

March 22, 1938.

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2,111,603

PHASE MODULATION

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2 Sheets-Sheet 1

Fig. 1

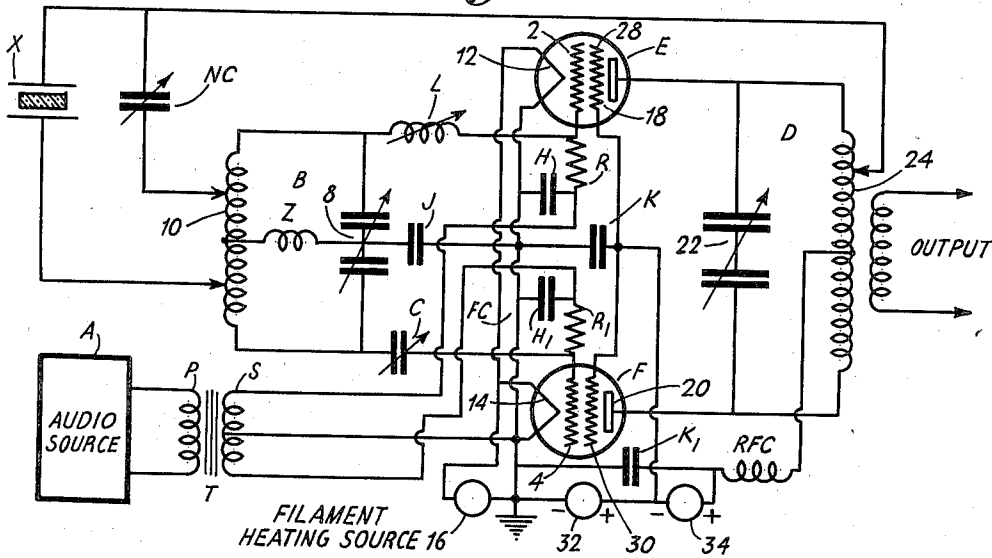
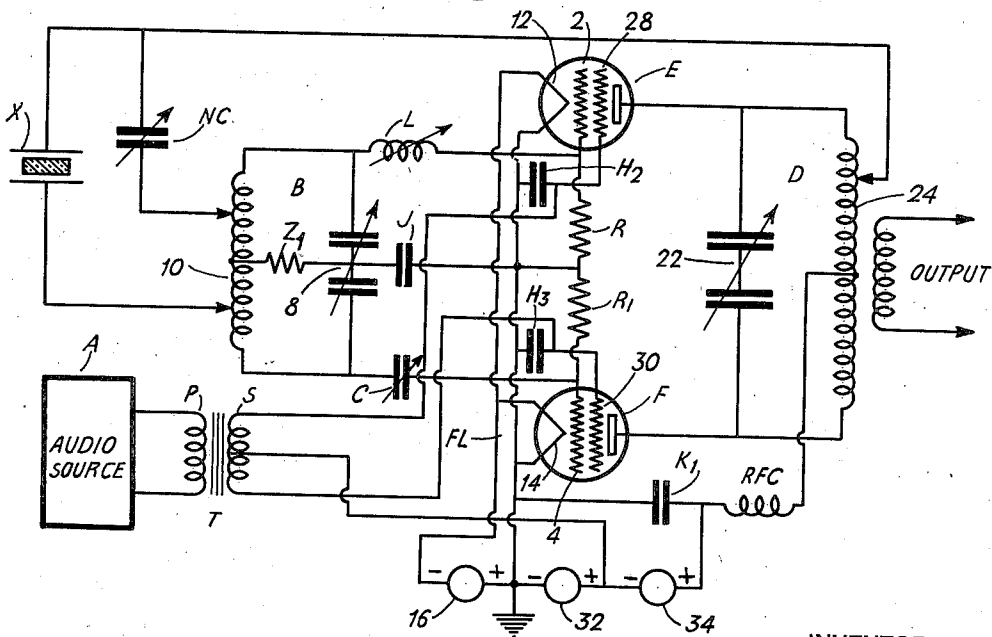


