

April 20, 1948.

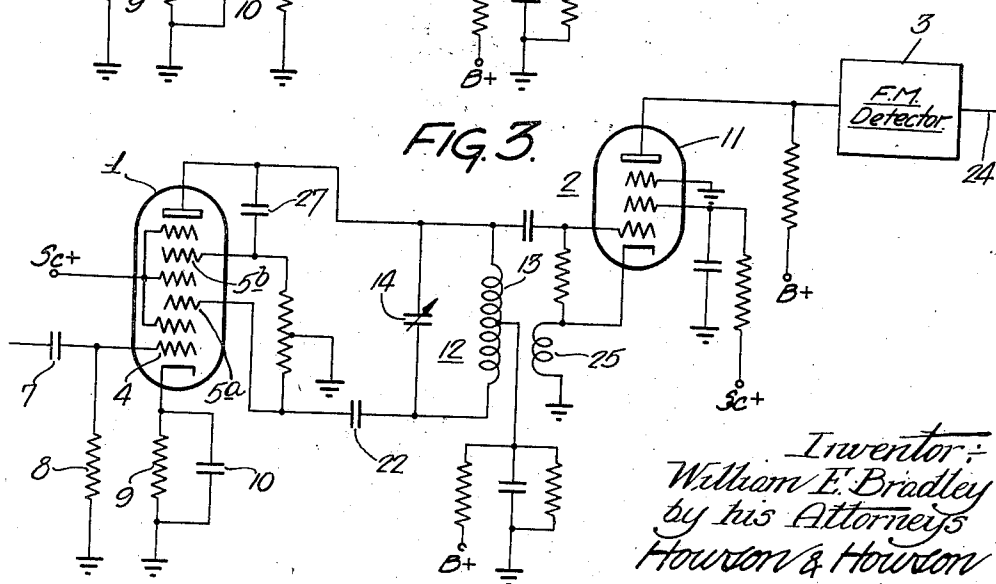
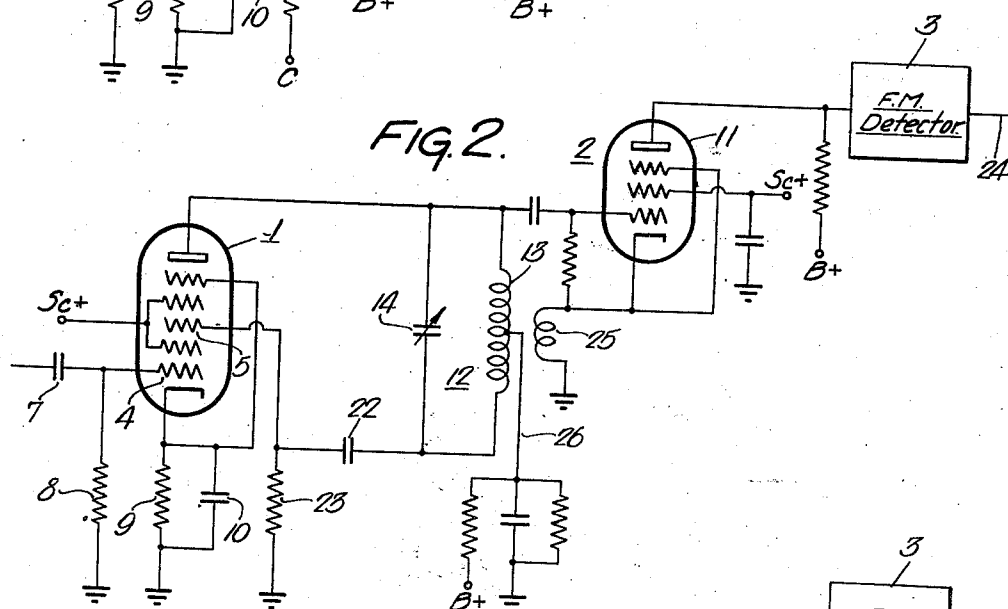
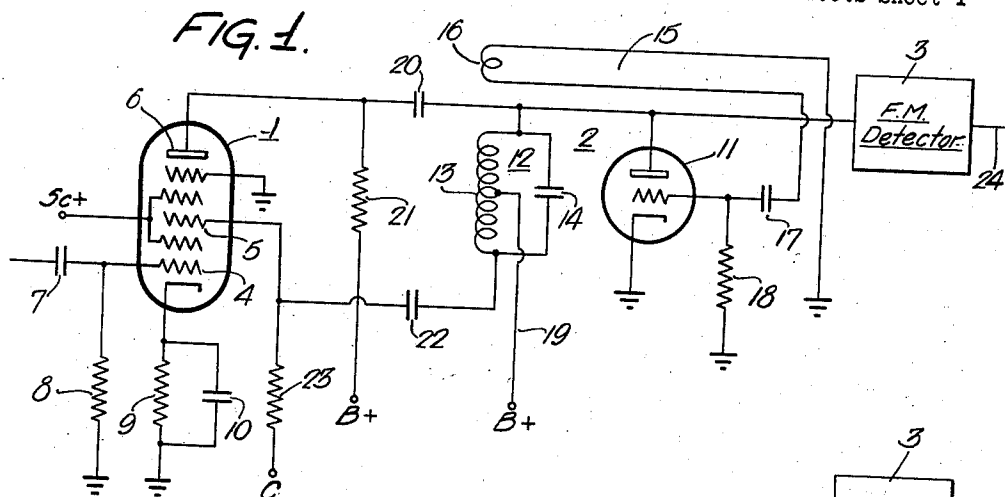
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2,440,073

