

Oct. 31, 1944.

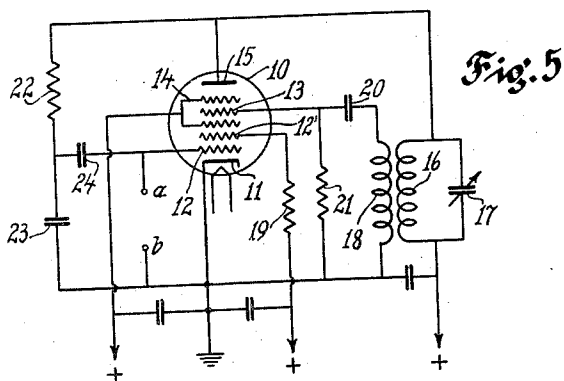
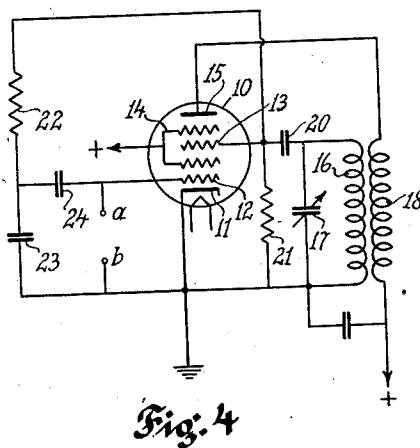
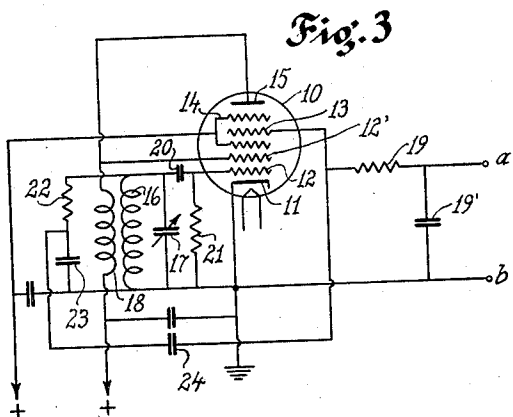
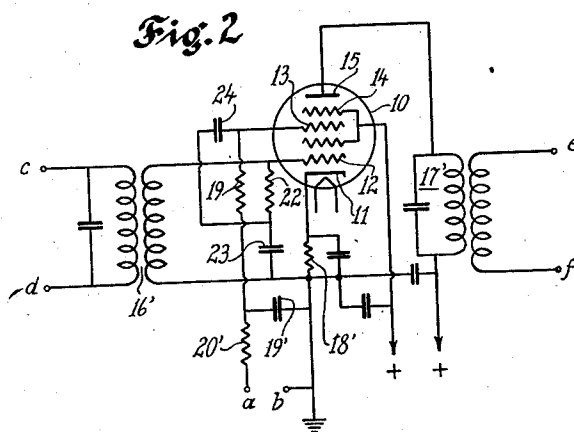
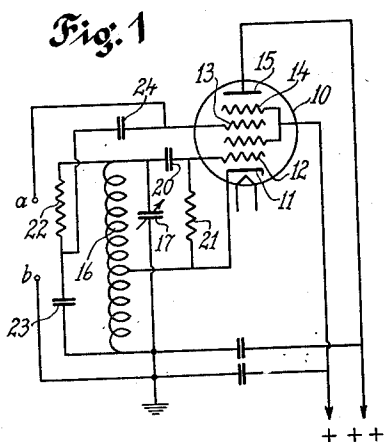
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2,361,731

