

Feb. 16, 1943.

N. BISHOP

2,311,026

CRYSTAL STABILIZED FREQUENCY MODULATION SYSTEM

Filed April 24, 1941

2 Sheets-Sheet 1

Fig. 1.

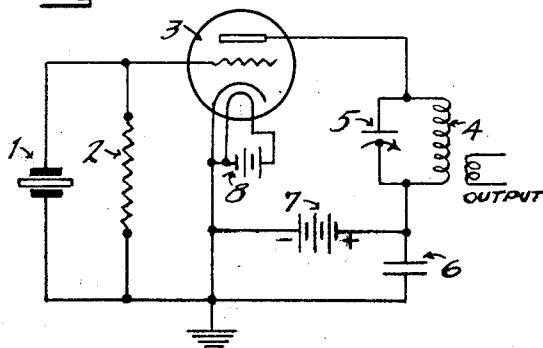


Fig. 3.

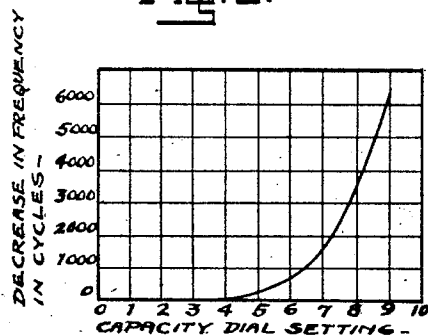


Fig. 2.

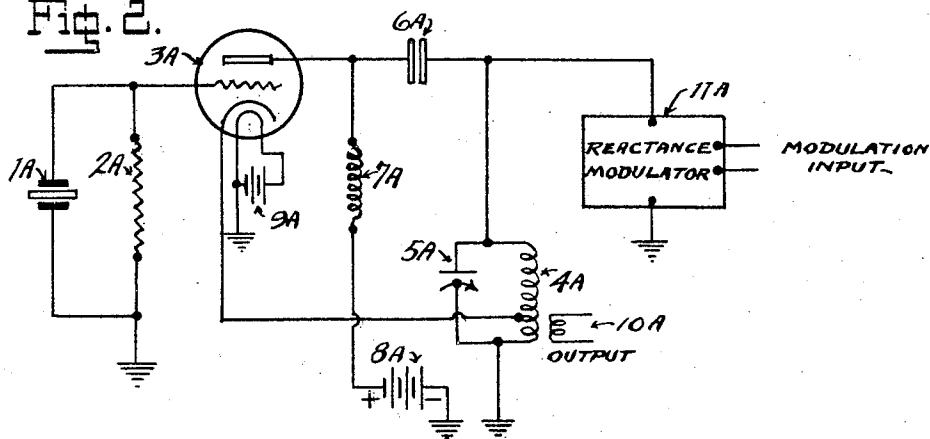
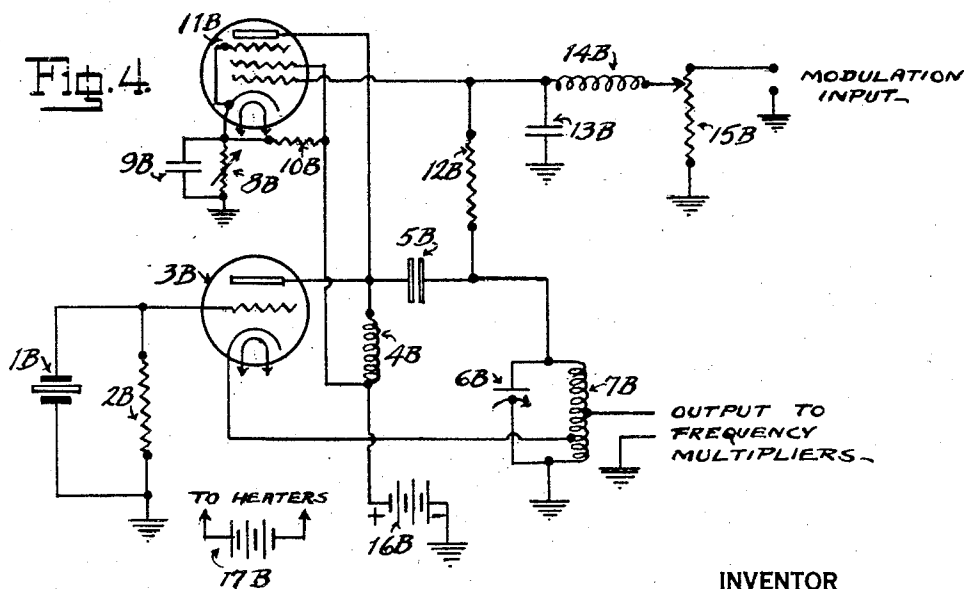


