April 20, 1943. E. S. WINLUND 2,316,927

FREQUENCY MODULATION

Filed Sept. 26, 1941

FIG. 1.

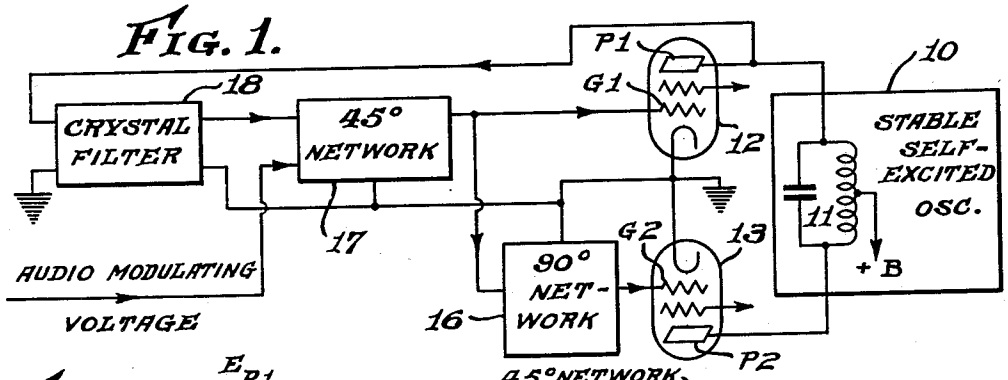


FIG. 2.

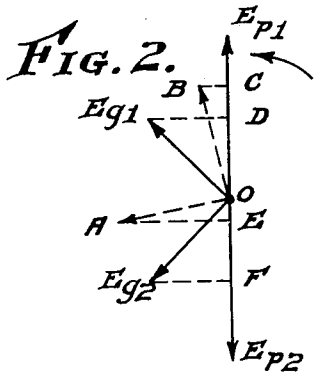


FIG. 3.

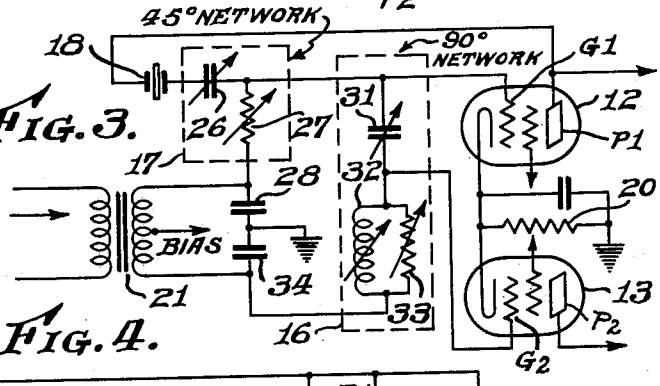


FIG. 4.

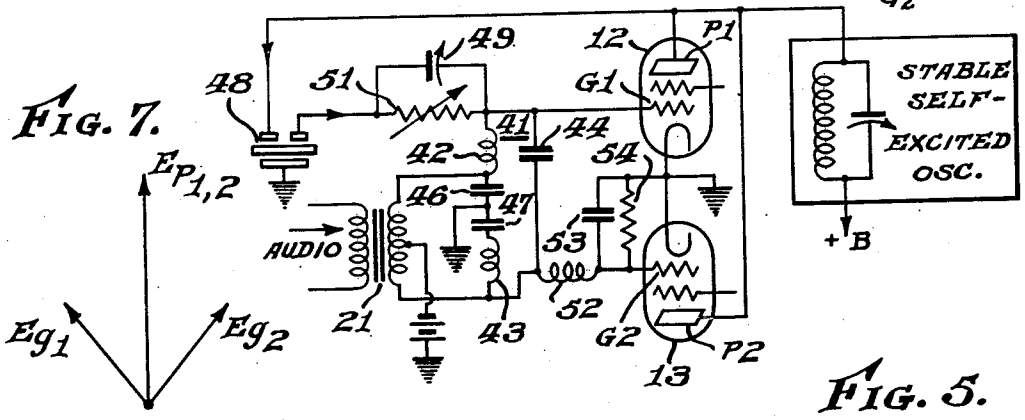


FIG. 5.

