

**Oct. 13, 1942.**

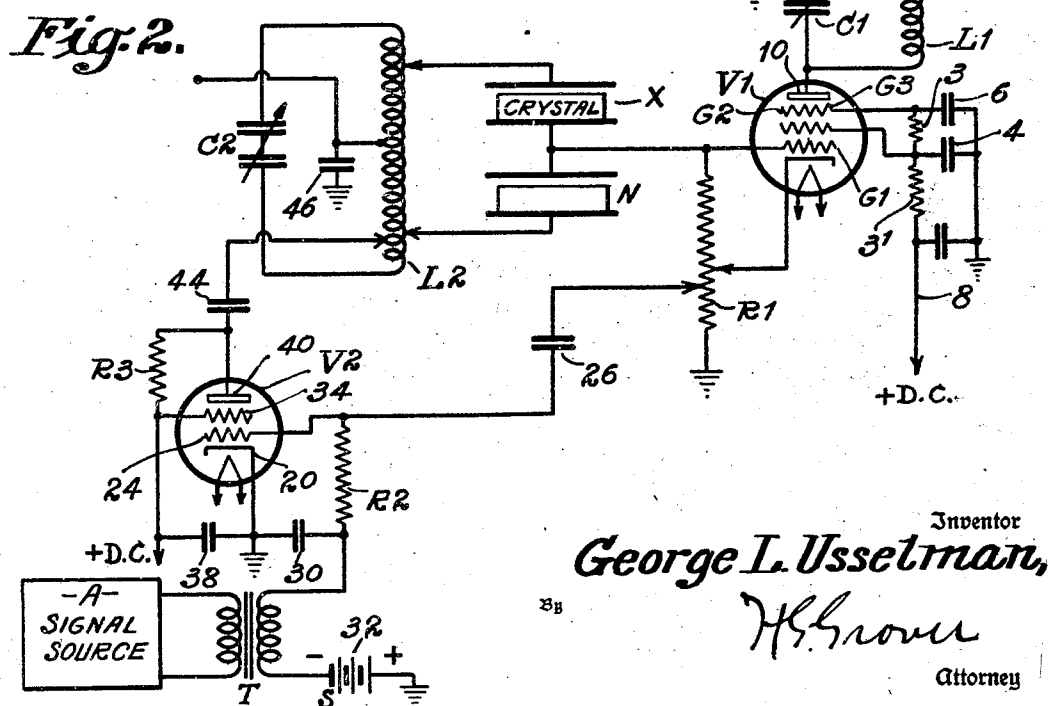
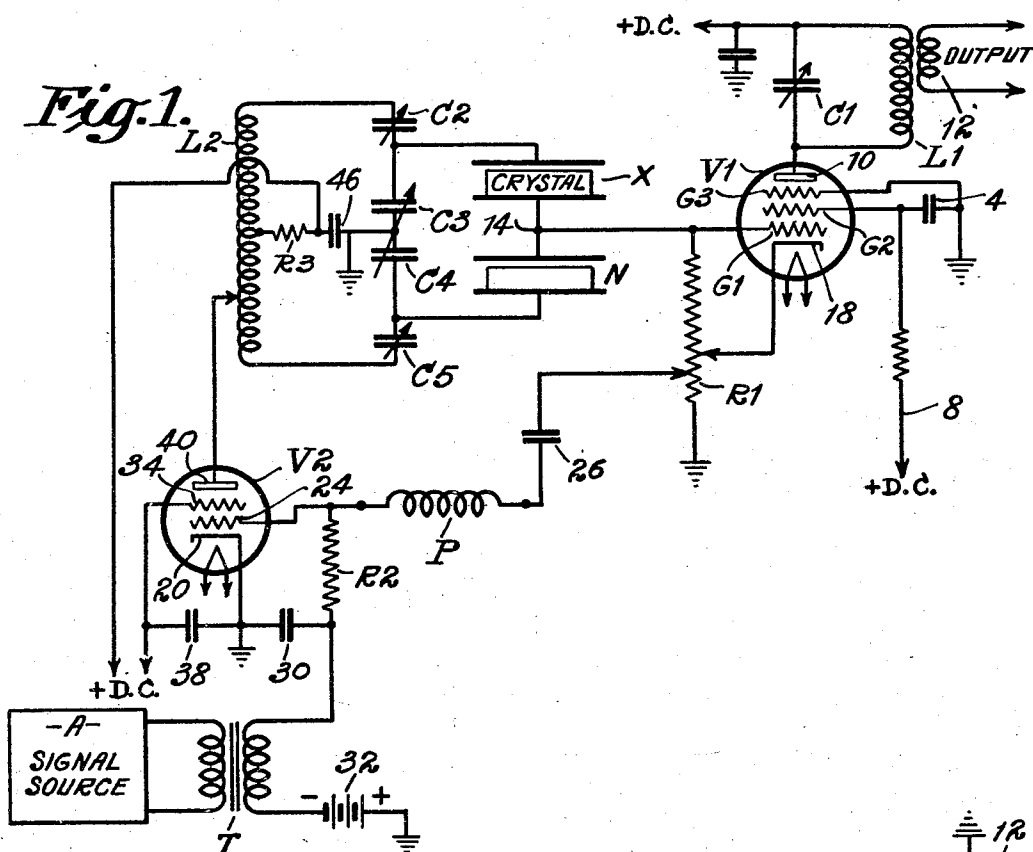
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**2,298,437**

## FREQUENCY MODULATION

Filed June 5, 1940

3 Sheets-Sheet 1



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**FREQUENCY MODULATION**  
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**2,298,437**