Fig. 4.



INVENTOR
NATHANIEL BISHOP.
BY
John W. Mattern
ATTORNEY

Feb. 16, 1943.

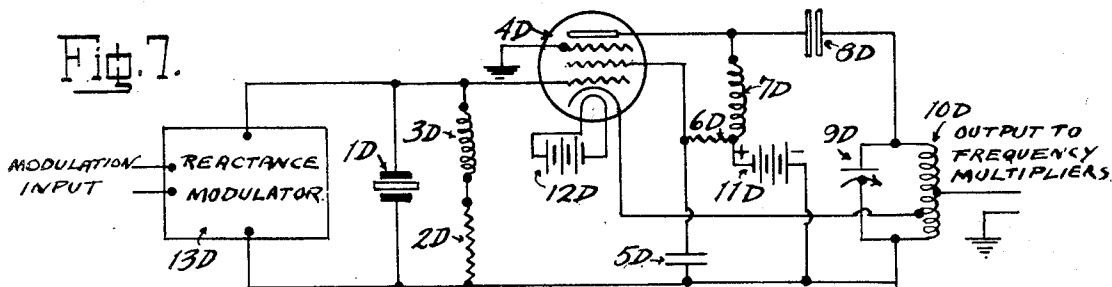
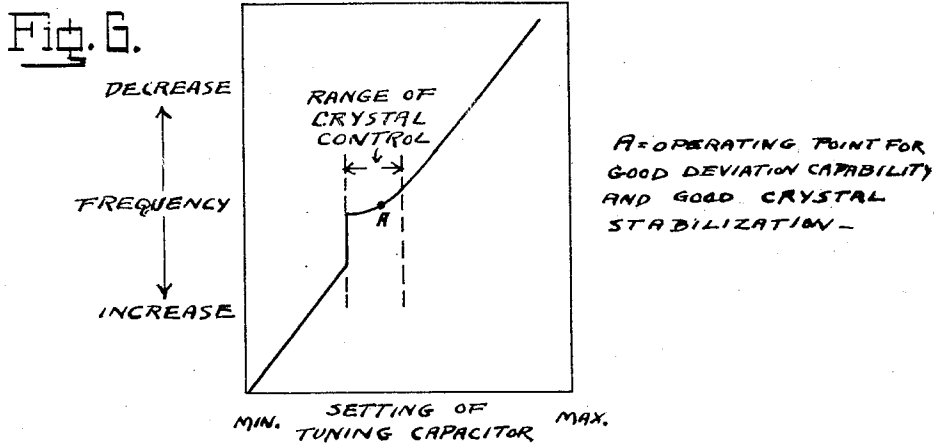
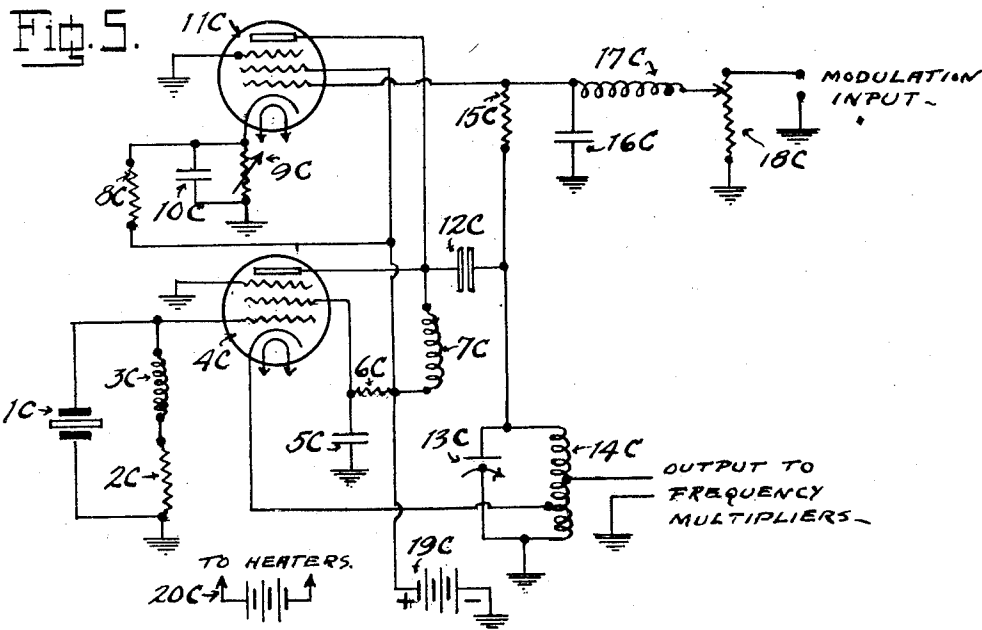
N. BISHOP

