June 12, 1945. K. RATH 2,378,245

VARIABLE FREQUENCY OSCILLATOR

Filed March 17, 1942 2 Sheets-Sheet 1

Fig. 1

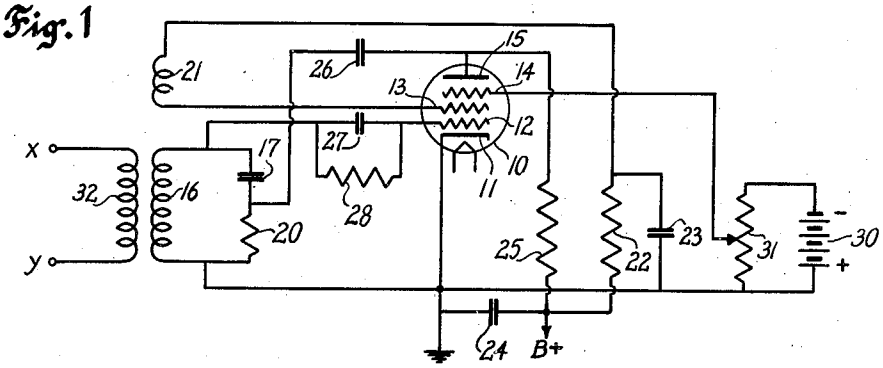


Fig. 2

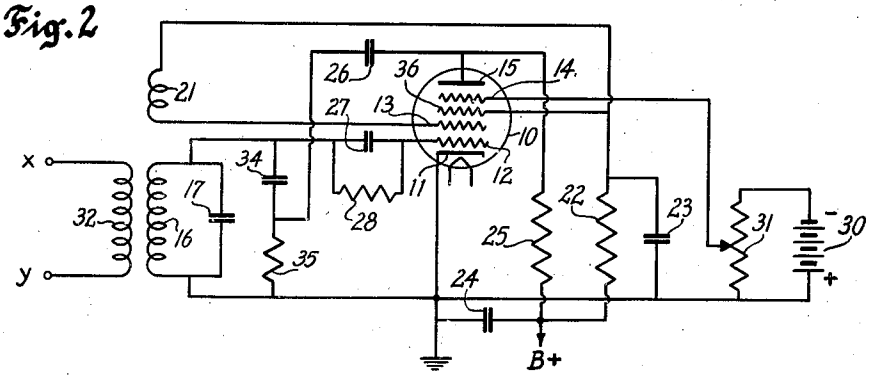


Fig. 3

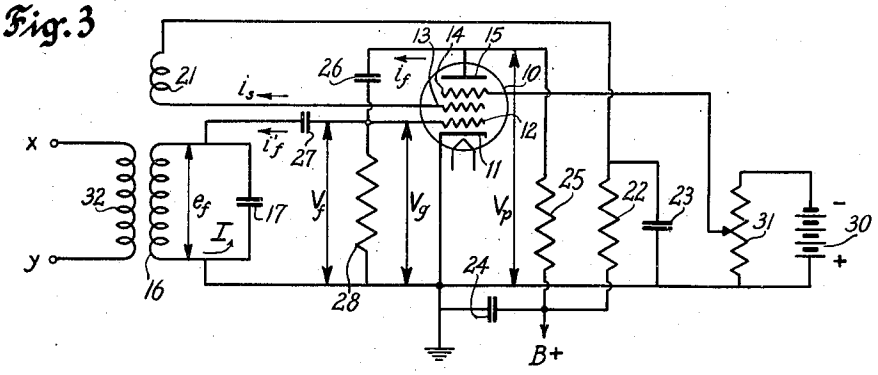
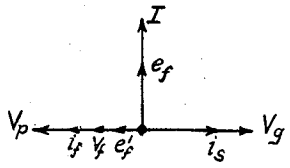


Fig. 4



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June 12, 1945. K. RATH 2,378,245

