March 31, 1942. O. E. DE LANGE 2,278,063

FREQUENCY MODULATION SYSTEM

Filed July 9, 1937 3 Sheets-Sheet 1

FIG. 1

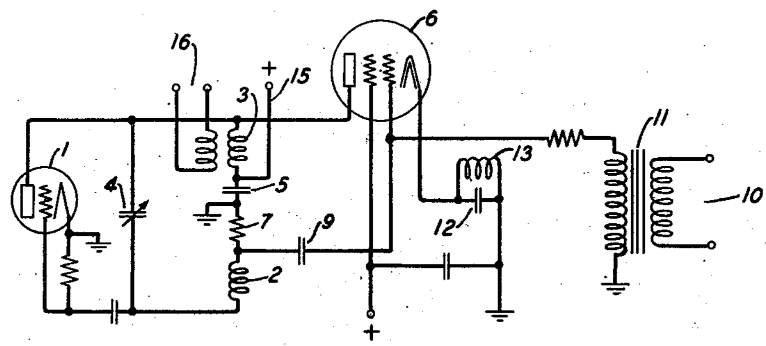

FIG. 2

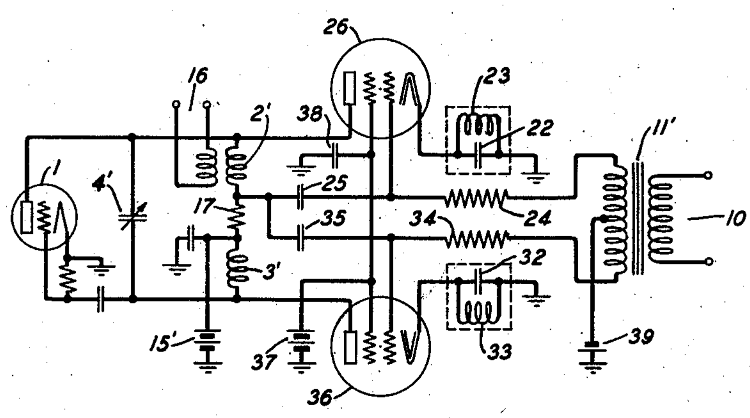

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FIG. 3

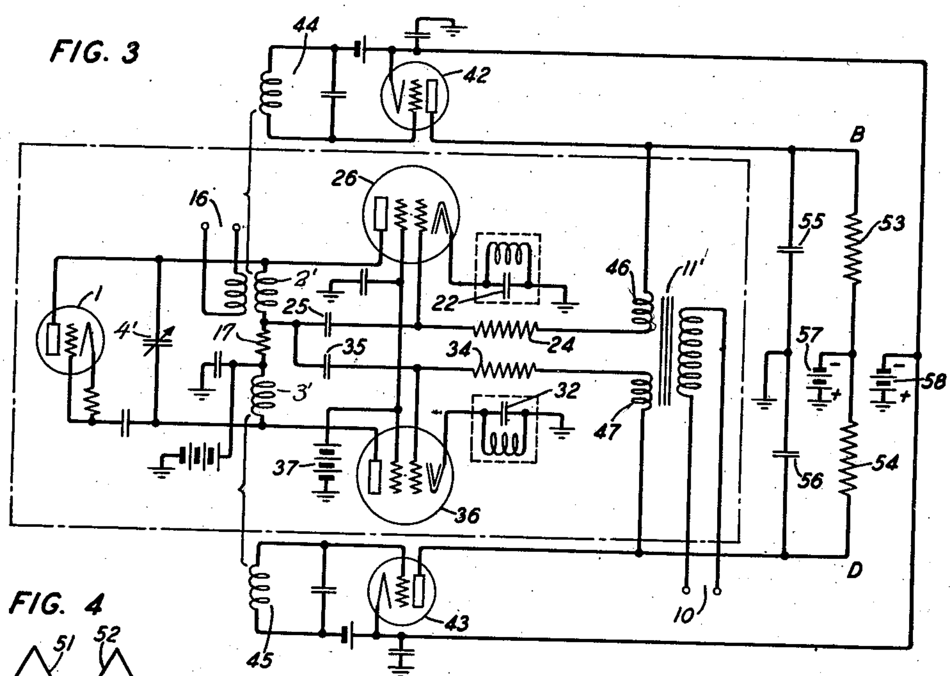

FIG. 4

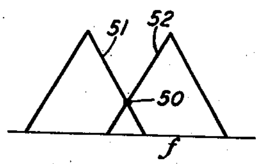

FIG. 5

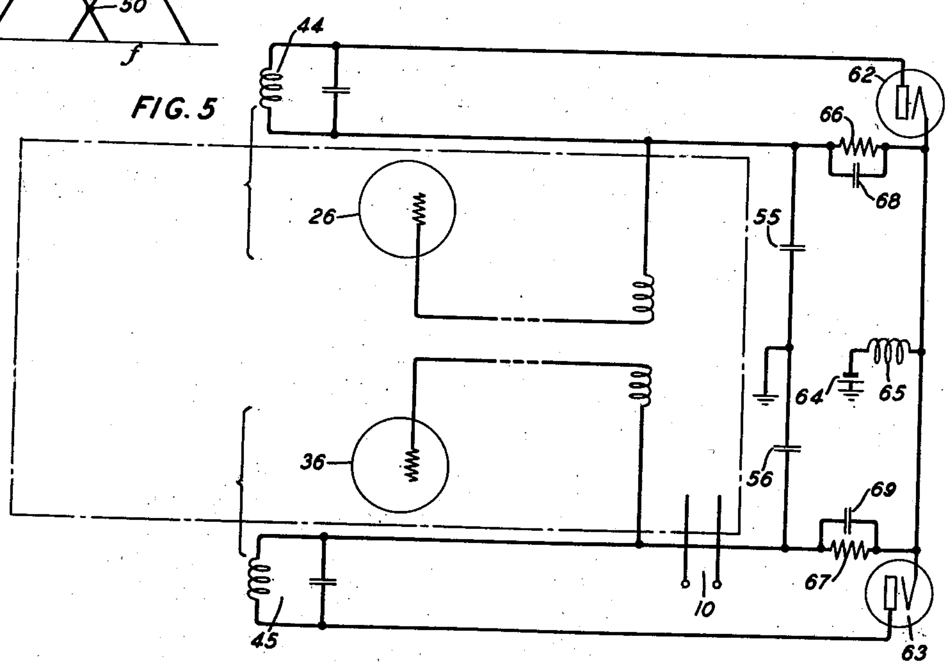

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FIG. 6

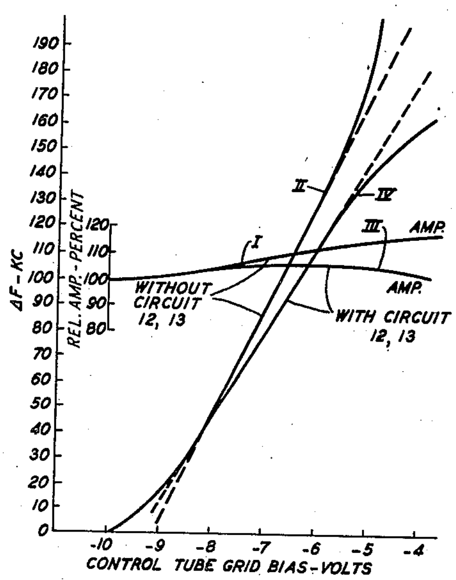


FIG. 7

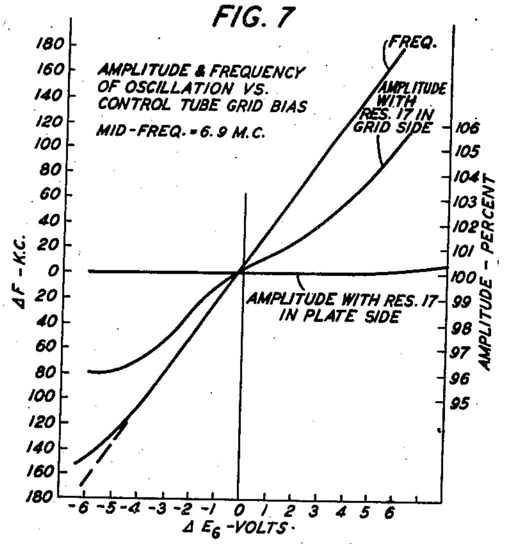


FIG. 8

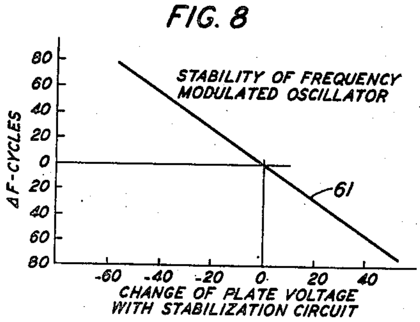
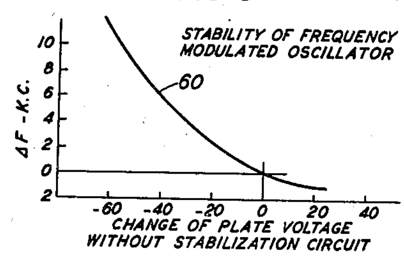


FIG. 9



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FREQUENCY MODULATION SYSTEM

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Application July 9, 1937, Serial No. 152,674

17 Claims. (Cl. 179—171.5)

The present invention relates to frequency modulation of high frequency waves by signal or other modulating waves.

Among the objects of the invention are, to increase the extent or degree of modulation, to improve the quality or linearity of the modulation and to increase the frequency stability.