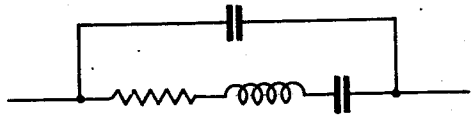
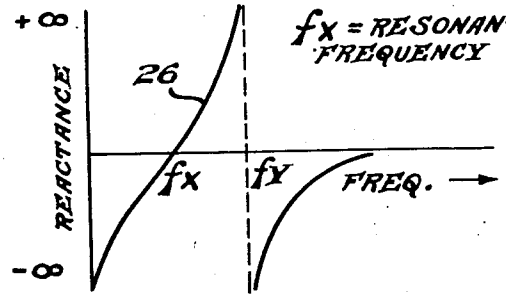


FIG. 6.



Inventor

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UNITED STATES PATENT OFFICE

2,316,927

FREQUENCY MODULATION

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Application September 26, 1941, Serial No. 412,411

7 Claims. (Cl. 179—171.5)

My invention relates to the production of a frequency modulated signal and particularly to the production of a frequency modulated signal which has a stable carrier frequency or mean frequency.

An object of the invention is to provide an improved method of and means for holding the center frequency of a frequency modulated signal substantially constant.

A further object of the invention is to provide an improved method of and means for stabilizing the carrier wave oscillator of a frequency modulated transmitter and minimizing frequency "drift."

In practicing a preferred embodiment of the invention, the carrier wave oscillator is frequency modulated by varying the mutual conductance of reactance tubes in accordance with the modulating signal while, at the same time, frequency drift of the oscillator due to changes in line voltage, etc., is held to a minimum by means of an automatic phase shift control obtained through a feed-back stabilizing circuit.

In one embodiment of the invention a stable self-excited oscillator is frequency modulated by a pair of reactance tubes so connected that one of them constitutes an inductive reactance and the other a capacitive reactance load on the oscillator tank circuit, the values of reactance varying in accordance with the modulating signal. Thus a frequency modulated signal is produced. The above-mentioned reactance changes are obtained by applying the modulating signal to the grids of the reactance tubes whereby their impedances and, therefore, their reactive current outputs, are changed.

The stabilizing feed-back circuit preferably includes a piezoelectric crystal. The crystal is series resonant at the carrier wave frequency whereby the phase of its voltage output is either lagging or leading depending upon whether the frequency of oscillation is above or below the said resonant frequency. The connections are such that the radio frequency voltage fed back to the reactance tube grids (the radio frequency voltages on these grids having a fixed relative phase relation of 90 degrees in the example assumed) is shifted in phase with any phase shift in the crystal output. This shift in phase and, in turn, the change in reactance load on the oscillator, is such as to tend to hold the oscillator frequency constant.

It will be apparent that the two above-described frequency control actions, i. e., the stabilizing action and the modulating action, oppose each other. The modulating signal circuit, however, has a stronger control action than does the crystal feed-back circuit whereby the desired modulation of the oscillator signal may be obtained.

The invention will be better understood from the following description taken in connection with the accompanying drawing in which:

Fig. 1 is a block diagram showing one embodiment of the invention,

Fig. 2 is a vector diagram illustrating the operation of the circuit shown in Fig. 1,

Fig. 3 is a circuit diagram showing, by way of example, a specific circuit for the embodiment of Fig. 1,

Fig. 4 is a circuit diagram illustrating a second embodiment of the invention,

Fig. 5 shows the equivalent circuit for a piezoelectric crystal such as that employed in the above-mentioned embodiments of the invention,

Fig. 6 shows the reactance characteristics of a piezoelectric crystal, and

Fig. 7 is a vector diagram illustrating the operation of the circuit shown in Fig. 4.