SYNCHRONIZED OSCILLATOR CIRCUIT

Filed Oct. 9, 1945

2 Sheets-Sheet 1



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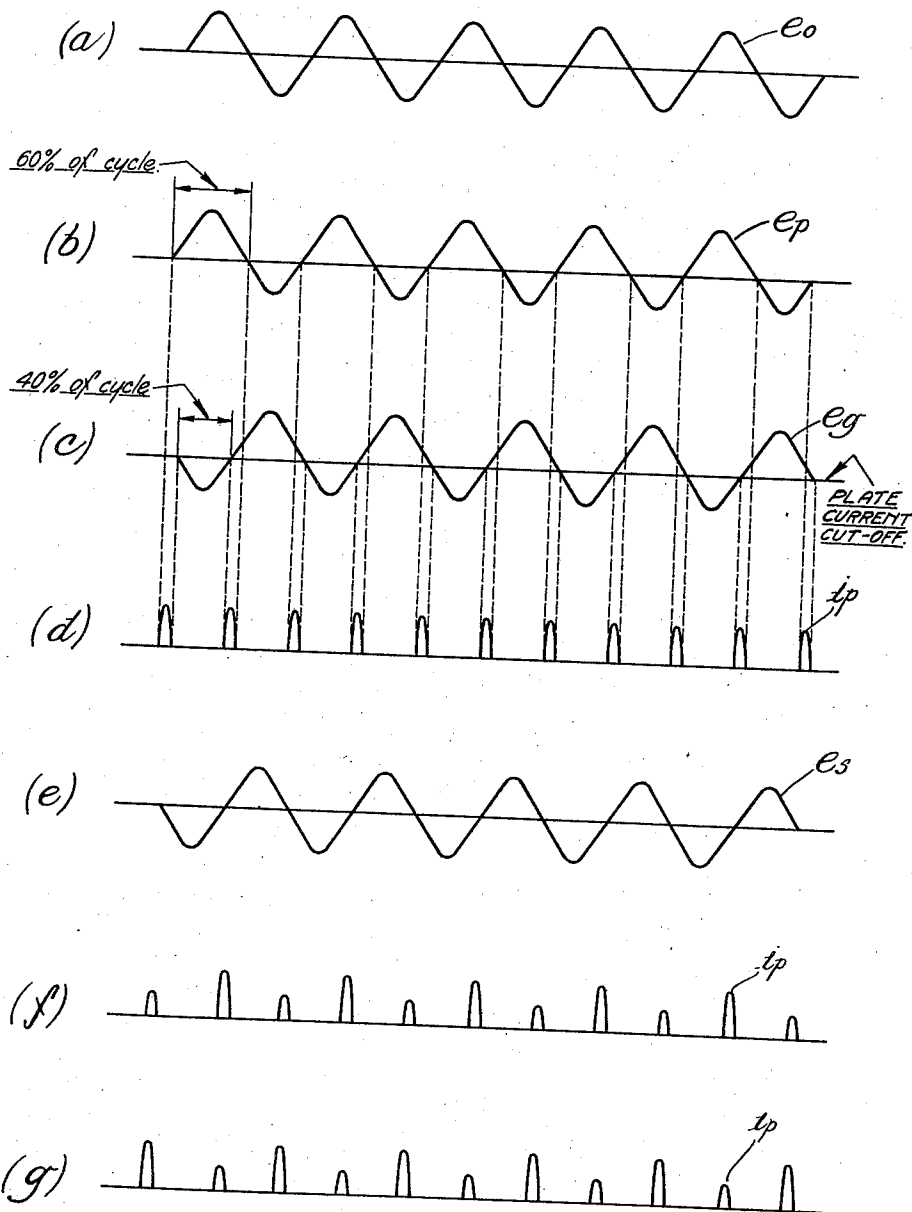
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FIG. 4.