3 Sheets-Sheet 2

*Fig. 3.*

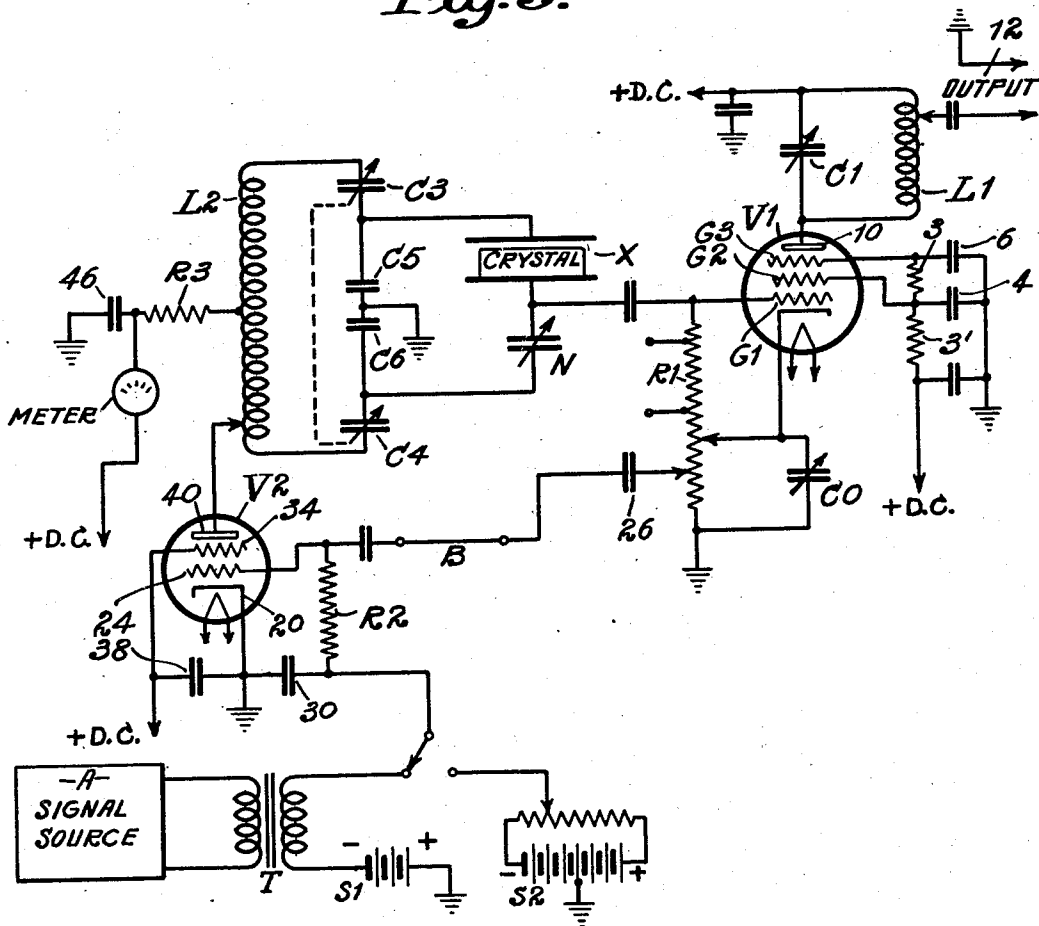
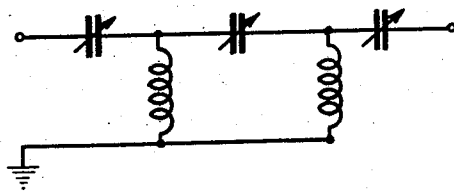


*Fig. 5.*



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## UNITED STATES PATENT OFFICE

2,298,437

## FREQUENCY MODULATION

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Application June 5, 1940, Serial No. 338,838

26 Claims. (Cl. 179—171.5)

This application concerns a new and improved method of and means for producing wave energy the frequency of which is modulated in accordance with signals.

In most crystal controlled frequency modulators known heretofore, it is possible for the modulator to drive the oscillator beyond the crystal controlled oscillating frequency. This produces distortion in the frequency modulation process. The present invention eliminates this possibility. No frequency modulation is possible when the crystal does not oscillate. Thus, we are assured of crystal controlled oscillations during the entire modulation process in this frequency modulator. The crystal oscillator circuit used in this frequency modulator is of the aperiodic type, except for the piezo-electric crystal, having the anode grids grounded for radio frequency. These features contribute considerably to the improved operation of this circuit.

In describing my invention reference will be made to the attached drawings wherein;

Figs. 1 to 4, inclusive, each show the essential features of a system for generating wave energy and modulating the frequency thereof in accordance with control potentials; and

Fig. 5 illustrates details of a phase shifting circuit used under certain circumstances in certain of the prior modifications.

The oscillators in the circuits of Figs. 1 to 4, inclusive, are all of the same general type. These oscillators are of the crystal controlled grounded anode type in which the second grid G2 of tube V1 is bypassed to ground for radio frequency by means of condenser 4. The third grid G3 may be grounded directly as shown in Fig. 1 or it may be biased through a resistance 3 and bypassed to ground for radio frequency by means of a separate condenser C6 as shown in Figs. 2, 3 and 4. Both the second and third grids in Figs. 2, 3 and 4 are supplied with positive potentials through resistors 3 and 3' from a source not shown by means of lead 8. Resistors 3 and 3' act as aperiodic smoothing impedances to keep radio frequency out of lead 8. The anode 10 of tube V1 is supplied with positive current and potential through tank circuit C1, L1 from a power source not shown. This source may be the same as the source which supplies voltage to lead 8 or it may be a separate source. The output circuit 12 for the frequency modulator is coupled to the tank coil L1 as shown. In Fig. 1 this coupling is inductive. In Figs. 2, 3 and 4 this coupling is capacitive. The control grid G1 of the oscillator tube V1 is connected to the crystal electrode at

a point 14 between the crystal X and the neutralizing condenser N as shown in Figs. 1, 2, 3 and 4. The potentiometer grid leak resistor R1 is connected between the control grid G1 of tube V1 and ground. The cathode 18 of tube V1 is tapped part way up on resistor R1.

The modulator circuits comprising modulation potential source A, transformer T, tube 34, reactances L2, C2, C3, etc., are substantially alike except for minor differences as stated below. The modulator circuit in Fig. 2 is in general similar to Figs. 1 and 3 with certain differences. The cathode 20 of tube V2 is grounded. The control grid 24 of tube V2 is excited by high frequency oscillations because it is connected to a tap on resistor R1 through a blocking condenser 26 as shown. Fig. 1 shows a phase shifting reactance P connected in this modulator grid radio-frequency excitation circuit.