Like parts in the several figures are indicated by the same reference characters.

Referring to Fig. 1, there is shown an embodiment of the invention that may be applied to a radio transmitter or the like comprising a stable self-excited oscillator indicated at 10 and having a tuned circuit 11.

Reactance tubes 12 and 13 connected in balanced relation with respect to the tuned circuit 11, and with respect to the input circuit for the modulating signal, are provided for frequency modulating the oscillator output. As will be explained below, the reactance tube circuit is of the type wherein one tube provides inductive reactance while the other tube provides capacitive reactance.

The radio frequency voltages that are fed back to the control grids G1 and G2 of the tubes 12 and 13, respectively, have a fixed phase relation that is obtained by means of any suitable phase shifting network 16. This is shown as a 90° network for explicitness. These voltages before being applied to the network 16, however, have been already shifted in phase to some extent such as 45 degrees by means of a suitable phase shifting network 17.

Thus it will be apparent that the radio frequency voltage as it appears on the control grids G1 and G2 may be represented by the vector diagram of Fig. 2 where the voltage E_{G1} on grid G1 is leading the voltage E_{P1} on the plate P1

by 45 degrees and where the voltage E_{G2} is lagging the voltage E_{P2} on the plate P2 by 45°, the voltages E_{G1} and E_{G2} being 90 degrees displaced in phase.

The circuit thus far described will operate to frequency modulate the oscillator in accordance with the audio signal or other modulating signal in a well known manner, the modulating signal on the grids G1 and G2 causing the reactive current output of each tube to vary with said signal.

In accordance with the present invention, frequency "drift" of the oscillator 10 is prevented by means of a phase shifting device, such as a piezoelectric crystal indicated at 18, in the feedback circuit. This feed-back circuit from the oscillator 10 may be traced through a conductor, the crystal 18, the 45 degree phase shifting network 17, and the 90 degree phase shifting network 16.

The crystal 18, the equivalent circuit of which is shown in Fig. 5, is series resonant at the carrier wave frequency or mid-frequency of the oscillator output (frequency *fx* in Fig. 6) whereby it is an inductive impedance element when the frequency of oscillation shifts to one side of the mid-frequency and a capacitive impedance element when the frequency shift is to the other side of the mid-frequency.

As a result, the crystal output will shift the phase of the radio frequency grid voltages E_{G1} and E_{G2} when there is a shift in the oscillator frequency, and this phase shift is in the direction to oppose any change in oscillator frequency. As previously noted, the modulating signal "over rides" this degenerative stabilizing action during the circuit operation. Otherwise the modulating signal could not change the oscillator frequency.

The above-described phase shift produced by the feed-back circuit is shown in Fig. 2 where the dotted vectors OA and OB represent the vectors E_{G1} and E_{G2}, respectively, shifted in phase. It will be noted that the capacitively reactive component of the voltage E_{G1} has been reduced from the value $E_{G1}D$ to the value BC while the inductively reactive component of the voltage E_{G2} has been increased from the value $E_{G2}F$ to the value AE. Such a phase shift is caused when the oscillator frequency becomes lower than the mid-frequency (frequency *fx* in Fig. 6) whereby the crystal presents capacitive impedance as shown by the curve 26 in Fig. 6.

It will be apparent that the above-described phase shift has decreased the capacitive current in the oscillator tuned circuit 11 and has increased the inductive current in the same circuit whereby the feed-back circuit tends to raise the oscillator frequency towards the original mid-frequency value. Thus, the oscillator is stabilized so that changes in line voltage, humidity, temperature, etc. have very little effect upon its frequency of oscillation.

A specific circuit for the embodiment of Fig. 1 is shown in Fig. 3 merely by way of example.

