March 22, 1938. H. E. GOLDSTINE 2,111,587

PHASE MODULATION

Original Filed Feb. 8, 1934 3 Sheets-Sheet 1

Fig. 1

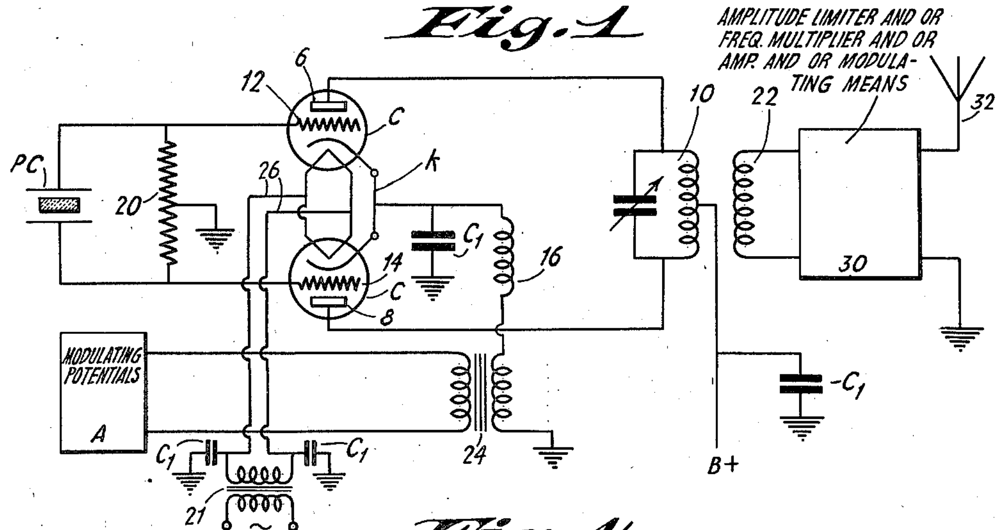



Fig. 4

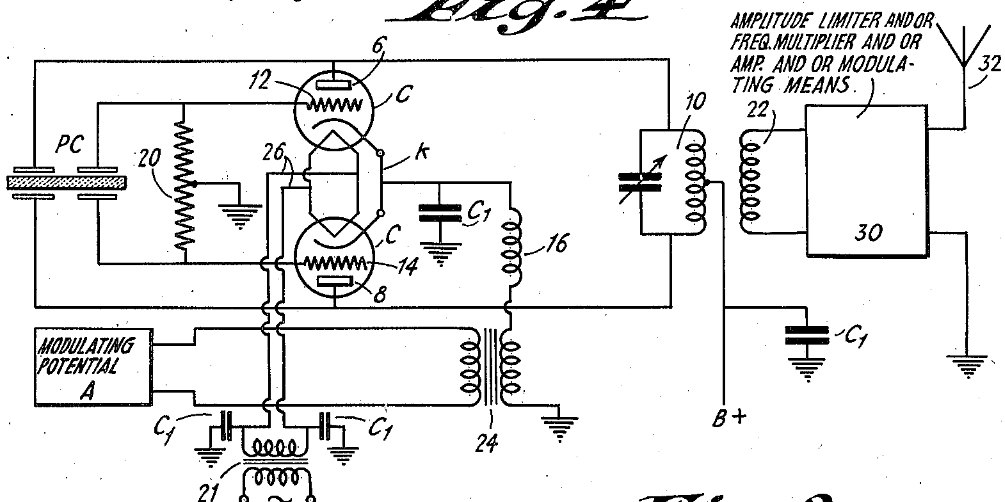



Fig. 3

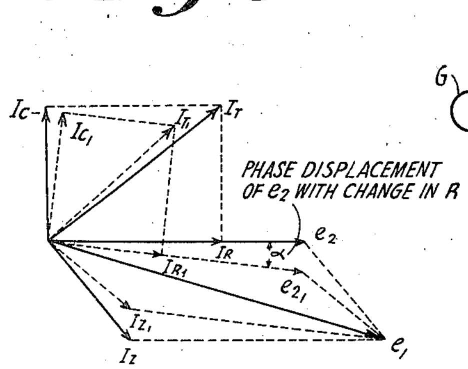
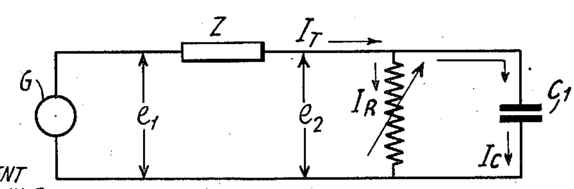