The phase shifting network shown in Fig. 5 may be used in place of P in Fig. 1. To include the network (Fig. 5) in the circuit in place of P the leads are opened at the connection points and the substitution made.

A resistor R2 is connected to the control grid 24 of tube V2. The other end of resistance R2 is bypassed to ground for radio frequency by means of a condenser 30 and it is also connected to one terminal of the secondary winding of transformer T. The other terminal of this secondary winding is connected through a source of negative bias 32 to ground. The primary winding of transformer T is connected to a signal source A. The screen grid 34 of tube V2 is bypassed to ground for radio frequency by condenser 38 and connected to a source of positive potential not shown which may be the same source connected to lead 8. The anode 40 of modulator tube V2 is supplied with positive current and potential through resistance R3 and the coil L2 of tank circuit C2, L2 in Figs. 1, 3 and 4. In Fig. 2 the anode of V2 is tapped through a blocking condenser 44 on coil L2 and receives its positive current and potential supply through resistor R3.

In Fig. 1 the coil L2 is paralleled by variable condensers C2, C3, C4 and C5 as shown. The connection between condensers C3 and C4 is grounded directly. The center point of coil L2 is bypassed to ground through resistor R3 and a blocking condenser 46. The positive current supply is connected to the circuit between resistor R3 and this blocking condenser 46. As stated before, the anode 40 of tube V2 is tapped on the lower part of coil L2. In Fig. 1 the other

electrode of crystal X is connected (that is, coupled) to the modulator tank circuit between condensers C2 and C3. This is the opposite end of the tank circuit from the end to which the anode 40 is connected. Likewise, the neutralizing condenser N is tapped on this tank circuit (on the same end of the tank circuit as the anode connection) between the condensers C4 and C5. The center connection point 14 between the crystal X and the neutralizing condenser N is, as stated, connected to the control grid G1 of oscillator tube V1.

In Fig. 3 and Fig. 4 the coil L2 is paralleled by variable condensers C3 and C4 and by fixed condensers C5 and C6. The condensers C3 and C4 are preferably operated by one control shaft. The connection between fixed condensers C5 and C6 is grounded directly. The coil L2 is by-passed to ground at its center point in the same manner as for Fig. 1. Likewise, the anode 40 of tube V2 is connected to the lower end of coil L2 as shown. The other electrode of crystal X is connected or coupled to the tank circuit between condensers C3 and C5 (Figs. 3 and 4) while the neutralizing condenser N is connected to the tank circuit between condensers C6 and C4. In practice, it is desirable to keep the middle condensers C3, C4 in Fig. 1 and C5, C6 in Figs. 3 and 4 substantially identical. Likewise, the outer condensers C2, C5 in Fig. 1 and C3, C4 in Figs. 3 and 4 should be alike.

In Fig. 2 the coil L2 is paralleled by the condenser C2. The center of coil L2 may be connected to ground directly or through a blocking condenser 46. The crystal X and neutralizing condenser N are tapped on coil L2 equal distances from the center or ground point. The crystal is tapped on the opposite side of the tank circuit from that on which the anode 40 of tube V2 is coupled.

In Figs. 1, 2, 3 and 4 the operation of the crystal oscillator circuit with tube V1 is the same. The operation of grounded anode crystal oscillator circuits has been described in prior art and need not be described here.

The operation of the modulators in these circuits requires either the use of a phase shifting network P in the grid excitation circuit of tube V2 or the slight detuning of the modulator tank circuit L2, C2, etc., to obtain the phase shift in the modulating radio-frequency excitation energy to be delivered to tube V1.

In Fig. 1 the tank circuit L2, C2, C3, C4, C5 is substantially in resonance. Excitation energy is taken from resistor R1 and after passing through phase shifter P it is delivered to the control grid 24 of tube V2. In passing through the phase shifting network P the phase of the excitation energy is rotated say about 90 degrees lagging (it could be 90 degrees or any other angle in the leading direction depending on the type of phase shifter P used). In passing through the tube V2 this energy is amplified and reversed substantially (180 degrees) in phase. After passing through the anode tank circuit L2, C2, C3, C4, C5, the phase is again reversed substantially 180 degrees and then it is delivered to the crystal X with a lagging phase angle of about 90 degrees. Now the oscillating current from the grid of tube V1 passes through the crystal and through condenser C3 to ground. Since condenser C3 carries both the crystal-oscillating current and the modulator tank oscillating current this is the element which couples the modulator tank circuit to the crystal oscillator circuit. The modulator current

in condenser C3 and the crystal current in condenser C3 provide the two controlling voltage components. The excitation voltage on the control grid of oscillator tube V1 is the resultant of these two components.

In Figs. 2, 3 and 4 the phase shift is obtained by slightly detuning the modulator tank circuit L2, C2, etc., preferably on the low capacity side of resonance. In this case the phase of the excitation energy on the control grid 24 of modulator tube V2 is the same as that on the control grid G1 of the oscillator tube V1. In passing through the modulator tube V2 this energy is amplified and reversed substantially (180 degrees) in phase. If the modulator tank circuit was in tune it would produce a 180 degree phase reversal but since the modulator tank circuit is slightly detuned it gives the excitation energy an additional phase rotation of say about 90 degrees in a direction depending on the direction of detuning. Consequently, the modulator and the oscillator components of the grid excitation are at approximately 90 degrees phase displacement and the control grid radio-frequency excitation voltage for the grid G1 of oscillator tube V1 is the resultant of these two components.

As stated before, Fig. 3 is the preferred form of this type of frequency modulator circuit. If the phase shifting network of Fig. 5 is connected in to replace link B in Fig. 3 and the modulator tank circuit L2, C2, etc., is made substantially resonant at the oscillator frequency, then Fig. 3 is substantially equivalent to Fig. 1. In Fig. 3, the phase of the excitation on the control grid 24 of modulator tube V2 is the same as that on the control grid G1 of oscillator tube V1. In passing through modulator tube V2 this energy is amplified and reversed substantially 180 degrees in phase. Since the modulator tank circuit L2, C3, C4, C5, C6 is slightly detuned it represents a reactance and the modulating excitation energy is given a further phase shift or rotation. It was found preferable to detune the modulator tank circuit on the low capacity side of resonance so that it could be said to represent an inductive reactance.

