Oct. 7, 1941.

K. RATH

2,258,470

ELECTRONIC REACTANCE DEVICE

Filed April 27, 1940

3 Sheets-Sheet 1

FIG. 1.

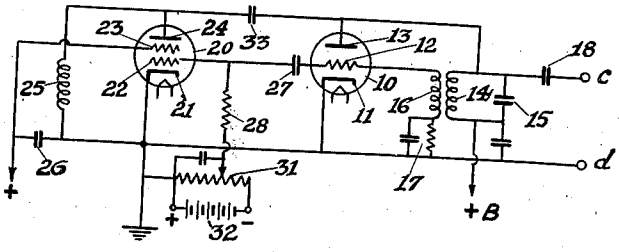


FIG. 2.

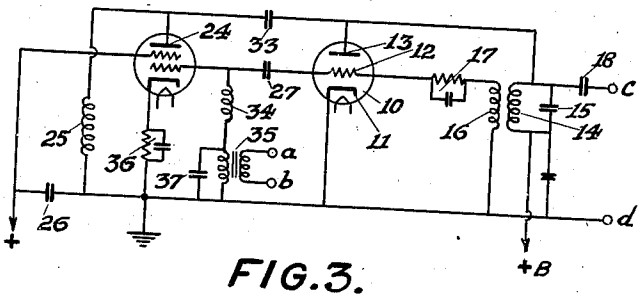


FIG. 3.

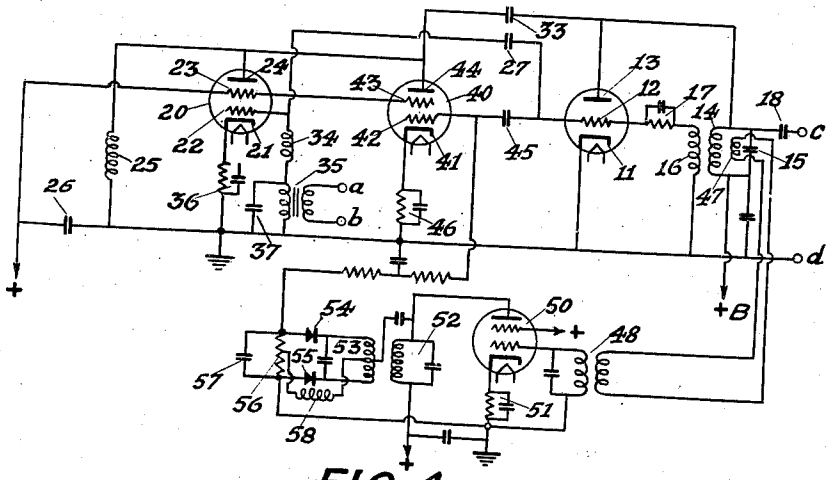
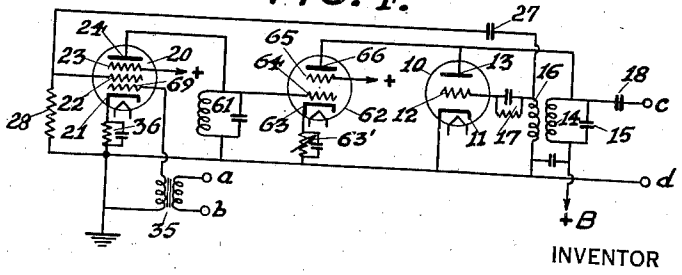


FIG. 4.



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FIG. 5.

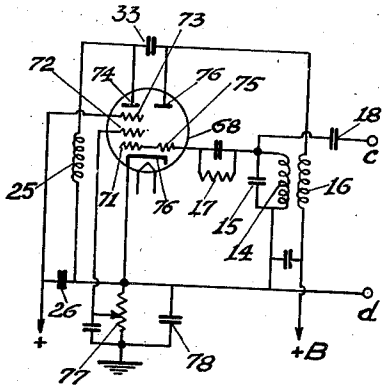


FIG. 6.

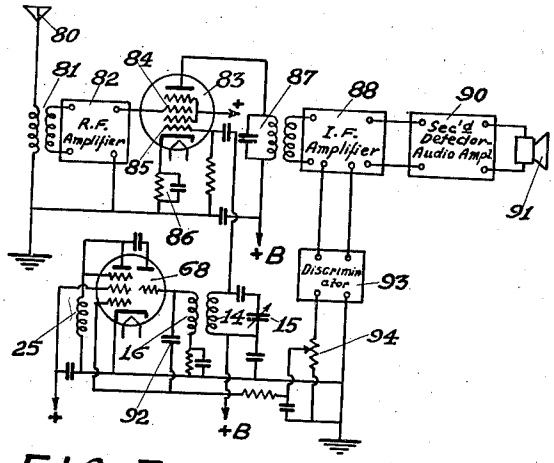


FIG. 7.

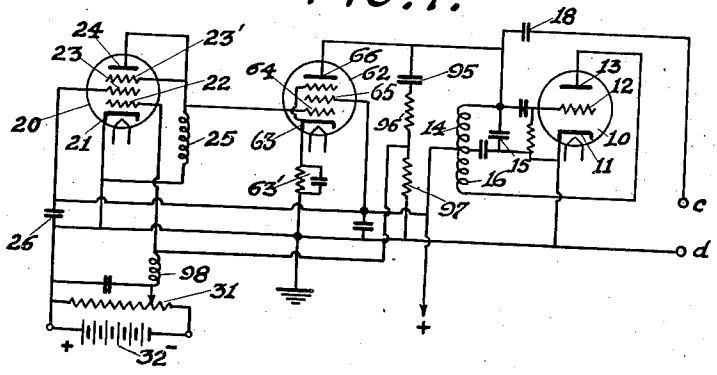


FIG. 8.