VARIABLE FREQUENCY OSCILLATOR

Filed March 17, 1942 2 Sheets-Sheet 2

Fig. 5

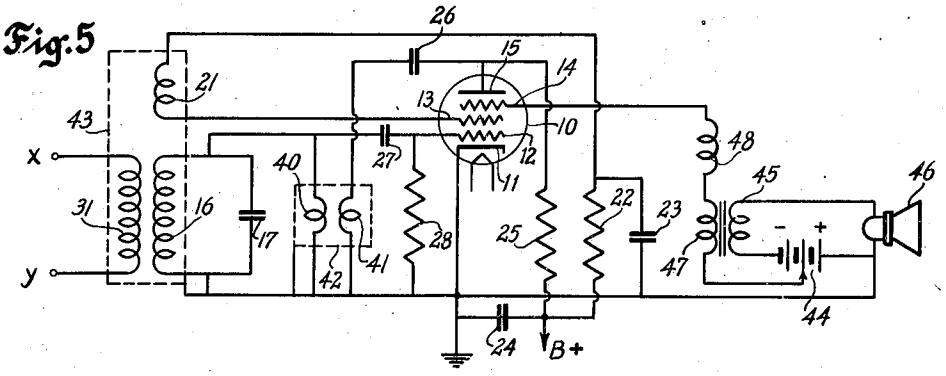


Fig. 6

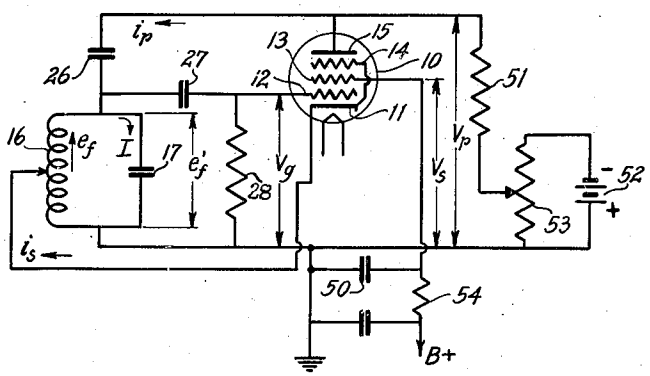


Fig. 8

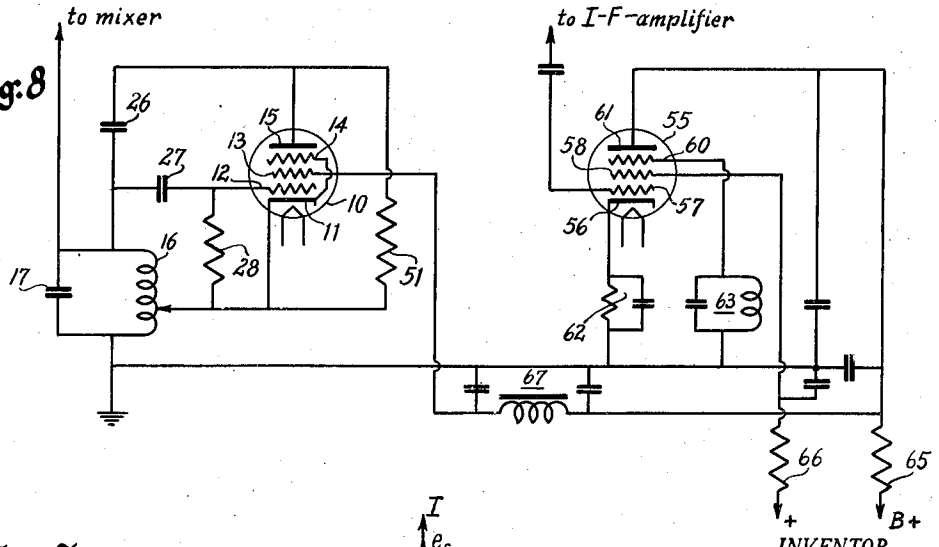
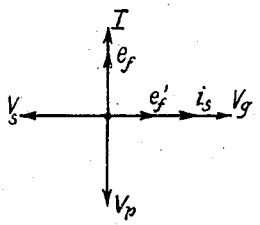


Fig. 7



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UNITED STATES PATENT OFFICE

2,378,245

VARIABLE FREQUENCY OSCILLATOR

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Application March 17, 1942, Serial No. 435,037

6 Claims. (Cl. 250—36)

The present invention relates to electrical oscillators for radio and other purposes and methods of operating same, more particularly to a single tube frequency controlled oscillator wherein the oscillating frequency may be varied or modulated in an easy and efficient manner in accordance with an electrical bias potential or modulating signal applied to the tube.