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UNITED STATES PATENT OFFICE

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SYNCHRONIZED OSCILLATOR CIRCUIT

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11 Claims. (Cl. 250—36)

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This invention relates to frequency modulation systems. More particularly, the invention relates to frequency modulation-responsive circuits, and still more specifically to frequency modulation detection systems of the synchronized oscillator type.

In my co-pending application, Serial No. 576,057, filed February 3, 1945, there is disclosed and claimed, a novel frequency modulation detector of the synchronized oscillator type which is characterized in that it does not absorb power from the source of frequency-modulated signal, and it is insensitive to amplitude variations and therefore does not require the use of a limiter. In the detector system of the said co-pending application, the oscillator is synchronized with the frequency-modulated carrier signal by a radio frequency control voltage which is in quadrature relation to the oscillator signal.

The present invention relates to a system which embodies the broad principles of the system disclosed in the said co-pending application, but which differs specifically from that system in respect to the manner in which the quadrature control signal is derived. Like the system of the said co-pending application, the system provided by the present invention does not absorb power from the source of frequency-modulated signal, and is insensitive to amplitude modulation.

The principal object of the present invention, therefore, is to provide a novel frequency modulation-responsive circuit which is insensitive to amplitude modulation.

Another object of the invention is to provide a circuit which is capable of transmitting frequency modulation with substantial power gain.

A further object of the invention is to provide an improved frequency modulation detection system comprising a novel frequency modulation amplifier circuit and a frequency modulation detector, by means of which combination the frequency-modulated signal is efficiently detected without response to amplitude modulation and without employing any amplitude limiter.

Still another object of the invention is to provide a novel frequency modulation-responsive circuit of the synchronized oscillator type in which the oscillator is synchronized by means of a quadrature signal derived by unique operation of a synchronizing tube, as described hereinafter.

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Other objects and features of the invention will be apparent from the following detailed description in connection with the accompanying drawings, in which

Figs. 1 to 3 are schematic illustrations of different embodiments of the invention; and

Fig. 4 comprises a series of explanatory diagrams.

Referring first to Fig. 1, there is illustrated one form of a frequency modulation detection system embodying the present invention. The system comprises essentially a vacuum tube 1, an oscillator 2, certain connections hereinafter described by which the tube 1 is adapted to synchronize the oscillator with a frequency-modulated signal, and a frequency modulation detector 3 connected to the oscillator so as to receive a frequency-modulated signal therefrom. Since the purpose of tube 1 is to synchronize the oscillator 2 with the incoming frequency-modulated signal, tube 1 may be aptly designated the "synchronizing tube," and it will be thus referred to in the description. The synchronization of the oscillator 2 is accomplished, according to the present invention, by a unique class C operation of the tube 1, which will be described later with specific reference to the explanatory diagrams of Fig. 4.

The synchronizing tube 1 is a multi-grid tube having RF input grids 4 and 5, and an output electrode or anode 6. The tube is adapted to receive a frequency-modulated signal by way of the coupling condenser 7 and the grid resistor 8. If desired, a cathode resistor 9 and shunt condenser 10 may be employed as a biasing means for the control grid 4.

The oscillator 2, as shown in Fig. 1, may comprise a tuned plate oscillator circuit operating in the usual class C manner. Such circuit may comprise a tube 11, a resonant tank circuit 12 including shunt-connected inductance and capacitance elements 13 and 14, and an inductive feedback circuit 15 including coil 16, condenser 17 and resistor 18. The necessary plate voltage for tube 11 may be supplied by the connection 19 to the mid-point of the inductance coil or winding 13.

The anode or plate 6 of the synchronizing tube 1 is connected to the upper end of the tank circuit 12 through condenser 20. The necessary plate voltage for tube 1 is supplied through the plate load resistance 21. However, the specific value

of the D. C. plate voltage is such as to effect a desired operation of the tube 1 as will be described further hereinafter. The grid 5 of tube 1 is connected to the lower end of the tank circuit 12 through the condenser 22, and this grid is also supplied with a bias voltage by way of resistor 23. The specific value of the bias voltage applied to grid 5 is also important in that it helps to effect the desired operation of tube 1, as will be seen later.