Fig. 2

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PHASE MODULATION

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Fig. 6

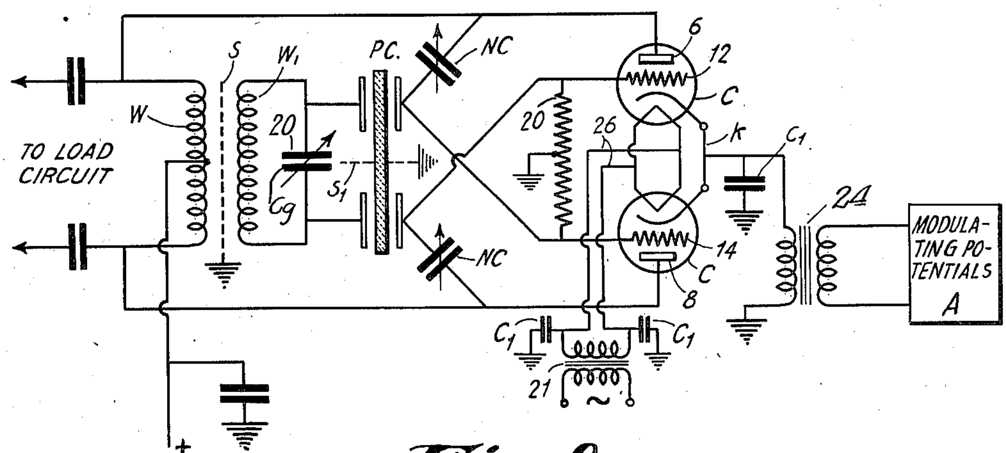


Fig. 9

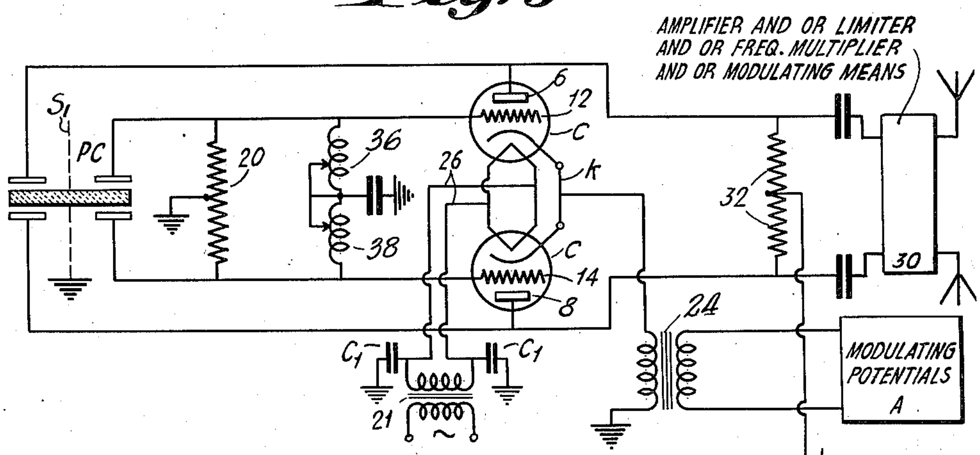


Fig. 5

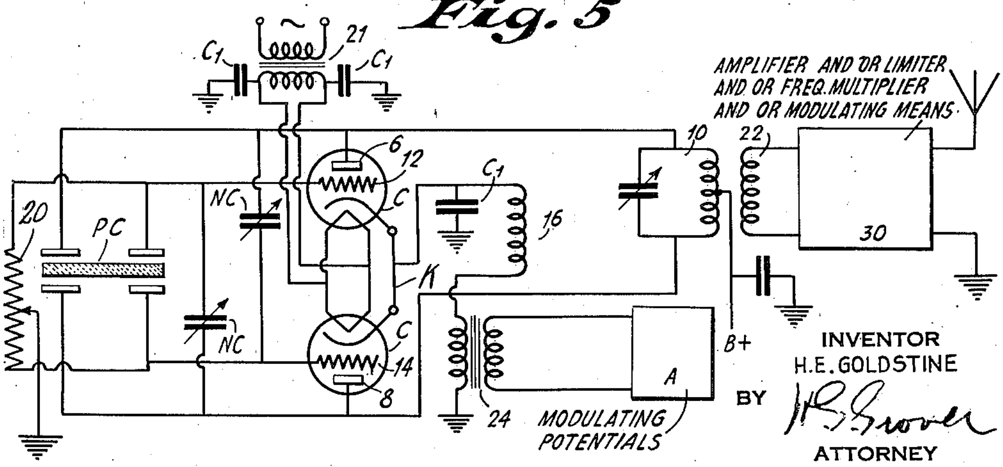


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*Fig. 7*

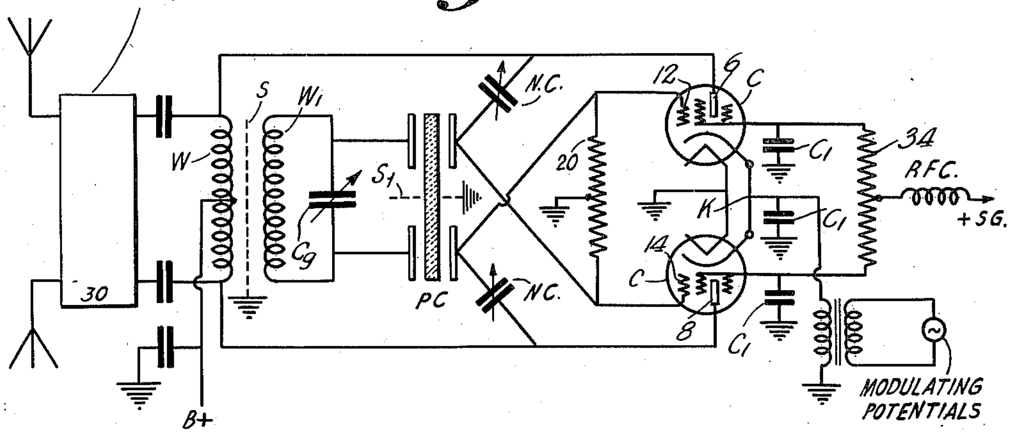
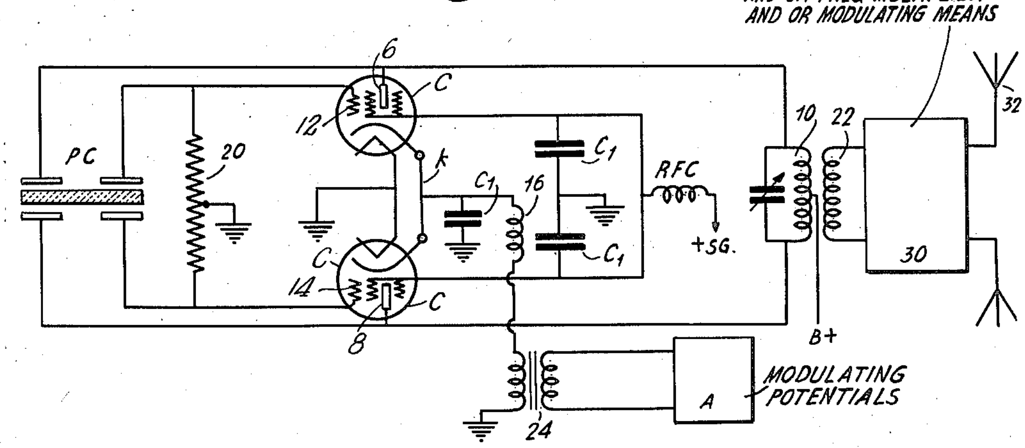



*Fig. 8*

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# UNITED STATES PATENT OFFICE

2,111,587

## PHASE MODULATION

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Application February 8, 1934, Serial No. 710,239
Renewed October 27, 1936

18 Claims. (Cl. 179—171)

This invention relates to the art of signalling by means of high frequency oscillations, the character of which varies in accordance with signals, and more in particular with a method of and means for displacing the phase of high frequency oscillations in a correct relationship to an applied signal voltage, thereby producing a signal so modulated that intelligent transmission may be made by using phase modulation.

In the usual method of modulating the output current of a transmitter the amplitude of the oscillations is made to vary in accordance with the signal to be transmitted. When the input signal is of low amplitude, so that a low percentage of modulation of the carriers is accomplished, the output of the transmitter is less than when the signal is of high amplitude and a larger percentage of modulation is impressed on the carrier. With amplitude modulation the transmitter must be operated below full power output to be able to follow the signal modulation to its peak value. When using amplitude modulation the power output of the transmitter varies in accordance with the percent modulation. In order that the transmitter may be capable of carrying full output on high percent of