An object of the invention is therefore to provide an oscillator utilizing a single electron discharge tube as a means both for the maintenance of sustained oscillations and to provide a controllable reactive impedance for varying the effective oscillating frequency in a purely electrical manner by controlling a bias potential or current effecting said tube.

Another object is to provide a regenerative electron tube oscillator wherein at least a portion of the total cathode current serves to provide an adjustable reactive component governed by a separate biasing or modulating potential and fed back upon the oscillatory circuit for the control of the oscillating frequency.

There has been in the past a wide usage of circuits embodying a separate reactance control tube capable of controlling or varying the resonant frequency of the oscillatory or tank circuit of a high frequency generator in a purely electrical manner by varying a bias potential applied to said tube. Thus, in automatic frequency control systems commonly used in superheterodyne 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 tuning detector or frequency responsive discriminator. Likewise, in the field of phase or frequency modulation the problem arises of modulating the frequency of a self-excited oscillator or the phase of an oscillator in accordance with the amplitude changes of an audio or other modulating signal wave.

A further use exists in the automatic stabilization of the carrier or center frequency of any type of radio transmitter to be held within specified limits with respect to an assigned value.

In these and other cases in the art, a special reactance control tube is used which in fact constitutes an amplifier excited by a quadrature potential derived from the currents flowing in the circuit to be controlled and supplying an amplified quadrature voltage which is impressed upon the circuit to vary its effective or virtual reactance and in turn the frequency or phase of the oscillations produced. The amount of reactive or quadrature current impressed upon the resonant circuit is varied by controlling the transconductance of the reactance tube by means of an electric bias potential applied to a suitable control element of the tube, causing thereby a variation of the apparent reactance of the oscillatory circuit and in turn a change of the frequency or phase of the oscillations produced.

The present invention purports to provide a new and improved frequency controlled oscillator of the above general type utilizing a single electron discharge tube both for the maintenance of sustained oscillations and as a means to supply a variable reactance for the control of the oscillating frequency within substantial limits in accordance with a biasing or modulating current or potential.

Another object of the invention is to provide an oscillator-modulator which is simple in design and requires a minimum of parts and circuit elements and accordingly is especially suited for small and portable phase or frequency modulated transmitters.

Still another object is to provide a frequency controlled regenerative oscillator, wherein a single electron discharge tube is used to perform the function of oscillator tuning reactance and phase shifting means to provide a reactance effect for the control of the oscillating frequency.

The above and further objects of my 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 schematic diagram of a single tube frequency modulated oscillator embodying the principles of the invention; Figure 2 is a diagram showing a modification of Figure 1; Figure 3 is a diagram showing a further modification of an oscillator embodying the invention; Figure 4 is a vector diagram explanatory of the function of the circuit shown in Figure 3; Figures 5 and 6 are circuit diagrams illustrating still further modifications of the invention; Figure 7 is a vector diagram explanatory of the function of the circuit shown in Figure 6; and Figure 8 is a diagram illustrative of an automatic frequency control system for use in radio receiving circuits embodying the principles of the invention. Like reference characters identify like parts throughout the different views of the drawings.

With the aforementioned objects in view, the invention contemplates the use of an electron discharge tube having at least two output electrodes such as the screen and plate in a normal pentode, an oscillatory circuit connected to an input or

any other electrode, and separate feedback circuit means from both output circuits to said oscillatory circuit. At least one of said feedback circuits is caused to supply a reactive current component impressed upon said oscillatory circuit to determine the frequency of the oscillations produced. Further means are provided to control at least the feedback current including or constituting the reactive or quadrature feedback in accordance with a bias or modulated potential applied to a further control element of the tube. In one embodiment the frequency control element may be the suppressor grid in a pentode of normal design, resulting in a varying distribution of the total cathode current between the screen and plate output electrodes and a corresponding variation of the amount of reactive feedback and in turn of the oscillating frequency.