Fig. 2



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2 Sheets-Sheet 2

Fig. 3

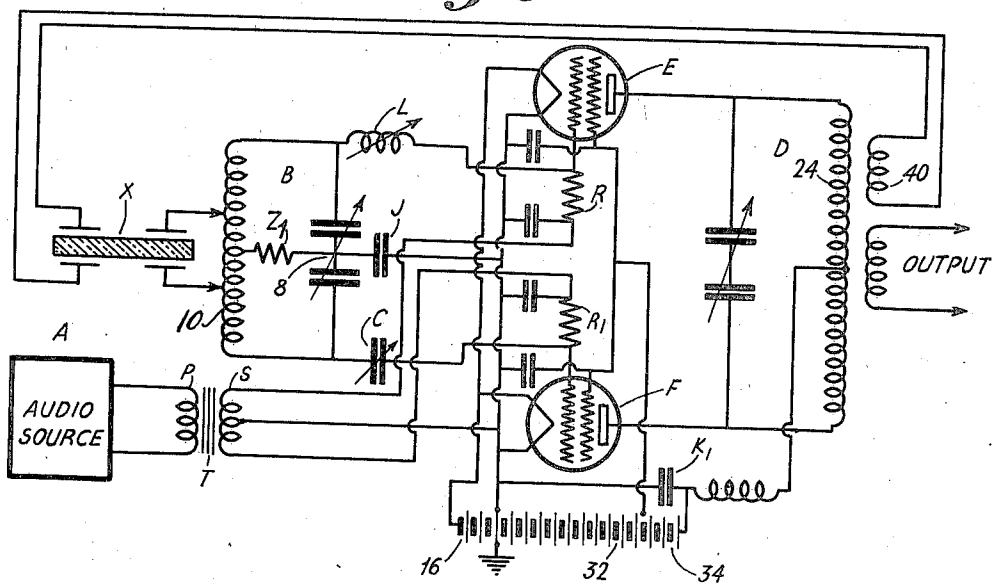
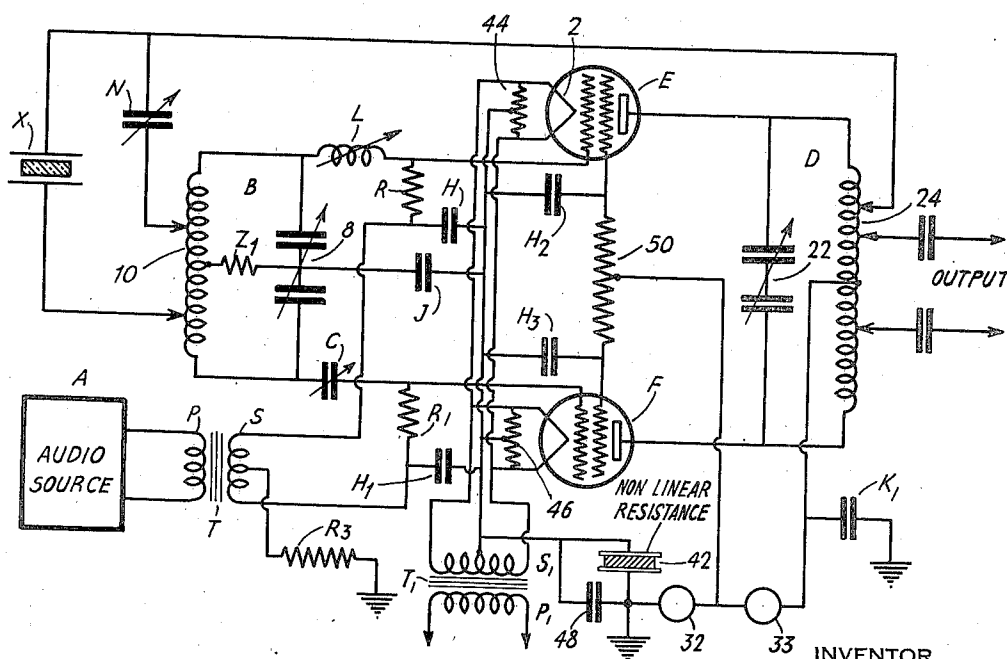


Fig. 4



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PHASE MODULATION

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22 Claims. (Cl. 179—171)

This invention relates to a signaling system and in particular to a system wherein oscillations of substantially constant amplitude and frequency are developed in a push-pull crystal controlled oscillator stage and simultaneously modulated in phase in accordance with potentials of tone or signal frequency.

In systems known in the prior art, phase modulation is often accomplished in a single tube crystal oscillator stage. Such a system has the disadvantage of producing amplitude modulation, as well as phase modulation. In the present system, any undesired amplitude modulation inadvertently produced is eliminated to a large extent because it is balanced out in the symmetrical push-pull circuit, so that only the phase modulated carrier appears in the output circuit.

