 to the conductor 34 over a grid conductor 41. It is advantageous to include in the connection a resistor R₁ and a by-pass capacitor C₁ as shown in Fig. 2. Plate battery B₂ has its negative pole connected to the conductor 22 of battery B₁, thereby completing the circuits for

the respective plate currents through filaments 10 and 15.

Means for developing an audio frequency modulation voltage on the reactance tube V₁ are provided. In the present embodiment of the invention this means comprises a transformer having a primary inductor L₃ and a secondary inductor L₄ in suitable inductive relation to each other to give the required coupling.

The primary inductor is included in the usual audio frequency circuit arranged to be energized in any suitable way by audio frequency modulation currents, as will be fully understood by those skilled in the art and therefore needs no further description or illustration here. These audio frequency modulation currents induce the corresponding modulating voltages in the inductor secondary L₄, which is arranged to impress these modulating voltages on the tube V₁, as, for example, by connecting one end of the inductor secondary L₄ to the suppressor grid 14 of the tube V₁ by a grid conductor 42, and the other end of the secondary to the negative bus conductor 24 of the battery system.

An oscillator tank circuit is provided in connection with oscillator tube V₂, this comprising two capacitors C₂ and C₃ connected in series with each other and in shunt with an inductor primary L₅.

The junction joint of capacitors C₂ and C₃ is connected to the cathode of vacuum tube V₂ in any suitable way, as, for example, by a conductor 43 leading to the negative bus conductor 24.

The tank circuit has one terminal coupled to the plate circuit of the oscillator tube V₂ through a suitable blocking capacitor C₄ and conductors 44, 45 leading to the junction of conductors 36 and 37 of the plate circuit.

The other terminal of the tank circuit is connected to the grid 17 of vacuum tube V₂ through a capacitor C₅, via conductors 45, 46 and 48. Resistor R₁' serves as a grid leak connecting the grid 17 to the negative bus conductor 24 by means of conductors 47 and 48.

The tank circuit is designed, constructed and dimensioned as to inductance, capacitance and resistance to be resonant at the predetermined central frequency required for the oscillation currents.

Means are provided for developing a current which will be at all times 90° out of phase with the oscillatory current in the tank circuit. In the present embodiment of the invention this means comprises the inductor primary L₅ of the tank circuit and an inductor secondary L₆, inductively related to each other, the inductor secondary L₆ being connected at one end to the plate or anode 20 of the double diode tube and at the other end to the plate or anode 20' of the double diode tube by conductors 49 and 49', respectively. The inductor secondary L₆ is shunted by a capacitor C₆, connected between conductors 49 and 49' as shown, the inductor secondary L₆ and the capacitor C₆ being most advantageously so dimensioned as to provide a secondary tank circuit resonant at the center frequency of the oscillating current required.

It will be seen that the pair of diode rectifying devices will alternately rectify the half waves of the alternating current in the secondary tank circuit which is at all times 90° out of phase with the oscillating current in the primary tank circuit.

A network in the nature of a double filter system, one for each diode, has one terminal con-

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nected to the cathode of one diode rectifying device and another terminal connected to the cathode of the other rectifying device. In the present embodiment of the invention this network comprises capacitors C_7 and C_8 and resistors R_2 and R_3 connected by conductors 50, 51, 51', 52, 52', 53 and 53'. The junction of conductors 52' and 53' is connected to the grounded negative bus conductor 24.

The grid 12 of the reactance tube V_1 is connected by a grid control conductor 54 to a point on the network conductor 53 between the resistor R_2 and the capacitor C_7 , as shown in the drawing, Fig. 1.

The cathode 18 of one diode rectifying device is connected by a conductor 55 to the junction of conductors 52 and 53 of the network, while the cathode 18' of the other diode rectifying device is connected by conductor 55', and over conductor 31, to the junction of conductors 52' and 53'. As the negative bus conductor 24 is grounded as indicated at Gr, the above-mentioned junction point of conductors 52' and 53' will be kept, substantially, at ground potential.