Referring to Figure 1, I have shown a schematic diagram for single tube frequency controlled regenerative oscillator embodying the principles of the invention. The latter comprises an electron discharge tube **10**, in the example shown of the normal pentode type provided with a cathode **11** which may be of either the directly heated or equi-potential type, a first control grid **12**, a screen grid **13**, a suppressor grid **14** used as a second (frequency) control grid, and an anode or plate **15**—all arranged substantially in the order named with respect to the cathode. An oscillatory tank circuit comprising an inductance **16** shunted by a capacity **17**, the latter having a resistance **20** connected in series therewith, is connected to the cathode **11** and the control grid **12** and sustained electrical oscillations are maintained therein by supplying suitable feedback voltage from the screen grid serving as an output electrode by the provision of feedback or tickler coil **21** inserted in the screen grid circuit and arranged in inductive coupling relation with the tank circuit inductance **16**. The screen grid is connected to the positive pole marked B+ of a suitable high tension supply source in series with a voltage drop resistance **22** and associate ground or cathode by-pass condensers **23** and **24** for the high frequency currents. In a circuit of this type, the control grid **12**, screen grid **13** and associated circuits constitute a regenerative or feedback oscillator of known type, the details of which may be varied as will be understood by those skilled in the art. The plate **15** is supplied with operating voltage from the source B+ through a load impedance, preferably a resistance **25** which serves to develop oscillating voltage therebetween and cathode by electron coupling with the oscillator circuit associated with grids **12** and **13** in a manner well understood. The plate voltage developed is fed back upon the tank circuit **16**, **17**, **20** by directly connecting the plate **15** to the junction point between the tank circuit condenser **17** and series resistance **20** through a blocking condenser **26**. As will appear from the following, a reactive or quadrature voltage will be developed in this manner in the oscillatory circuit, resulting in a corresponding variation of the oscillating frequency. Items **27** and **28** indicate the usual self-biasing grid condenser and leak resistance to provide a suitable grid operating bias potential for the oscillator circuit. The amount of reactive feedback voltage is controlled by varying the bias of the suppressor grid **14** in any suitable manner such as by means of a potentiometer **31** connected to a suitable biasing source such as a battery **30** providing a varying negative bias for effecting the frequency control of the oscillations produced. Alternatively, the reactive feedback control may be effected in accordance with a suitable modulating potential supplied from a microphone circuit or the like and impressed upon grid **14**.

The function and operation of the circuit aforedescribed will be further understood from the following: Considering the oscillating or circulatory current in the tank circuit **16**, **17**, **20** caused by an E. M. F. induced in the inductance **16**, and neglecting the effect of the resistance **20** which may be of comparatively small value, the capacitative oscillating voltage drop developed by the condenser **17** and impressed between the cathode **11** and grid **12** will then lag the current in the tank circuit by 90°. Hence, the oscillating current flowing in the screen grid circuit being in phase with the grid potential will also lag the current in the tank circuit and, by proper choice of the winding sense of the tickler coil **21** relative to the tank circuit inductance **16**, the E. M. F. induced in the latter by the screen grid current may be caused to be in phase with the tank circuit current thus overcoming the ohmic losses in the circuit and resulting in the maintenance of sustained oscillations at a frequency equal to the tuning or resonating frequency of the circuit. From the foregoing, it will be seen that the in-phase relation of the feedback voltage induced in the inductance **16** by the screen grid current is due to a double 90° phase shift, first by the condenser **17** and then by the mutual inductance between the coils **21** and **16**.

Referring now to the plate output circuit, it will be seen that the oscillating voltage developed between the plate **15** and ground by electron coupling with the oscillator circuit is 180° out of phase with the potential on grid **12** and this voltage is directly impressed upon the tank circuit **16**, **17**, **20** without any additional phase shift by developing voltage across the resistance **20** by the proper design of the stopping condenser **26**. In other words, since only a single quadrature phase shift is involved (i. e. by the condenser **17**) for the plate feedback current, the feedback voltage developed by the resistance **20** will lead the tank circuit current, thus representing the equivalent of an increase of the effective or virtual inductance of the tank circuit and resulting in a corresponding variation of the oscillating frequency.