2,311,026

CRYSTAL STABILIZED FREQUENCY MODULATION SYSTEM

Filed April 24, 1941

2 Sheets-Sheet 2



INVENTOR
NATHANIEL BISHOP.
BY
James W. Mattern
ATTORNEY

UNITED STATES PATENT OFFICE

2,311,026

CRYSTAL STABILIZED FREQUENCY
MODULATION SYSTEM

Nathaniel Bishop, Fairfield, Conn.

Application April 24, 1941, Serial No. 390,135

1 Claim. (Cl. 179—171.5)

The present invention relates to a crystal stabilized frequency modulation system wherein it is proposed, according to the invention, to use a piezo electric crystal for the stabilization of the carrier frequency generated by an oscillator, which oscillator is to be frequency modulated by a reactance modulating device, having the characteristic that the reactance that the device introduces into the oscillator circuit varies with the modulating voltage applied to the device.

The use of a vacuum tube reactance modulator and an ordinary vacuum tube oscillator as a means of producing frequency modulated signals is a technique well known to the art. Because of the difficulty of maintaining adequate stability of the carrier frequency, such use has been limited to experimental work. Systems using reactance modulated oscillators are now in use, wherein stability is maintained by beating the output of the reactance modulated oscillator with the output of a separate crystal oscillator, and then by applying the difference frequency to electrical or electro-mechanical circuits which react back on the modulated oscillator in such a way as to tend to hold the carrier frequency constant. It will be noted that such systems do not use the crystal oscillator directly in the signal generating circuits.

The only systems at present in use in which a piezo electric crystal is used directly in the signal generating circuits of a frequency modulation transmitting system are (1) the phase shift method as disclosed in patents to Edwin H. Armstrong, wherein a small phase shift at a relatively low frequency requires several stages of frequency multiplication to arrive at an operating frequency with sufficient frequency deviation to give a useful frequency modulated signal, and (2), a system of frequency modulation of a crystal controlled oscillator by reactance variations in the plate circuit as disclosed in the patent to Irving Langmuir, No. 2,032,620. It is well-known to those versed in the art that the amount of frequency change produced by reactance variation in the plate circuit of a normal or pure crystal controlled oscillator, by which is meant a crystal oscillator in which the output frequency is largely determined by the natural period of the crystal itself, can only be an extremely small percentage of the frequency determined by the natural period of the crystal.

The circuits and systems briefly outline above indicate that a simpler and more direct means of obtaining stable frequency modulated signals would be highly desirable, and it is an object of my invention to provide a system and circuits by means of which these desirable results are obtained.