It has been proposed to vary the frequency of an oscillator by changing the plate impedance of a discharge tube associated with the frequency-determining circuit such that the plate current is out of phase with the voltage, for example, in phase quadrature with the voltage in such circuit.

In accordance with this invention, this basic type of circuit has been modified to provide frequency modulation by signal waves, and the various forms which the improved circuit may take will be indicated in the following description and illustrated by examples in the drawings.

Fig. 1 is a schematic circuit diagram of a circuit embodying the invention using a single control tube;

Fig. 2 is a similar circuit diagram using a pair of control tubes in push-pull.

Fig. 3 is a modification embodying a frequency stabilizing circuit in accordance with the invention;

Fig. 4 shows idealized curves illustrating the action of this frequency stabilizing circuit;

Fig. 5 shows a modification of the circuit of Fig. 3 and may be substituted for all that portion of Fig. 3 outside the broken line; and

Figs. 6, 7, 8, and 9 show curves illustrating the performance of the various circuits.

Referring first to Fig. 1, the oscillator comprises space discharge tube 1 with tuned or tank circuit comprising inductances 2 and 3 and capacity 4, with coupling between inductances 2 and 3. Condenser 5 is a stopping condenser. Plate voltage for tubes 1 and 6 is supplied over conductor 15. Control tube 6 has its grid circuit connected across resistance 7 shown serially included in one branch (e. g. the inductance arm) of the tank circuit, one end of which resistance is grounded. Series condenser 9 is included in the grid lead to tube 6 and modulating voltages are applied to this grid from any suitable signal input 10 through transformer 11. In the cathode-ground lead of tube 6 are included a capacity 12 and direct current by-pass in the form of choke coil 13, for a purpose to be described. Screen grid voltage for tube 6 is supplied over circuit 14 from a positive potential source indicated. The load coupling circuit is shown at 16.

