

Aug. 22, 1944.

C. TRAVIS

2,356,483

FREQUENCY CONTROL SYSTEM

Filed July 2, 1942

Fig. 1.

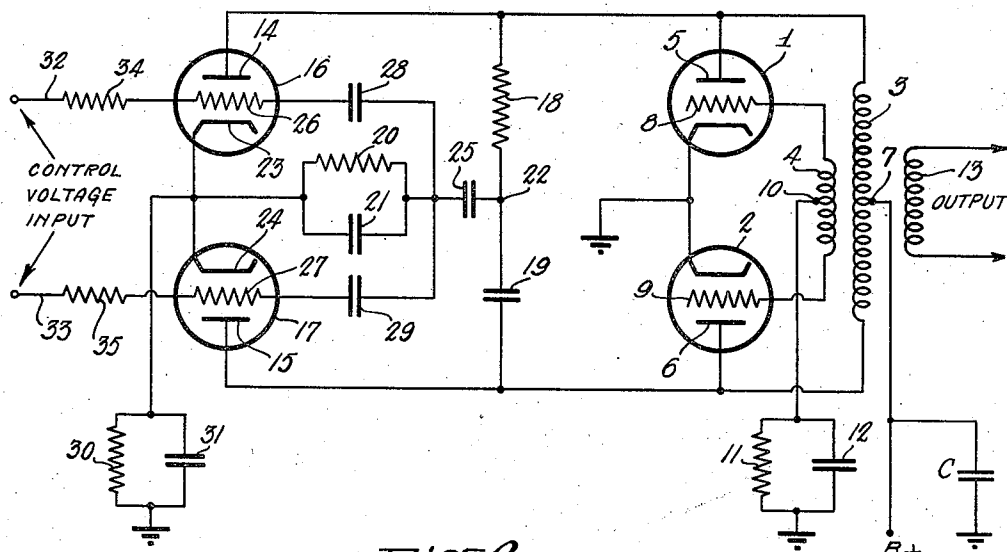


Fig. 2.

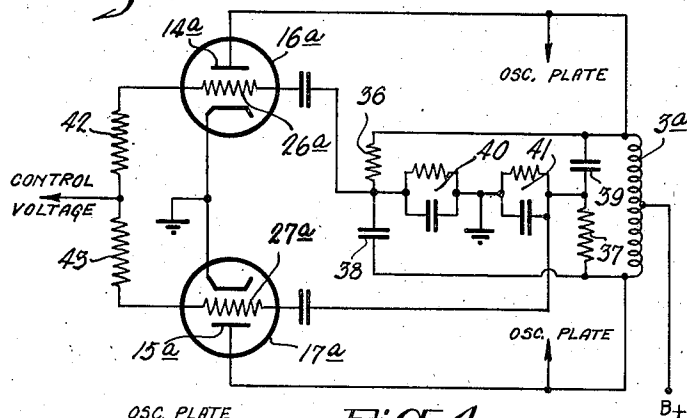


Fig. 3.

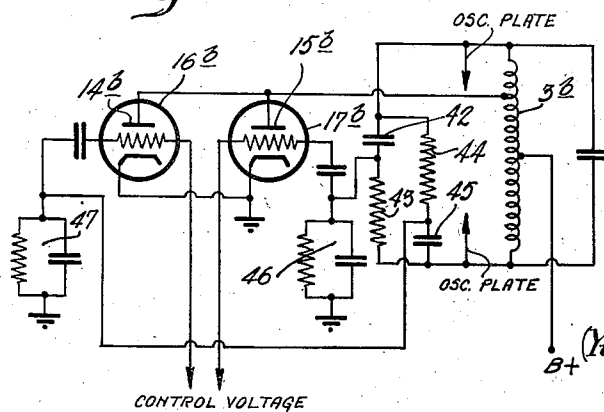
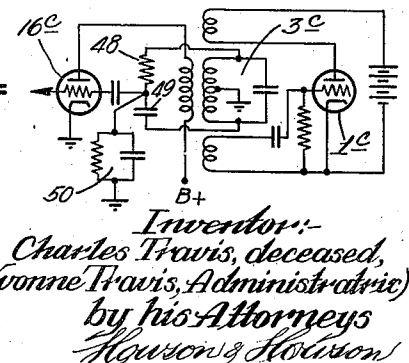


Fig. 4.