The common junction of the capacitors C_7 and C_8 and resistors R_2 and R_3 , which is where the conductor 50 is connected intermediate the said resistors, is connected to the electrical mid point of the inductor secondary L_2 by conductor 56, radio frequency choke coil L_7 , and conductors 57, 58, and 59, this connection serving as the return path for the full wave rectified current.

At Cr is indicated a controlling device, comprising a control crystal, which in the present embodiment of the invention is shown as connected by conductors 60 and 61 between the return path for the rectified currents and the grounded negative bus conductor 24 of the battery B_1 . As shown, the connection of the controlling device is at the junction point of conductors 57 and 58 so that the radio frequency choke coil L_7 is between the crystal and the network.

Means are provided for applying a radio frequency voltage to the control crystal, this means, in the present embodiment of the invention, comprising a conductor 62 suitably connected to the plate circuit of tube V_2 , as, for example, at the junction of conductors 35 and 36, a blocking capacitor C_9 , conductor 63, resistor R_4 , conductor 64, and conductors 58 and 60, heretofore referred to.

The magnitude of the resistor R_4 is selected so that the current therethrough be substantially in phase with the radio frequency voltage existing between the anode 16 and ground. This means that both the reactance of the condenser C_9 and the impedance of the crystal Cr at the operating frequencies should be low compared with the value of resistance R_4 . The voltage across the control crystal will then be in phase with the oscillator voltage at the resonant frequency of the crystal, and will lead or lag that voltage by a sizable angle with slight deviations of frequency as will now be more fully described:

Referring now to Fig. 3, vector $g-o$ represents the voltage across the crystal when the frequency of the oscillator is equal to the resonant frequency of the crystal. The vectors $o-a$ and $o-b$ represent, respectively, the voltages across each half of the inductor secondary L_2 . The voltages applied to the double diode rectifier tube V_3 will be the vectorial sum of the vectors shown, $g-a$ being applied to one diode and $g-b$ to the other diode. Under the conditions assumed,

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these voltages will be equal and therefore equal currents will be rectified. Therefore, in the network, since the resistors R_2 and R_3 are of equal resistance, the potential between points x and y of the network will be zero and no corrective voltage will be applied to the control element or grid 12 of reactance tube V_1 .

Referring now to Fig. 4, if the frequency of oscillation is lower than the resonant frequency of the crystal, the reactance of the crystal will be capacitive, wherefore the voltage across the crystal will be represented by vector $g-o$ at an angle different from that shown in Fig. 3. In the best embodiment of the invention the circuit comprising inductor L_2 and capacitor C_8 has a relatively low Q (where $Q=\omega L/R$, a formula well known to those skilled in the art), either as a result of selection of the electrical constants of the circuit or by the insertion of resistors (not shown) in series with either the inductance or capacitance.

With a relatively low Q , the voltage across the secondary tank circuit will remain substantially as it would be at the resonant frequency of the crystal, as indicated by the vectors $o-c$ and $o-d$. The coupling between inductor L_2 and L_6 is such that a voltage, represented by a vector between g and d , applied to that part of the double diode connected to capacitor C_7 will develop a greater current charging such capacitor. The voltage applied to the other part of the double diode will be as represented by the vector $g-c$, whereby the resultant current charging the capacitor C_8 will be less.

As the charge in capacitor C_7 increases while the charge in capacitor C_8 decreases, the leakage current through resistor R_2 will exceed the current through resistor R_3 , so that there will be a differential voltage between points x and y , which results in an increase in voltage applied to the control grid 12 of the reactance tube V_1 .

As the control grid 12 becomes more positive, the internal impedance of the reactance tube V_1 decreases and the shunting effect of inductor L_2 upon the oscillating tank circuit, which includes L_2 , C_2 , and C_3 , increases, thereby increasing the frequency of oscillation.

Fig. 5 illustrates the vector relation when the frequency of oscillation is higher than the resonant frequency of the crystal. A voltage represented by the sum of vectors $g-o$ and $o-e$ will be applied to that part of the double diode connected to capacitor C_8 and a voltage represented by the sum of vectors $g-o$ and $o-f$ is applied to that part of the double diode connected to capacitor C_7 . The result is that the current which charges capacitor C_8 exceeds the current which charges capacitor C_7 , so that the point x of the network assumes a voltage which is negative with respect to the voltage at y . The application of this negative voltage to the control grid 12 of reactance tube V_1 will decrease the shunting effect of inductor L_2 upon the tank circuit and thereby decrease the frequency of oscillations.