Except for the signal input coupling, the load coupling and the cathode network 12, 13 this circuit resembles a circuit shown by Travis in Proc. I. R. E., volume 23, No. 10, October, 1935, page 1135, Fig. 8. In attempting to adapt that circuit to a frequency-modulating system it was found that the amplitude variations were larger than could be tolerated. It was found that where large variations of frequency are needed as in a frequency-modulating system it could no longer be assumed that the resistance and inductance of the tank circuit vary by the same amount, as the mutual conductance of the control tube is changed, but that while they do change in the same direction the resistance changes the more rapidly and the result is a change in amplitude as the frequency is changed.

It was found, however, in accordance with this invention that the inclusion of a capacity reactance (12) in the cathode ground lead of the tube 6 minimized the amplitude changes and permitted satisfactory frequency modulation of wide extent. This may be accounted for by the fact that with the condenser 12 in circuit and of the proper size the resistance component of the total impedance represented by the plate circuit of tube 6 in parallel with inductance 3 may be made to vary with variations of the mutual conductance of tube 6 in such a way as to keep the ratio of this resistance to the effective inductance of the total impedance constant. This has the effect of keeping the tuned impedance constant and therefore the amplitude of the generated oscillations of varying frequency constant.

The correct value of capacity 12 does not appear to be critical and its best value can be found by trial. In one case when applicant was using an R. C. A. type 37 tube as oscillator, an R. C. A. type 36 tube as control tube and a mean frequency of about 4 megacycles modulated to an extent of about ±50 kilocycles, a suitable value for capacity 12 was 100 micromicrofarads.

While Fig. 1 has the resistance 7 connected in the grid circuit of oscillator 1 and can be used in that way, applicant has found it preferable to place both resistance 7 and the load coupling circuit in the plate circuit and in the succeeding figures they will be so shown. Greater freedom from amplitude variations is obtained by connecting resistance 7 in the plate branch of the tuned circuit and this is also true of the load coupling.

The type of operation obtained with the circuit of Fig. 1 is indicated by the curves of Fig. 6, where curves I and II show amplitude and frequency variations when capacity 12 and its by-pass 13 are absent and curves III and IV are corresponding curves with 12 and 13 in circuit. It is seen that there is a wide region over which the changes of amplitude are small and that with proper choice of operating point this circuit will produce quite linear modulation of ±50 kilocycles with amplitude changes which never exceed 2 per cent or ±40 kilocycles with practically no amplitude change. In this figure the mean frequency was of the order of 4 megacycles.

An improvement in linearity of modulation can be obtained by use of a pair of control tubes in push-pull relation as disclosed in Fig. 2. In this figure, tube 1 is the oscillator tube with tuned circuit comprising inductance portions 2' and 3' and tuning condenser 4' as in Fig. 1. The two control tubes are shown at 26 and 36 with their cathodes connected to ground through respective cathode networks 22, 23 and 32, 33. Plate voltage is supplied from source 15' for all three tubes. Resistance 17 is in this figure connected between the alternating current ground and the plate of the oscillator so that this resistance is in the plate branch of the tuned circuit rather than in the grid branch. The control grids of the tubes 26 and 36 are connected through respective condensers 25 and 35 to the ungrounded end of resistance 17 whereby these grids receive a high frequency voltage from across resistance 17. These grids are also connected through respective impedances, shown as resistance 24 and 34, to the extremities of a speech input coil 11' the primary of which is connected to input circuit 10. Impedances 24 and 34 could, if desired, comprise radio frequency choke coils. The midpoint of the secondary winding of transformer 11' is connected through bias battery 39 to ground. The load circuit coupling is shown at 16 from across the plate coil of the oscillator. The screen grid voltage for tubes 26 and 36 is supplied from source 37 with by-pass condenser 38 to ground.

Due to the parallel connection of the control grids of tubes 26 and 36 to the resistance 17 the tube 26 appears to the plate path of the oscillator tank circuit as a positive reactance in series with a positive resistance while tube 36 appears to the grid path of the tank circuit as a negative reactance in series with a negative resistance. The result is that if both tubes have the same mutual conductance their effects tend to neutralize each other in producing variation of the frequency. When, however, their mutual conductances are varied in opposite directions by the impressed signal their effects on the frequency of the generated wave are in the same direction and additive. Each tube is operated at a point where changes in its mutual conductance have little effect on the amplitude of oscillation so that the combination likewise has but a small effect upon the amplitude as the mutual conductances are varied. It is possible by this circuit to obtain for the same amplitude change a much greater frequency shift than is obtained with a single control tube.