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UNITED STATES PATENT OFFICE

2,356,483

FREQUENCY CONTROL SYSTEM

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Application July 2, 1942, Serial No. 449,505

17 Claims. (Cl. 250—36)

This invention relates to frequency control systems, and more particularly to circuits for obtaining quadrature voltages in frequency control systems.

There are now various usages of controllable oscillator circuits in which it is desired to change the frequency by applying a control voltage. One of the most useful applications of these circuits is in frequency modulation transmitters where it is desired to frequency-modulate a carrier wave in accordance with an audio frequency signal or the like. Another use of such a circuit is in alternate carrier television, where one frequency control system may be used to maintain the normal frequency of the oscillator at a fixed value, and a second may be used to shift the oscillator to change the carrier frequency at periodic intervals. Other uses of automatic frequency control are known in the electronics art and will not be enumerated in full here.

It is customary, in a frequency control circuit, to employ at least one control tube which is caused to simulate a controllable reactance by means of a so-called quadrature voltage which is in phase quadrature relation with the oscillator tank circuit voltage. It is important that the phase of the quadrature voltage be accurate and that its magnitude be sufficient in all instances. Control circuits employed in the past have been deficient in these respects, particularly at high frequencies, e. g. above 2 megacycles.

It is one object of the present invention to produce accurate quadrature phase voltage in an oscillator frequency control circuit.

It is a further object of the invention to increase the magnitude of the quadrature voltage which may be derived from a given signal source.

It is another object of the invention to provide a phase quadrature circuit in which the capacitance of the control tubes do not affect the accurate operation of the oscillator.

It is another object of the invention to provide a frequency control system for an oscillator having substantially linear control of the frequency by the control voltage.

Other objects of the invention will be apparent from the following description and the accompanying drawing, in which:

Fig. 1 is a wiring diagram of the preferred embodiment of the invention employing a balanced oscillator and a balanced frequency control system;

Fig. 2 is a wiring diagram of a modified form

of the invention using a single direct current control voltage;

Fig. 3 is a wiring diagram of another modified form of the invention in which the anodes of the control tubes are connected to the same point on the oscillator tank circuit inductance; and

Fig. 4 is a wiring diagram of further modification.

Referring first to Fig. 1, there is shown an oscillator comprising tubes 1 and 2, a plate coil 3 and a grid coil 4. The plates 5 and 6 are connected to the opposite ends of the plate tank coil 3, and the center tap 7 of the plate coil is connected to a source of high voltage plate potential. The tank coil 3 may be tuned by the distributed capacity of the winding, or if desired a tuning condenser may be connected thereacross. The grids 8 and 9 may be connected to the ends of the grid coil 4, the center tap 10 of which may be connected to ground through a suitable biasing resistor 11 by-passed by the condenser 12. Also coupled to the plate coil 3 is the output coil 13 which is connected to a load, e. g., a further amplifier or an antenna system, or, in the case of a radio receiver the first detector or converter. Also shown connected to the ends of the plate coil 3 are the plates 14 and 15 of the frequency control vacuum tubes 16 and 17, which are shown in the drawing as triodes, but which may be any other form of multi-element tube as is well known in the art.

Connected across the tank coil 3 is a phasing-circuit which includes the serially connected resistor 18 and condenser 19. This circuit also includes a resistor 20 and a condenser 21, in parallel, connected between the junction point 22 (of elements 18 and 19), and the cathodes 23—24. This connection may also include the direct current blocking condenser 25. As will be described later, the impedances of elements 18, 19, 20 and 21 are related in a particular manner so that a substantially perfect quadrature excitation voltage may be obtained therefrom and applied to the grids 26 and 27 which are connected for radio frequency to the junction point 22 through direct current blocking condensers 28 and 29, and the direct current blocking condenser 25. Connected between the cathodes 23 and 24 and ground is a conventional biasing resistor 30 and its by-pass condenser 31. Since the radio frequency by-pass condenser 31, the direct current blocking condenser 25, and the plate supply by-pass condenser C all have negligible impedance at the oscillator frequency, the parallel elements 20—21 of the quadrature voltage deriving cir-

cuit 18, 19, 20, 21 may be regarded as connected directly between the junction 22 and the center tap 7 of winding 3.