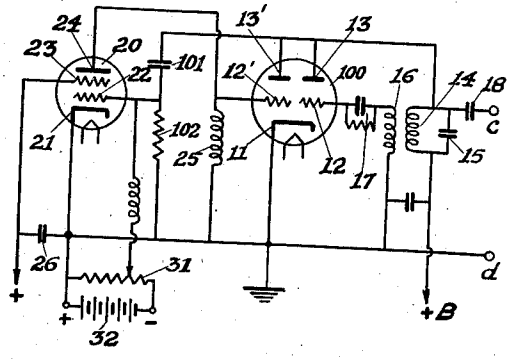
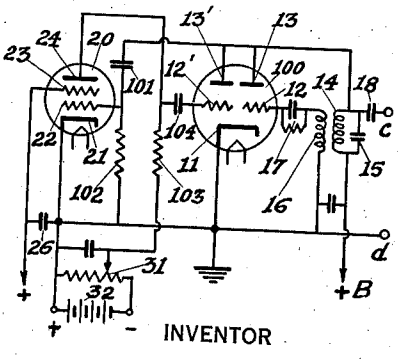


FIG. 9.



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FIG. 10.

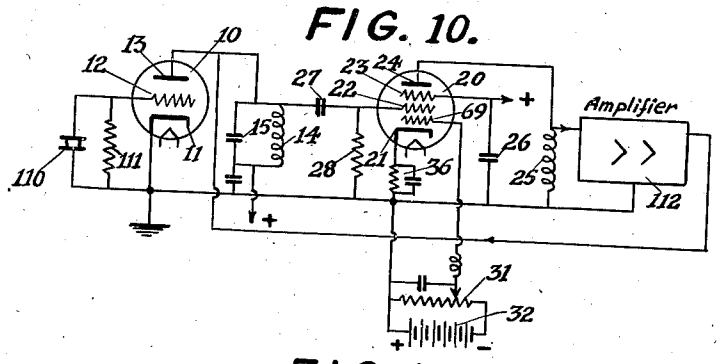


FIG. 11.

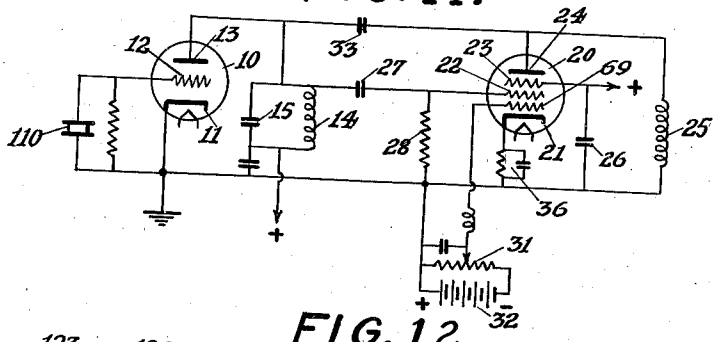


FIG. 12.

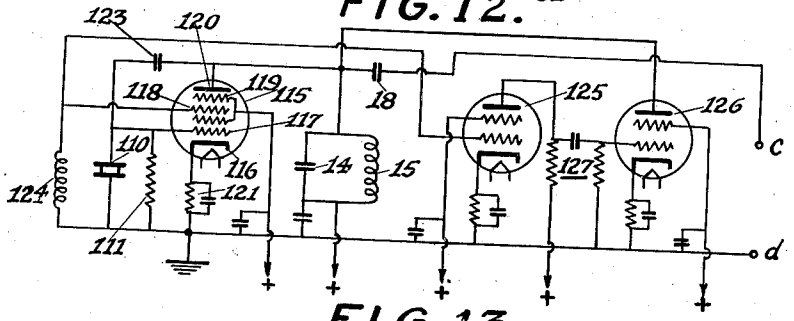
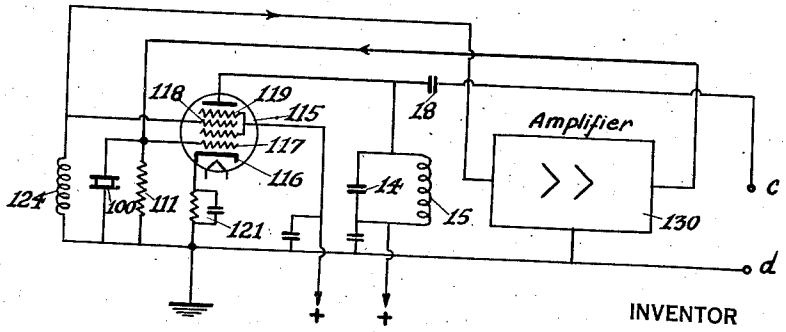


FIG. 13.



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Patented Oct. 7, 1941 2,258,470

UNITED STATES PATENT OFFICE

2,258,470

ELECTRONIC REACTANCE DEVICE

Karl Rath, New York, N. Y., assignor to Radio Patents Corporation, a corporation of New York

Application April 27, 1940, Serial No. 331,975

15 Claims. (Cl. 250—40)

The present invention relates to electronic reactance devices, more particularly for use in combination with oscillatory systems for controlling the tuning or oscillating frequency in dependence upon an electric controlling magnitude such as a current or potential.

An object of the invention is to utilize an electron discharge tube associated with an alternating current system such as an electron tube oscillator as a means for generating a reactive alternating potential or current which can be controlled easily and efficiently in accordance with an electric controlling magnitude applied to a grid or other control element of the tube to vary the effective reactance of said system such as for adjusting the tuning or oscillating frequency thereof.