The frequency modulation detector 3 may be of conventional form, and therefore, it is represented simply in block form. For example, the detector may be of the well known Seeley type, and may be coupled in any suitable manner to the plate circuit of the oscillator tube 11. The audio output from the detector is derived by way of the output connection 24.

The operation of the system may best be described with the aid of the explanatory diagrams of Fig. 4. In Fig. 4(a) there is represented the alternating voltage e_o generated by the oscillator 2, while in Fig. 4(e) there is represented the unmodulated carrier signal e_s which is supplied to the grid 4 of the synchronizing tube 1. It should be noted that the normal frequency of the oscillator voltage e_o is substantially equal to the frequency of the carrier signal e_s , but the oscillator voltage is in phase opposition to the carrier signal, i. e., 180° out of phase therewith.

The oscillator voltage is applied to the plate 6 of tube 1 through the condenser 20. The D. C. plate voltage supplied to the plate 6 from the source B+ is such that the plate is positive (with respect to cathode) approximately three-fifths, or 60%, of each cycle, as shown in Fig. 4(b) wherein the plate voltage e_p is represented.

A similar voltage of opposite phase is derived from the lower end of the tank circuit 12 and is applied to the grid 5 of tube 1 through condenser 22. The D. C. bias applied to this grid is such that the plate current in tube 1 is cut off during approximately two-fifths, or 40%, of each cycle, as shown in Fig. 4(c) wherein the voltage applied to grid 5 is represented as e_g .

As a result of the voltages e_p and e_g , plate current flows in tube 1 only during very brief intervals, twice during each cycle, each interval being about one-tenth of a cycle in duration. Consequently, relatively short pulses of plate current are produced, as shown at i_p in Fig. 4(d), there being two pulses during each cycle. These pulses of plate current are utilized to synchronize the oscillator 2 with the incoming frequency modulated signal, as will now be explained.

It should be noted that the relatively short pulses of plate current i_p are centered about the zero-voltage points of the unmodulated carrier signal e_s . Therefore, when the frequency-modulated signal is at its center frequency, its only effect on the plate current pulses i_p is slightly to affect their symmetry while not affecting their energy content. Since with class C amplifiers this slight lack of symmetry, as shown both by theory and by practice, is of no significance, no attempt has been made to illustrate it in the drawings. One of the important advantages, incidentally, which the class C mode of operation offers resides in the fact that it makes the operation of the system substantially insensitive to changes in plate-current wave shape.

When the frequency-modulated signal is at its center frequency, the plate current pulses i_p are of substantially equal amplitude. At such time, the plate current contains no frequency com-

ponent at the oscillator frequency, but contains only even harmonics thereof. Consequently the pulses i_p exert no effect on the oscillator frequency. However, when the frequency-modulated signal deviates from its center frequency, the plate current is varied in a manner to produce a frequency component at the oscillator frequency, which component is in quadrature relation to the oscillator voltage e_o . The quadrature signal thus produced is applied to the oscillator tank circuit and varies the oscillator frequency so as to synchronize the oscillator with the incoming signal, substantially as described in the above-identified copending application.

Suppose, for example, that the frequency of the incoming carrier signal e_s increases, which is equivalent to a phase shift slightly to the left in Fig. 4(e). In such case, the odd-numbered plate current pulses in Fig. 4(d) occur during portions of the positive alternations of the signal voltage e_s , while the even-numbered plate current pulses occur only during portions of the negative alternations of the signal voltage e_s . This means that throughout the interval of each odd-numbered plate current pulse the signal voltage e_s aids the flow of plate current, while throughout the interval of each even-numbered pulse the signal voltage e_s retards the flow of plate current. Consequently odd-numbered plate current pulses are increased in magnitude in proportion to the frequency deviation of the signal, while the even-numbered plate current pulses are correspondingly decreased in magnitude, as shown in Fig. 4(f). As a result of this action the plate current now has a fundamental frequency component in quadrature relation to the oscillator voltage e_o , which component causes the oscillator frequency to increase until the plate current pulses are substantially equal in magnitude and the oscillator voltage is in its normal phase relation to the carrier signal.