modulation it must be run at a value below its full output rating on the average modulation. For example, when a broadcast program is sent out over the usual broadcast transmitter the average modulation is about 30%. The transmitter must be so adjusted that while it only delivers a small amount of its power on the average modulation it can carry the peaks or the louder parts of the signal without distortion. Thus the transmitter must be operated below its full output most of the time and less power radiated than would be possible with this transmitter. In phase modulation, however, the phase relation of the carrier and the side bands varies in such a manner that the resultant output remains constant. In phase modulation the output of the transmitter remains constant and the modulation side bands and carrier vary in such a manner that the output energy remains constant. A phase modulated transmitter may be operated at maximum output constantly. This results in increased efficiency and permits more radiation power when using equipment of the same power rating. The oscillations modulated in phase as indicated above may be altered in characteristics at signal frequency in any of the succeeding stages prior to transmission. The amplitude of the phase modulated wave may be increased or the frequency of the phase modulated wave may be increased with or without increasing the phase shift. Furthermore, the wave may be limited as to amplitude to remove amplitude modulation components before or after the operations mentioned in the preceding sentence.

In the usual type of phase modulation transmitters, elaborate equipment is needed to produce quality of modulation.

An object of the present invention is to provide a device which is simple in nature and structure and which modulates a large amount of power output with good quality modulation by means of a signal of comparatively small power.