A more specific object is to provide an electronic reactance tube for controlling the oscillating frequency of a regenerative electron tube oscillator so as to enable a control or modulation of the oscillating frequency over a substantial range in accordance with a controlling magnitude such as sound or other modulating signals comprising an extended band of component frequencies.

Further objects and advantages of the invention will become more apparent from the following detailed description taken with reference to the accompanying drawings forming part of this specification and wherein:

Figure 1 is a circuit diagram of a regenerative electron tube oscillator embodying a variable reactance tube in accordance with the invention for controlling the oscillating frequency,

Figure 2 shows an oscillator similar to Figure 1 for producing frequency modulated oscillations in accordance with the invention,

Figure 3 is a diagram of a frequency modulated oscillator similar to Figure 2 embodying further features for improving and stabilizing the operation according to the invention,

Figure 4 shows an improved oscillator circuit with electronic frequency control according to the invention,

Figure 5 shows an oscillator similar ot Figure 1 using a composite discharge tube including the oscillating and control unit,

Figure 6 shows a complete superheterodyne radio receiver in block diagram form embodying a local oscillator equipped with electronic frequency control for effecting automatic tuning adjustment of the receiver,

Figure 7 shows a diagram similar to Figure 4 embodying further features of improvement according to the invention,

Figures 8 and 9 illustrate further modifications of oscillating circuits equipped with electronic frequency control according to the invention,

Figures 10 and 11 are diagrams illustrating the invention as embodied in a piezo-electric crystal oscillator, and

Figures 12 and 13 are further modifications of oscillating systems of the type shown in Figures 4, 7, 10 and 11.

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

With the aforementioned objects in view, the invention in general involves the use of an electron discharge tube as a variable reactance or source of reactive alternating or oscillating current adjustable by varying a bias potential applied to the tube in any suitable manner. In the specific embodiment of controlling the oscillating frequency of a regenerative oscillator, the reactive potential or current produced by the control tube is injected into or impressed upon the oscillatory or tank circuit of an oscillator to vary the apparent reactance and accordingly the oscillating frequency in dependence upon a controlling electric magnitude such as a biasing current or potential.

For the above purpose the invention makes use of the effect of a variable space charge or virtual cathode brought about in an electron discharge tube between a first accelerating preferably grid-like electrode maintained at a relatively high positive steady potential with respect to the cathode or source of electrons and a further decelerating electrode located at the side of said accelerating electrode away from the cathode and maintained at a substantially lower potential with respect to the accelerating electrode. Thus, the first or accelerating electrode may be the screen grid of an electron tube of standard design maintained at a suitable positive steady potential with respect to the cathode, while the second or decelerating electrode may be the plate of the tube maintained at cathode D. C. potential or biased at a suitable negative potential with respect to the cathode in such a manner as to substantially prevent a steady electron current from being conveyed to said plate and to bring about a variable space charge or virtual cathode at a certain point between the screen grid and the plate. This space charge will have a density varying in accordance with the frequency of an input oscillating potential applied to a control grid or any other control element for the space current

passing through the tube. This oscillating space charge will produce by electrostatic induction a corresponding potential on the plate or any other output electrode. The induced output potential is displaced in phase by 90° relative to the space charge variations, that is, in turn to the impressed input potential applied to the control grid or other control element and will cause a reactive current to flow in an associated output or plate circuit for the tube. In other words, the space charge which takes the form of a concentrated sheath or electrons spaced at a predetermined distance from the plate constitutes an electrical condenser with the space charge or electron sheath forming one of the electrodes and the plate of the tube forming the cooperating electrode of the condenser.

The magnitude of the reactive or capacitative current according to the invention is controlled by varying the acceleration or deceleration of the electrons resulting in a varying distance of the electron sheath or virtual cathode from the plate and/or by adjusting the intensity of the electron or space discharge current in any suitable manner such as by means of a varying bias potential applied to a separate control grid or other control element or by varying the decelerating potential on the plate or other output electrode of the tube.

According to the present invention a variable reactance tube of the above type is excited by a potential derived from the oscillating current established in a resonant or oscillatory circuit such as the tank circuit of a regenerative electron tube oscillator and the reactive potential produced by virtue of the space charge or virtual cathode is injected into the oscillatory circuit in varying amounts determined by an electric controlling potential applied to the same or a separate control grid or other control element of the tube, thereby to vary the apparent reactance of the circuit and in the case of an oscillator the frequency of the oscillations produced.

Referring to Figure 1 of the drawings, there is shown a regenerative electron tube oscillator of standard design comprising an electron discharge tube 10, in the example shown a triode having a cathode 11, a control grid 12 and an anode or plate 13. The latter is connected to the positive pole of a suitable source of space current indicated at +B through an oscillating or tank circuit comprising an inductance coil 14 shunted by a condenser 15, and returned to ground or cathode through a by-pass condenser. The grid circuit of the tube includes a feedback or tickler coil 16 arranged in inductive coupling relation with the tank circuit inductance 14 and a biasing resistance 17 by-passed by a condenser. A circuit of this or any equivalent type known in the art will generate sustained electrical oscillations having a frequency equal to the tuning frequency to which the circuit 14—15 is resonant. The oscillations may be applied by way of a coupling condenser 18 to a suitable utilization circuit connected to terminals *c*—*d*.