In all embodiments of my invention a pair of thermionic tubes have their control grids and anodes connected in push-pull relation by resonant circuits. Excitation energy is supplied to the resonant grid circuit from a piezo electric crystal or other equivalent mechanical vibrator, which is in turn connected to the anode circuit, from which energy of a frequency and phase angle which is the average frequency and phase angle of the oscillations in the anode tank circuit is fed back to the grid resonant circuit. Thus, a flywheel effect is obtained, whereby there is a transfer of energy to the tuned grid circuit from the crystal or equivalent element and to the crystal or equivalent element from the tuned anode circuit. Due to said flywheel effect and the filter effect of the crystal or similar element, oscillations of constant frequency and phase and amplitude are developed in the tuned grid circuit. This circuit is connected by phase shifting means to the grids of the tubes and the tube impedances are varied in opposition by the modulating potentials so that the oscillations in each tube are relatively phase shifted and differentially amplitude modulated. Oscillations are set up in the tuned anode circuit of a phase which is determined to a large extent by the phase of the oscillations from the tube supplying the greater amount of energy to the tuned anode circuit. The resonance inertia of the crystal or equivalent element tends to hold a constant frequency and phase angle which is the average frequency and phase angle of the oscillations in the anode circuit.

The modulating potentials may be applied to the control grid or to the anode where triodes or screen grid tubes are utilized or to the screen grid electrodes when screen grid tubes are utilized.

A novel feature of one modification resides in means in the form of a non-linear element in the cathode return circuit for controlling or limiting the potential on the tube electrodes irrespective of the amount of current flowing in the tube. This element may be a resistance in which the resistance varies inversely as the current intensity therethrough, or in which the current varies substantially as the square of the applied potential.

The crystal may be operated at its fundamental frequency or at a harmonic thereof. The grid circuit may be tuned to the operating frequency of the crystal. The anode circuit may be tuned to the operating frequency of the crystal or to a harmonic thereof.

Many other novel features in my system and advantages derived from the use thereof will become apparent from the following detailed description thereof and therefrom when read in connection with the attached drawings throughout which like reference characters indicate like parts insofar as possible, and in which:

Fig. 1 shows diagrammatically a circuit arranged in accordance with my invention. In this circuit, a pair of thermionic tubes are connected in oscillation generating circuits. The tube impedances are modulated at signal frequency to modulate the phase of the oscillations generated;

Fig. 2 is a modification of the arrangement of Fig. 1. In Fig. 2, the modulating potentials are applied to the screen grid electrodes, whereas they are applied to the control grid electrodes in Fig. 1;

Fig. 3 is a modification of the arrangement of Fig. 1. In Fig. 3, a crystal having four electrodes has replaced the two-electrode crystal of Fig. 1; while

Fig. 4 is a modification of the arrangement of Fig. 1. In Fig. 4, the potentials applicable to the electrodes in the tubes are controlled or limited by means of a non-linear device connected in the cathode return circuit thereof.

In Fig. 1, a pair of thermionic tubes E and F have their control grids 2 and 4 connected as shown to the terminals of a resonant circuit B comprising a condenser 8 in parallel with an inductance 10. A variable phase shifting inductive reactance L is connected between the grid 2 and one terminal of B. A variable shifting capacitive reactance C is connected between the control grid 4 and the other terminal of B. The cathodes or filaments 12 and 14 of the tubes are heated by means of a circuit FC connecting said filaments with the heating source 16. The electrical center of the condenser 8 is connected to