With the above and other objects in view, embodiments of the invention are shown in the accompanying drawings, and these embodiments will be hereinafter more fully described with reference thereto, and the invention will be finally pointed out in the claim.

In the drawings:

Fig. 1 shows a schematic circuit of a triode crystal oscillator, this being a known circuit and illustrated for the purpose of explanation.

Fig. 2 shows a schematic circuit of a crystal stabilized frequency modulation system, according to the invention.

Fig. 3 is a graph showing a curve illustrating the variation in output frequency of a triode crystal stabilized with changes in plate load reactance, according to the circuit shown in Fig. 2.

Fig. 4 shows a schematic circuit according to the invention in which a pentode reactance modulator is used in combination with a triode crystal stabilized oscillator.

Fig. 5 shows a schematic circuit in which a pentode reactance modulator is used in combination with a pentode crystal stabilized oscillator.

Fig. 6 is a graph showing a tuning curve characteristic of the circuits illustrated in Figs. 4 and 5.

Fig. 7 shows a schematic circuit according to the invention in which frequency modulation of the crystal stabilized oscillator is obtained by reactance variation in the input or grid circuit.

The theory of operation of the system of crystal stabilized frequency modulation, according to my invention, and the circuits illustrative thereof may best be understood by a preliminary explanation of a simple triode crystal oscillator of known form as shown schematically in Fig. 1, and which comprises the following elements:

- 1—Crystal plate and mounting.
- 2—Grid resistor.
- 3—Triode vacuum tube with heater, cathode, grid, and plate.
- 4—Plate coil.
- 5—Plate tuning capacitor.
- 6—Plate by-pass capacitor.
- 7—Source of plate potential.
- 8—Source of heater potential.

The values of the plate coil 4 and the plate tuning capacitor 5 are chosen so that this tuned circuit is resonant at the crystal frequency at about the mid-capacity setting of the plate tuning capac-

itor. It will be noted that plate load of the triode 3 is a positive reactance at the crystal frequency when the circuit is tuned to a higher frequency than the crystal frequency.

The operation of the circuit illustrated in Fig. 1 is well known to the art but, for the sake of completeness, the following description is given here. The condition for oscillation in this circuit is that sufficient voltage of the proper phase is fed back from the output circuit to the input circuit by way of the plate to grid capacity of triode 3, to neutralize the losses in the crystal and the grid circuit of the oscillator. This condition is met as the capacity of the plate tuning capacitor 5 is increased to the point where the positive reactance of the plate load is high enough to feed back the requisite voltage. If the capacity of the capacitor 5 is increased beyond this starting point, the feedback, and consequently the output of the oscillator, increases until the conditions of oscillation are no longer met and oscillation ceases. The important phenomenon which is noted as one observes such an oscillator during the process of tuning the plate circuit, is that the frequency of the oscillator decreases as the capacity of the capacitor 5 is increased in the tuning range just before oscillation ceases. This change in frequency is very small, in the order of 100 or 200 cycles for a 7000 kilocycle crystal. The small range of frequency variation, with changes in plate load reactance, makes the combination of a normal crystal oscillator and a reactance modulator impracticable for the generation of frequency modulated signals.

According to my invention, I propose to provide the means of making it possible to get a relatively large range of frequency variation of a crystal stabilized oscillator with variations in the reactance of circuits in the oscillator external to the crystal itself, thus allowing the frequency modulation of such an oscillator by means of a so-called reactance modulator circuit.

In Fig. 2 I have shown one circuit, according to the invention, and which comprises the following elements:

- 1A—Crystal plate and mounting.
- 2A—Grid resistor.
- 3A—Triode vacuum tube with heater, cathode, grid and plate.
- 4A—Plate coil.
- 5A—Plate tuning capacitor.
- 6A—Plate blocking condenser.
- 7A—Plate choke coil.
- 8A—Source of plate potential.
- 9A—Source of heater potential.
- 10A—Output coupling coil.
- 11A—Reactance modulator.