There is further shown in Figure 1 in accordance with the present invention an electronic reactance tube 20 serving for adjusting the frequency of the oscillations produced and having in the example shown a cathode 21, a control grid 22, a positive or screen grid 23 forming an accelerating electrode, and a plate 24 forming the decelerating electrode of the tube. The latter is connected to the cathode through a high impedance such as a choke coil 25, whereby the steady plate potential is equal to that of the cathode which latter may be grounded in the usual manner. The screen grid 23 is connected to a suitable source of positive steady potential indicated by the plus sign in the diagram and grounded for high frequency current through by-pass condenser 26. The control grid 22 is excited by the oscillating frequency applied by way of a coupling condenser 27 connecting the grid 12 of the oscillating tube 10 to the grid 22 of the reactance tube 20 and a grid-leak resistance 28 connected between the grid 22 and cathode in series with a variable portion of an adjustable potentiometer resistance 31 shunted across a negative biasing source 32 for controlling the oscillating frequency.

There is produced between the positive (accelerating) grid 23 and the (decelerating) plate 24 of tube 20 a virtual cathode or sheath of electrons causing a reactive or quadrature potential at oscillating frequency to be induced on the plate 24 whose magnitude is determined by the bias potential on the control grid 22 adjustable by the aid of potentiometer 31. This reactive potential is fed to the oscillator or tank circuit 14—15 effectively shunted across the reactance tube 20 through coupling condenser 33. With an arrangement of this type it is possible, therefore, to adjust the frequency of the oscillations generated in the tank circuit 14—15 by varying the adjustment of the potentiometer resistance within a substantial range and in a most easy and efficient manner. The return impedance 25 between the plate 24 and cathode 22 of the reactance tube may be replaced by a high ohmic resistance or a resonant circuit tuned to the oscillating frequency and serves to cause a substantial amount of the reactive current to be injected into the oscillating circuit 14—15 and to establish and stabilize proper D. C. operating potential on the plate 24.

The reactance control or control of the induced capacitative potential on the plate 24 or equivalent output electrode may be effected in various other manners such as by adjusting the screen grid potential, by varying the cathode heating current or by controlling a negative decelerating potential applied to the plate as shown in Figure 9 to be described later.

Referring to Figure 2, there is shown an oscillator of the type of Figure 1 adapted for producing frequency modulated oscillations in accordance with sounds or other modulating signals. For this purpose, the control system 28, 31, 32 in Figure 1 is replaced by an audio frequency transformer 35 having its primary terminals *a*—*b* connected to a microphone circuit or any other modulating signal source and having its secondary connected between the grid 22 and ground in series with a choke coil 34. The latter together with a by-pass condenser 37 shunting the secondary of the transformer 35 serves to prevent high frequency current from entering the modulating circuit.

Referring to Figure 3, there is shown a frequency modulated oscillator similar to that according to Figure 2 embodying an additional reactance tube according to the invention for stabilizing and improving the operation of the system. Reactance tube 20 serves to frequency modulate the oscillations in the tank circuit 14—15 in substantially the same manner as in the case of Figure 2. According to the present improvement there is provided a further reactance tube 40 having a cathode 41, a control grid 42,

a positive or screen grid 43 and plate 44. The screen grid 43 of tube 40 in the example shown is directly connected to the screen grid 23 of tube 20 and the plate 44 is directly connected to the plate 24 of tube 20. If desirable, however, the screen grid and plate of tube 40 may be biased differently from the respective bias potentials for the tube 20 to suit existing requirements. The control grid 42 is excited by the oscillating frequency by way of a coupling condenser 45 in a manner similar to the excitation of grid 22 of tube 20. Item 46 is a biasing network in the cathode-to-ground lead to provide proper negative operating bias for the control grid 42 and the decelerating plate 44. In addition, the grid 42 is controlled by a bias potential having an amplitude varying proportionately to the departure of the carrier or center oscillating frequency from the resonant frequency of a tuned circuit resonant to the carrier frequency and embodied in a frequency sensitive or discriminator system of any suitable type known in the art.

In the example shown, there is derived for the latter purpose a fraction of the oscillating energy by means of coupling winding 47 arranged in inductive relation with the tank circuit inductance 14 and impressed upon the grid of a high frequency amplifier tube 50 by way of a tuned transformer 48, said tube being provided with a biasing network 51 inserted in its cathode-to-ground lead in accordance with known practice. The amplifier signals are impressed upon the primary tuned circuit 52 of a band-pass filter having a secondary tuned circuit 53. The latter is connected to a balanced rectifier comprising a pair of rectifying elements 54 and 55 and a load resistance 56 shunted by by-pass condenser 57. The center points of the load resistance 56 and the secondary winding of the band-pass filter are connected through a choke coil 58 and the center point of the secondary winding of the band-pass filter is further coupled to the high potential side of the primary 52 through a condenser or the like in such a manner that the sum and difference of the primary and secondary voltages of the band-pass filter are rectified and combined differentially, the differential potential having a magnitude representative of the departure of the oscillating frequency from the normal or carrier frequency to which the filter 52—53 is resonant. Dependent on the size of the smoothing condenser 57 the differential output potential of this frequency responsive or discriminating system established between the high potential side of the resistor 56 and ground and impressed upon the control grid 42 of the reactance tube 40 will vary according to the frequency variation caused by the modulating signal or alternatively, if condenser 57 is of sufficiently high capacity, the variations will follow only relatively slow or progressive variations or drift of the carrier or center frequency falling outside the range of the modulating frequencies. In the former case the arrangement may be such that additional frequency modulation is produced by the tube 40 in a sense opposite to the modulation effected by tube 20 thereby causing inverse feedback resulting in reduced distortion and improved operational stability of the system. This is especially advisable if the oscillator is followed by a number of succeeding circuits such as power amplifiers and limiting devices, etc., preceding the final utilization circuit such as a transmitting antenna or the like. In this case, the fractional energy energizing the discriminator circuit is preferably derived from the ultimate end of the system such as the antenna circuit in which case distortions introduced in the train of any of the circuits between the master oscillator and the final utilization circuit may be minimized or substantially suppressed by the action of the inverse feedback system.