the filament heating circuit FC by a condenser J. The impedance Z raises the point on 10 to a small radio frequency potential relative to the electrical center of 8 and to ground. Thus, the electrical center of 10 is floating at radio frequency relative to ground, provided the impedance Z is of sufficient value. This prevents splitting tuned circuit B and prevents parasitic oscillations. A tuned circuit D is connected between the anode electrodes 18 and 20 of tubes E and F, respectively. The tuned circuit D comprises a condenser 22 and an inductive reactance 24. This circuit may be tuned to the crystal frequency or a harmonic thereof. A movable point on the inductive reactance 24 is connected as shown to one terminal of a piezo electrical crystal X, the other terminal of which is connected to a movable point on the inductance 10. The capacity of the crystal holder of X may be neutralized by a condenser NC connected as shown in parallel with the holder of X. The points on 10 and 24 are selected so that regeneration is produced when the crystal oscillates. If the crystal should stop oscillating, its holder capacity being neutralized by NC, no oscillations are produced. The direct current grid circuit of tube E comprises a resistance R and one half of the secondary winding S of a transformer T, the primary winding of which is connected to any modulation potential source A. The grid direct current circuit of tube F comprises a resistance R_1 and the other half of the secondary winding S of transformer T. The terminals of R and R_1 are grounded, as shown by radio frequency bypass condensers H and H_1 . These condensers are of sufficient value to bypass the oscillations to be modulated, but not of sufficient value to short-circuit the secondary winding S. The screen grid electrodes 28 and 30 are supplied by direct current potentials from a direct current source 32. Radio frequency potentials appearing in the screen grid electrodes are bypassed to the filaments by a bypass condenser K. Direct current potentials for the anodes 18 and 20 of tubes E and F are supplied from the source 34 connected as shown by way of a radio frequency choke RFC to a point on the inductance 24. The choke RFC prevents radio frequency potentials from reaching the source 34. Any radio frequency potentials which inadvertently pass RFC are shunted around the sources 34 and 32 by a radio frequency bypass condenser K_1 .

In describing the operation of the system illustrated in Fig. 1, it will first be assumed that no modulating potentials are being supplied from A and T to the control grids of the tubes. The tubes, due to their plate impedances as determined by the resonant circuit D and their tuned grid circuit connections, and the presence of crystal X and the coupling between the same and B and D, will generate high frequency oscillations which will appear in the tank circuit D. Part of this energy in D is returned to the input circuit B by way of a crystal X to produce regeneration in a manner apparent to one skilled in the art, so that a flywheel effect is obtained in the circuit. Thus, sustained oscillations of a fundamental frequency or a frequency which is a harmonic of the crystal frequency of constant amplitude and frequency, are produced in the tubes and circuits and appear in D. The excitation voltage impressed on the grid of tube E is retarded by phase shifting inductance L and grid bias resistance R. The excitation voltage impressed on the grid of tube F is advanced by

the phase shifting capacity C and biasing resistance R_1 , so that the voltages which would be supplied from X by way of B in phase opposition to the control grids 2 and 4 are relatively displaced in phase by L and C. If these impedances L and C are balanced so that they have the same effect on the high frequency voltages supplied to the grids 2 and 4 and if the direct current bias to the grids 2 and 4 is equal, in the absence of modulating potentials, the high frequency power supplied by each tube to the tank circuit D will be the same and the oscillations therein will have a constant phase angle which will coincide with the average phase angle of the excitation voltage reaching the grids. The crystal X, due to its resonance inertia, tends to hold a constant frequency and phase angle which is the average frequency and phase angle of the oscillations supplied thereto from the plate tank circuit D, due to the resonance energy of the crystal. Thus, the crystal is feeding oscillations of constant frequency and phase angle to the tank circuit B, and for this reason the phase and frequency of the oscillations in the grid tank circuit B are also constant.

Now assume that modulating potentials of any nature are produced in A and supplied from A by way of T and resistances R and R_1 to the control grids 2 and 4 of the tubes E and F. These modulating potentials are superimposed on the equal direct current potentials supplied to the control grids so that the potentials of the control grids 2 and 4 will vary in phase opposition at the signal frequency and the tube having the lower bias at any particular instant will supply the more power to the tuned tank circuit D. Since the excitation to the grids 2 and 4 of the two tubes E and F respectively has a phase difference as determined by L and C, power supplied to the tank circuit D from the anodes 18 and 20 of the two tubes E and F will have a phase difference. The phase of the oscillations appearing in the circuit D will change approaching that of the tube having the lower grid bias (less negative) and therefore supplying the more power to the tank circuit D. The amount of phase change in the circuit D will be substantially proportional to the difference in power delivered by the tubes E and F to the circuit D. The phase shift, however, will be limited by the phase difference of the excitation voltages applied to the grids 2 and 4 of E and F from B by way of L and C, respectively.

From the above description, it will be apparent that the potential variations from A will act on the impedances of tubes E and F to produce corresponding variations of phase of the otherwise normally constant frequency oscillations produced in D.