A further object of the present invention is to provide a novel scheme and means for impressing on high frequency oscillations phase variations truly representative of the signal so that a good quality modulation is obtained and to accomplish the same by the use of a minimum amount of apparatus operating extremely efficiently.

The above objects are obtained in accordance with the present invention by modulating oscillations of constant frequency at the source of production, that is, in the oscillator. For example, if a crystal oscillator is used to produce constant frequency oscillations, modulation may be accomplished in the crystal oscillator. In a crystal oscillator the crystal voltage works into the grid to cathode capacity and a resistive component caused by the grid to cathode current of the tubes. This is the input impedance of the tubes and, as the grid current is caused to vary by changing the applied grid voltage, that is, by changing the potential applied to the grids of the oscillators at signal frequency, the grid to cathode resistive components varies and the variations produce a phase shift proportional to the variations of the grid to cathode resistances.

Any tube that draws sufficient grid to cathode current, so that the resistive component is sufficient, may be modulated in this manner, whether the tube be an oscillator or an amplifier.

The novel features of my invention have been pointed out with particularity in the claims appended hereto.

My novel method of producing phase variations in oscillations which are characteristic of signal currents, and devices for accomplishing the same will be described in detail hereinafter. In this description reference will be made to the drawings, throughout which like symbols indicate like parts, and in which:

Figure 1 shows an arrangement for producing oscillations and for modulating the same as to phase in accordance with my novel scheme;

Figure 2 shows diagrammatically the manner in which phase modulation is accomplished in accordance with the present invention.

Figure 3 is a vector diagram illustrating the manner in which the phase shift is obtained in certain voltages in the circuit of Figure 2; while,

Figures 4 to 9 inclusive show various modifications of the arrangement of Figure 1.

A specific embodiment of the invention will now be described. In describing said embodiment reference will be made to Figure 1 of the invention in which, for purposes of illustration, an oscillator and phase modulating means, arranged in accordance with the present invention have been shown.

In Figure 1 a pair of thermionic tubes C have their anode electrodes 6 and 8 connected, as shown, to a parallel tuned circuit 10. The circuit 10 is tuned to a frequency slightly above the frequency it is desired to produce so that the circuit 10 as to said frequency is inductive. The control grids 12 and 14 of tubes C are connected together by way of a leak resistance 20, as shown. A piezo-electric crystal PC is connected as shown between the control grids 12 and 14 of tubes C. Due to the capacity between the electrodes 6 and 12 and 8 and 14 and the impedance of the tuned circuit 10, oscillations of constant frequency are produced in the tubes C and their associated circuits when the electrodes of tubes C are energized by direct current potential sources (not shown) the positive terminal of which is connected to the lead marked B+ and the negative terminal of which is connected to ground or the cathode return circuit. The frequency of the oscillations produced is determined by the value of the elements included in the circuits described and in particular by the physical dimensions of the piezo-electric crystal PC. The anode to cathode and grid to cathode alternating current circuits of both tubes C are completed by connecting the cathodes to ground by way of radio frequency by-pass condenser $C_1$ connected as shown.

The cathode electrodes K are heated by means of a filamentary heating element and heating circuit 26 which may be energized from any source not shown directly or by way of a transformer 21. To prevent high frequency oscillations from reacting on this transformer each side of the filament heating circuit 26 is connected to ground by way of a by-pass condenser $C_1$ as shown.

In operation the circuit 10 is tuned to a frequency slightly above the natural frequency of the crystal PC. The external impedance of the plate circuit is high. The resistance 20 furnishes the effective grid bias for the oscillators due to grid rectification. The positive potential may be applied to the anode electrodes 6 and 8 by way of the tuned circuit 10, which may be connected with any source of direct current potential.

The arrangement just described will, as is well known, produce sustained oscillation of good amplitude and constant frequency, which frequency will be determined in part by the piezo-electric crystal PC and in part by the tuned circuit 10. The oscillations so produced may be induced by way of the inductance in circuit 10 on an inductance 22 connected by way of additional apparatus 30 to utilization circuit 32.

The manner in which the oscillations produced in the tubes C are modulated in phase at signal frequency will now be described. A source of modulating potentials A, as, for example, an alternating current source of constant and audible frequency, or a source of voice modulations or music impresses potentials at the signal frequency on the primary winding of a transformer 24, the secondary winding of which is connected, as shown, in series with the radio frequency choke coil 16. In this manner controlling potentials at signal frequency appearing in 24 are applied between the cathodes K of tubes C and the control grids 12 and 14. Radio frequency reactor 16 forces the radio frequency oscillations produced in the tubes C to return to the cathodes K by way of the by-pass condenser $C_1$ connected as shown so that they do not react by way of the transformer 24 on source A. The condenser $C_1$ forms a low impedance path by which the radio frequency current may return to the cathode without pasing through the modulator but is of high impedance to the modulating potentials. The potentials supplied at signal frequency to the cathodes K vary the potential of the cathode with respect to the grid electrodes 12 and 14 and thereby vary the impedances between the grids and cathodes of said tubes, and consequently vary the grid to cathode currents.