Now, as stated before, the condenser C5 (Fig. 3) carries both modulator tank current and oscillator crystal and grid current, so that this condenser acts as coupling between the modulator and the oscillator circuits. Also, the condenser C6 (Fig. 3), which carries the neutralizing condenser current and the modulator tank current, and which is on the same end of the tank circuit as the anode connection, by like reasoning acts as the uncoupling between the modulator and the oscillator circuits. Neutralizing condenser N is adjusted to have substantially the same capacity as the crystal X. Since condensers C5 and C6 (Fig. 3) have the same capacity and also since the neutralizing condenser N and the crystal X have the same capacity the modulator circuit is neutralized and it cannot affect the crystal oscillator circuit unless the crystal is oscillating. In other words, the crystal must be oscillating before high frequency modulating excitation energy can be transmitted from the modulator circuit L2, C2, etc., to the crystal oscillator circuit. Therefore, this circuit insures crystal controlled frequency modulation.

Another advantage which this circuit has is that when modulator currents are cut off the crystal oscillator will continue to function as long as it is supplied with steady electrode potentials. Now since the crystal oscillator circuit is coupled

to the modulator circuit in the manner described above when the crystal is oscillating, the radio-frequency excitation potentials on the control grid of oscillator tube V1 is the resultant of the two excitation components, one from the modulator tank circuit and the other from the crystal oscillator circuit, the two components being disposed at say about 90 degrees phase angle. Since the modulator tank circuit is detuned in the direction stated above, it represents an inductive reactance and the modulating excitation energy in passing through it is rotated in phase say 90 degrees in the lagging direction. Consequently, the phase of the modulator excitation component leads the oscillator excitation component by approximately 90 degrees.

As stated before, the radio-frequency excitation potential on the control grid of the oscillator tube V1 is the resultant of these two excitation components. If the amplitudes of the currents and voltages in the modulator tube V2 are modulated by the signal oscillations from source A, the amplitude of the modulator excitation energy component delivered from the modulator circuit to the control grid of the oscillator tube V1 will also be modulated in amplitude according to the signal. There is another factor which has an effect on the phase angle of the modulator excitation energy component. The anode of modulator tube V2, being tapped across a portion of the inductance coil of the modulator tank circuit, constitutes a variable resistance across part of this inductance. Consequently, during the process of modulation the variation of anode current in effect causes some change in the tuning of the modulator tank circuit. Therefore, the modulation excitation energy component, which we assumed to have a 90 degree phase relation to the oscillation energy component, not only is modulated in amplitude but also is varied in phase angle a few degrees each side of the average 90 degree relationship during the modulation cycle. As seen from the vector relations, this causes the amplitude and the phase angle of the resultant grid excitation energy of the oscillator to vary according to the signal oscillations. These phase changes are added to each cycle of the oscillations and, consequently, cause a change in the frequency of the oscillations. For any value of modulator bias within the operating range, the frequency shift or change is limited to a value where an equal and opposite excitation energy phase shift occurs which is caused by the opposite tuning of the various circuits due to the frequency change. There is also a limit to the possible total range of modulation caused by limitations in modulator tube current and by the angle of the excitation energy components.

The output circuit C1, L1 of this frequency modulator is electronically coupled to the oscillation circuit by means of the anode 10 of tube V1. This insures minimum reaction on the modulating system.

The neutralizing elements N may, if desired, be omitted and when this is done it appears preferable to obtain the phase shift necessary for providing on the grid of V1 the phase displaced excitation voltages as described hereinbefore, by slightly detuning the modulator tank circuit L2, C2, etc. Under these circumstances the phase shifting element is not included in the connection between the grid G1 and grid 24 in Figs. 1, 2, 3 and 4. When the phase shift is obtained by detuning the tank circuit, the excitation from

the modulator, that is the voltage supplied from R1 to 26, is amplified in V2 and supplied to crystal X from the modulator in phase with the voltage of the oscillator V1 except for the phase shift occasioned by detuning the tank circuit L2, C2, etc.

In my United States application Serial No. 361,506, filed October 17, 1940, I have illustrated several modifications wherein the neutralizing condenser NC is omitted. These modifications include also additional novel features not disclosed herein. For example, the piezo-electric crystal is effectively in series with the grid and cathode of the tube V1 as illustrated in the several modifications of the present application. In my said other application referred to above, the crystal is effectively shunted by the impedance between the grid G1 and the cathode of tube V1.

I have found in working with a frequency modulator such as illustrated in Figs. 1 to 4, inclusive, and, in particular, in Figs. 3 and 4, that the neutralizing condenser C may also be used to adjust the amount of frequency swing or frequency modulation deviation. In other words, the amount of feedback from the modulator V2 and tank circuits L2, C2, etc., to the crystal X of the oscillator circuit, etc., may be adjusted by means of changing the capacity of the neutralizing condenser N. This then affects the ability of the modulator to modulate the frequency of the crystal oscillator. Adjustment of the modulator anode circuit is primarily used to determine or produce the amount of frequency modulation deviation.

The neutralizing condenser N may comprise a capacity (variable condenser) or a crystal X, the capacity between the electrodes of which is adjustable and similar to the capacity between the electrodes of the crystal X. When a crystal is used for neutralizing purposes, the optical axis thereof is of such orientation that the crystal does not oscillate.

Moreover, I found during operation that a small air gap in the crystal holder gives a greater range of frequency modulation than a wide air gap does.