The high frequency oscillations produced in E and F and modulated in phase in accordance with the modulating potentials from A may be supplied from the tank circuit D to any utilization circuit. For example, they may be supplied to a radiating system directly or to an output circuit, as shown, which in turn may be coupled to the radiating system by way of amplitude limiters, amplifiers, or frequency multipliers.

The system shown in Fig. 2 is similar in nature and operation to the system of Fig. 1, except as otherwise noted hereinafter. In Fig. 2, the modulating potentials have been applied to the screen grid electrodes 28 and 30, rather than to the control grid electrodes, as in Fig. 1. The changes in the direct current circuits necessary for this

modification will be apparent, by a mere inspection of the drawings to one skilled in the art. The terminals of the secondary winding S are connected directly to the screen grid electrodes instead of to the control grid electrodes. The electrical center of the secondary winding S is connected to the source 32, instead of to the filament circuit FC, as in Fig. 1. The inductance Z of Fig. 1, which raises the point on 10 above ground radio frequency potential, has been replaced by a resistive impedance Z₁.

The operation of this arrangement is the same as the operation of the arrangement shown in Fig. 1. In Fig. 2, however, phase modulation of the oscillations produced is accomplished by modulating the potentials applied to the screen grid electrodes to thereby modulate the tube impedances, whereas in Fig. 1, the tube impedances are modulated by applying the modulating potentials to the grid electrodes. The result is the same in each case.

The nature of the circuit of Fig. 3 and the operation thereof is similar to the nature and operation of the circuit of Fig. 1, except as otherwise noted hereinafter. In Fig. 3, a resistive impedance Z₁ replaces the inductive impedance Z of Fig. 1. Moreover, here the crystal X has two pairs of electrodes, one pair of which is connected by movable points on the inductance 10 and the other pair of which is connected to an inductance 40 inductively coupled to the inductance 24. This arrangement eliminates the necessity of the use of a neutralizing condenser NC and further increases symmetry in the circuits developing the oscillations of constant frequency in the absence of signaling potentials.

In the system of Fig. 4, I have added additional grid biasing means in the form of a resistance R₃ connecting the electrical center of S to ground and by way of ground to a non-linear resistance 42, which is in turn connected to a point on the secondary winding S₁ of a transformer T₁, the primary winding P₁ of which may be connected to any source of alternating current. The secondary winding S₁ is connected to the filaments 2 and 4, respectively. In order to balance out any hum in the filter circuit, the electrical center of S₁ is also connected as shown to the electrical centers of resistances 44 and 46 connected in shunt to the filaments 2 and 4, respectively. The non-linear resistance 42 is shunted by a bypass condenser 48. The screen grid electrodes 28 and 30 are supplied with direct current potentials by way of a tapped resistor 50 connected as shown to the source 32.

In operation, high frequency oscillations of constant frequency and phase and amplitude are produced in the tubes E and F and circuits B and D in the absence of modulating potentials from A when the tube electrodes are energized by the sources connected as shown. When modulating potentials are supplied from A to the grid electrodes, the high frequency oscillations produced are modulated in phase in the manner described in detail hereinbefore in accordance with the modulating potentials. When the tubes E and F are oscillating, grid bias is supplied by the potential drop produced by the currents flowing in R₃. The value of R₃ is made such that a bias is produced between the control grids and filaments of a value such that the tubes E and F operate most efficiently to produce oscillations. The non-linear resistance 42 prevents excessive plate current from flowing in the circuits when oscillations are not being produced. The non-linear re-

sistance 42 is preferably provided with a metal surface to insure good contact over the two faces or contacting portions of the resistance element. The contact plates or electrodes are preferably large to thereby furnish additional cooling surface. The center points of resistors 44 and 46 are connected to the electrical center of S₁ and to one terminal of non-linear resistance 42 to thereby insure a low impedance path to ground for the relatively low oscillator frequency to which this particular embodiment of my invention is preferably adapted.