Typical results obtainable with the circuit of Fig. 2 (without circuit elements 22, 23 and 32, 33) are illustrated by the curves of Fig. 7 and these curves also illustrate the improvement secured by including resistance 17 in the plate branch of the tuned circuit instead of in the grid branch and taking voltage across plate branch as load voltage as was discussed in connection with resistance 7 of Fig. 1. It is seen from these curves that with the use of the two control tubes and the resistance 17 in the plate branch of the tuned circuit substantially linear modulation is obtainable over a region twice as great as that illustrated by the curves of Fig. 6 with practically no perceptible change in amplitude. When the resistance 17 was included in the grid branch of the tuned circuit very large changes in amplitude were observed. The mean frequency about which the modulation took place in the case of Fig. 7 was 6.9 megacycles. While the circuit elements 22, 23 and 32, 33 are shown in Fig. 2 they were not used in the circuit when the curves of Fig. 7 were made. As the curves indicate, very good results were obtained in this particular circuit without the use of these circuit elements. The dotted line inclosure around these cathode impedances in Figs. 2, 3 and 5 is to indicate that these circuit elements may be omitted although applicant has found them advantageous in some cases with circuits of the type shown in these figures.

Fig. 3 discloses the same circuit as in Fig. 2 with the addition of means for maintaining the frequency of the generated oscillations very stable. This latter effect is secured by the use of a pair of tuned detectors 42 and 43 whose tuned grid circuits 44 and 45 are respectively coupled to the inductances of the tank circuit of the oscillator and are tuned one slightly below and the other slightly above the normal frequency so that these detectors have "crossed characteristics" as indicated in Fig. 4. For example, referring to Fig. 4, if the mid-frequency is at point 50 the detector 42 has a resonant characteristic with a slope indicated by line 52 passing through the point 50, while the detector 43 has a characteristic with a slope indicated by line 51 passing through the point 50. The effect of this will be described presently. Lines 51 and 52 represent idealized circuits though it is not at all necessary that these characteristics be linear.

Referring again to Fig. 3, the secondary of the speech input coil 11' is divided into portions 46, 47 and across the outer terminals are connected a pair of resistances 53, 54 and a pair of condensers 55 and 56. The plate of detector 42 is connected to the upper terminal of winding 46, while the plate of detector 43 is connected to the lower terminal of winding 47 as shown in the figure. The cathodes of the detectors 42 and 43 are connected together and through battery 58 to ground, the polarity being such that the cathodes are made negative to ground. The common terminal of resistances 53 and 54 is connected to the negative pole of battery 57 with its positive pole connected to ground. Since the cathodes of control tubes 26 and 36 are grounded to low frequency and direct voltages battery 57 applies a negative biasing potential to the control grids of these tubes (similarly to battery 39 of Fig. 2). Battery 57 tends to make the plates of detectors 42 and 43 negative but this is offset by battery 58 which may be of sufficiently higher voltage than battery 57 to apply resultant normal positive voltage to the detector plates. Condensers 55 and 56 are small enough to offer high reactance to currents of much lower than speech frequency but relatively small reactance to currents of speech and higher frequencies.

Assuming that the oscillator is operating at its correct normal frequency (point 50, Fig. 4) and that no modulating waves are being applied to the circuit 10, equal high frequency voltages are applied to the grids of detectors 42 and 43 producing equal steady plate current in the detector output circuits and producing the same voltage at points B and D with respect to ground. It is assumed also that battery 57 has been adjusted to produce the desired bias voltage on the control grids of tubes 26 and 36. If now the frequency of oscillation should rise, the output current from detector 43 will decrease and that from detector 42 will increase (see Fig. 4) causing the potential of point B and of the control grid of tube 26 to become more negative and that of point D and control grid of tube 36 more positive and restoring the oscillator frequency to its normal value 50 as shown by the curves of Fig. 4.