Also connected to the grids 26 and 27 are the leads 32 and 33 which are connected through suitable filter elements, e. g. resistors 34 and 35 to prevent the passage of radio frequency, and thence to a suitable source of control voltage. The circuit shown in Fig. 1 is particularly adapted for operation from a pair of control voltages, and these voltages are preferably equal and opposite and balanced to ground. Complete circuits for the obtaining of these control voltages are shown in United States Patent No. 2,240,428, patented April 29, 1941, and in the copending application of David B. Smith, Serial No. 401,494, filed July 8, 1941.

As is well known, in a system of this general type the quadrature voltage causes the control tubes to appear as reactances which are variable by the control signal to vary the frequency of the oscillator. The present invention is concerned particularly with the means for obtaining the quadrature voltage, as will now be described in detail.

In order to derive the full benefit of the present invention, the resistor 20 should be made equal to the resistor 18, and condenser 21 should have the same reactance as condenser 19. With these preliminary conditions fulfilled, the current I_1 in the circuit which includes plate-to-cathode of the tube 17, the parallel circuit 20—21, the condenser 25 and the condenser 19 may be represented by the equation

$$I_1 = \frac{E - e}{jx}$$

where E is the voltage applied to the plate 15 by the oscillator tank coil, e is the voltage to ground at the junction 22, and x is the reactance of the condenser 19, which has already been set equal to the reactance of the condenser 21. The current I_2 through the circuit which includes plate-to-cathode of the tube 16, the parallel circuit 20—21, the condenser 25, and the resistor 18 may be represented by the equation

$$I_2 = \frac{-(E + e)}{R}$$

in which R is the resistance of resistor 18. In the above equations, the voltages on the plates of the control tubes are considered positive and negative, respectively, since these two voltages are taken from opposite ends of the tank coil and are 180° out of phase. The sum of the currents I_1 and I_2 , which is the total current flowing from the junction 22 to cathodes through the parallel circuit 20—21, will be given by the equation

$$I_1 + I_2 = \frac{e}{Z} \text{ or } e \left(\frac{1}{Z} \right)$$

where

$$\frac{1}{Z} = \left(\frac{1}{R} + \frac{1}{jx} \right)$$

whence

$$I_1 + I_2 = e \left(\frac{1}{R} + \frac{1}{jx} \right)$$

Substituting the aforementioned values of I_1 and I_2 and rearranging terms gives the equation

$$\frac{2e}{E} = \frac{\left(\frac{1}{jx} - \frac{1}{R} \right)}{\left(\frac{1}{jx} + \frac{1}{R} \right)}$$

From this equation it is apparent that when the absolute values of R and x are equal, the ratio

$$\frac{2e}{E}$$

will be a pure imaginary, indicating that the voltage e applied to the grids 26 and 27 is exactly 90° out of phase with the voltage E or $-E$ appearing at the two ends of the tank coil. This is, of course, the desired condition.

From the foregoing relations, it may also be seen that the quadrature excitation voltage, when the absolute values of R and x are equal, is equal to one-fourth the end-to-end tank voltage. This is a substantially higher voltage than can be obtained from the conventional series resistance-capacitance circuit.