REACTANCE SYSTEM

Filed Dec. 12, 1940

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

Fig. 6

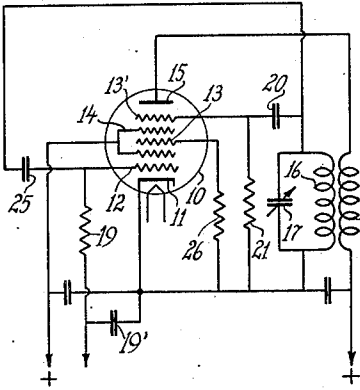


Fig. 7

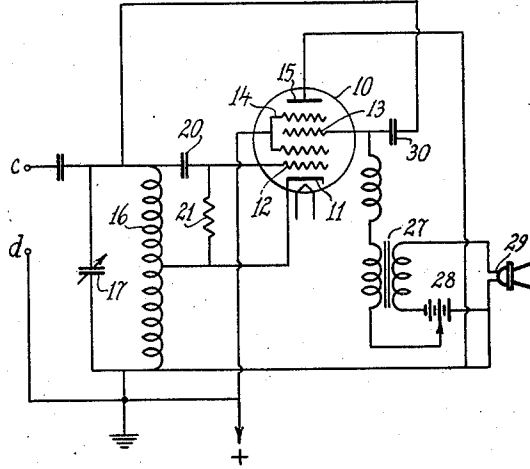


Fig. 8

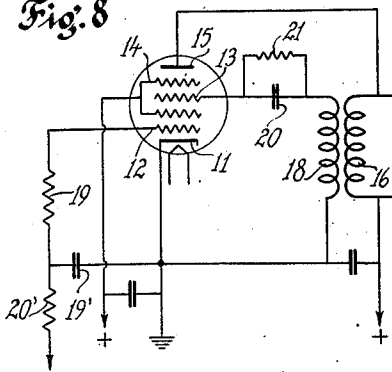


Fig. 9

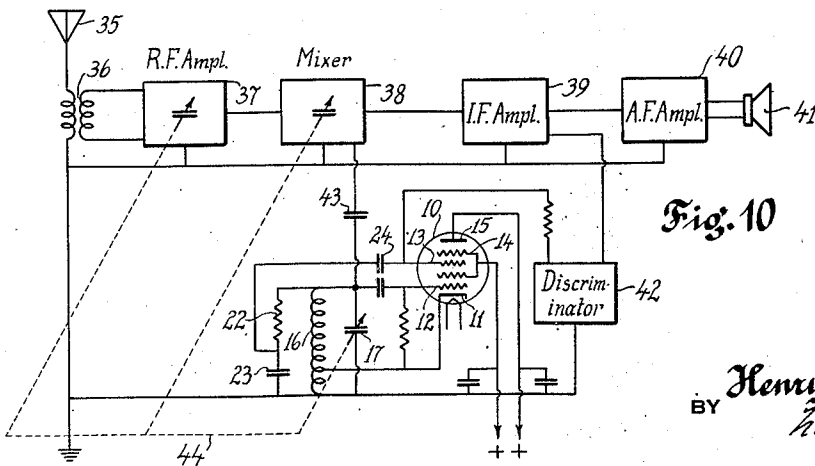
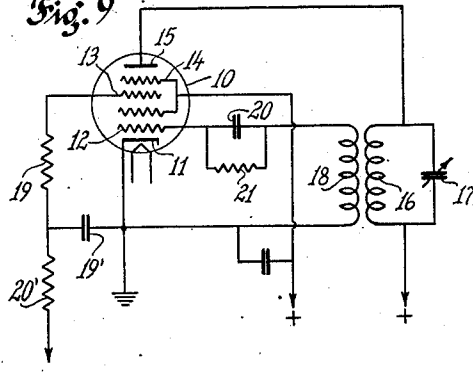


Fig. 10

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2,361,731

REACTANCE SYSTEM

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8 Claims. (Cl. 250—36)

The present invention relates to tuning control systems for oscillatory circuits embodying a reactance control discharge tube for varying the tuning or resonant frequency of the circuit in accordance with an electric controlling potential or current.

In particular, the invention is concerned with electrical oscillators of the self-excited type embodying a composite oscillator and reactance control tube, wherein the oscillating frequency may be controlled in an easy and efficient manner in accordance with a varying electrical bias potential applied to said tube.