In Fig. 4, I have illustrated a practical embodiment of a frequency modulator arranged in accordance with the present invention. The oscillation generation and frequency modulation portion of this circuit is similar to the modification illustrated in Fig. 3. Moreover, like parts have been designated by like reference characters in Figs. 3 and 4 and the operation of the oscillation generator and frequency modulator illustrated in Fig. 4, it is believed, will be understood without further description. In Fig. 4, however, the output of the oscillation generator V1 comprising the tank circuit C1, L1 wherein the frequency modulated wave energy appears is coupled by condenser 50 to the grid electrode 63 of a radio-frequency amplifier tube 65. Negative bias potential is supplied to grid 63 through choke coil 12. In practice, I have found that a wire wound resistor of about 20,000 ohms works best. The anode 69 of this tube is connected as shown with a tank circuit comprising an inductive reactance 70 and a capacity reactance 72. The amplified frequency modulated wave energy is obtained from this tank circuit by means of coupling condenser 74 and output leads 76.

The audio-frequency signal source in Fig. 4 is connected to the modulator tube V1 by transformer T as in the prior modifications. However, in this modification, additional modulating means

and circuit details are disclosed. The secondary winding of transformer T is connected to a switch 80 in such a manner that, in one position, it is connected as shown with tone rectifier tube 84 to produce a rectified tone potential through low pass filter 102 across the resistors 86 and 88. These resistors are connected by leads 90 and 90' and switch contacts 91 and 91' of switch W to the grid 24 of tube V2 and to the grid of a compensator tube when tone keying is to be used. Switch contact 91' is connected to the grid of a compensator tube not shown. In the other position of the switch 80 the secondary winding of the transformer T is connected directly across resistors 12-13 and to leads 96 and 96' and from leads 98 and 98' by switch 91 to the grid 24 of tube V2 and by switch 91' to the grid of the compensator tube not shown so that the oscillations generated may be modulated in accordance with voice signals. In other words, the triple-pole double-throw switch 80 selects either voice modulation or tone signal modulation, whichever is desired. The double-pole multiple contact switch W permits modulation by voice signals, tone signals (spacing wave keying), relayed keyed spacing wave keying or steady dash for calibrating purposes.

Relay keying is accomplished by connecting the front and back contacts of the keying relay to the pair of leads 100 and thereby to the control grid 24 of tube V1 and through lead H to the grid of the compensator tube not shown. The compensator tube not shown in Fig. 4 is keyed in phase opposition to the modulator tube V2 so that a substantially constant current load is drawn from the anode power rectifier. This permits a large amount of smoothing to be used without regard to voltage regulation requirements. Steady bias potentials are applied between the leads G and N for test and calibrating purposes and to supply fixed bias potentials for spacing wave keying.

The low pass filters 102 and 103 are used in the tone and relay spacing wave keying circuits to eliminate or reduce the higher harmonic frequencies incidental to square wave keying in order to restrict the band of modulating frequencies.

The remaining leads not discussed above in connection with Fig. 4 comprise means for supplying electrode potentials, etc.

The leads marked 115 v. at the left of Fig. 4 of the drawings serve as means for supplying alternating current to the thermostat control crystal temperature regulator at 80'. The leads A and B are connected with the audio-frequency signal source used for modulation purposes. The next lead designated by an E supplies negative bias potential when telephony modulation is carried out. The lead F supplies negative bias potential when tone signal keying is accomplished. Leads G and N, as stated above, supply negative bias potentials for relay keying and for calibrating purposes. The lead H (connected by switch 81' to lead H) is connected to the grid of a compensator tube such as for example shown in my United States application Serial No. 85,435, filed June 10, 1936, now Patent No. 2,153,656, issued April, 1939. This compensator tube cooperates with the keying tube as disclosed in said application to regulate the drain on the source of direct current supplying the system when keyed.

Lead D supplies negative bias for the control grid of the amplifier tube 65. Lead J supplies positive potential to the anode of tube V1, while

lead I supplies positive potential to the anode of the tube V2 and to the screen grids of all of the tubes. Lead K supplies positive potentials to the anode of tube 65 while leads L and M supply alternating current to the cathode heaters of all the tubes.

The amplitude modulation incidentally caused by the frequency modulator is nearly all suppressed by tube 65 and that little which remains can be eliminated in a radio transmitter by the use of subsequent amplitude limiter stages such as the usual frequency multiplier stages. The frequency modulated carrier energy may then be amplified and/or multiplied in frequency in succeeding transmitter stages before it is delivered to the antenna.

Any suitable type of phase shifting network P may be used in these circuits. It may be of the type shown in Fig. 1 or like that shown in Fig. 5. It may instead be a series coil, parallel condenser arrangement. It may be a combination of resistances and coils or condensers or both. There may be only one stage or many stages in the phase shifting network.

It should be noted that the terminating load on the phase shifting network P, such as the resistor R2 and the control grid capacity of the modulator tube V2, affects the operation of the network and must be taken into consideration for phase shift calculations.

It may be noted in Figs. 3 and 4 that a condenser CO has been connected between the cathode of tube V1 and ground. This capacity seems to aid and strengthen the oscillator oscillations.

What is claimed is:

1. In a wave length modulation system, an oscillation generator of the electron discharge tube type having electrodes including a cathode and a control grid coupled in an oscillation generating circuit including a piezo-electric crystal and other electrodes coupled in an output circuit, an additional electron discharge tube having an anode and having a control electrode coupled to said generating circuit to derive excitation voltages therefrom, a circuit coupling the anode of said additional tube to said piezo-electric crystal to feed amplified excitation voltage to said crystal and from the crystal to the control grid of said first tube, means for shifting the phase of the amplified voltage fed by said additional tube to said control grid, and means for controlling the gain of said additional tube to modulate the wave length of the oscillations generated.

2. In a wave length modulation system, an oscillation generator of the electron discharge tube type having electrodes including a control grid coupled in an oscillation generating circuit including a piezo-electric crystal and having other electrodes coupled in an output circuit, a second electron discharge tube having an anode and having a control electrode coupled to said generating circuit to derive excitation voltages therefrom, phase shifting means in said last named coupling, a circuit coupled to the anode of said second named tube and to said piezo-electric crystal, to feed excitation voltage by way of said crystal to said generating circuits, and means for controlling the gain of said second tube to thereby control the wave length of the oscillations generated.