Since the crystal voltage is working into the grid to cathode capacities of the tubes, and the resistive components caused by the respective grid to cathode direct currents, these variations of potentials and of currents result in a phase shift which is proportional to the variation of the resistive component in the grid to cathode circuits. This in turn phase modulates the resultant current in the common anode circuit of the oscillators C so that high frequency oscillations, modulated in phase in accordance with the potentials in A appear in the circuit 10 and may be impressed therefrom to a load circuit.

The cathodes of tubes C are swinging as to potential in accordance with the modulating potentials from source A. The modulating potentials are applied in phase to the cathodes so that both cathodes swing in the same direction simultaneously. Assuming that the cathodes both swing positive irrespective of the instantaneous grid radio frequency potential there will be a phase shift in the radio frequency output of each tube. This phase shift will be in the same direction. This phase shift in the same direction of the radio frequency energy in the outputs of both tubes results from the fact that the modulating potentials are in phase on the grids and the carrier wave potentials are in phase opposition.

The oscillations so produced and modulated may be passed through an amplitude limiter or a frequency multiplier or an amplifier or one or more of said several devices, all of which may be included in the unit 30. The phase modulated amplitude limited or frequency multiplied or amplified oscillations, or both frequency multiplied and amplified oscillations, may be utilized in any manner. For example, they may be impressed on a line for transmission or may be impressed, as shown, on an aerial system 32 for radiation. Furthermore, as indicated above the phase modulated oscillations may be further modulated in any known manner, before transmission. This modulation may take place any place in the circuits but preferably takes place after the phase modulation as described above is accomplished.

Although it is thought that the manner in which phase modulation has been accomplished will be understood from the above, a further brief explanation of what takes place in the circuits associated with the tubes C to produce phase modulation at signal frequency will be given.

In giving this explanation reference will be made to the fundamental Figure 2, which represents the voltages in the circuit and on the electrodes of either of the tubes C of the arrangement of Figure 1. To simplify this explanation it will be assumed that only one tube C is being utilized, that is, that only half of the oscillator in Figure 1 is being utilized. The explanation applies equally to the case where both tubes are considered and is made with reference to one tube only for purposes of simplicity. In explaining this circuit reference will be made to the vector diagrams of Figure 3 in which:

$I_R$ is the grid current;

$I_{R_1}$ is the grid current when the resistance R has been changed due to modulating potentials;

Z is the impedance of the circuit, the electrodes, etc.;

$e_1$ is the input voltage;

$e_2$ is the voltage on the tube side of the impedance Z;

$I_Z$ is the total current in the circuit; and,

$I_C$ is the current through the tube capacity of the circuit.

Referring to Figure 2, G represents the quartz crystal input to one of the tubes C. The crystal may be considered as a constant voltage generator. We can make such an assumption for the crystal has so much stored energy (circulating current) that there is a persistency of oscillation greater than the audio frequency. If the crystal response curve (resonance curve) is about fifty cycles wide then any audio frequency above that will not affect the output voltage and will not react back on the crystal's frequency of oscillation. This crystal output voltage is impressed into an impedance, made up of series elements and shunt elements. Z represents the series element and R and C the shunt elements. By varying the grid voltages (raising and lowering the cathode voltage) the resistive element of the shunt impedance is varied. The grid current changes and this changes the phase of the grid voltage in accordance with the input tone voltage $E_T$.

Referring to vector diagram 3, it may be seen that as we change the input impedance of one of the tubes by varying R, the phase of the grid voltage is changed. The oscillations repeated in this tube will be linearly modulated in phase and will appear on the anode of said tube and in the circuit 10. The impedance input of the other tube C will be changed at the same time by the change in R and this tube will in like manner feed oscillating energy linearly modulated in phase but in different sense to the circuit 10. The added energy will be of a phase which is a resultant of the phases of the separate energies. With this system I can get practically linear phase displacement for input tone voltage over a large enough range so that the effective phase swing after multiplication in the doubler stages gives a displacement equal to 100% in amplitude modulation.

Obviously many different types of crystal control oscillators may be used to replace the oscillator shown in Figure 1. Practically any type of piezo-electric controlled oscillator circuit may be used to produce the oscillations which may in turn be modulated in phase in accordance with my novel scheme as illustrated in Figure 1.