Alternatively, the system according to Figure 3, when using a smoothing condenser 57 of sufficient capacity, and by proper design of any additional filter elements arranged between the discriminator and the control tube, may serve to compensate relatively slow and progressive variations or drift of a carrier frequency only such as due to ambient temperature changes or the like resulting in a highly constant and stable carrier frequency which latter constitutes one of the pre-requisites to ensure dependable and efficient frequency modulation in practice. As is understood any other frequency demodulator or discriminator system may be employed in a system according to Figure 3, such as a frequency responsive circuit described in my co-pending patent applications Serial No. 318,972 filed February 14, 1940, and Serial No. 328,006 filed April 5, 1940, entitled "Frequency variation response circuit" and "Frequency sensitive system," respectively.

Referring to Figure 4, there is shown a further exemplification of an oscillator embodying electronic frequency control in accordance with the invention. According to this embodiment there is provided a high gain amplifying tube 62 having in the example shown a cathode 63, a control grid 64, a screen grid 65 and a plate 66 and being provided with a grid biasing network 63' inserted in the cathode-to-ground lead. This tube serving as an amplifier is effectively shunted across the oscillator tank circuit 14—15 and has its grid directly connected to the plate 24 of the reactance tube 20. The plate 24 is returned to ground in the example shown through a tuned circuit 61 replacing the choke coil 55 in the previous illustrations. The circuit 61 is preferably tuned to the same frequency as the tank circuit 14—15 but may be replaced by a choke coil or any other high impedance as will be understood. In an arrangement according to Figure 4, the reactive potential produced at the plate of the control tube 20 is efficiently amplified to produce a corresponding amplified current injected or forced into the tank circuit 14—15 to vary the apparent reactance and in turn the oscillating frequency in a manner substantially similar to that described hereinabove. Since the tube 62 constitutes a phase reversing device, this system will provide a varying apparent inductance injected into the tank circuit 14—15 as compared with the previous illustrations wherein the injected apparent reactance is of a capacitative nature. Figure 4 further differs from the preceding figures by the employment of a separate control grid 69 adjacent to the cathode 21 energized by the modulating or frequency adjusting potential resulting in improved operation and additional advantages desirable in special cases. In Figure 4 the reactance or frequency control may be effected in the manner shown by controlling tube 20 in a suitable manner to bring about a variation of the characteristic or density of the space charge or virtual cathode in the manner described hereinabove. Alternatively, a control may be effected by adjusting the gain or output of the tube 62 in any known manner by a grid bias control or the like. In the example

shown this is indicated by making the bias resistor 63' in the cathode lead variable to control the output current injected into the tank circuit 14—15 and to correspondingly vary the apparent inductance, i. e. in turn the oscillating frequency.

Referring to Figure 5, there is shown a circuit similar to Figure 1 employing a single composite electron tube comprising a common cathode 76, a first section having an input grid 71, a control grid 72, a screen grid 73 and a plate 74 serving as a variable reactance and a second oscillating section comprising a control grid 75 and a plate 76. The control grids 71 and 75 are directly connected and the oscillating frequency is controlled by varying the bias resistor 77 connected in the cathode-to-ground lead and shunted by a by-pass condenser 78.

Referring to Figure 6, there is shown a block diagram for a superheterodyne radio receiver embodying an adjustable oscillator according to the invention for effecting automatic tuning control. Radio signals received by the antenna 80 are impressed upon a radio frequency amplifier 82 by way of input transformer 81. The amplified radio frequency signals are applied to the input or injector grid 84 of an electronic mixer tube 83 of known design having a further control grid 85 excited by the local oscillating signals and being provided with a biasing network 86 in the cathode-to-ground lead. The intermediate frequency signals produced by combining the input signals with the local oscillating signals are transmitted by way of a resonant output circuit 87 to an intermediate frequency amplifier 88 for selective and efficient amplification. The amplified intermediate frequency signals are then applied to a second detector and audio frequency amplifier 90 feeding a suitable translating device such as a loud speaker 91.

A fraction of the intermediate frequency energy is applied to a discriminator 93 of any known type such as shown in Figure 3 adapted to produce an electric potential across a voltage divider 94 whose magnitude varies proportionately to the frequency departure of the intermediate signal frequency from the fixed tuning frequency of the intermediate frequency amplifier for which the receiver is designed. This discriminating potential is impressed upon the control grid of the reactance control section of a composite oscillator and control tube 68 of substantially the same type as shown in Figure 5. In this manner the local oscillating frequency generated in the tank circuit 14—15 and impressed upon the oscillating grid 85 of the mixer tube 83 will be automatically adjusted to its proper value to result in an intermediate signal frequency substantially coinciding with the center of the frequency response or resonance curve of the intermediate frequency amplifier in a manner known in automatic tuning systems for radio receivers.

Referring to Figure 7 there is shown as oscillating circuit of the type according to Figure 4 using a pair of pentode tubes 20 and 62, the former serving as a source of variable reactive potential in accordance with the invention and the latter serving as a high gain amplifier for the reactive or tuning potential to be injected into the oscillating circuit 14—15. The suppressor grid 23' of the control tube is preferably tied to the plate as shown, but if desired may be connected to the cathode in the usual manner as in the case of the amplifier 62. The control grid 22 of the reactance tube is excited from the oscillator by way of a voltage divider comprising a condenser 95 and a pair of resistors 96 and 97 in series and effectively shunted across the tank circuit 14—15, the grid 22 being connected to the junction between the resistors 96 and 97. The control grid 22 is further negatively biased by the source 32 in conjunction with potentiometer 31, a choke coil 98 being provided in the bias lead to block high frequency potential from the biasing or other control source.