3. In a wave length modulation system, an oscillation generator of the electron discharge tube type having electrodes including a control grid coupled in an oscillation generating circuit including a piezo-electric crystal and having other

electrodes coupled in an output circuit, a second electron discharge tube having an anode and having a control electrode coupled to said generating circuit to derive excitation voltages therefrom, a circuit tuned to a frequency slightly different from the mean frequency of operation of said oscillation generator coupled to the anode of said second named tube and to said piezo-electric crystal to feed phase displaced amplified voltages to said crystal and to said generating circuit, and means to control the gain of said second tube in accordance with signals to modulate the length of the oscillations generated.

4. In a wave length modulation system, an oscillation generator of the electron discharge tube type having electrodes including a control grid coupled in an oscillation generating circuit including a piezo-electric crystal and having other electrodes coupled in an output circuit electronically coupled to the generating circuit, a second electron discharge tube having an anode and having a control electrode coupled to said generating circuit to derive excitation voltages therefrom, phase shifting means in said coupling, a circuit coupled to the anode of said second named tube and to said piezo-electric crystal to feed amplified voltage by way of said crystal to said generating circuit, and means for modulating the gain of said second named tube in accordance with signals to thereby modulate the length of the oscillations generated by said first tube and circuit.

5. In a wave length modulation system an oscillation generator of the electron discharge tube type having electrodes coupled in an oscillation generator circuit including a piezo-electric crystal coupled between two of the tube electrodes, and having other electrodes coupled in an output circuit, a second electron discharge tube having an output electrode and having a control electrode coupled to said generating circuit to derive excitation voltages therefrom, means coupling said output electrode of said second tube to an electrode of said first tube by way of said crystal so that said crystal and said second tube provide on said last mentioned electrode of said first tube two voltages the resultant of which controls the frequency of operation of said generator, means for relatively shifting the phases of the said two voltages, and means for modulating the impedance of the second tube to control the wave length of the oscillations generated.

6. In a wave generating and wave length modulation system, an electron discharge device having electrodes including an output electrode a cathode and a plurality of control electrodes, an oscillation circuit coupled between said cathode and plurality of said control electrodes, one of which operates in said oscillation circuit as an anode, a piezo-electric crystal in said circuit, an output circuit coupled with said output electrode, a modulator tube having an anode, a cathode and a control electrode, a circuit coupled to the anode and cathode of said modulator tube, means coupling a point on said last circuit to said piezo-electric crystal, an excitation circuit coupling said oscillation generating circuit to the control electrode of said modulator tube, and means for modulating the impedance of said second named tube in accordance with control potentials.

7. In a wave generating and wave length modulation system, an electron discharge device having output electrodes including a cathode and having a plurality of control electrodes, an oscil-

lation circuit coupled between said cathode and a plurality of said control electrodes, one of which operates in said oscillation circuit as an anode, a piezo-electric crystal in said circuit, an output circuit coupled with said output electrodes and coupled to said oscillation circuit by the electron stream of said tube, a modulator tube having an anode, a cathode and a control electrode, a tank circuit coupled to the anode and cathode of said modulator tube, means coupling a point on said tank circuit to said piezo-electric crystal, an excitation circuit including phase shifting means coupling said oscillation circuit to a control electrode of said second named tube, and means for modulating the impedance of said second named tube in accordance with control potentials.

8. In a wave generating and wave length modulation system, an electron discharge device having output electrodes including a cathode and having a plurality of control electrodes, an oscillation generating circuit coupled between said cathode and a plurality of said control electrodes, one of which operates in said oscillation circuit as an anode, a piezo-electric crystal in said circuit, an output circuit connected with said output electrodes and coupled to said oscillation generating circuit by the electron stream of said tube, a modulator tube having an anode, a cathode and a control electrode, a tank circuit tuned to a frequency slightly different from the frequency of operation of said generating circuit coupled to the anode and cathode of said modulator tube, a coupling between said tank circuit and said piezo-electric crystal, an excitation circuit coupling said oscillation generating circuit to the control electrode of said second named tube, and means for modulating the impedance of said second named tube in accordance with control potentials.

9. In a wave generating and wave length modulation system, an electron discharge device having an anode, a cathode and a plurality of grid electrodes, an oscillation generating circuit coupled between a pair of said grid electrodes and said cathode, a piezo-electric crystal included in said circuit, an output circuit coupled with said anode and cathode, a tank circuit comprising parallel inductance and capacity, means including said piezo-electric crystal connecting a point on said tank circuit to one of said grid electrodes of said oscillation generating circuit, a neutralizing condenser connecting said piezo-electric crystal to a second point on said tank circuit, a modulator tube having an anode, a cathode and a control grid, means coupling said modulator tube anode to a point on said tank circuit, means coupling the control grid of said modulator tube to a point on said oscillation generating circuit, and means for modulating the impedance of said modulator tube in accordance with control potentials to thereby modulate the length of the waves generated.

10. In a wave generating and wave length modulation system, an electron discharge device having a cathode, an anode and two control electrodes, an oscillation circuit including a piezo-electric crystal coupled between said cathode and said two control electrodes, said oscillation circuit being aperiodic except for said crystal, one of said control electrodes operating in said oscillation circuit as an anode, a coupling between said one of said control electrodes and a point of substantially fixed radio-frequency potential, said cathode and other control electrode operating at

a radio-frequency potential above said fixed potential, an output circuit coupled with said anode and cathode and coupled to said oscillation circuit substantially by the electron stream only of said tube, a modulator tube having an anode, a cathode and control electrodes, a tank circuit tuned approximately to the frequency of operation of said oscillation circuit coupled to the anode and cathode of said modulator tube, a connection between a point on said tank circuit and a control electrode of said first named device, an excitation circuit connecting said oscillation circuit to a control electrode of said second named tube, and means for modulating the impedance of said second named tube in accordance with control potentials to modulate the frequency of the output oscillations.