The manner in which high or low frequency oscillations of constant phase are produced in E and F and phase modulated therein at signal frequency will be apparent from the detailed description of the prior modifications. During operation, the resistance R₃ supplies a large part of the negative grid bias. The other part of the negative grid bias is supplied by the rectified grid current passing through phase shifting resistors R and R₁. The plate current, passing through the non-linear element 42, supplies positive bias to the cathode elements 2 and 4 and has the effect of adding negative grid bias. When the circuits stop oscillating, the negative grid bias caused by the rectified grid current is lost. Ordinarily, this would cause the plate current to increase to such an extent as to damage the tubes. The non-linearity of the element 42 inhibits this increase in plate current to a large extent. The extent to which the plate current is limited depends upon the size of the non-linear resistance 42, because the biasing or limiting action is increased or multiplied by the falling current rising resistance character of the element, which tends to hold a constant voltage across its electrode. For example, if the tubes E and F stop oscillating the negative bias produced by grid rectified current in R₁, R₂ and R₃ decreases so that normally the grids would be less positive and the tubes would draw excessive plate current. However, as the plate current tends to increase through 42 the potential drop through 42 increases at a greater rate. This potential drop makes the cathodes more positive relative to ground which has the same effect as making the grids more negative. This feature is very effective in reducing the plate current to a value lower than normal when the circuits stop oscillating for any reason. The non-linear resistance may be of any known type but is preferably of the type known in the art as "Thyrte".

Although I have shown tubes of the directly heated screen grid electrode type, it will be realized that I contemplate the use of tubes of the screen grid or pentode type. Moreover, such tubes may have directly or indirectly heated filaments. Also, three-element tubes may be used by neutralizing grid and plate capacities as it is generally done.

What I claim is:

1. In a wave producing and modulating system, a pair of electron discharge tubes each having a control grid, a cathode and an anode, a tuned resonant circuit, an inductive reactance coupling one terminal of said resonant circuit to the control grid of one of said tubes, a capacitive reactance coupling the control grid of the other of said tubes to the other terminal of said resonant circuit, a second tuned resonant circuit connected between the anodes of said tubes, a piezo electric crystal having a plurality of pairs of electrodes, a circuit connecting a pair of said electrodes in shunt to a part of said first named resonant cir-

cuit, a circuit coupling a second pair of the electrodes of said crystal to said second named resonant circuit, a source of modulating potentials, a biasing and phase shifting resistance connecting the control grid of each of said tubes to the filament of each of said tubes, and a circuit connecting said source of modulating potentials to points on said resistances.

2. In a phase modulated wave signaling system, a pair of tubes each having a control grid a cathode and an anode, a tuned resonant circuit connected by phase shifting reactances between the control grids of said tubes, a second tuned resonant circuit connected between the anodes of said tubes, a piezo electric crystal having two electrodes one of which is connected to a point on said first named resonant circuit, a circuit connecting the other electrode of said crystal to a point on said second named resonant circuit, a neutralizing condenser connected between the electrodes of said crystal, biasing and phase shifting resistances connected between the control grid and cathode of each tube, a source of modulating potentials connected to points on said resistances and a non-linear resistance connected in a direct current circuit between the anodes and cathodes of said tubes.

3. A system as recited in claim 2 wherein said non-linear resistance is also connected in a direct current circuit between the control grids and cathodes of said tubes.

4. In a signaling system a pair of electron discharge tubes each having a control grid, a cathode and an anode, a circuit coupling the control grid of one of said tubes to the control grid of the other of said tubes by way of reactances of different character, a tuned resonant circuit connected between the anodes of said tubes, a piezo electric crystal connected at one electrode to said first named circuit, a connection between another electrode of said crystal and a point on said second named circuit, a source of modulating potentials connecting the control grids of said tubes in push-pull relation, a direct current circuit connecting the control grids of said tubes to the cathodes of said tubes, and a non-linear resistance in said last named circuit.

5. A system as recited in claim 4 wherein said non-linear resistance is also connected in a direct current circuit between the anodes and cathodes of said tubes.

6. A system as recited in claim 4 wherein the capacity between the electrodes of said crystal is neutralized.

7. In a signaling system a pair of electron discharge tubes each having a control grid, an auxiliary electrode a cathode and an anode, an alternating current circuit connected by phase shifting reactances of different character between the control grids of said tubes and to the cathodes, an alternating current circuit connected between the anodes of said tubes and to the cathodes, a piezo-electric crystal having a plurality of electrodes one of which is connected to said first named circuit, a connection between another electrode of said crystal and a point on said second named circuit, and means for applying modulating potentials in phase displaced relation to like electrodes in each of said tubes.

8. A signaling system as recited in claim 7 wherein a non-linear resistance is connected in a direct current circuit between the anodes and cathodes of said tubes.

9. A signaling system as recited in claim 7

wherein said second named alternating current circuit is tuned to a harmonic of the frequency of said crystal.

10. A system as recited in claim 2 wherein said non-linear resistance is also connected in a direct current circuit between the control grids and cathodes of said tubes.