An object of the invention is therefore to provide a system for controlling the resonant frequency of an oscillatory circuit utilizing an electron discharge tube performing the function both of an amplifier and reactance control element.

Another object is to provide a self-excited electrical oscillator circuit utilizing a single electron discharge tube serving both as an oscillating element and a reactance control device for varying the frequency of the oscillations.

There has been in the past a wide usage of circuits embodying a reactance control tube capable of controlling or varying the resonant frequency of a tuned circuit in a purely electrical manner by varying a bias potential applied to said tube. Thus, in automatic frequency control systems provided in superheterodyne radio receivers the problem arises of effecting a variation of the local oscillator frequency as a function of the sense and magnitude of a direct current potential developed by a frequency discriminator. Likewise, in the field of phase or frequency modulation the problem arises of modulating the frequency of a self-excited oscillator in accordance with the amplitude changes of an audio or other modulating signal wave. In these and other cases in the art a special reactance control tube is utilized which in fact constitutes an amplifier excited by a quadrature potential derived from currents flowing in the resonant circuit to be controlled and supplying an amplified quadrature voltage which is developed across said resonant circuit thereby to vary its apparent or virtual reactance. The amount of quadrature current injected into the resonant circuit is varied by controlling the transconductance of the reactance tube in accordance with an electric bias potential applied to a control grid resulting in a variation of the apparent reactance and in turn of the virtual tuning adjustment of the resonant circuit. The

quadrature control potential for the reactance tube is produced by a suitable phase shifting means associated with the resonant circuit.

The present invention provides a new and improved electronic reactance circuit of the above general type utilizing a single electron discharge path as an effective element for both an oscillator or amplifier and a variable reactance device whose virtual impedance determinative of the tuning or oscillating frequency may be varied over substantial limits by means of a direct current control potential.

A further object of the invention is to provide an oscillator-modulator which is simple in design and requires a minimum of parts and circuit elements so as to be suitable especially in small portable or mobile phase or frequency modulated transmitters.

Still a further object is to provide a combined amplifier and/or oscillator and reactance control circuit, wherein a single electron discharge path performs partly the functions of the oscillator or amplifier, tuning reactance as well as phase shifting means for effecting the reactance control.

The above and further objects and novel aspects of the invention will become more apparent as the following description proceeds taken with reference to the accompanying drawings forming part of this specification and wherein:

Figure 1 shows a self-excited oscillator circuit embodying the principles of the invention wherein a special phase shifting network is provided for producing reactive oscillating current for the control of the effective oscillating frequency.

Figure 2 shows a tuned amplifying circuit embodying the principles of the invention.

Figures 3 to 5 are modifications of oscillating circuits of the type shown in Figure 1.

Figures 6-9 show modifications of circuits according to the invention wherein a single electron discharge tube is utilized to perform the function of both oscillator, variable reactance, and phase shifting means for controlling the oscillating frequency in a purely electrical manner, and

Figure 10 is a block diagram of a radio receiver embodying a composite oscillator-reactance control tube according to the invention for automatic tuning or frequency control.

Like reference numerals identify like parts throughout the different views of the drawings.

With the aforementioned objects in view the present invention contemplates the utilization of

a single electron discharge path operatively associated with an amplifier which may be a simple amplifier or of the regenerative or degenerative type or with a self-excited oscillatory circuit for maintaining sustained electrical oscillations and at least one further control element excited by a potential in quadrature phase relation to the oscillations of the discharge stream through said path to produce an additional oscillating current component suitably coupled with or superimposed upon the normal oscillations of the system and resulting in control of the virtual or effective oscillation frequency. The magnitude of the quadrature oscillating component is varied in accordance with a suitable control potential providing a variable bias for said tube to effect a corresponding variation of the tuning or oscillation frequency.