When speech currents are applied to circuit 10 they produce variations in the oscillator frequency as described in connection with Fig. 2. The detectors 42 and 43 would endeavor to counteract the changes in frequency but they are prevented from accomplishing this by virtue of the condensers 55 and 56 which prevent a voltage of the signaling frequency from being developed across the points B and D. As noted above these condensers are so large that only voltages of frequencies below the lowest modulating frequency can exist across the points B and D. Thus the system allows for variation of frequency at rates high enough for modulation but at the same time prevents frequency drifts.

The performance of the frequency stabilizing circuit of Fig. 3 is indicated by the curves of Figs. 8 and 9 in which curve 60 (Fig. 9) indicates the change of oscillator frequency in kilocycles as the plate voltage is varied, where the stabilizing circuit was absent, while curve 61 (Fig. 8) shows the change of oscillator frequency in cycles with changes in plate voltage where the stabilizing circuit was used. The improvement in stability obtained was about 150-fold. Plate voltage was taken as the independent variable because frequency-modulated oscillators are fundamentally unstable with varying plate voltage. It was found that a similar degree of stability was obtained with respect to variations in the setting of tuning condenser 5 over a considerable frequency range, the frequency of oscillation being determined almost entirely by the tuned circuits 44 and 45.

One disadvantage of the circuit of Fig. 3 is that the detector plates must be at the same direct current potential as the grids of the control tubes. This necessitates putting the cathodes of these detector tubes at a negative potential with respect to ground sufficient to give the desired detector plate voltage. This disadvantage is obviated in the circuit of Fig. 5 in which the triode detectors of Fig. 3 are replaced by diode detectors 62 and 63. The circuit of Fig. 5 may be used wherever a diode detector will be of sufficient sensitivity. In this figure the control grid bias is supplied from battery 64 through a choke coil 65. The detected currents produce a voltage drop across the respective resistances 66 and 67 which are applied to the grids of the control tubes for frequency stabilization. These resistances are by-passed by condensers 68 and 69, respectively. By tapping these by-pass condensers across only a part of the resistances 66 and 69 it is possible to increase the impedance across the tuned circuits and so increase the sharpness of these circuits.

The invention is not to be construed as limited to the particular circuits that have been disclosed, since these are illustrative, but the scope of the invention is indicated in the claims.

What is claimed is:

1. A frequency modulation system comprising an oscillator having a parallel resonant circuit for determining the frequency, a resistance in one branch of said circuit, a grid-controlled tube having a grid circuit coupled to said resistance and a plate circuit effectively across said resonant circuit whereby variations in its plate resistance vary the frequency of oscillations produced, means to impress modulating waves upon the grid of said tube, and means to counteract the tendency of the variations in plate resistance of said tube to vary the amplitude of the generated oscillations.

2. A frequency modulating system according to claim 1 in which the means to counteract the tendency of the variations in plate resistance of said tube to vary the amplitude of the generated oscillations comprises an impedance in the portion of the plate circuit of said tube that is common to its grid circuit.

3. A frequency modulation system comprising an oscillator having a parallel resonant circuit for determining the frequency, connected between the anode and grid, a connection of substantially zero impedance at the frequency of the generated oscillations from the cathode to an intermediate point of one branch of said parallel resonant circuit, a resistance included in series in said branch between said intermediate point and the anode end of said branch, a grid-controlled discharge tube having a grid and having a cathode-anode circuit, means connecting said grid to derive voltage variations from across said resistance, means effectively connecting its cathode-anode impedance across said resonant circuit whereby variations in its anode-cathode resistance vary the frequency of oscillations produced, and means to impress modulating waves upon the grid circuit of said discharge tube.

4. A frequency modulation system according to claim 3, comprising a load circuit coupled to said branch of said resonant circuit between said intermediate point and the end of the branch to which the oscillator anode is connected.