For the purpose of the present description the element 11A is generalized as a reactance modulator, which may be any suitable device, electronic, such as a reactance tube, or electromechanical, such as a small capacitor, one plate of which may be vibrated by an electromechanical transducer. Specific circuits having the desired characteristics will be described later. Comparing the oscillator in Fig. 2 with that in Fig. 1 it will be seen that, if the crystal 1 in Fig. 1 were replaced by a short circuit or a large capacitor the circuit would not oscillate, as insufficient or no excitation voltage would exist between the control grid of tube 3 and its cathode. In Fig. 2, however, the crystal 1A may be replaced by a large capacitor and the circuit will still oscillate by virtue of the excitation voltage exist-

ing between the cathode of tube 3A and ground, which in effect exists between the cathode and the control grid. In the case of Fig. 2 the voltage between the cathode of tube 3A and ground is obtained by tapping the cathode above the grounded end of the plate tuning coil 4A. A part of the total load circuit is thereby made common to the grid and plate circuits of the oscillator. The most important effect of this connection is that the frequency variation obtainable by plate tuning has been increased many times. In other words I have found that a circuit such as Fig. 2 allows a wide range of output frequency to be obtained while still maintaining a degree of stabilization due to the presence of the piezo electric crystal in the control grid circuit. As is shown in Fig. 6 such a circuit can be made to oscillate over a much wider range of frequencies than that range wherein the crystal is acting to stabilize the frequency. However, operation must be confined to that range designated in Fig. 6, "Range of crystal control," to derive any beneficial stabilizing effects from the crystal.

The curve illustrated in Fig. 3 shows the variation in output frequency of a triode crystal stabilized oscillator similar to Fig. 2, with various settings of the plate tuning capacitor. Frequency variation is plotted against dial divisions on the tuning capacitor control. "0" frequency corresponds to the frequency obtained as the capacity of the tuning capacitor is increased, to the point where the crystal just starts to oscillate.

It will be noted that very little change in frequency is apparent for the first few divisions of capacity increase after the crystal starts. As the capacity is still further increased the change in frequency becomes greater and is greatest at the point just below where oscillation ceases. It will be seen that in order to get adequate frequency modulation by reactance variation it is necessary to operate on a relatively steep portion of this characteristic. The shape of this curve also indicates that a non-linear relation exists between plate circuit reactance and output frequency, which will require special treatment of the reactance modulator to give a linear relation between the voltage applied to the reactance modulator and the change in frequency that it produces in the oscillator. In brief, therefore, the theory of operation of the specific circuits to be described, is that by inserting a suitably mounted piezo electric crystal in the control grid circuit of a vacuum tube oscillator it is possible to adjust the output frequency of the oscillator to a point where frequency modulation may be produced by a reactance modulator coupled to the oscillator, of sufficient deviation to be extremely useful for communication purposes, while at the same time maintaining a degree of carrier frequency stabilization due to the presence of the crystal far in excess of that possible if the crystal were not inserted in the circuit. The fact that crystals of a relatively high frequency may be used with success in these circuits allows the design of extremely simple, stable, and efficient frequency modulation transmitters, without resorting to the more complicated circuits now known to the art.

The circuits illustrated up to this point have been shown in simplified form for the purposes of explanation. The hereinafter described circuits, illustrated in Figs. 4, 5, and 7, have been operated in actual use and have performed successfully as generators of frequency modulated signals.