Oscillatory output energy may be derived from the oscillator in any suitable manner such as by way of a coupling coil **32** arranged in inductive relation with the tank circuit inductance **16** and forming part of a subsequent circuit or utilization system connected to the terminals marked *x–y*.

Referring to the modification shown in Figure 2, the ohmic resistance in the tank circuit has been eliminated and a separate phase shift network comprising a condenser **34** and resistance **35** in series is connected in parallel to the oscillatory tank circuit. In this case, the plate **15** is connected to the junction between condenser **34** and resistance **35** through the blocking condenser **26**. The function of this circuit is similar to that of the circuit according to Figure 1, the only exception being the fact that there are three consecutive 90° phase shift operations taking place in the reactive (plate) feedback circuit causing a resultant quadrature voltage to be injected into the tank circuit for the control of the oscillating frequency. The first phase shift is caused by the condenser **17**, the second phase

shift by the condenser 26, and the third phase shift by the condenser 34. The regenerative or in-phase feedback component is produced in a manner similar to Figure 1 involving two subsequent 90° phase shift operations balancing or cancelling each other and resulting in a regenerative action and maintenance of sustained oscillations. A further feature shown in Figure 2 consists in the provision of an additional positively biased screen grid 36 located between the frequency control grid 14 and the main screen or output grid 13. In this manner reactions of the grid 14 upon the regenerative or in-phase feedback current and the stability of the oscillator are minimized or eliminated, in contrast to Figure 1 wherein the grid serves to vary the distribution of the total cathode current upon the regenerative and degenerative feedback circuits in the manner described.

Figure 3 shows a circuit similar to Figure 2, wherein the grid leak resistance 28 is connected between grid 12 and cathode 11 and forms part of the feedback path together with the feedback condenser 26 connected between grid 12 and plate 13.

Figure 4 represents the vector diagram explanatory of the function of Figure 3. I indicates the current flowing in the tank circuit 16, 17, V_g represents the capacitative voltage developed by the condenser 17 lagging the current I by 90° and being applied to the grid 12 and cathode 11 of the tube. The screen grid current i_s is in phase with voltage V_g and induces a regenerative voltage e_r in the tank circuit serving for the maintenance of the oscillations. Grid voltage V_g also causes plate voltage V_p displaced by 180° and developed by the preferably non-reactive plate load impedance 25. Plate voltage V_p causes in-phase current i_r to flow through feedback circuit 26, 28 by proper design of feedback condenser 26, resulting in voltage drop V_f developed by resistance 28. Voltage V_f in turn causes feedback voltage e_r' impressed upon the tank circuit which voltage, as seen from the diagram, is in quadrature with the oscillating current I. In this manner, both regenerative and reactive feedback voltages are impressed upon the tank circuit resulting both in the maintenance of sustained oscillations and control of the oscillating frequency in the manner understood from the above.

Referring to Figure 5, I have shown a further modification of the invention similar to the preceding circuit but including a feedback path comprising blocking condenser 26 in series with the primary 41 of a coupling transformer having a secondary 40 connected across the oscillatory tank circuit 16, 17. The inductances of the transformer primary and secondary are of a small value and chosen to affect as little as possible the tank circuit constants and the phase of the feedback current. By the proper design of the feedback condenser 26, the E. M. F. induced in the secondary 40 will be substantially in phase with the current in the tank circuit in a manner similar to the E. M. F. induced by the tickler 21; however, in view of the fact that the E. M. F. induced by the latter is applied in series relation to the tank circuit current while the E. M. F. induced in the secondary 40 is applied in parallel relation to the tank circuit current a quadrature relationship will exist between the two feedback voltages resulting in both a regenerative and quadrature feedback for the maintenance of the sustained oscillations and control of the oscillating frequency. In Figure 5 I have shown a microphone circuit connected to the frequency control grid 14, said control circuit comprising a microphone 46, a battery or other current source 44, and the primary 45 of an audio frequency transformer. The grid 14 is connected to a suitable tap point of the source 44 in series with the secondary 47 of the audio transformer and a high frequency choke coil 48 in such a manner that the battery 44 serves to supply both suitable negative biasing potential for the grid and at the same time the operating current for the microphone. The induction coils 16, 21 and 31 are suitably shielded by means of a metallic screen 43 in accordance with well known practice, and other details like the supply of the heating and other operating current may be according to conventional standards well known to those skilled in the art.