5. A frequency modulating system comprising an oscillator having a parallel-resonant frequency-determining circuit effectively connected between the oscillator plate and grid, a low-impedance path for the generated oscillations from the cathode to an intermediate point of one branch of said resonant circuit, a resistance connected to the portion of said branch between said intermediate point and the oscillator anode, a pair of grid-controlled discharge tubes having plate circuits, means coupling said plate circuits respectively to portions of said branch on respectively opposite sides of said intermediate point and in respectively opposite phase, means connecting the grids of said tubes to said resistance an input circuit for modulating waves, means coupling said input circuits to said grids in opposite phase, whereby a given modulating impulse produces, through the medium of said discharge tubes, frequency varying effects on the oscillation generating circuit that are additive.

6. In a frequency modulating system, an oscillation generator having a parallel resonant circuit, a resistance connected therein, a pair of grid-controlled tubes having plate circuits, means coupling said plate circuits in push-pull relation to one branch of said resonant circuit, means connecting the grids of said tubes in parallel

to said resistance, and a circuit carrying modulating waves coupled differentially to said grids.

7. In a frequency modulating system, a tube including a cathode and an anode serving as oscillation generator, a reactance and resistance connected between its anode and cathode, said reactance being included in and forming part of the frequency determining resonant circuit, a grid-controlled tube having a cathode and grid and having a plate circuit, means effectively coupling said cathode and grid to said resistance, means effectively connecting its plate resistance across said resonant circuit, and means to apply modulating waves to the grid of the latter tube.

8. A modulating system according to claim 7, including a load circuit and means coupling said load circuit to said reactance.

9. In a frequency-modulating system, an oscillation generator having a frequency-determining resonant circuit, means to vary the effective value of one of the reactive components of said circuit in accordance with signal impulses to produce frequency-modulation of the generated oscillations, means for stabilizing the mean frequency of the oscillations comprising a pair of tuned detectors tuned to frequencies on respectively opposite sides of said mean frequency, said detectors coupled to the resonant circuit and connected to react on the said means to produce frequency-modulation, in such direction as to counteract departures from the mean frequency, and means preventing said stabilizing means from exerting control of the frequency except with respect to relatively slow variations in frequency whereby the stabilizing means does not prevent frequency modulation in accordance with the signal impulses.

10. In a frequency-modulation system, an oscillation generator having a frequency-determining resonant circuit, a pair of grid-controlled tubes having their plate impedances oppositely connected to said circuit, means to impress on their grids voltage waves in approximately phase quadrature to the voltage across the resonant circuit, means to impress signal waves differentially on said grids, a pair of tuned detectors coupled to said resonant circuit and having overlapping but displaced resonance characteristics respectively above and below the mean resonance of the circuit, means to impress the detected currents on said grids in a direction to effectively oppose departures from normal frequency of the generated oscillations, and means preventing control of the generated frequency by said detected currents except in response to frequency variations of less than signal frequency.

11. A system according to claim 10, in which said detectors are simple rectifiers connected across the respective tuned circuits and to the respective grids.

12. A frequency-modulating system comprising an oscillator tube having a resonant circuit one of the reactances of which is included between the plate and cathode of the tube, a resistance connected to said reactance and included between the plate and cathode, a pair of grid-controlled tubes having their plate impedances oppositely and symmetrically coupled to the resonant circuit with respect to the oscillator cathode and their grid-cathode circuits connected across said resistance, a signal input differentially coupled to the grids of said pair of tubes, whereby the generated oscillations are frequency-modulated in accordance with signal waves impressed on said pair of tubes, a pair of tuned detectors coupled to said resonant circuit and tuned respectively above and below the mean resonant frequency, means to impress the detected outputs from said detectors on the grids of said pair of tubes to counteract variations in the frequency of the generated oscillations from normal, and filter means in the grid circuits of said pair of tubes for preventing the counteracting effects of said detectors except for slower variations in oscillator frequency than those corresponding to the signal modulation.