In Fig. 3 the radio frequency signal is fed back from the plate P1 of the tube 12 through the piezoelectric crystal 18 and through a 45 degree phase shift network 17 comprising a condenser 26 and a resistor 27, both preferably adjustable for adjusting the phase shift. Since a by-pass condenser 28 holds the lower end of resistor 27 at ground potential for R. F. voltages, the voltage E_{G1} on the grid G1 is the voltage across resistor 27. The R. F. voltage is next fed to the grid G2 through a 90 degree phase shift network 16 comprising a condenser 31 in series with an inductance coil 32 that is shunted by a resistor 33, the units 31, 32 and 33 preferably being variable for adjusting the phase.

The lower end of the LR combination 32—33 is held at ground potential for the R. F. voltages by means of a by-pass condenser 34. Since the grid G2 of the tube 13 is connected to the junction point of the condenser 31 and the coil 32, the R. F. voltage E_{G2} on grid G2 is the voltage across the LR combination 32—33. This voltage E_{G2} leads the voltage E_{G1} by 90 degrees in the specific example assumed.

The above-described phase relations are as illustrated in Fig. 2 and as described in connection with Fig. 1.

The audio signal or other modulating signal is applied through a transformer 21 to the grids G1 and G2 in balanced or push-pull relation, the center point of the transformer secondary being connected through a suitable biasing source such as a by-passed cathode resistor 20 and to the cathodes of the tubes 12 and 13.

Fig. 4 shows another specific embodiment of the invention wherein the plates of the tubes 12 and 13 are connected in parallel. The vector diagram for this circuit is shown in Fig. 7.

In Fig. 4 the input circuit of the tubes 12 and 13 includes a tuned circuit 41 tuned to the carrier wave frequency and comprising inductance coils 42 and 43 and a tuning condenser 44. The midpoint of circuit 41 is connected to ground through by-pass condensers 46 and 47. The modulating voltage is applied to the tubes in push-pull relation as in Fig. 3.

The R. F. voltage is fed back from the plates P1 and P2 through a piezoelectric crystal 48 which may be a two-terminal unit as in Fig. 3 or a four-terminal unit as illustrated. As in Fig. 3, the crystal preferably resonates at the carrier wave frequency. From the crystal 48 the R. F. voltage passes through a 45 degree phase shift network comprising a condenser 49 and a resistor 51 putting a voltage E_{G1} on the grid G1 leading the voltage E_{P1} on the tube plates by 45 degrees in the example illustrated.

The R. F. voltage at the other end of tuned circuit 41 is 180 degrees displaced from E_{G1}. It is shifted an additional 90 degrees by a network comprising an inductance coil 52 in series with a condenser 53 shunted by a resistor 54. The voltage appearing across the RC combination 54—53 is applied to the grid G2. This voltage shown as E_{G2} in Fig. 7 is now 45 degrees lagging the plate voltage E_{P1}.

It will be apparent that the operation of the circuit of Fig. 4 is the same as previously described in connection with Fig. 1.

It may be noted that the piezoelectric crystal in the feedback circuit preferably is operated over a substantially linear portion of its phase shift characteristic in order to minimize distortion of the transmitted signal.

While I have referred specifically to 45 degree and 90 degree phase shifting networks, it should be understood that other amounts of phase shift may be employed. Just by way of example, the first phase shift may be 10 degrees and the second phase shift 170 degrees, but this would require more audio swing.

I claim as my invention:

1. In combination, an oscillator, a reactance tube circuit coupled to said oscillator to control its frequency, said circuit including a vacuum tube and means for feeding back a high frequency voltage from said oscillator to said tube

and for also shifting the phase of said voltage during said feed-back by an amount which is effectively less than ninety degrees plus or minus, means for applying a modulating voltage to said tube for frequency modulating the output of said oscillator, and a phase shifting unit in said feed-back means for shifting the phase of the high frequency voltage fed back in response to a change in the frequency thereof and in such direction as to tend to hold constant the frequency of said oscillator output.