It is particularly important that the charging currents flowing into capacitors C_7 and C_8 , respectively, will be integrated over several audio cycles. Hence, with the circuit system and instrumentalities of the invention, the control crystal will exercise a control of the center or mid frequency. Any tendency of the average frequency of operation to drift away from the resonant frequency of the crystal will be compensated for by a change in the effect of the reactance

tube V₁, as will be understood from the explanation hereinbefore given.

The effect of the modulating voltage applied through the transformer having inductors L₃ and L₄ to the other control grid (suppressor grid) 14 of the reactance tube V₁ is to vary the frequency of oscillation above and below the mid or center frequency which is determined by the crystal. This shift in frequency, however, should not exceed minimum and maximum frequency values such that the vector $g=0$ representing the voltage across the crystal does not rotate through an angle greater than 90° from its position as shown in Fig. 3.

Even though the frequency of oscillation departs from the resonant frequency of the crystal the latter will exert a stabilizing effect and maintain the required average frequency of oscillations, because of the integrating effect of the capacitors C₇ and C₈ in storing the rectified currents for several audio cycles.

It will be obvious to those skilled in the art that the principle involved in the system disclosed in detail above and illustrated in Fig. 1 may be embodied in other circuit systems than that illustrated in said Fig. 1. For example, both anodes or plates 20 and 20' of the two diode rectifiers may be connected together and to the ungrounded terminal 60 of the crystal control device, and current may be taken from each end of inductor L₅ through a network designed to give a 90° phase shift from the oscillator voltage so as to provide a potential, which may then be applied to the cathodes of the double diode rectifier V₃.

Such a modified system is illustrated in Fig. 6, and will be obvious to those skilled in the art from the description hereinbefore given in connection with Fig. 1. The phase changing network is shown by capacitors C₁₀ and C₁₂ together with resistors R₅ and R₇ for cathode 18 and capacitors C₁₁ and C₁₃ together with resistors R₆ and R₈ for cathode 18' of vacuum tube V₃. Blocking capacitors C₁₄ and C₁₅ serve to isolate the rectified currents and R-F choke coils L₈ and L₉ provide paths for the return currents.

The phase shifting network shown in Fig. 6 is designed so that the voltages appearing on the cathode-connected terminals of condensers C₁₄, C₁₅, respectively, will be symmetrical in phase, preferably in quadrature, with respect to the voltage of the oscillator output taken from anode 16. This voltage, by virtue of the high value of resistor R₄, will again be in phase with the voltage across the crystal Cr at the resonant frequency of the latter. With the network suitably balanced with respect to ground, equal and substantially opposite potentials will appear on the cathodes 18, 18' of tube V₃ and the voltage applied to each diode portion of that tube will again be the resultant of two out-of-phase vectors as explained with reference to Figs. 3, 4, and 5. Leads 44, 45 serve to connect the tank circuit to the anode and grid, respectively, of oscillator tube V₂, and the common terminal of condensers C₂, C₃ of this circuit is grounded as is the case in the arrangement of Fig. 1. Conductor 54 again represents the feedback path to the grid 12 of reactance tube V₁.

What is claimed is:

1. A frequency modulation system of the type wherein a corrective voltage to compensate for deviations from a mean frequency is used to vary the operating frequency of an oscillator modulated by audio frequency, comprising a control circuit, phase shifting means for applying to said

control circuit two equal and substantially opposite voltages alternating at said operating frequency, piezo-electric crystal means connected across the control circuit for applying thereto an additional voltage alternating at the same frequency, said last voltage being symmetrical in phase with respect to said first two voltages at the resonant frequency of said crystal means, means for respectively combining said last voltage with said first two voltages, and means including an integrating network for deriving said corrective voltage from said combined voltages, said integrating network having a time constant of a value such as to render said last means ineffective for frequency variations due to signal modulation.