13. In a frequency modulating system, an oscillation generator having a resonant frequency-determining circuit, a source of signal waves, and means to produce in said resonant circuit an effective variation in the tuning reactance to vary the frequency of the generated oscillations comprising a grid-controlled space discharge device, means to derive from said resonant circuit and to impress across two of the electrodes of said device a voltage in quadrature with the generated wave, means to vary the impedance of said device in accordance with the signal waves, thereby producing a tendency toward amplitude modulation of the generated oscillations, means to translate the corresponding changes in internal impedance of said device into changes in the effective reactance of said resonant circuit and means for counteracting the tendency of the variations in impedance of said device to cause amplitude modulation of the generated oscillations.

14. In a frequency modulating system, an oscillation generator having a resonant frequency-determining circuit, a source of modulating waves, and means to produce in said resonant circuit an effective variation in the tuning reactance to vary the frequency of the generated oscillations comprising a pair of space discharge tubes having plate circuits, and grid circuits, means connecting said plate circuits to points of opposite phase in said resonant circuit, means differentially relating the grid circuits of said tubes to said source of modulating waves whereby their plate impedances are differentially varied by the modulating waves, and means causing the variations in plate impedances to have cumulative effect on the effective reactance of said resonant circuit.

15. A wave-length modulation system comprising in combination, means for generating wave energy to be modulated comprising an electron discharge device including electrodes connected in oscillation generating circuits, and means for modulating the length of the wave generated by said oscillation generator comprising a reactance tube having an anode, a control electrode, and a cathode, means coupling said anode and cathode with said generating circuits to control the frequency of the oscillations generated, phase displacing means coupling the control electrode of said reactance tube to said generating circuits, means for controlling the gain of said reactance tube at signal frequency to thereby modulate the length of the generated waves, said anode, control electrode and cathode having a common connection to ground, and means comprising an impedance included in the connection between said cathode and ground to oppose modulation of the amplitude of the generated oscillations in response to the control of the gain of said reactance tube at signal frequency.

16. A wave-length modulation system comprising in combination, an electron discharge device having electrodes including an anode and a cath-

ode coupled in a high frequency alternating current circuit wherein wave energy the wave-length of which is to be modulated is caused to flow, and means for modulating the length of the wave energy flowing in said circuit comprising a reactance tube having an output electrode, a control electrode and a cathode, high frequency coupling means coupling said output electrode and cathode of said tube to different points on said high frequency circuit for impressing between the output electrode and cathode of said tube high frequency alternating voltage from said high frequency circuit, said tube serving to determine in part the reactance of said high frequency alternating current circuit and thereby control the wave-length of the wave energy flowing in said high frequency alternating current circuit, a direct current impedance and reactive means for deriving from said high frequency circuit and impressing on the control electrode of said reactance tube a high frequency voltage which is displaced in phase relative to the high frequency voltage impressed by said coupling means on the output electrode of said tube, and means for controlling the gain of said reactance tube at signal frequency to thereby modulate the length of the wave energy flowing in said high frequency alternating current circuit.

17. In a system for modulating a characteristic other than the amplitude of a high frequency wave, a tube having a cathode, a grid and an anode, means subjecting the grid with respect to the cathode to high frequency waves to be modulated, a high frequency resonant circuit having inductance and capacity effectively in parallel connected to said anode and cathode, a reactance tube having a cathode, a control electrode and a plate, a direct current connection between said cathodes, a low high frequency impedance, direct current connection substantially directly connecting together said anode and plate, means comprising a direct current element and a condenser operating to subject the control electrode of said reactance tube to a voltage which is displaced substantially 90 degrees with respect to the high frequency voltage at a point on said circuit having inductance and capacity in parallel; means for subjecting the control electrode of said reactance tube to modulating potentials with respect to the cathode of said reactance tube to modulate the oscillations in said circuit having inductance and capacity and a load circuit coupled to said circuit having inductance and capacity.

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