When the frequency of the carrier signal decreases from its center frequency, which is equivalent to a phase shift slightly to the right of the sinusoid e_s in Fig. 4(e), it will be apparent that the even-numbered pulses in Fig. 4(d) are increased in magnitude, while the odd-numbered pulses are correspondingly decreased in magnitude, as shown in Fig. 4(g). The quadrature signal thus produced decreases the oscillator frequency until the plate current pulses are substantially equal in magnitude and the oscillator voltage is in its normal phase relation to the carrier signal.

Thus the oscillator is synchronized with the frequency-modulated carrier signal by the above-described action, which may be likened to a balanced or push-pull action. It may be said that the system is perfectly balanced when the incoming carrier signal is at its center frequency and the plate current pulses are equal in magnitude, and it becomes slightly unbalanced when the signal deviates from its center frequency in either direction.

It will be seen from the foregoing description that the odd-numbered pulses in Fig. 4(d) constitute a quadrature control signal tending to raise the frequency of the oscillator, while the even-numbered pulses constitute a quadrature control signal tending to lower the frequency of the oscillator. When all of the pulses are of like magnitude, as in Fig. 4(d), no frequency control occurs because the quadrature signals effectively balance one another. But when the pulses are of unlike magnitude, as in Fig. 4(f) or Fig. 4(g),

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one or the other of the quadrature signals predominates and varies the frequency of the oscillator.

As previously indicated, the system is insensitive to amplitude modulation. Any amplitude modulation of the incoming signal will not produce, nor affect, the control action above described, and will not affect the oscillator. Thus it will be seen that the system discriminates against any amplitude variation or modulation of the incoming signal, without the aid of a limiter.

Furthermore, the system does not absorb power from the source of frequency-modulated signal, and only a small input signal is required. The quadrature signal for synchronizing the oscillator is produced entirely by the synchronizing tube circuit under control of the input signal voltage. Moreover, it should be noted that the current pulses delivered from the synchronizing tube to the oscillator tank circuit do not affect the energy in the tank circuit, since the pulses are delivered thereto when the tank voltage is midway between its maximum and minimum values, i. e. when the tank voltage is passing through its zero value.

By reason of its novel features, the system is adapted to discriminate completely against amplitude modulation and to transmit frequency modulation with substantial power gain. The frequency-modulated signal is readily detected by a conventional frequency modulation detector as represented by the block 3.

In Fig. 2, there is shown a modified form of the system in which the oscillator 2 is of a different type than that employed in Fig. 1. In this instance, the tank circuit 12 is connected in the grid circuit of the oscillator tube 11, and is supplied with feedback voltage by way of the coil 25 connected in the cathode circuit. Plate voltage for the synchronizing tube 1 is supplied by way of the connection 26 to the midpoint of the tank coil 13. It will be noted further that the grid 5 of tube 1 is connected to ground, the bias therefore being derived in part by means of the resistor-condenser combination 9-10, and in part by means of the grid condenser-grid leak combination 22-23.

Except for the specific differences noted, the system of Fig. 2 is similar to that of Fig. 1, and the corresponding elements in Fig. 2 are similarly designated. The system of Fig. 2 operates in the same manner as does that of Fig. 1, as hereinbefore described.

In Fig. 3, there is illustrated a further modification of the system in which the synchronizing tube 1 has two grids 5a and 5b in place of the grid 5 of the preceding figures. The two grids 5a and 5b are coupled to the opposite ends of the tank circuit 12 through condensers 22 and 27 respectively. The oscillator 2 is similar to that of Fig. 2.

In the operation of the system of Fig. 3, the grids 5a and 5b control the production of the plate current pulses. Thus the voltages applied to the grids 5a and 5b control the plate current pulses in the same way that the voltages e_p and e_g in Fig. 4 perform this function. Except for the brief pulse intervals, the voltage on one or the other of the grids 5a and 5b is below the plate current cut-off value, thus preventing plate current from flowing during most of each cycle. The two grids should of course be properly biased to obtain the desired control action. The bias for these grids may be obtained from the resistor-

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condenser combination 9-10, or it may be obtained from an additional bias source.

Although the invention has been described with particular reference to the several embodiments illustrated, it will be apparent that it is capable of other forms of physical expression, and is not to be limited by the disclosure herein, but only by the scope of the appended claims.