Referring to Figure 1, there is shown a basic oscillatory circuit embodying the principles of the invention. This circuit utilizes an electron discharge tube 10, in the example shown of the hexode type comprising the following electrodes arranged in the order named: a cathode 11, a first control grid 12, a screen grid 14, a second control grid 13, and an anode or plate 15. An additional suppressor grid connected to ground or cathode may be provided between the screen grid 14 and the anode 15. The cathode 11, first grid 12 and the screen grid 14 used as an anode in conjunction with an oscillatory or tank circuit comprising inductance 16 shunted by a variable condenser 17 form a regenerative oscillator of the modified Hartley type wherein the screen grid is operated at zero radio frequency potential and the cathode 11 and control grid 12 are operated above ground or any other zero reference point of the circuit at radio frequency potentials. The direct current potential applied to the screen grid 14 as indicated by the + sign supplies the power for generating and sustaining the oscillations in the oscillatory tank circuit 16, 17. The frequency of the oscillations is determined substantially by the values of the inductance 16 and the capacity 17. Item 20 represents the conventional grid blocking condenser and 21 a grid leak resistance for producing suitable bias potential for the grid 12 in a manner well understood.

Alternating or oscillating voltage developed across the inductance 16 is impressed upon a phase shifting network comprising in the example shown a resistance 22 and a reactive impedance such as a condenser 23 connected in series therewith. The potential developed across condenser 23 is impressed upon the second control grid 13 by way of condenser 24 of large capacity. The constants of the resistance 22 and condenser 23 of the phase shifting network are so chosen that the potential applied to grid 13 by way of the capacity 24 which serves to block the direct current upon this grid from the phase shifting network is in quadrature with the oscillating voltage applied to grid 12 from tank circuit 16, 17.

It can be shown in a tube of the type illustrated or in general in any electron discharge tube having a pair of control grids and a positively biased screen grid interposed between said control grids, that the plate current will be determined substantially by the following theoretical equation:

$$I_p = I_0 + k_1 e_1 + k_2 e_2 + k_3 e_1 e_2 \quad (1)$$

wherein e_1 and e_2 represent the alternating voltages applied to the control grids, I_0 is the steady

or quiescent plate current and k_1, k_2, k_3 are constants depending on the characteristics of the particular tube used.

In the case of Figure 1:

$$e_1 = A_1 \sin \omega t$$

$$e_2 = A_2 \sin (\omega t + 90^\circ) = A_2 \cos \omega t$$

Hence, the above equation may be written as follows:

$$I_p = \frac{I_0}{a} + \frac{k_1 A_1 \sin \omega t}{b} + \frac{k_2 A_2 \cos \omega t}{c} + \frac{k_3 A_1 A_2 \sin \omega t \cos \omega t}{d} \quad (2)$$

In Equation 2 term a represents the steady plate current, term b represents the normal oscillating plate current, term c the reactive or quadrature oscillating current, and d the second harmonic term, which will be substantially attenuated by the tuned circuit.

From the foregoing it is seen that the term I_p which is a part of the total cathode current of the tube contains a reactance term (b) of the plate current by which is meant a quadrature oscillating current with respect to the normal oscillating current. Due to the tapping of the cathode 12 from the inductance 16 of the oscillatory tank circuit this term of the plate current and hence of the cathode current will be developed across the lower portion of the oscillating inductance 16 and if varied in its magnitude will have the effect of a variable reactance shunted across the oscillating tank coil. Thus, by varying the direct current bias on the grid 13 by the provision of a suitable biasing or control source connected to the terminals a, b the control by this grid may be varied which will have the effect of varying the constant k_2 i. e. in turn the value of the quadrature oscillating current and the equivalent virtual reactance of the oscillating tank circuit. The bias for the grid 13 may be supplied e. g. by the AFC voltage produced by the discriminator in an automatic tuning system of a radio receiver or the bias voltage may represent the output of a microphone or other modulating circuit of a phase or frequency modulated transmitter. The bias potential is applied to the grid 13 through a high frequency choke coil or a high ohmic resistance as shown in Figs. 2, 3 and 7 to 10 or in any other suitable manner in order not to short circuit the radio frequency potential on grid 13 to ground through the biasing source.