In the arrangement of Figure 4 the oscillator may be of the pushpull type in which the feed back necessary to insure the production of constant oscillations may be obtained by interconnecting the anodes and control grids by way of a piezo-electric crystal PC on which four electrodes bear as shown. The anode circuit 10 may be tuned to a frequency slightly above the frequency of the oscillations generated as determined by the crystal PC or if desired may be tuned to the frequency of said oscillations. The plate to grid electrode of the tube C may be neutralized by capacities NC as shown in Figure 5 or may be unneutralized as shown in Figure 4 depending upon the requirements of the particular case and on the degree of stability necessary in the oscillator. The modulating potentials are applied in both these circuits in a manner similar to which they are applied to the oscillator of Figure 1, and since phase modulation is accomplished in the circuits of Figures 4 and 5 in substantially the same manner in which it is accomplished in the circuit of Figure 1, a description of the manner in which said phase modulation is accomplished is thought unnecessary at this point.

In some cases inductive feed back may be desirable. The oscillator generator in this case may be as illustrated in Figure 6, in which the anodes 6 and 8 of tubes C are connected together by way of a winding W, which is coupled to a winding $W_1$, connected to a pair of the electrodes of the piezo-electric crystal system PC as shown. Energy from the anodes of the tubes is fed from the winding W to the winding $W_1$ and from the said last named winding by way of the crystal to the electrodes 12 and 14. The winding $W_1$ may be tuned to the desired frequency, that is, to the natural frequency of the crystal PC or slightly above said frequency or to a harmonic thereof by the capacity $C_g$. To insure magnetic coupling only between the anodes 6 and 8 and the control grids 14 and 12 respectively, an electrostatic shield S may be interposed between the windings W and $W_1$ as shown. A further isolation of the electrodes, to and from which energy is supplied, may be insured by interposing a second electrostatic shield $S_1$ between the respective electrodes of the crystal PC as shown. If desired, the anodes and control grids of the opposed tubes may be interconnected by neutralizing condensers NC as shown.

The modulating potentials are applied between the cathode and control grid of the tubes C to accomplish phase modulation of the oscillations produced in said tubes in the same manner in which phase modulation is produced in the prior modifications. The load circuit which may be additional amplifiers or an antenna or a transmission line may be coupled by way of a pair of coupling condensers to the inductance W as shown.

The tubes C of the oscillation generator may be triodes as shown in Figure 6 or may be of the screen grid type as shown in Figure 7. When tubes of the screen grid type are utilized the screen grid electrodes may be energized at a positive potential by way of a resistance 34 connected as shown through a radio frequency choke RFC to a source of potential. The arrangement of Figure 7 may in other respects be similar to the arrangement of Figure 6.

Of course my invention contemplates the use of any type of tubes in these oscillation generators. For example the triodes C of Figure 4 may be replaced by screen grid electrode tubes C as shown in Figure 8.

While I have shown the load circuit as being either inductively or capacitively coupled to the output electrodes of the oscillator, it will be understood that other forms of coupling may be utilized. For example, I may include a resistance 32 in the anode load circuit and points on this resistance may be coupled by coupling condensers as shown in Figure 9 to the unit **30**. Moreover, if desired, the grid to plate capacity may be balanced or tuned out by connecting variable inductances **36** and **38** between the respective control grids and ground as shown in Figure 9. The circuit arrangement of Figure 9 is otherwise sufficiently similar to the circuits described hereinbefore to make unnecessary a detailed description of the operation thereof at this point.

Of course, it should be understood that the modulating potentials may be applied by other circuits than those shown in the prior figures and may be applied between electrodes of the tubes other than the electrodes to which they are applied in said circuits. For example, the modulating potentials may be fed to the grid or cathode by many different circuit arrangements. Moreover, in a multi-electrode tube the electrodes other than the grid and cathode may be likewise modulated without departing from the spirit of the present invention.

The modulating potentials in the source A may represent signals which it is desired to convey to a distant point or may be merely for the purpose of wobbling the carrier wave to obtain the benefits of phase or frequency diversity. In the latter case the wobbled oscillations may be modulated at signal frequency as to phase or frequency or amplitude or any combination of the said types of modulation. Such modulation may take place in any stage of the transmitter but preferably takes place in a stage following the phase modulator stage including the generator tubes C.

Having thus described my invention and the operation thereof, what I claim is:

1. The combination with an oscillation generator including a pair of thermionic tubes, each having an anode, a control electrode, and a cathode and a tuned output circuit connected between said anodes, an input circuit connected with the control electrodes and to ground and frequency determining apparatus connected with said input circuit, of means for modulating the phase of the oscillations produced comprising an impedance connecting the cathodes of said tubes to ground, and a circuit for applying modulating potentials to said impedance and from said impedance in phase to the cathodes of said tubes.

2. The combination with an oscillation generator including a pair of thermionic tubes each having an anode, a cathode, and a control electrode, an output circuit tuned to a frequency slightly above the frequency of the oscillations to be produced connected with the anodes of said tubes, a frequency determining element in the input circuit between the control electrodes of said tubes, resistive means connecting the control electrodes to ground, of means for modulating the phase of the oscillations produced comprising an impedance connecting the cathodes of said tubes to ground, and a circuit for applying controlling potentials to said impedance and from said impedance in phase to the cathodes of said tubes.