Referring now to Fig. 2, there is shown a modified form of the control circuit in which a single control voltage is used and quadrature radio frequency grid voltages are applied to grids 26a and 27a in opposite phase. The oscillator circuit may be the same as shown in Fig. 1, or it may take any other suitable form. For economy of space, only the oscillator tank coil is shown. In this instance the grids of the frequency control tubes are supplied with quadrature voltages through a phase shifting network system comprising the resistors 36 and 37, the condensers 38 and 39, and the parallel networks 40 and 41. It is to be noted that the resistance-capacitance network comprising the resistance 36 and capacitance 38 is reversed relative to the network comprising the resistance 37 and the capacitance 39, so that the phase on grid 26a is 90° advanced while the phase on grid 27a is 90° retarded, thereby placing both grids in phase quadrature with the oscillator tank circuit but 180° out of phase with each other. A single alternating current (e. g. audio) or direct current control voltage may then be used to control the oscillator frequency. In the circuit shown in Fig. 2 the parallel circuits 40 and 41 correspond to the parallel circuit in Fig. 1 and coact with the elements 36, 38, and 37, 39, respectively, in the same manner as described in connection with Fig. 1. The relation

$$R = \frac{1}{\omega C}$$

obtains in this instance for the same reasons as in Fig. 1. The resistors 42 and 43 should be high in value as compared to the impedance of the resistors 36—37 and condensers 38—39, in order to prevent any serious deviation from quadrature due to the loading effect which they produce.

The circuit shown in Fig. 3 is a further embodiment of the invention in which the plates 14b and 15b of the control tubes 16b and 17b are connected to the same point on the tank coil 3b while the grids are connected through the blocking condensers to reversed series resistance-capacitance circuits 42—43 and 44—45, respectively. The parallel networks 46 and 47 are connected between the junction points of the series networks and the cathodes of the control tubes through ground. In this case, as in the form of invention shown in Fig. 1, two control voltages of opposite phase are required. In this instance also the relation

$$R = \frac{1}{\omega C}$$

obtains for the reasons previously shown.

Referring generally to the above-described em-

bodiments, in a balanced system of the type shown there are three different voltages involved, i. e. the control voltage, the quadrature voltage, and the output voltage of the control tubes. It is necessary in any case that two of the three voltages must be applied in opposite phase while the third must be applied in like phase. Thus in Fig. 1, for example, the control voltage is applied to the grids of the control tubes in opposite phase; the output voltages of the control tubes are applied to the tank coil in opposite phase; and the quadrature voltage is applied to the grids of the control tubes in like phase. Figs. 1 to 3 of the drawing show the three possible arrangements of the balanced system and illustrate the application of the present invention to each arrangement.

The invention is not limited, however, to the use of balanced or push-pull control tubes. Thus in Fig. 4 there is shown an embodiment of the invention employing a single control tube 16c and a single oscillator tube 1c having an associated tank circuit 3c. In this instance the plate circuit of the control tube is inductively coupled to the tank circuit. The series resistance-capacitance circuit 48-49 is connected across the tank circuit. The parallel network 50 is connected between the junction point of the series circuit and the cathode of the control tube through ground. The quadrature voltage is applied to the grid of the control tube from said junction point. In this instance, as before, the resistors of the series and parallel networks are equal, the reactances of the condensers are equal, and the relation

$$R = \frac{1}{\omega C}$$

obtains.

It will be understood, of course, that the invention is not limited to the specific embodiments shown. For example, the tubes may be multi-grid tubes instead of the simple triodes illustrated; and other modifications may be made without departing from the invention.

What is claimed is:

1. A frequency control circuit for shifting the frequency of an oscillator having a tank coil, comprising a pair of control tubes having triode elements, means connecting the plate of each of said tubes to the oscillator tank coil, a network including series-connected resistance and capacitance elements connected in shunt to said tank coil, means connecting the grids of said tubes to the junction of said elements, a connection between the cathodes of said tubes and said junction, and a network including parallel-connected resistance and capacitance elements in said connection, said first named resistance and capacitance elements being equal respectively to said last-named resistance and capacitance elements, the resistance of each of said resistance elements being substantially equal to the reactance of each of said capacitance elements at the operating frequency.