11. In a wave generating and wave length modulation system an electron discharge device having a cathode and a plurality of control electrodes, an oscillation circuit comprising a piezo-electric crystal in a holder and an impedance in series between said cathode and one of said control electrodes, a connection of low radio-frequency impedance between another of said control electrodes and ground radio-frequency potential, said other control electrode operating in said oscillation circuit as an anode, an output circuit connected with said anode and cathode of said tube, a modulator tube having an anode, a cathode and a control electrode, a tank circuit tuned substantially to the frequency of said operation of oscillation circuit coupled to the anode and cathode of said modulator tube, a connection between one terminal of said piezo-electric crystal and a point on said tank circuit spaced from the point thereon to which said anode of said modulator tube is coupled, a neutralizing condenser coupling the other terminal of said crystal to a point on said tank circuit, an excitation circuit coupling said oscillation circuit to the control electrode of said second named tube, and means for modulating the impedance of said second named tube in accordance with control potentials.

12. In a wave length modulation system, an oscillation generator of the electron discharge tube type having electrodes including a control grid coupled in an oscillation generator circuit including a piezo-electric crystal between said control grid and another electrode, an additional electron discharge tube having an anode and having a control electrode coupled to said aforesaid circuit to derive excitation voltages therefrom, a coupling including said crystal in series between the anode of said additional tube and the grid of said first tube to feed voltage from said additional tube to said generator, means for shifting the phase of the excitation voltage fed by said additional tube to said generator, and means for modulating the impedance of the additional tube in accordance with signals.

13. In a wave generating and wave length modulation system, an oscillation generator comprising, an electron discharge device having a cathode, an output electrode, and a control electrode, an oscillation circuit coupled with electrodes of said device including said cathode and said control electrode, a piezo-electric crystal in said circuit, an output circuit coupled with said output electrode and cathode, a modulator tube having an anode, a cathode and a control electrode, means for impressing voltages of the generated frequency from said generator on said modulator tube including a coupling between said

control electrode of said modulator tube and one of said two aforementioned circuits, means for impressing voltages relayed by said modulator tube on said crystal, means for introducing a phase displacement of about 90 degrees in the voltage impressed on said crystal, and means for modulating the potential on an electrode in said tube in accordance with signals.

14. In a wave generating and wave length modulation system, an oscillation generator comprising, an electron discharge device having a cathode, an output electrode, and a control electrode, an oscillation circuit coupled with electrodes of said device including said cathode and said control electrode, a piezo-electric crystal and an impedance in said circuit, an output circuit coupled with said output electrode and cathode, a modulator tube having an anode, a cathode and a control electrode, a coupling between said control electrode of said modulator tube and one of said circuits, an output circuit including said impedance coupled to the anode of said modulator tube, said impedance in said oscillation circuit and modulator tube output circuit serving to couple said circuits to feed amplified voltage from said modulator tube to said generator, phase displacing means in one of said last two couplings, and means for modulating the potential on an electrode in said tube in accordance with signals.

15. In a wave generating and wave length modulation system, an oscillation generator comprising, an electron discharge device having a cathode, an output electrode, and a control electrode, an oscillation circuit coupled with electrodes of said device including said cathode and said control electrode, a piezo-electric crystal in said circuit in series between said control grid and cathode, an output circuit coupled with said output electrode and cathode, a modulator tube having an anode, a cathode and a control electrode, a coupling including an impedance between said control electrode of said modulator tube and one terminal of said crystal, a phase shifter in said coupling, an inductance, a coupling between the anode of said modulator tube and a point on said inductance, a coupling between a point on said inductance and the other terminal of said crystal, and means for modulating the potential on an electrode in said tube in accordance with signals.

16. In a wave length modulation system, an oscillation generator of the electron discharge tube type having electrodes including a control grid coupled in an oscillation generating circuit including a piezo-electric crystal and having other electrodes coupled in an output circuit, an additional electron discharge tube having an anode and having a control electrode coupled to said generating circuit to derive excitation voltages therefrom, a circuit tuned to a frequency slightly different from the mean frequency of operation of said oscillation generator, a coupling between a point on said tuned circuit and the anode of said second named tube, a coupling between a different point on said tuned circuit and said oscillation generating circuit, a connection between a point on said tuned circuit and the cathodes of both of said tubes, and means to control the gain of said additional tube in accordance with signals to thereby modulate the length of the oscillations generated.

17. In a wave length modulation system, an electron discharge device having oscillation generating electrodes, an oscillation generating circuit, including a frequency controlling piezo-electric crystal, regeneratively coupled to said elec-

trodes, the generated voltage phase on at least one of said electrodes being of a certain phase, means for deriving voltage of the generated frequency from said circuit and feeding said derived voltage by way of said crystal back to said one of said electrodes whereat the generated voltage phase is of said certain phase, means for shifting the phase of said last named voltage fed back to said one electrode to an extent such that the said fed back voltage and the said generated voltage are substantially in phase quadrature on said one electrode, and means for modulating the amplitude of the fed back voltage in accordance with signals.

18. In a wave generating and wave length modulation system, oscillation generating means including an electron discharge device having a cathode, an electrode serving as an anode, and a control electrode, an oscillation circuit comprising a piezo-electric crystal, a reactance, and an impedance in series between said cathode and said control electrode, and a circuit including said impedance between said cathode and said electrode serving as an anode, an output circuit coupled with said oscillation circuit, and means for modulating the length of the oscillations generated including, a modulator tube having an anode, a cathode and a control electrode, a tank circuit, comprising a reactance shunted by said first reactance, coupled to the anode and cathode of said modulator tube, said first reactance providing a coupling between the said tank circuit and the oscillation circuit, an excitation circuit coupling said oscillation circuit to said control electrode of said modulator tube, and means for modulating the impedance of said modulator tube in accordance with control potentials.

19. In a wave generating and wave length modulation system, oscillation generating means including an electron discharge device having a cathode, an electrode serving as an anode, and a control electrode, an oscillation circuit comprising a piezo-electric crystal, a reactance, and an impedance in series between said cathode and said control electrode, and a circuit including said impedance between said cathode and said electrode serving as an anode, a reactance in shunt to said impedance for improving the operation of said generating means, an output circuit coupled to said oscillation circuit, a modulator tube having an anode, a cathode and a control electrode, a tank circuit, comprising a reactance shunted by said first reactance, coupled to the anode and cathode of said modulator tube, said first reactance providing a coupling between said tank circuit and the oscillation circuit, an excitation circuit coupling said oscillation circuit to said control electrode of said modulator tube, and means for modulating the impedance of said modulator tube in accordance with control potentials.