3. In combination with an oscillation generator including a pair of thermionic tubes each having an anode, a cathode, and a control electrode, a reactive output circuit connected between the anodes of said tubes, a frequency determining piezo electric crystal in an input circuit connected between the control electrodes of said tubes and to ground, of means for modulating the phase of the oscillation produced comprising a transformer having its secondary winding connected between the cathodes of said tubes and ground and its primary winding connected to a source of modulating potential.

4. The combination of an oscillator comprising a pair of thermionic tubes each having a cathode, a control electrode and an anode, and having frequency determining and generating input and output circuits comprising a reactance connected with the anodes of said tubes, and frequency determining apparatus connected between the control electrodes of said tubes, and circuits raising the cathodes of said tubes above ground alternating current potential, of means for applying modulating potentials in phase to the cathodes of said tubes to vary the potential of said cathodes in phase at the frequency of the modulating potentials to thereby modulate the phase of the oscillations produced, and a load circuit coupled to the output circuit of said oscillator.

5. Signalling means comprising a pair of thermionic tubes having their anodes connected together by a circuit including an inductance, and a frequency determining circuit including an inductance coupled to said first named inductance connected between their control-grid electrodes, circuits including an impedance between the control grid electrodes of said tubes and ground and a source of direct current potential between the anodes of said tubes and ground for energizing the electrodes of said tubes to produce sustained oscillations in said tubes and said circuits, and means for modulating the phase of the oscillations produced, comprising a circuit including an impedance connected between the cathodes of said tubes and ground, means for applying modulating potentials to said impedance and from said impedance to the cathode electrode of each of said tubes, the modulating potentials applied to the cathodes being in phase.

6. Signalling means comprising a pair of thermionic tubes each having an anode, a cathode and a control grid, said tubes having their anodes connected together by an inductive reactance and a frequency determining circuit connected between their control grids, an impedance connected between the control grids of said tubes and the cathodes of said tubes, means for energizing the electrodes of said tubes to produce sustained oscillations in said tubes and said circuits, and means for modulating the phase of the oscillations produced, comprising a transformer having a primary winding coupled to a source of modulating potentials, and a secondary winding connected between the cathode of each of said tubes and ground.

7. Signalling means comprising a pair of thermionic tubes each having an anode, a cathode, and a control grid and having their anodes connected together by a resonant circuit tuned to substantially the frequency of the oscillations it is desired to generate, and a frequency determining circuit connected between their control grids, means for energizing the electrodes of said tubes to produce sustained oscillations in said tubes and said circuits, and means for modulating the phase of the oscillations produced, comprising a resistance connected between the control grids and cathodes of said tubes, a transformer having a primary winding coupled to a

source of modulating potential, and a secondary winding connected between the cathodes of said tubes and ground to apply modulating potentials in phase to the cathodes of said tubes.

8. Signalling means comprising a pair of thermionic tubes having their anodes connected in pushpull relation, a piezo-electric crystal having pairs of electrodes, a circuit connecting a pair of said crystal electrodes to the control grid electrodes of said tubes, a circuit connecting another pair of said crystal electrodes to the anodes of said tubes, means for energizing the electrodes of said tubes to produce sustained oscillations in said tubes and said circuits, and means for modulating the phase of the oscillations produced, comprising a reactance connecting the cathodes of said tubes to ground, a resistance connecting the control grid electrodes of said tubes to ground, and a source of modulating potentials coupled to said reactance.

9. The combination with an oscillator of the pushpull type comprising a pair of thermionic tubes having their anode electrodes coupled in push-pull relation by way of an impedance and their control grids coupled in push-pull relation by way of a piezo-electric crystal and their cathodes and control grids connected to ground by way of impedances, and circuits for energizing the electrodes of said tubes to produce oscillations therein of a frequency determined by the physical dimensions of said crystal and means for modulating the oscillations so produced in phase at signal frequency comprising a circuit for applying modulating potentials to the impedance between said cathodes and ground to swing said cathodes relative to ground potential at a modulation frequency rate.

10. A signalling system including means for producing high frequency oscillations of constant frequency comprising a pair of thermionic tubes having anode, cathode and control grid electrodes, a resistance connected between the anode electrodes of said tubes and to a source of potential, a resistance connected between the control grid electrodes of said tubes and to ground, a piezo-electric crystal having a pair of electrodes connected to the control grids of said tubes, said crystal having another pair of electrodes connected to the anodes of said tubes, inductive means for tuning out the capacitive coupling between the grid and plate of each tube, an impedance connected between the cathode electrodes of said tubes and ground, said impedance being shunted by a radio frequency by-passing condenser, a source of modulating potentials, and a circuit for applying modulating potentials from said source to said impedance.