According to experiments conducted by applicant with a system shown in Figure 7, a frequency shift over a range of about 40 k. c. was obtained by varying the bias potential on the control grid 22 from 0 to about —6 volts thus making this system well suited for directly obtaining wide band frequency modulations without requiring a prohibitive amount of frequency doubling stages necessary in systems known and at present employed in the art.

Referring to Figure 8, there is shown another modification of a regenerative oscillator embodying electronic frequency control according to the invention. According to this embodiment, the oscillator comprises a pair of electron discharge paths arranged in parallel comprised, in the example shown, of a double triode 100 having a common cathode 11, control grids 12 and 12' and plates 13 and 13', respectively. The plates of both sections are connected together and to the tank circuit in the manner described previously. The control grid 12 of one triode section is regeneratively coupled with the oscillating circuit to provide regenerative control potential for maintaining the oscillations, while the grid 12' is excited by the reactive control potential produced on the plate of the control tube 20 to provide adjustable reactive current injected into the tank circuit for controlling the oscillating frequency. The control grid 22 of the reactance tube 20 is excited by the oscillating frequency by way of a potential divider comprising a relatively large condenser 101 and a resistance 102 and is additionaly biased by the frequency control source, such as a D. C. source 32 and adjustable potentiometer 21 or a source of modulating currents in the manner understood from the above.

Referring to Figure 9, there is shown a circuit substantially similar to Figure 8, but differing from the latter by the provision of a negative biasing source 32 and associate potentiometer 31 for varying the negative or decelerating potential on the plate 24 to control the induced reactive potential on the plate and in turn the oscillating frequency in accordance with the invention. In this embodiment the choke coil 25 returning the plate of the reactance tube to the cathode is replaced by an ohmic resistance and the reactive potential is applied to the grid 12' of the tube 100 by way of a relatively large coupling condenser 104.

Figure 10 shows a further exemplification of the invention embodied in a piezo-electric crystal oscillator comprising oscillating tube 10, plate tank circuit 14—15 and a piezo-electric crystal element 110 and grid-leak resistance connected between the grid 12 and cathode 11 in accordance with standard circuits of this type. The phase shifting or reactor tube 20 is excited by the oscillating potential in the manner described previously and the quadrature potential amplified by an amplifier 112 of any suitable design. The amplified reactive or quadrature current is impressed upon or injected into the plate circuit of

the oscillator as shown. Alternatively, amplified potentials obtained at the output of the amplifier 112 may be impressed upon the grid circuit of the oscillator tube in a manner well understood. By an arrangement of this type the oscillating frequency and/or phase of the oscillations maintained in the circuit 14—15 may be controlled by adjusting the potentiometer 31 or in accordance with variations of modulating signal energy derived from a microphone circuit or the like and impressed upon the control grid 69 of the phase shifting tube 20. Alternatively, frequency and/or phase control may be effected by varying the gain of the amplifier 112 in any suitable manner, thereby controlling the amplitude of reactive current or potential impressed upon the plate or grid circuit, respectively, of the oscillator.

Figure 11 shows a system similar to Figure 10 wherein the amplifier 112 is omitted and the quadrature potential induced on the plate 24 of the reactor tube 20 is impressed directly upon the plate tank circuit 14—15 of the oscillator by way of a coupling condenser 33 in a manner similar to that shown in previous illustrations.

Referring to Figure 12 there is shown a further modification of the invention embodying a combined oscillator and phase shifting tube 115 having a cathode 116, oscillating control grid 117, accelerating or screen grid 119, a decelerating grid 118 and a plate 120. Item 121 is a standard biasing network in the cathode-to-ground lead. A piezo-electric crystal 110 and grid-leak resistance 111 are connected between the oscillating grid and ground similar as shown in Figures 10 and 11. In order to maintain oscillations in the plate circuit 14—15 a separate feedback is provided in the form of a condenser 123 connecting the plate 120 with the grid 117. The decelerating grid 118 is returned to ground through a choke coil 124, whereby a quadrature potention at oscillating frequency will be induced upon this grid by the virtual cathode or variable space charge brought about by the action of the accelerating or screen grid 119. The quadrature potential induced on the grid 118 is directly applied to the input of a two-stage resistance coupled amplifier of known design comprising an input tube 125 and an output tube 126 inter-coupled by means of a resistance coupling network 127 of known design. The amplified quadrature current is impressed upon or injected into the plate circuit of the oscillator to correspondingly vary the oscillating frequency in a manner understood from the above. The frequency control may be effected by varying the gain of the amplifier 125—126 in any known manner such as by grid-bias control of one or more amplifying stages. Depending on the number of amplifying stages used, it is possible to cause the reactive current impressed upon the oscillating circuit to be either leading or lagging, thus varying the apparent capacity or inductance of the circuit as may be desired. Any other type of amplifier may be employed which is substantially free from causing undesirable additional phase shift or any spurious phase shift caused in the amplifier or associate circuit may be neutralized by suitable compensating means well known.

As is understood, this modification of the invention is not limited to a crystal oscillator but applies with equal advantage to any type of oscillator such as a standard oscillator as shown in the previous illustrations.

Referring to Figure 13, there is shown a modification of Figure 12 wherein the amplified quadrature potential obtained at the output of the amplifier 130 is impressed upon the grid circuit of the oscillating tube 115.