2. In combination, an electron tube oscillator capable of having its frequency varied and including an oscillator tank circuit, means for varying the resonant frequency of the tank circuit, said means including a pair of electron control tubes having their anodes connected in push-pull relation across the tank circuit, a first network comprising a resistance and a capacitance connected in series across at least a portion of said tank circuit, and a second network con-

nected between the junction of said resistance and capacitance and the cathodes of said control tubes, said second network comprising a resistance and capacitance in parallel, said second resistance and capacitance having the same electrical values as said first-mentioned resistance and capacitance respectively, the resistance of each of said resistance elements being substantially equal to the reactance of each of said capacitance elements at the operating frequency.

3. In an electrical system for forming frequency-controlled oscillations, means for generating self-sustained oscillations comprising a space discharge device and an associated resonant circuit including reactive elements, a pair of space discharge devices for controlling the frequency of said oscillations, said devices having an input and an output circuit, means for coupling the output circuit to one of the reactive elements of the resonant circuit, a network comprising a resistor and a capacitor connected in series across said output circuit, the resistance of said resistor being substantially equal to the reactance of said capacitor at the operating frequency, a connection for radio frequency between the input circuits of said control devices and the junction between said resistor and capacitor, and a second network connected between said junction and a common terminal of said discharge devices.

4. In combination, an electron tube oscillator capable of having its frequency varied and including an oscillator tank circuit, means for varying the resonant frequency of the tank circuit, said means including a pair of electron control tubes each having at least a cathode, an anode and a grid, said anodes being connected to said tank circuit, a series resistance-capacitance circuit connected across at least a portion of the tank circuit, each of said grids being connected to a center tap of said last-named circuit, a parallel resistance-capacitance circuit between said grids and a point of low radio frequency potential, and means for applying a control voltage to said grids, the elements of said resistance-capacitance circuits all having the same value of impedance at the operating frequency.

5. In combination, an electron tube oscillator capable of having its frequency varied and comprising an oscillator tank circuit including an inductance, means for varying the resonant frequency of the tank circuit including a pair of electron control tubes each having at least a cathode, an anode, and a grid, two series resistor-condenser circuits connected across at least a portion of said tank circuit inductance, the resistor of one series circuit being connected to the same side of the tank inductance as the condenser of the other series circuit, a connection from the grid of one of the control tubes to the junction between the resistor and condenser of one series circuit, a similar connection between the grid of the other tube and the junction in the second series circuit, connections between each of said junctions and ground for radio frequencies including parallel resistor-condenser circuits, the resistor and condenser of each parallel circuit being respectively equal in impedance at the operating frequency to the resistor and condenser of the series circuit with which it is associated, and means for applying control voltage to said grids to control the operation of the control tubes.

6. An electron tube oscillator as described in claim 5 in which the condenser in each parallel

circuit includes the tube grid-to-cathode capacity.

7. In combination, an electron tube oscillator capable of having its frequency varied and including an oscillator tank circuit, means for varying the resonant frequency of the tank circuit, said means including a pair of electron control tubes each having at least a cathode, an anode, and a control grid, said anodes being connected together and to the tank circuit, two series resistor-condenser circuits connected across at least a portion of said tank circuit, the condenser of one series circuit being connected to the tank circuit at the same point as the resistor of the other series circuit, one of said control grids being connected for alternating currents to the junction of the resistor and condenser in one series circuit, the other grid being connected for alternating currents to the junction in the other series circuit, circuits between said grids and cathodes each including a resistor and condenser in parallel, each of said last-named resistors and condensers being of the same value as the resistor and condenser of the series circuit associated with the same grid.

8. A circuit for deriving a quadrature voltage from a source of oscillations, comprising a series resistor and condenser connected across said source, and a parallel resistor and condenser connected between the junction of said resistor and condenser and a point of substantially zero potential, said resistors being equal in value, said condensers being equal in value, and the resistance of each resistor being substantially equal to the reactance of its associated condenser at the operating frequency, and said quadrature voltage appearing at said junction.