2. A frequency modulation system as set forth in claim 1, wherein said phase shifting means comprises a pair of inductively coupled resonant circuits, one of said circuits being the tank circuit of the oscillator.

3. A frequency modulation system as set forth in claim 1, wherein said phase shifting means comprises a network connected across the inductive branch of the tank circuit of the oscillator.

4. A system for producing frequency-modulated electrical oscillations, comprising an oscillator vacuum tube, a tank circuit coupled to said tube, audio frequency means for varying the effective impedance of said tank circuit, a control circuit, a full wave rectification network in said control circuit, phase shifting means connected between separate branch terminals of said rectification network for deriving from said tank circuit two equal voltages respectively lagging and leading the output voltage of the oscillator by a phase angle of substantially 90 degrees, an integrating network in said control circuit, said integrating network having a time constant of the order of several audio cycles, piezo-electric crystal means connected across said rectification and integrating networks, means for exciting said crystal means by a voltage derived from the oscillator output, said exciting voltage being substantially in phase with said output voltage when the oscillator operates at the resonant frequency of said crystal means, means for combining said exciting voltage with said lagging and leading voltages across respective branches of said rectification network, and means for deriving from said integrating network a corrective voltage representative of the difference between the outputs of said respective branches.

5. A system for producing frequency-modulated electrical oscillations, comprising an oscillator vacuum tube, a tank circuit coupled to said tube, audio frequency means for varying the effective impedance of said tank circuit, a control circuit, a full wave rectification network in said control circuit, a broadly tuned circuit having negligible phase shift over the frequency deviation range inductively coupled to said tank circuit, means including said broadly tuned circuit for applying to respective input electrodes of said rectification network a pair of equal and opposite voltages substantially in quadrature with the output voltage of the oscillator, an integrating network connected across the output electrodes of said rectification network, said integrating network having a time constant of the order of several audio cycles, a piezo-electric crystal connected across said rectification and integrating networks, means including a high value resistor connected between said tank cir-

cuit and said crystal for exciting the latter by a voltage substantially in phase with the output voltage of the oscillator at the resonant frequency of the crystal, means for superimposing said exciting voltage upon said lagging and leading voltages, respectively, means including said integrating network for comparing said superimposed voltage combinations, and means for deriving from said integrating network a corrective voltage representative of the difference in magnitude between said voltage combinations.

6. A system for producing frequency-modulated electrical oscillations, comprising an oscillator vacuum tube, a tank circuit coupled to said tube, audio frequency means for varying the effective impedance of said tank circuit, a control circuit, a full wave rectification network in said control circuit, a phase shifting network connected between said tank circuit and two output electrodes of said rectification network, said phase shifting network being designed to apply to said electrodes two equal voltages respectively lagging and leading the output voltage of the oscillator by a phase angle of substantially 90 degrees, an integrating network connected across said output electrodes, said integrating network having a time constant of the order of several audio cycles, a piezo-electric crystal connected across said rectification and integrating networks, means including a high value resistor connected between said tank circuit and said crystal for exciting the latter by a voltage substantially in phase with the output voltage of the oscillator at the resonant frequency of the crystal, means for applying said exciting voltage in multiple to the input electrodes of the two branches of said rectification network, means including said integrating network for comparing the outputs of said

two branches, and means for deriving a corrective voltage representative of the difference between said outputs.

7. A frequency modulation system comprising an oscillator circuit, a source of signal waves, a reactance modulator circuit coupled across said oscillator circuit for varying the frequency of oscillation of said oscillator circuit in accordance with waves from said source, means for deriving two voltages of opposite phase from the output of said oscillator circuit, said two voltages being phase displaced 90° with respect to the voltages from said oscillator circuit, a piezo electric crystal coupled to the output of said oscillator circuit for deriving a voltage whose phase varies with the oscillator frequency, means for combining said derived voltage with each one of said two voltages to produce different outputs, means for separately rectifying each of said different outputs and storage means for combining said rectified outputs differentially to produce a control voltage, means for applying said control voltage to said modulator circuit for controlling the frequency of oscillation of said oscillator circuit.

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