Although the oscillatory circuit 14—15 in the examples shown is self-excited by the regenerative action of the oscillator tube, it is understood in accordance with the spirit of the invention and as coming within the scope thereof that the circuit 14—15 may be energized from an outside source having a fixed and constant frequency in which case the tuning adjustment of the circuit may be varied by electronic control arrangements of the type shown or the phase of the oscillations set up in the circuit by the outside source may be adjusted or controlled to produce phase modulated oscillations in accordance with variations of a modulating signal. A system of this type is obtained for instance with reference to Figure 10 by omission of the tube 10 and its associated grid circuit 110—111 and space current source and by exciting the circuit 14—15 from an outside source such as a separate master oscillator. In this case the tuning of the circuit and/or the phase of the oscillatory currents set up therein by the exciting source may be adjusted or controlled by varying the bias on the grid 69 or the gain of the amplifier 112 in a manner understood from the above to produce phase modulated oscillations or for any other purpose desired.

It will be evident from the foregoing that the invention is not limited to the specific details, arrangements of parts and circuits shown and disclosed herein for illustration, but that numerous modifications and variations will suggest themselves to those skilled in the art employing the principle of and coming within the broader scope of the invention as defined by the appended claims. The specification and drawings are accordingly to be regarded in an illustrative rather than in a limiting sense.

I claim:

1. An electric system comprising a circuit traversed by an alternating current, an electron discharge tube having at least a cathode, an accelerating electrode, and a decelerating electrode arranged to bring about a concentrated electron space charge adjacent to said decelerating electrode, means including circuit connections from said circuit to said tube for varying the electron space current of said tube in accordance with said alternating current, and coupling means between said decelerating electrode and said circuit to introduce quadrature voltage induced upon said decelerating electrode by said space charge into said circuit.

2. An electric system comprising a circuit traversed by an alternating current, an electron discharge tube having at least a cathode, an accelerating electrode and a decelerating electrode arranged to produce a concentrated electron space charge adjacent to said decelerating electrode, means including circuit connections from said circuit to said tube for varying the electron space current of said tube in accordance with said alternating current, coupling means between said decelerating electrode and said circuit to inject quadrature voltage induced upon said decelerating electrode by said space charge into said circuit, a source of biasing potential, and means for controlling the injected quadrature voltage in accordance with said biasing potential to correspondingly vary the effective reactance of said circuit.

3. An electric system comprising a resonant

circuit traversed by an alternating current, an electron discharge tube having at least a cathode, an accelerating electrode and a decelerating electrode arranged to produce a concentrated electron space charge adjacent to said decelerating electrode, means including circuit connections from said resonant circuit to said tube for varying the electron space current of said tube in accordance with said alternating current, coupling means between said decelerating electrode and said resonant circuit to inject quadrature voltage induced upon said decelerating electrode by said space charge into said resonant circuit, a source of bias potential, and means for controlling the injected quadrature voltage in accordance with said bias potential to correspondingly vary the effective tuning of said circuit.

4. An electric system comprising a parallel tuned resonant circuit traversed by an alternating current, an electron discharge tube having at least a cathode, a control electrode, an accelerating electrode and a decelerating electrode arranged in the order named to produce a concentrated electron space charge adjacent to said decelerating electrode, circuit connections from said resonant circuit to said control electrode for varying the electron space current of said tube in accordance with said alternating current, coupling means between said decelerating electrode and said resonant circuit to develop quadrature voltage induced upon said decelerating electrode by said space charge across said resonant circuit, a source of bias potential, and means including circuit connections from said source to said tube for controlling the developed quadrature voltage in accordance with said bias potential to correspondingly vary the effective tuning of said circuit.

5. An electric system comprising a circuit traversed by an alternating current, an electron discharge tube having a cathode, a control grid, a screen grid, and a plate arranged in the order named, means for maintaining said screen grid at a positive potential with respect to said cathode, further means for maintaining said plate at a substantially negative potential with respect to said screen grid to produce a concentrated electron space charge adjacent to said plate, coupling connections from said circuit to said control grid to vary the electron space current of said tube in accordance with said alternating current, and coupling means between said plate and said circuit to introduce quadrature voltage induced upon said plate by said space charge into said circuit.

6. An electric system comprising a circuit traversed by an alternating current, an electron discharge tube comprising a cathode, a control grid, a screen grid and plate arranged in the order named, means for maintaining said screen grid at a positive potential with respect to said cathode, further means for maintaining said plate at a substantially negative potential with respect to said screen grid to produce a concentrated electron space charge adjacent to said plate, circuit connections from said circuit to said control grid for varying the electron space current of said tube in accordance with said alternating current, coupling means between said plate and said circuit to introduce quadrature voltage induced upon said plate by said space charge into said circuit, a source of bias potential, and means including circuit connections from said source to said tube for controlling the effectiveness of said space charge in accordance with said bias potential to correspondingly vary the effective reactance of said circuit.

7. An electric system comprising a resonant circuit traversed by an alternating current, an electron discharge tube comprising a cathode, a control grid, a screen grid and a plate arranged in the order named, means for maintaining said screen grid at a positive potential with respect to said cathode, further means for maintaining said plate at a substantially negative potential with respect to said screen grid to produce a concentrated electron space charge adjacent to said plate, circuit connections from said resonant circuit to said control grid for varying the electron space current of said tube in accordance with said alternating current, coupling means between said plate and said resonant circuit to develop quadrature voltage induced upon said plate by said space charge across said resonant circuit, a source of bias potential, and means including circuit connections from said source to said tube for controlling the effectiveness of said space charge in accordance with said bias potential to correspondingly vary the effective tuning of said resonant circuit.