11. Means for producing high frequency oscillations of constant frequency comprising a pair of thermionic tubes having anode, cathode and control grid electrodes, an impedance connected between the anode electrodes of said tubes and to a source of potential, a resistance connected between the control grid electrodes of said tubes and to ground, a piezo-electric crystal having different electrodes connected to the control grids of said tubes, said crystal having other electrodes connected to the anodes of said tubes, a neutralizing condenser connected between the anode of one of said tubes and the control grid of the other of said tubes, a neutralizing condenser connected between the anode of said last named tube and the control grid of said first named tube, an impedance connected between the cathodes of said tubes and ground, said impedance being shunted by a radio frequency by-passing condenser, a source of modulating potentials and a circuit for applying modulating potentials from said source to said impedance.

12. Means for producing high frequency oscillations of constant frequency comprising a pair of thermionic tubes each having anode, cathode and control grid electrodes, an inductive reactance connected between the anode electrodes of said tubes and to a source of potential, a resistance connected between the control grid electrodes of said tubes and to ground, a piezo-electric crystal having different electrodes connected to the control grids of said tubes, said crystal having other electrodes coupled to the anodes of said tubes, a neutralizing condenser connected between the anode of one of said tubes and the control grid of the other of said tubes, a neutralizing condenser connected between the anode of said last named tube and the control grid of said one of said tubes, an impedance connected between the cathode electrodes of said tubes and ground, said impedance being shunted by a radio frequency by-passing condenser, a source of modulating potentials, and a circuit for applying modulating potentials from said source to said impedance.

13. Means for producing high frequency oscillations of constant frequency comprising a pair of thermionic tubes each having anode, cathode and control grid electrodes, an inductance connected between the anode electrodes of said tubes and to a source of potential, a resistance connected between the control grid electrodes of said tubes and to ground, a piezo-electric crystal having two pairs of electrodes, an inductance connected to an electrode of each of said pairs, said inductance being coupled to said first named inductance, a connection between the other electrode of each of said pair of electrodes and the control grid of a different one of said tubes, a shield between said pairs of crystal electrodes, an electro-static shield between said inductances, and means for varying the potential on the cathode of each of said tubes at signal frequency.

14. The combination with an oscillator of the pushpull type comprising a pair of thermionic tubes having their anode electrodes coupled by way of an inductive reactance and their control grids coupled by way of a piezo-electric crystal and their cathodes connected to ground by way of an impedance of means for energizing the electrodes of said tubes to produce oscillations therein of a frequency determined by the physical dimensions of said crystal and means for modulating the oscillations so produced in phase at signal frequency comprising a circuit for applying modulating potentials to said impedance.

15. The combination with an oscillator comprising a pair of thermionic tubes having their anode electrodes coupled in push-pull relation by way of an impedance and their control grids coupled in push-pull relation by way of a piezo electric crystal and their cathodes connected together and to ground, means for energizing the electrodes of said tubes to produce oscillations therein of a frequency determined by the physical dimensions of said piezo electric crystal including a resistance connecting the control grid of each tube to ground and a source of direct current potentials connected with the impedance connected to the anodes of said tubes, and means for modulating the oscillations so produced in phase at signal frequency comprising an inductive reactance shunted by a radio frequency by-

pass condenser in said connection between the cathodes of said tubes and ground and a circuit for applying modulating potentials to said inductive reactance.

16. The combination with an oscillator comprising a pair of thermionic tubes having their anode electrodes coupled in push-pull relation by way of an impedance and their control grids coupled in push-pull relation by way of a resonant circuit and their cathodes connected together and to ground; of means for energizing the electrodes of said tubes to produce sustained oscillations therein of a frequency determined by the resonant circuit including, an impedance connecting the control grids of said tubes to ground, and means for applying direct current potentials to the anodes of said tubes; and means for modulating the oscillations so produced in phase at signal frequency comprising an impedance connected between the cathodes of said tubes and ground, and a circuit for applying modulating potentials to said impedance.

17. In a signalling system, a pair of electron discharge tubes each having an anode, a cathode, and a control grid, an alternating current circuit coupling the anodes of said tubes to a work circuit, an alternating current circuit coupling the control grids of said tubes together and to a resonant frequency determining means, an impedance connecting the control grids of said tubes to ground, and means for modulating the phase of alternating current flowing in at least one of said circuits in accordance with modulating potentials comprising a source of modulating potentials connected between the cathodes of said tubes and ground.

18. In a signalling system, an oscillation generator comprising a pair of electron discharge tubes each having an anode, a cathode, and a control electrode, means connecting said anodes to a work circuit, means connecting said control grids in an oscillatory circuit in which the circulating energy loss per cycle of wave energy of the frequency it is desired to produce is low, a connection between a point on said last circuit and a point of relatively fixed potential, and means for modulating the phase of the oscillations produced at a modulating potential rate comprising a source of modulating potentials having one terminal connected to the cathodes of said tubes and another terminal connected to said point of relatively fixed potential to vary the potential of said cathodes at signal frequency relative to said point of relatively fixed potential.

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