Referring to Figure 6, I have shown a further modification of the invention utilizing a tube which serves both as a relay or amplifier for the maintenance of sustained oscillations and a means for supplying a variable phase shifted or quadrature voltage injected into the oscillatory circuit for effecting a frequency control of the oscillations produced. For this purpose, the plate 15 is operated at cathode potential or at a potential negative with respect to the cathode by the provision of a suitable biasing source such as a battery 52 shunted by an adjustable potentiometer 53. In an arrangement of this type, provided a proper adjustment of the plate biasing potential, an electron current flow to the plate is substantially prevented and a concentrated electron space charge or virtual cathode will be produced adjacent to the plate 15. The charge density of this virtual cathode fluctuates in the rhythm of the cathode current, i. e., at the frequency of the oscillations produced and will cause a capacitative or displacement current to flow through the outer plate circuit including a preferably non-reactive load impedance 51. The latter causes a voltage drop between the plate and cathode lagging by 90° the oscillating voltage between grid 12 and cathode 11. This quadrature voltage generated by space charge coupling of the plate with the electron stream is fed back through condenser 26 upon the oscillatory circuit in such a manner as to produce a reactive feedback voltage for the control of the oscillating frequency.

Figure 7 shows the vector diagram explanatory of the operation of Figure 6. The letter I again indicates the oscillatory current flowing in the tank circuit 16, 17, V_g represents the oscillating voltage between the grid 12 and the cathode 11, V_s is the screen oscillating voltage, i_s is the screen current and e_r the induced regenerative voltage in the tank circuit serving for maintaining the oscillations in a manner similar to that described hereinabove. As pointed out, grid voltage V_g further causes a plate voltage V_p produced by space charge coupling and lagging behind the grid voltage by 90°. Plate voltage V_p, by suitable design of the capacity of the condenser 26, drives a leading current i_p through feedback condenser 26 and the tank circuit 16, 17, resulting in a quadrature feedback voltage being impressed upon the tank circuit. The amount of quadrature feedback may be controlled in any suitable manner by varying the degree of the space charge coupling such as by controlling the negative bias of the plate 15 by the aid of potentiometer 53.

Another method of controlling the quadrature feedback or oscillating frequency consists in varying the screen grid potential which also will re-

sult in a control of the space charge coupling. An arrangement of the latter type is shown in Figure 8 in the form of an automatic frequency control system for use in a superheterodyne radio receiver. The oscillator shown is substantially similar to that of Figure 6 and serves as combined local oscillator and reactance tube at present provided in automatic frequency control systems. The oscillating frequency is adjusted by the potential supplied from a discriminator varying both in sign and magnitude in accordance with the departure of the intermediate frequency from the center frequency of the band pass characteristic of the intermediate frequency amplifier of the receiver. The discriminator shown especially suited for use in connection with the variable frequency oscillator proposed by the invention is of the type disclosed by U. S. Patent 2,208,091 utilizing the space charge coupling within a multi-grid tube as a phase shifting means for producing a time responsive or discriminating potential.