2. In combination, an oscillator, a reactance tube having its plate circuit connected to said oscillator to control its frequency, said tube having an input circuit, means for feeding back a high frequency voltage from said oscillator to the input circuit of said reactance tube and for also shifting its phase during said feed-back by an amount which is effectively less than ninety degrees plus or minus, means for applying a modulating voltage to the input circuit of said reactance tube for frequency modulating the output of said oscillator, and a phase shifting unit in said feed-back means for shifting the phase of the high frequency voltage fed back in response to a change in the frequency thereof and in such direction as to tend to hold constant the frequency of said oscillator output.

3. In combination, an oscillator, a reactance tube having its plate circuit connected to said oscillator to control its frequency, said tube having an input circuit, means for feeding back a high frequency voltage from said oscillator to the input circuit of said reactance tube and for also shifting its phase during said feed-back by an amount which is effectively less than ninety degrees plus or minus, means for applying a modulating voltage to the input circuit of said reactance tube for frequency modulating the output of said oscillator, and a piezoelectric crystal in said feed-back means for shifting the phase of the high frequency voltage fed back in response to a change in the frequency thereof and in such direction as to tend to hold constant the frequency of said oscillator output.

4. In combination, a stable self-excited oscillator, a reactance tube having its plate circuit connected to said oscillator to control its frequency, said tube having an input circuit, means for feeding back a high frequency voltage from said oscillator to the input circuit of said reactance tube and for also shifting its phase during said feed-back by an amount which is effectively less than ninety degrees plus or minus, means for applying a modulating voltage to the input circuit of said reactance tube for frequency modulating the output of said oscillator, and a piezoelectric crystal in said feed-back means for shifting the phase of the high frequency voltage fed back in response to a change in the frequency thereof and in such direction as to tend to hold constant the frequency of said oscillator output, said crystal being series resonant at substantially the mid-frequency of said frequency modulated output.

5. In combination, a stable self-excited oscillator, a pair of reactance tubes having plate circuits connected to said oscillator to control its frequency, said tubes each having input circuits, means for feeding back a high frequency voltage from said oscillator to the input circuits of said reactance tubes in such phase relation that one of said tubes simulates inductive reactance while the other tube simulates capacitive reactance, means for so applying a modulating voltage to said reactance tubes that the output of said oscillator is frequency modulated in accordance therewith, and a phase shifting unit in said feedback means for shifting the phase of said high frequency voltage at the input circuits of said tubes in response to a change in the frequency thereof and in such direction as to tend to stabilize the frequency of said oscillator output.

6. In combination, a stable self-excited oscillator, a pair of reactance tubes having their plate circuits connected to said oscillator to control its frequency, said tubes each having an input circuit, means for feeding back a high frequency voltage from said oscillator to the input circuits of said reactance tubes in such phase relation that one of said tubes simulates inductive reactance while the other tube simulates capacitive reactance, means for so applying a modulating voltage to said reactance tubes that the output of said oscillator is frequency modulated in accordance therewith, and a piezoelectric crystal in said feedback means for shifting the phase of the said high frequency voltage at the input circuits of said tubes in response to a change in the frequency thereof and in such direction as to tend to stabilize the frequency of said oscillator output.

7. In combination, a stable self-excited oscillator, a pair of reactance tubes having their plate circuits connected to said oscillator to control its frequency, said tubes each having an input circuit, means for feeding back a high frequency voltage from said oscillator to the input circuits of said reactance tubes in such phase relation that one of said tubes introduces inductive reactance while the other tube introduces capacitive reactance, means for so applying a modulating voltage to said reactance tubes that the output of said oscillator is frequency modulated in accordance therewith, and a piezoelectric crystal in said feedback means for shifting the phase of said high frequency voltage at the input circuits of said tubes in response to a change in the frequency thereof and in such direction as to tend to stabilize the frequency of said oscillator output, said crystal being series resonant at the mid-frequency of said frequency modulated output.

EDMOND S. WINLUND.