20. In a wave generating and wave length modulation system, oscillation generating means including an electron discharge device having a cathode, an electrode serving as an anode, and a control electrode, an oscillation circuit comprising a piezo-electric crystal, a reactance, and an impedance in series between said cathode and said control electrode, and a circuit including said impedance between said cathode and said electrode serving as an anode, an output circuit coupled with said oscillation circuit, and means for modulating the length of the oscillations generated including a modulator tube having an anode, a cathode and a control electrode, a tank

circuit, comprising a reactance shunted by said first reactance, coupled to the anode and cathode of said modulator tube, said first reactance providing a coupling between the said tank circuit and the oscillation circuit, an excitation circuit coupling said oscillation circuit to said control electrode of said modulator tube, a multiple stage phase shifter in said excitation circuit coupling and means for modulating the impedance of said modulator tube in accordance with control potentials.

21. In a wave generating and wave length modulation system, oscillation generating means including an electron discharge device having a cathode, an electrode serving as an anode, and a control electrode, an oscillation circuit including a piezo-electric crystal regeneratively coupling said control electrode, said electrode serving as an anode and said cathode for the production of sustained oscillations, an output circuit coupled to said oscillation circuit, and means for modulating the length of the oscillations generated in accordance with signals including, a source of signals, a modulator tube having an anode, a cathode and a control electrode, an excitation circuit coupling said oscillation circuit to said control electrode of said modulator tube to feed to said control electrode voltages of the generated frequency, a coupling between the cathode of said device and said tube, a high frequency circuit including said crystal coupling the anode of said tube to the control electrode of said device and connections coupling said source of signals to said modulator tube to modulate the conductivity thereof in accordance with signals.

22. In a wave generating and wave length modulation system, an electron discharge device having a cathode, an anode, and a plurality of control electrodes, an oscillation circuit comprising, a piezo-electric crystal, an inductance and an impedance in series between said cathode and one of said control electrodes and a connection including said impedance between the other of said control electrodes and said cathode, an output circuit connected with said anode, a modulator tube having an anode, a cathode and a control electrode, a tank circuit comprising, a capacity shunted by said inductance, coupled to the anode and cathode of said modulator tube, an excitation circuit coupling said impedance to said control electrode of said second named tube, and means for modulating the impedance of said second named tube in accordance with control potentials.

23. In a wave generating and wave length modulation system, an electron discharge device having a cathode, an anode, and a plurality of control electrodes, an oscillation circuit comprising a piezo-electric crystal, a reactance, and an impedance in series between said cathode and one of said control electrodes, and a circuit including said impedance between said cathode and the other of said control electrodes, an output circuit connected with said anode and coupled to said oscillation generation circuit by the electron stream of said tube, a modulator tube having an anode, a cathode and a control electrode, a tank circuit, comprising a second reactance shunted by said first reactance, coupled to the anode and cathode of said modulator tube, an excitation circuit coupling said oscillation circuit to said control electrode of said modulator tube, and means for modulating the impedance

of said modulator tube in accordance with control potentials.

24. In a wave generating and wave length modulation system, an electron discharge device having an anode, a cathode and a plurality of grid electrodes, an oscillation generating circuit comprising a piezo-electric crystal and a reactance in series between one of said grids and said cathode, and an impedance between another of said grids and said cathode, an output circuit connected with said anode and cathode, a tank circuit comprising a second reactance shunted by said first reactance, a modulator tube having an anode, a cathode and a control grid, means connecting said modulator tube anode to a point on said tank circuit, means coupling the control grid of said modulator tube to a point on said impedance, and means for modulating the impedance of said modulator tube in accordance with control potentials to thereby modulate the length of the waves generated.

25. In a wave generating and wave length modulation system, an electron discharge device having a cathode, an anode and two auxiliary electrodes, an oscillation circuit including a piezo-electric crystal and a reactance in series between said cathode and one of said auxiliary electrodes, the tuning of said oscillation circuit being determined primarily by said crystal, another of said auxiliary electrodes operating in said oscillation circuit as an anode, a connection between said other of said auxiliary electrodes and a point of substantially fixed radio-frequency potential, said cathode and one auxiliary electrode operating at a radio-frequency potential above said fixed potential, an output circuit connected with said anode and cathode and coupled to said oscillation generation circuits substantially by the electron stream only of said tube, a modulator tube having an anode, a cathode and a control electrode, a tank circuit including said reactance tuned approximately to the fre-

quency of operation of oscillation of said oscillation circuit, means coupling the anode of said second tube to a point on said tank circuit, an excitation circuit connecting said oscillation circuit to a control electrode of said second named tube, and means for modulating the impedance of said second named tube in accordance with control potentials to modulate the frequency of the output oscillations.

26. In a wave generating and wave length modulation system, an electron discharge device having a cathode, an anode and two auxiliary electrodes, an oscillation circuit including a piezo-electric crystal and a capacity in series between said auxiliary electrodes, a connection between a point on said circuit and the cathode of said device, the tuning of said oscillation circuit being determined primarily by said crystal, one of said auxiliary electrodes operating in said oscillation circuit as an anode, a connection between said one of said auxiliary electrodes and a point of substantially fixed radio-frequency potential, said cathode and other auxiliary electrode operating a radio-frequency potential above said fixed potential, an output circuit connected with said anode and cathode and coupled to said oscillation circuit substantially by the electron stream only of said tube, a modulator tube having an anode, a cathode and a control electrode, a tank circuit comprising an inductance and a capacity in series with said first named capacity in shunt to said inductance, means coupling the anode of said second tube to a point on the inductance of said tank circuit, an excitation circuit connecting said oscillation generating circuit to the control electrode of said modulator tube, and means for modulating the potential of the control electrode of said modulator tube in accordance with control potentials to modulate the frequency of the oscillations in said output circuit.

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