From the foregoing it is seen that in a system proposed by the invention a single electron discharge stream is utilized both as an oscillating element for a self-excited oscillator as well as a reactance control path for controlling the oscillation frequency as distinguished from the prior art arrangements requiring separate oscillator and reactance control devices. It will be evident, however, that the invention is not limited to oscillators and means to control the frequency thereof in the manner described, but that the novel principle can be applied with equal advantage to a tuned amplifier stage for electrically adjusting or controlling the tuning or alignment of the amplifier.

A circuit of this type is shown in Figure 2. In the latter, an oscillatory input voltage is impressed from a suitable source connected to terminals $c-d$ between the grid 12 and cathode 11 of the amplifier by way of a resonant transformer 16', and amplified voltage developed by the res-

onant circuit 17' in the plate circuit of the tube is applied to output terminals *e-f* inductively or in any other suitable manner. Quadrature potential derived from the phase shifting network 22, 23 is impressed upon control grid 13 through blocking condenser 24 in a manner similar to that shown in Figure 1 whereby a quadrature output current component will be developed in addition to the normal output current. Adjustment of the circuit may be effected by controlling the quadrature output current by means of a suitable bias potential applied to grid 13 by way of terminals *a-b* and via a low-pass filter comprising a pair of series resistors 19 and 20' and a shunt condenser 19'. In this manner the circuit may be adjusted or aligned to the proper peak or resonance point. By using several tubes in cascade, tuning may be effected by a single control voltage simultaneously biasing all the tubes, thereby eliminating the problem of gang-ing and aligning a number of mechanically coupled tuning elements.

Figure 3 shows an oscillator circuit similar to that according to Figure 1 utilizing a discharge tube of the pentagrid converter type comprising a further positive or anode grid 12' located between the control grid 12 and screen grid 14. The anode grid 12' in this case is regeneratively coupled with the oscillating tank circuit 16, 17 through a tickler coil 18 to form a self-excited regenerative oscillator system associated with the lower portion of the electron discharge path of the tube. The remaining portion of the electron discharge path serves as an amplifier for the quadrature or tuning control potential derived from the oscillator tank circuit by means of the phase shifting network 22, 23 and impressed upon the control grid 13 by way of condenser 24 of large capacity. The amplified quadrature current developed in the plate circuit and controlled in accordance with the bias voltage on the grid 13 derived from a control source connected to *a-b* is suitably fed back upon the oscillator circuit 16, 17 such as through the tickler coil 18 by directly connecting the plate 15 with the oscillating grid 12' as shown. The screen grid 14 in this case serves to prevent interaction between the oscillating and amplifying (reactance) path of the tube.

The circuit shown in Figure 4 is similar to Figure 3 but utilizes a hexode type electron tube in place of a pentagrid converter wherein the functions of the grids 12 and 13 are interchanged, that is the oscillating system comprising tank circuit 16, 17 and the tickler coil 18 are connected to the grid 13 and plate 15 while the quadrature potential derived from the tank circuit is impressed upon the grid 12. In such an arrangement the normal and quadrature oscillating currents are superimposed or coupled through the electron stream compared with the physical coupling through the tank circuit in the case of Figures 1 and 3.

Figure 5 shows a modification of the circuit according to Figure 4 utilizing a pentagrid converter type electron tube provided with an additional negative control grid 12' between grid 12 and screen 14 to produce amplified quadrature current in its output circuit including for this purpose suitable load impedance such as an ohmic resistance 10. The amplified quadrature current controlled by the bias on grid 12 is electron stream coupled with the upper or oscillating discharge path of the tube resulting in efficient controlling action and increased range of the frequency control of this circuit.