11. In a phase modulation system, a pair of tubes each having a control grid, an anode, and a cathode, a first alternating current circuit, a phase advancing reactance connecting said circuit to the control grid of one tube, a phase retarding reactance connecting said alternating current circuit to the central grid of the other tube, a second circuit connecting the anodes of said tubes together, means including frequency stabilizing means for producing regeneration in said tubes and circuits to produce oscillatory energy of substantially constant frequency in said second circuit, and means for modulating the internal impedances of said tubes in phase displaced relation at signal frequency to vary the phase of the produced oscillations at signal frequency.

12. In a signaling system a pair of electron discharge tubes each having grid electrodes, a cathode and an anode, a piezo-electric crystal, a circuit tuned to a frequency equal to the natural frequency of said crystal, multiplied by a whole number, a reactance coupling one terminal of said circuit to the control grid of one of said tubes, a reactance of different character coupling the control grid of the other of said tubes to the other terminal of said circuit, a second circuit connected between the anodes of said tubes, a connection between said piezo-electric crystal and said first named circuit, a coupling between said crystal and said second named circuit, a source of modulating potentials, and a circuit connecting said source of modulating potentials between like electrodes in said tubes.

13. A system as recited in claim 12 wherein a non-linear resistance is connected in a direct current circuit between the anodes and cathodes of said tubes.

14. In a signaling system a pair of electron discharge tubes each having a control grid, a cathode and an anode, a piezo-electric crystal, a circuit tuned to a harmonic of the frequency of said crystal coupled by reactances of different character between the control grid of one of said tubes and the control grid of the other of said tubes, a second circuit connected between the anodes of said tubes, a connection between the piezo-electric crystal and said first circuit, a circuit connecting said crystal to said second named circuit, a source of modulating potentials, and a circuit connecting the control grids of said tubes in push-pull relation to said source of modulation potentials.

15. A system as recited in claim 11 wherein a non-linear resistance is connected in a direct current circuit between the anodes and cathodes of said tubes.

16. A phase modulation system as recited in claim 11 wherein said frequency stabilizing means comprises a piezo-electric crystal.

17. A phase modulation system as recited in claim 11 wherein said frequency stabilizing means comprises a crystal and wherein said second named alternating current circuit is tuned to a harmonic of the normal frequency of said crystal.

18. In a phase modulation system, a pair of tubes each having a screen grid, a control grid, an anode, and a cathode, a first alternating cur-

rent circuit, a connection between a point on said circuit and the control grid of one of said tubes, a phase shifting reactance connecting a different point on said circuit to the control grid of the other tube, a connection between a third point on said circuit and the cathode of said tubes, a second alternating current circuit connecting the anodes of said tubes together, a connection between a point on said second alternating current circuit and the cathodes of said tubes, means including frequency stabilizing means for producing regeneration in said tubes and circuits to produce oscillatory energy of substantially constant frequency in said second named alternating current circuit, and means for impressing modulating potentials in phase displaced relation on the screen grid electrodes of said tubes to thereby vary the phase of the oscillations produced in said second named alternating current circuit at signal frequency.

19. A phase modulation system as recited in claim 11 wherein a point on said first named alternating current circuit is connected to the cathodes of said tubes by an impedance to raise the alternating current potential of said point above the potential of said cathodes to prevent parasitic oscillation in said tube and circuits.

20. A phase modulation system as recited in claim 11 wherein said first named alternating

current circuit comprises an inductance and a condenser, in parallel, said condenser having an element connected to the cathode of said tubes and an impedance connecting said condenser element to a point on said inductance whereby the latter point is floating at radio frequency relative to the cathodes of said tubes.

21. A system as recited in claim 2 wherein a point on said first named tuned resonant circuit is connected by an impedance to the cathodes of said tubes.

22. The method of producing oscillations modulated in phase in accordance with signal voltages which includes the simultaneous steps of regeneratively generating two high frequency oscillations of the same frequency but displaced in phase by limited amounts, stabilizing the frequency of said oscillations to prevent unwanted phase or frequency displacement, combining said oscillations to produce oscillations of a phase which is the resultant of said oscillations of displaced phase, and differentially amplitude modulating said phase displaced oscillations being combined at signal frequency to thereby control the relative amplitudes of the oscillations combined and consequently the phase of the resulting oscillations in accordance with the signals.

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