9. In a frequency-control system for an oscillator in which the output of the control tube means is connected in the oscillator circuit, a source of quadrature voltage for the control tube means comprising a resistor and a reactive impedance in series across the oscillator output, a resistor and a reactive impedance connected in parallel between the juncture of said first resistor and said first reactive impedance and a point of substantially zero alternating potential, a connection between said juncture and the grid means of said control tube means, said resistors being equal and said reactive impedances being equal and of the same sign, and the resistance of each resistor being substantially equal to the associated reactive impedance at the operating frequency, and means for applying control voltage to said grid means.

10. In a frequency control system for an oscillator in which the output circuit of a control tube controls the frequency of the oscillator, a source of quadrature voltage for the control tube comprising a series resistor and reactor connected across at least part of said oscillator, and a parallel resistor and reactor connected between the juncture of said first-named resistor and reactor and a point of substantially zero alternating potential in said oscillator circuit, said second named resistor being equal in value to said first named resistor, and said second named reactor being equal in value and of the same sign as said first named reactor, and the resistance of each resistor being substantially equal to the reactance of the associated reactor at the operating frequency.

11. In combination, an oscillator circuit having at least one winding an intermediate point

of which is connected to a point of substantially fixed potential, means for deriving a quadrature voltage from said winding, said means comprising a resistor and a condenser connected in series across a part of said winding, said part including portions on either side of said intermediate point, and a resistor and condenser connected in parallel in an alternating current path extending between said point of fixed potential and the junction of the first-named resistor and condenser, a frequency control tube having an output circuit coupled to said oscillator circuit, and a connection between a control element of said control tube and said junction.

12. The combination claimed in claim 11, characterized in that said winding is connected in the anode circuit of said oscillator.

13. The combination claimed in claim 11, characterized in that the impedances of said resistors and condensers are substantially equal in magnitude at the mean operating frequency of the oscillator.

14. A frequency control system for an oscillator having a tank coil, comprising a pair of control tubes having their respective plates connected to electrically spaced points on said tank coil, and sources of opposite phase quadrature voltages for said control tubes respectively, each of said sources consisting of a series condenser and resistor connected across part of said tank coil and a parallel resistor and condenser connected between the juncture of said series resistor and condenser and a point of substantially zero alternating potential, both of the resistors and both of the condensers being equal in value, and a connection between each of said junctures and the associated control tube.

15. A circuit for controlling the frequency of an oscillator having a tuned tank coil, comprising a pair of control tubes, the plates of said control tubes being connected together and to the tank coil, means for providing quadrature voltages to the grids of said control tubes, said quadrature voltages being of opposite phase with respect to each other, said means consisting of a series resistor-condenser circuit connected between points of different potential on said tank coil, and a resistor and condenser of the same value connected in parallel between the juncture of said first resistor and condenser and a point of substantially zero alternating voltage, a connection between said juncture and the grid of one of the control tubes, and a source of separate control voltage for each of said tube grids.

16. In combination with an oscillator whose frequency is variable, a pair of control tubes, each having an output electrode and a control electrode, means for connecting said output electrodes to the oscillator to apply the output voltage of said tubes to the oscillator, means for deriving a quadrature voltage from the oscillator and for applying said voltage to the control electrodes of said tubes, and means for applying control voltage to the control electrodes of said tubes, the voltages applied by two of the aforesaid means being in opposite phase, and the voltage applied by the other of said means being in the same phase, said second means comprising a network including at least one series resistance-reactance path and a parallel resistance-reactance path connected to the junction of the resistance and reactance elements of the series path, said network being constructed and arranged to provide an exact quadrature voltage at said junction.

17. A circuit for deriving a quadrature voltage from a source of oscillations, comprising a first network including series-connected resistance and reactance elements, means for applying a voltage from said source across said network, and a second network including parallel-connected resistance and reactance elements connected between the junction of said series-connected elements and a point of substantially zero

5 potential, said resistance elements being equal in value, said reactance elements being equal in value, and each resistance being substantially equal to the associated reactance at the operating frequency, and said quadrature voltage appearing at said junction.

YVONNE TRAVIS.

*Administratrix of the Estate of Charles Travis,
Deceased.*