Referring to Figure 6, there is shown still a further modification of an oscillator-reactance tube circuit according to the invention. The tube utilized in this embodiment is of the hexode type similar to that provided in Figure 1 but comprising an additional (suppressor) control grid 13' arranged between the screen grid 14 and plate 15. The oscillating tank circuit 16, 17 and tickler coil 18 are connected to the grid 13' and plate 15 to form a regenerative oscillating system. The control grid 12 is excited in phase with the oscillating frequency by directly coupling it to the tank circuit 16, 17 through coupling condenser 25. Control grid 13 is operated at cathode potential or if desirable at a negative potential with respect to the cathode whereby this grid will be excited by a potential in phase quadrature to the space current oscillations by space charge coupling with the grid 12 as will be further understood from the following. Electrons accelerated by the screen grid 14 are attracted through the control grid 12 and will partly pass the openings of the screen grid to be slowed down or repelled by the decelerating action of grid 13 which is at a substantially negative potential with respect to the screen grid 14. As a result of this decelerating action a concentrated electron space charge or virtual cathode will be formed within the space between the screen grid 14 and control grid 13. The intensity of this virtual cathode varies in the rhythm of the space current variation i. e. the same as control potential applied to the grid 12. The variable space charge or virtual cathode causes a corresponding current to flow through the outer circuit connected to grid 13 and including a non-reactive impedance such as resistance 26 which current being a displacement current will be in phase quadrature to the fluctuations of the virtual cathode, that is in turn to the potential upon the grid 12. As a result thereof a potential will be developed on grid 13 which is in phase quadrature to the potential on the oscillating control grid 13'. In this manner a quadrature or reactive current component due to the control action of grid 13 will be superimposed upon the normal oscillating current in the output circuit of the tube resulting in a variation of the effective tuning in accordance with a direct current biasing potential applied to the control grid 12 from an AFC circuit or any other biasing or controlling source. It is seen therefore that in a circuit according to Figure 6 a single electron discharge path is utilized as an effective element in performing the function of both oscillator as well as phase shifting and reactance control means in a most simple and efficient manner.

Figure 7 shows a modification of a combined oscillator-reactance control circuit utilizing a virtual cathode or space charge coupling for producing a reactance or frequency control component of the total oscillating current. The discharge tube utilized is similar to that shown in Figure 1. Grid 13 of this tube is excited in phase from the tank circuit 16, 17 by way of blocking condenser 30. The plate 15 is grounded to serve as a decelerating electrode so as to develop a quadrature potential in the cathode-plate path that is across the bottom part of the tank circuit inductance 16 by virtue of the capacitive coupling of the plate 15 with the space charge or virtual cathode formed between the screen grid 14 and plate 15. The reactance and frequency control is effected by varying the bias potential on the grid 13 resulting in a corresponding varia-

tion of the intensity of the virtual cathode and in turn of the reactive control voltage developed across the oscillating tank circuit. The control potential in the example shown is supplied by the secondary of an audio frequency transformer 27 having its primary connected to a source of direct current 28 in series with a microphone 29 or equivalent control element. The source 28 simultaneously serves to supply constant negative bias for the grid 13 to ensure most favorable operating conditions. In this manner frequency modulated oscillations may be derived from the tank circuit 16, 17 exciting an antenna or other transmission circuit by way of an amplifier connected to terminals c—d or alternatively for exciting a frequency multiplier to increase the frequency deviation to an extent required in wide band frequency modulation. Similarly, the circuit may be employed as a phase modulator in which case a suitable corrective network may be inserted between the microphone circuit and the tube to increase the control potential directly in proportion to the modulating frequency so as to obtain modulated oscillations having a phase deviation proportional only to the amplitude of the modulating signals.