8. An electric system comprising a parallel tuned resonant circuit traversed by an alternating current, an electron discharge tube comprising a cathode, a control grid, a screen grid and a plate, means for maintaining said screen grid at a positive potential with respect to said cathode, further means for maintaining said plate at a substantially negative potential with respect to said screen grid to produce a concentrated electron space charge adjacent to said plate, circuit connections from said resonant circuit to said control grid for varying the electron space current of said tube in accordance with said alternating current, coupling means between said plate and said resonant circuit to develop quadrature voltage induced upon said plate by said space charge across said resonant circuit, a source of bias potential, and means including circuit connections from said source to said tube for controlling the effectiveness of said space charge in accordance with said bias potential to correspondingly vary the effective tuning of said resonant circuit.

9. An electric system comprising a circuit traversed by an alternating current, an electron discharge tube comprising a cathode, a control grid, a screen grid and a plate arranged in the order named, means for maintaining said screen grid at a positive potential with respect to said cathode, further means for maintaining said plate at a substantially negative potential with respect to said screen grid to produce a concentrated electron space charge adjacent to said plate, circuit connections from said circuit to said control grid for varying the electron space current of said tube in accordance with said alternating current, coupling means between said plate and said circuit to inject quadrature voltage induced upon said plate by said space charge into said circuit, a source of bias potential, a connection from said source to said control grid for controlling the effectiveness of said space charge in accordance with said bias potential to correspondingly vary the effective reactance of said circuit.

10. An electric system comprising a circuit traversed by an alternating current, an electron discharge tube comprising a cathode, a screen grid and a plate arranged in the order named, means for maintaining said screen grid at a posi-

tive potential with respect to said cathode, further means for maintaining said plate at a substantially negative potential with respect to said screen grid to substantially prevent a steady electron current flow to said plate and to produce a concentrated electron space charge adjacent to said plate, means including circuit connections from said circuit to said tube for varying the electron space current of said tube in accordance with said alternating current, coupling means between said plate and said circuit to inject quadrature voltage induced upon said plate by said space charge into said circuit, a source of bias potential, and means for controlling the injected quadrature voltage to correspondingly vary the effective reactance of said circuit.

11. An electric system comprising a circuit traversed by an alternating current, an electron discharge tube comprising a cathode, a control grid, a screen grid and a plate arranged in the order named, means for maintaining said screen grid at a positive potential with respect to said cathode, further means for maintaining said plate at a substantially negative potential with respect to said screen grid to substantially prevent a steady electron current flow to said plate and to produce a concentrated electron space charge adjacent to said plate, circuit connections from said circuit to said control grid for varying the electron space current of said tube in accordance with said alternating current, coupling means between said plate and said circuit to inject quadrature voltage induced upon said plate by said space charge into said circuit, a source of biasing potential, connections from said source to said control grid for controlling the effectiveness of said space charge in accordance with said biasing potential to correspondingly vary the effective reactance of said circuit.

12. In a system for producing oscillations comprising a discharge device and an oscillatory circuit connected to said device to maintain sustained electrical oscillations in said circuit at a frequency determined by the tuning frequency of said circuit, means for controlling the oscillations comprising an electron discharge tube having a cathode, an accelerating electrode and a decelerating electrode, means for maintaining said accelerating and said decelerating electrode at relatively positive and negative potentials to produce a concentrated electron space charge adjacent to said decelerating electrode, means including circuit connections from said oscillatory circuit to said tube for varying the electron space current of said tube in accordance with the oscillations produced, coupling means between said decelerating electrode and said oscillatory circuit for injecting quadrature oscillating potential induced upon said decelerating electrode by said space charge into said oscillatory circuit, a source of bias potential, and means for controlling the injected quadrature potential in accordance with said bias potential to correspondingly vary the frequency of the oscillations produced.

13. In a system for producing oscillations comprising a discharge device and an oscillatory circuit connected to said device to maintain sustained electrical oscillations in said circuit at a frequency determined by the tuning frequency of said circuit, means for controlling the oscillations comprising an electron discharge tube having a cathode, a control grid, a screen grid and a plate arranged in the order named, means for maintaining said screen grid at a positive potential with respect to said cathode, further means for maintaining said plate at a substantially negative potential with respect to said screen grid to produce a concentrated electron space charge adjacent to said plate, circuit connections from said oscillatory circuit to said control grid for varying the electron space current of said tube in accordance with the oscillations produced, coupling means between said plate and said oscillatory circuit to inject quadrature oscillating voltage induced upon said plate by said space charge into said oscillatory circuit, a source of bias potential, and circuit connections from said source to said tube for controlling the effectiveness of said space charge to correspondingly vary the frequency of the oscillations produced.

14. An electric system comprising a circuit traversed by an alternating current, an electron discharge tube having a cathode, an accelerating electrode and a decelerating electrode to produce a concentrated electron space charge adjacent to said decelerating electrode, means including coupling connections from said circuit to said tube for varying the electron space current of said tube in accordance with said alternating current, and coupling means including a phase reversing device between said decelerating electrode to said circuit to inject quadrature voltage induced upon said decelerating electrode by said space charge into said circuit.

15. An electric system comprising a circuit traversed by an alternating current, an electron discharge tube having a cathode, an accelerating electrode and a decelerating electrode to produce a concentrated electron space charge adjacent to said decelerating electrode, means including circuit connections from said circuit to said tube for varying the electron space current of said tube in accordance with said alternating current, coupling means including a phase reversing discharge tube between said decelerating electrode and said circuit to inject quadrature voltage induced upon said decelerating electrode by said space charge into said circuit, a source of variable bias potential, and means for controlling the injected quadrature voltage in accordance with said bias potential to correspondingly vary the effective reactance of said circuit.

KARL RATH.