I claim:

1. In a frequency modulation-responsive circuit, a vacuum tube adapted to receive an incoming frequency-modulated signal, an oscillator adapted to generate an alternating voltage whose normal frequency is substantially equal to the frequency of the unmodulated signal, means for operating said tube so as to produce current pulses substantially centered about the zero-voltage points of the unmodulated signal, there being two pulses for each cycle of said signal, and means for utilizing said pulses to vary the frequency of said oscillator voltage according to the frequency variations of the modulated signal.

2. In a frequency modulation-responsive circuit, a vacuum tube adapted to receive a frequency-modulated signal, an oscillator, means for controlling said tube so as to produce two current pulses during each cycle of the oscillator voltage, said pulses having their relative amplitudes varied by the frequency variations of said signal, and means for utilizing said pulses to control the frequency of said oscillator.

3. In a frequency modulation-responsive circuit, a vacuum tube adapted to receive a frequency-modulated signal, an oscillator including a resonant tank circuit, means for controlling said tube so as to produce two current pulses during each cycle of the oscillator voltage, said pulses having their relative amplitudes varied by the frequency variations of said signal, and means for applying said pulses to said tank circuit to control the frequency of said oscillator.

4. In a frequency modulation-responsive circuit, a vacuum tube including a plate, a control grid, and at least one other grid, an oscillator, means for deriving opposite-phase voltages from said oscillator and for applying said voltages to said plate and said other grid respectively, means for causing said voltages to produce pulses of plate current in said tube, and means for applying to said control grid a frequency-modulated signal whose frequency variations produce variations of said pulses which vary the frequency of said oscillator accordingly.

5. In combination, an oscillator whose frequency is to be varied according to frequency variations of a frequency-modulated signal, a vacuum tube including a cathode, an anode and a plurality of control elements, means for supplying the frequency-modulated signal to one of said control elements, means connecting said anode and another of said control elements to said oscillator so as to apply opposite-phase voltages to said anode and said other control elements, and means for causing said voltages to produce pulses of plate current in said tube whose relative amplitudes are affected by frequency variations of said signal.

6. In a frequency modulation-responsive circuit, a vacuum tube including a control grid and at least two other grids, an oscillator, means for deriving opposite-phase voltages from said oscillator and for applying said voltages to said other grids, means for causing said voltages to produce pulses of plate current in said tube, and means for applying to said control grid a frequency-

modulated signal whose frequency variations produce variations of said pulses which vary the frequency of said oscillator accordingly.

7. In a frequency modulation-responsive system, an oscillator, means for producing a pair of quadrature control signals comprising alternately occurring pulses which are normally of the same magnitude, one of said signals tending to raise the frequency of said oscillator and the other signal tending to lower the frequency of the oscillator, and means for relatively varying the magnitudes of said signals in response to a frequency-modulated signal, whereby to vary the oscillator frequency according to the frequency variations of said modulated signal.

8. In a frequency modulation-responsive system, an oscillator including a resonant tank circuit, means for producing a pair of quadrature control signals comprising alternately occurring pulses which are normally of the same magnitude, means for applying said signals to said tank circuit, whereby one of the signals tends to raise the frequency of said oscillator and the other signal tends to lower the frequency of the oscillator, and means for relatively varying the magnitudes of said signals in response to a frequency-modulated signal, whereby to vary the oscillator frequency according to the frequency variations of said modulated signal.

9. In a frequency modulation-responsive system, an oscillator adapted to produce an alternating voltage of predetermined frequency, means for producing a pair of control signals comprising alternately occurring pulses in coincidence with the zero-voltage points of said voltage, said pulses being normally of the same magnitude, means for relatively varying the magnitudes of the pulses constituting the respective control signals

in response to a frequency-modulated signal, and means for utilizing said control signals to vary the frequency of said oscillator voltage.

10. A method of synchronizing an oscillator with a frequency-modulated carrier wave, which comprises operating the oscillator at a normal frequency corresponding to the frequency of the unmodulated carrier wave, producing two current pulses during each cycle of the unmodulated carrier wave and the oscillator voltage, varying the relative amplitudes of said pulses according to frequency variations of the modulated carrier wave, and varying the operating frequency of the oscillator according to the amplitude variations of said pulses.

11. In a system wherein it is desired to synchronize an oscillator with a frequency-modulated carrier wave, an oscillator whose normal frequency corresponds to that of the unmodulated carrier wave, means for producing two current pulses during each cycle of the unmodulated carrier wave and the oscillator voltage, and for causing the relative amplitudes of said pulses to vary according to frequency variations of the modulated carrier wave, and means for utilizing said pulses to control the oscillator frequency according to the frequency variations of the modulated carrier wave.

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