Figure 8 shows another circuit utilizing a variable space charge or virtual cathode for producing a quadrature oscillating component. The tube used is of the pentode type similar to the tube shown in Figure 1. The oscillating system 16, 17, 18 is operatively connected to the control grid 13 and anode 15. Grid 12 connected to the biasing source is operated at cathode or negative potential and accordingly will be excited by a potential in phase quadrature with the space current oscillations due to variable space charge coupling with the electron stream. This coupling is due to the space charge formed, between the grid 12 and the screen 14, by electrons which after passing the screen 14 and deceleration by the grid 13 are returned so as to pass the screen grid 14 in the opposite direction and become finally decelerated by the grid 12 to form a second space charge or virtual cathode adjacent to the latter in addition to a first virtual cathode formed by other electrons between the screen 14 and grid 13 as described hereinabove. The excitation of grid 12 in quadrature to the space current oscillations will cause a corresponding quadrature oscillating component in the output circuit which in turn will result in a variation of the effective or virtual tuning or control of the oscillating frequency in substantially the same manner as in the preceding circuits.

Referring to Figure 9 there is shown a circuit similar to Figure 8 wherein the functions of the grids 12 and 13 have been interchanged, that is the oscillatory system 16, 17, 18 is associated with the grid 12 and the plate 15, while the grid 13 is space charge excited in quadrature with the oscillating space current by the virtual cathode formed between the screen 14 and the grid 13 as understood from the foregoing.

In Figure 10 there is shown a circuit, partly in block diagram form, of a superheterodyne radio receiver embodying a composite oscillator-reactance tube circuit in accordance with the invention for effecting automatic frequency or tuning adjustment. Radio signal waves intercepted by the antenna 35 are impressed upon a radio frequency amplifier by way of a coupling transformer 36. The amplified radio frequency signals are then applied to a first de-

tector or mixer 38 which may be of the pentagrid or any other type wherein the incoming signals are combined with locally generated signals of different frequency to produce intermediate frequency signals. The latter are applied to an intermediate frequency amplifier 39 including a second detector to deliver audio or other demodulated output signals. The latter may be further amplified by means of an audio frequency amplifier 40 to a level sufficient for feeding a translating device such as a loud speaker 41. The local oscillator is of the type as shown in Figure 1 comprising a vacuum tube 10 with an oscillating and reactance control system associated therewith for controlling the frequency of the oscillating potential impressed upon the mixer 38 by way of condenser 43. The adjustable tuning members of the radio frequency amplifier, the mixer and local oscillator are suitably coupled mechanically as indicated by dotted lines 44 for uni-control of the receiver in a manner well known. A fraction of the intermediate frequency signal energy is applied upon a discriminator 42 of any suitable type known in the art and adapted to produce a control potential varying both in sense and magnitude in dependence upon and in proportion to the deviation of the intermediate signal frequency from the assigned center frequency of the resonance characteristic of the intermediate frequency amplifier 39. The discriminating potential is impressed upon the grid 13 of the oscillator-reactance tube with such polarity that the ensuing variations of the oscillating frequency will counteract the initial frequency deviation of the intermediate frequency signal from the assigned frequency in such a manner as to bring about or maintain the receiver in exact tuning adjustment.

It will be evident from the foregoing that the invention is not limited to the specific details and circuit arrangements described and disclosed herein for illustration but that the underlying idea and principle of the invention are susceptible of numerous variations and modifications coming within the broader scope and spirit of the invention as defined in the appended claims. The specification and drawings are accordingly to be regarded in an illustrative rather than a limiting sense.

I claim:

1. In combination, a circuit traversed by alternating current, an electron discharge device comprising a cathode and an anode, a first control grid near said anode and a second control grid near said cathode, means for impressing alternating potential from said circuit upon said first grid, phase shifting means consisting of space charge coupling within said device for applying alternating potential from said circuit to said second grid substantially in phase quadrature to the potential upon said first grid, a source of variable potential arranged to control the bias of said second grid, and an output circuit operatively connected to said anode.