Fig. 4 illustrates a circuit, according to the in-

vention, wherein a triode crystal stabilized oscillator is combined with a pentode reactance modulator for the generation of a crystal controlled frequency modulated signal, and combines the following elements:

- 1B—Crystal plate and mounting.
- 2B—Oscillator grid resistor.
- 3B—Triode vacuum tube having a heater, cathode, grid and plate.
- 4B—Plate choke for oscillator and modulator (radio frequency).
- 5B—Plate blocking capacitor.
- 6B—Plate tuning capacitor.
- 7B—Plate coil tapped for cathode and output connections.
- 8B and 10B—Modulator cathode voltage divider, adjustable for bias adjustment.
- 9B—Modulator cathode by-pass capacitor.
- 11B—Pentode reactance modulator having heater, cathode, control grid, screen grid, suppressor grid, and plate.
- 12B—Modulator control grid phasing resistor.
- 13B—Modulator control grid phasing capacitor.
- 14B—Radio frequency blocking choke.
- 15B—Modulation control, adjustable voltage divider.
- 16B—Source of plate, screen, and biasing potential for tubes 3B and 11B.
- 17B—Source of heater potential for tubes 3B and 11B.

In operation the cathode tap on the output circuit of oscillator 3B is adjusted to provide the desired feed back. The plate tuning adjustment 6B is set to operate on the steep portion of the frequency versus plate reactance curve as illustrated in Fig. 3. The plate circuit of the reactance modulator tube 11B is in parallel with the oscillator plate circuit. The phase of the radio frequency voltage applied to the grid of tube 11B is adjusted by the proper choice of resistor 12B and capacitor 13B, so as to make tube 11B draw a lagging current from the plate circuit of tube 3B. Tube 11B then appears as an inductance in shunt with the plate load of tube 3B which consists of the shunt impedance of capacitor 6B and inductance 7B. The operating point of tube 11B as an inductive load is determined by the cathode bias adjustment as afforded by the adjustable voltage divider 8B and 10B. The modulation voltage is applied to the control grid of tube 11B through the adjustable voltage divider 15B and the radio frequency choke coil 14B. Modulation voltage applied to the grid of tube 11B varies its transconductance and thereby modulates the amount of lagging current that it draws from the load circuit. This appears to the plate circuit of triode 3B as a load whose reactance is varying at the modulating frequency, hence the output frequency of the oscillator is modulated in accordance with the applied modulation voltage.

In order to obtain a linear relation between the applied modulating voltage and the frequency change of the oscillator, which is necessary for distortionless transmission by means of frequency modulation, the operation of the reactance modulator is altered from the way which such a circuit is normally used to modulate an ordinary vacuum tube oscillator. In such an application, the change in lagging current drawn by the reactance modulator with changes in applied control grid voltage, or modulation, must have a linear relation in order to produce a linear relation between control grid voltage, or modulation, and

the oscillator frequency change. Such is not the case when a crystal stabilized oscillator is modulated by such a tube, particularly if a wide frequency swing, or deviation, is desired. An examination of Fig. 3 indicates that a frequency versus load reactance curve of such an oscillator is non-linear except over a small portion of the steep part of the characteristic. This situation is easily remedied in the circuit of Fig. 4 by operating tube 11B with an abnormally high cathode bias. The non-linearity so produced counterbalances the non-linearity of the reactance versus frequency characteristic by the process known as pre-distortion so that the overall grid voltage, or modulation, versus frequency curve is made substantially linear.

Fig. 5 illustrates the combination of a pentode crystal stabilized oscillator and a pentode reactance modulator for the same type of operation as the circuit illustrated in Fig. 4. The use of a well shielded pentode instead of a triode in the oscillator portion of the circuit has the advantage that the internal grid to plate capacity feedback path is essentially removed and substantially all feedback is confined to the mutual impedance between the cathode and ground, thus leaving the amount of feedback used entirely within the control of the designer. This circuit is more flexible than Fig. 4 and shows increased stability and greater range of frequency swing with modulation, than the triode circuit. The circuit of Fig. 5 comprises the following elements:

- 1C—Crystal plate and mounting.
- 2C—Oscillator grid resistor.
- 3C—Oscillator grid choke (radio frequency).
- 4C—Pentode vacuum tube having heater, cathode, grid, screen, suppressor grid, and plate.
- 5C—Oscillator screen by-pass capacitor.
- 6C—Oscillator screen potential dropping resistor.
- 7C—Radio frequency plate choke.
- 8C and 9C—Modulator cathode voltage divider, adjustable for bias adjustment.
- 10C—Modulator cathode by-pass capacitor.
- 11C—Pentode vacuum tube having heater, cathode, grid, screen, suppressor grid, and plate.
- 12C—Oscillator plate blocking capacitor.
- 13C—Oscillator plate tuning capacitor.
- 14C—Plate coil tapped for cathode and output connections.
- 15C—Modulator control grid phasing resistor.
- 16C—Modulator control grid phasing capacitor.
- 17C—Radio frequency blocking choke.
- 18C—Modulation control, adjustable voltage divider.
- 19C—Source of plate, screen, and bias potentials.
- 20C—Source of heater potential for tubes 4C and 11C.

The operation of the circuit in Fig. 5 is essentially the same as that of Fig. 4, but as previously stated increased stability and range of frequency swing with modulation are obtainable due to the complete control of feedback afforded by the choice of the cathode tap on coil 14C.

If enough feedback is used either in the circuits of Fig. 4 or Fig. 5 the circuits will oscillate over the entire tuning range of the plate coil and tuning capacitor. The crystal however will take control over a limited range near the resonant frequency of the crystal circuit. The operating point must be chosen in the range where the crystal is vibrating if the stabilizing effect of the

crystal is to be realized. Fig. 6 illustrates a tuning curve of the oscillator as the tuning capacitor is varied. It will be noted that the slope of the curve is much less in the region where the crystal is operating to stabilize the frequency. This range is identical in shape to the curve shown in Fig. 3.

The circuits described up to this point have illustrated how a crystal stabilized oscillator may be frequency modulated by reactance variation in the plate or load circuit of the oscillator. Frequency modulation of a crystal stabilized oscillator may be obtained by reactance variation in other parts of the oscillator circuit, such as the input circuit or (grid circuit) of the crystal stabilized oscillator. As one example of this refer to Fig. 7 which shows a pentode crystal stabilized oscillator which has a reactance modulator directly connected across the crystal. The circuit of Fig. 7 comprises the following elements:

- 1D—Crystal plate and mounting.
- 2D—Oscillator grid resistor.
- 3D—Oscillator grid choke (radio frequency).
- 4D—Pentode vacuum tube having heater, cathode, grid, screen, suppressor grid, and plate.
- 5D—Oscillator screen by-pass capacitor.
- 6D—Oscillator screen potential dropping resistor.
- 7D—Radio frequency plate choke.
- 8D—Oscillator plate blocking capacitor.
- 9D—Oscillator plate tuning capacitor.
- 10D—Plate coil tapped for cathode and output connections.
- 11D—Source of plate, screen, and bias potentials.
- 12D—Source of heater potential for tube 4D.
- 13D—Reactance modulator.

In this case the reactance modulator 13D could

have the characteristics of a varying capacity. If a reactance modulator tube is used the characteristics of a capacity may be obtained by applying oscillator voltage of the proper phase to the control grid of the reactance modulator, so as to make it draw a leading current from the oscillator circuit.

I have shown by a description of the theory and by description of certain specific circuits how the carrier frequency of an oscillator designed for generating a frequency modulated signal may be stabilized by use of a piezo electric crystal for frequency control directly in the signal generating circuit. It should not be construed that the description of these particular circuits outlines the practical limits of application of the principles of the invention. It will be obvious to anyone skilled in the art that many modifications may be used, without departing from the scope of my invention as set forth in the appended claim.

Having thus described my invention what I claim and desire to secure by Letters Patent is:

A frequency modulation system comprising a piezo electric crystal stabilized oscillator having an input circuit including a piezo electric crystal and a tuned output circuit, means for regeneratively coupling said input and output circuits comprising a connection from said tuned output circuit to said input circuit, said connection including the piezo electric crystal in series, whereby the excitation voltage applied to said input circuit consists of the sum of the voltage across the crystal and the voltage derived regeneratively from the tuned circuit, a reactance tube modulator coupled to the tuned output circuit, and means for applying modulating potentials to said reactance tube.

NATHANIEL BISHOP.