2. In combination, a circuit traversed by alternating current, an electron discharge device comprising a cathode and an anode, a first control grid near said anode, a second control grid near said cathode, and a screen grid at zero alternating potential arranged between said first and second control grids, means for impressing alternating potential from said circuit upon said first control grid, phase shifting means consisting of space charge coupling within said device for applying alternating potential from said cir-

cuit to said second control grid in substantially phase quadrature relation to the potential upon said first grid, a source of variable bias potential connected to said second grid, and an output circuit operatively connected to said anode.

3. A self-excited oscillator comprising an electron discharge tube having main input and output electrodes and a resonant oscillatory circuit coupled thereto in regenerative circuit arrangement to generate sustained electrical oscillations, at least one further control electrode within said tube effective in controlling the current in said circuit, phase shifting means consisting of space charge coupling within said tube for applying quadrature oscillating potential from said circuit to said control electrode to produce a quadrature oscillating current with respect to and superimposed upon the main oscillating current in said circuit, and a source of variable potential arranged to control said quadrature current to correspondingly vary the effective frequency of the oscillations produced.

4. A self-excited oscillator comprising an electron discharge tube having main input and output electrodes and a resonant oscillatory circuit coupled thereto in regenerative circuit arrangement to generate sustained electrical oscillations, at least one further control electrode within said tube effective in controlling the current in said oscillatory circuit, a screen grid at zero oscillating potential arranged to prevent direct reaction between the oscillator circuit and said control electrode, phase shifting means consisting of space charge coupling within said tube for impressing quadrature oscillating potential from said circuit to said control electrode to produce a quadrature oscillating current with respect to and superimposed upon the main oscillating current in said circuit, and a source of variable potential arranged to control said quadrature current to correspondingly vary the frequency of the oscillations produced.

5. A self-excited oscillator comprising an electron discharge tube having a cathode and an anode, a first control grid near said anode and a second control grid near said cathode, a resonant oscillatory circuit connected to said first grid and anode in regenerative circuit arrangement to generate sustained electrical oscillations, phase shifting means consisting of space charge coupling within said tube for impressing a phase-shifted oscillating potential from said circuit upon said second grid to produce a phase-shifted oscillating current with respect to and superimposed upon the main oscillating current in said circuit, said phase shift being of the order of ninety degrees, and a source of variable

potential arranged to control said phase-shifted current to correspondingly vary the effective frequency of the oscillations produced.

6. In combination, a circuit traversed by alternating current, an electron discharge device having a cathode and an anode, a pair of control grids in said device each being effective in controlling the space current to said anode, means for impressing alternating potential from said circuit upon one of said grids, solely space charge coupling within said device acting as phase shifting means for impressing alternating potential from said circuit upon the other of said grids in predetermined phase relation with respect to the potential upon said first grid to cause a phase-shifted current component with respect to and superimposed upon the main alternating current in said circuit, said phase shift being of the order of ninety degrees, a source of variable control potential arranged to control said phase-shifted component, and an output circuit operatively connected to said anode.

7. In combination, a circuit traversed by alternating current, an electron discharge device comprising a cathode, an anode and a pair of control grids each being effective in controlling the space current to said anode, a screen grid at zero alternating potential arranged between said control grids, means for impressing alternating potential from said circuit upon one of said control grids, solely space charge coupling within said device acting as phase shifting means for producing phase-shifted alternating potential upon the other of said grids to cause a phase-shifted current component with respect to and superimposed upon the main alternating current in said circuit, said phase shift being of the order of ninety degrees, a source of variable control potential arranged to control said phase-shifted component, and an output current operatively connected to said anode.

8. A self-excited oscillator comprising an electron discharge tube having a cathode, an anode, a first control grid near said anode, a second control grid near said cathode, a third control grid between said first and second control grids, and an acceleration grid between said second and third control grids, a resonant oscillatory circuit connected to said first control grid and anode in regenerative circuit relation to generate sustained electrical oscillations, means for impressing oscillating potential from said circuit to said second control grid, a substantially non-reactive impedance connecting said third control grid to said cathode, and a source of variable control potential connected to said second control grid.

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