The discriminator, in the example shown, comprises a multigrid tube **55** having a cathode **56**, a first or signal input grid **57**, a screen grid **58**, a second control grid which may be the suppressor of a normal pentode **60**, and a plate **61**. Intermediate frequency signal potential is impressed upon input grid **57** and serves to excite a tuned circuit **63** comprising an inductance and a condenser in parallel and resonating at the assigned intermediate frequency of the receiver, said tuned circuit being connected between the outer control grid **60** and ground or cathode and substantially exteriorly decoupled or shielded from the rest of the circuit. Due to the variable space charge coupling between grid **56** and grid **60**, the circuit **63** will develop a potential at intermediate frequency varying in phase both in sense and magnitude in accordance with the departure of the intermediate signal frequency from its assigned value. Due to the intermodulation effect of the grids **57** and **60**, there is produced in the plate circuit a direct current component varying substantially in proportion to the intermediate frequency departure from the assigned frequency and the corresponding plate voltage variations produced by means of a suitable plate load impedance such as a resistance **65** are utilized according to the invention to serve as screen supply voltage for the local oscillator by directly connecting the screen grid **13** of tube **10** to the plate **61** of tube **55** in series with a suitable filter **67** to eliminate both high frequency and modulating frequency components and to cause a control of the local oscillator for the compensation of spurious and slow carrier frequency variations as a result of oscillator drift, heat influences and other causes. Similar direct current variations occur in the screen grid circuit of the discriminator tube **55** but in opposite phase to the plate current variations, whereby, by the omission of the by-pass condenser for the screen grid resistance **66**, the screen voltage may be used for supplying the operating voltage for the screen grid of the oscillator **10** to obtain a frequency control in the proper sense for the compensation of the intermediate frequency deviations from their assigned frequency. Item **62** indicates a standard condenser-shunted resistance in the cathode return for the plate current to provide suitable grid operating bias.

It will be evident from the foregoing that the invention is not limited to the specific circuits and details shown and disclosed herein for illustration, but that the underlying novel principle will be susceptible of numerous modifications and variations 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 in a limited sense.

I claim:

1. In an oscillator, an electron discharge tube having at least a cathode, a first control grid, a screen grid forming a first output electrode, a second control grid and a second output electrode all arranged substantially in the order named, an oscillatory circuit connected between said first control grid and cathode, a regenerative feedback path between said screen grid and said circuit to apply in-phase feedback energy to said circuit to generate sustained electrical oscillations, a further feedback path between said second output electrode and said circuit including means to cause additional feedback energy in quadrature phase relation to said first energy to be impressed upon said circuit, means for applying varying bias potential to said second control grid to correspondingly vary the frequency of the oscillations produced, and further means for substantially preventing reaction between said second control electrode and said first output electrode.

2. In an oscillator, an electron discharge tube having at least a cathode, a first control grid, a screen grid forming a first output electrode, a second control grid and a second output electrode all arranged substantially in the order named, an oscillatory circuit connected between said first control grid and cathode, a regenerative feedback path between said screen grid and said circuit to apply substantially in-phase feedback energy to said circuit to generate sustained electrical oscillations, a further feedback path between said second output electrode and said circuit including phase shifting means to cause additional feedback energy in substantially quadrature phase relation to said first energy to be impressed upon said circuit, means for applying varying bias potential to said second control electrode to control the amount of quadrature feedback energy supplied by said second output electrode to correspondingly vary the frequency of the oscillations produced, and further means to substantially prevent variation of the in-phase feedback energy supplied by said screen grid in response to variations of said bias potential.

3. In an oscillator, an electron discharge tube having at least a cathode, a first control grid, a screen grid forming a first output electrode, a second control grid and a second output electrode all arranged substantially in the order named, an oscillatory circuit connected between said first control grid and cathode, a regenerative feedback path between said first output electrode and said circuit to apply substantially in-phase feedback energy to said circuit to generate sustained electrical oscillations, a further feedback path between said second output electrode and said circuit including phase shifting means to cause additional feedback energy in substantially quadrature phase relation to said first energy to be impressed upon said circuit, means for applying a varying bias potential to said second grid to control the amount of quadrature feedback energy to correspondingly vary the frequency of the oscillations produced, and a further screen grid between said first screen grid and said second control grid, and means for maintaining

said further screen grid at a high positive potential for steady current and at substantially zero potential for the oscillating current with respect to said cathode.

4. In an oscillator, an electron discharge tube having at least a cathode, a first control grid, a screen grid, a second control grid and an anode all arranged substantially in the order named, a parallel tuned oscillatory circuit comprising inductive and capacitative reactance elements in shunt relation, said circuit being connected between said first control grid and cathode, a non-reactive impedance in series with one of said reactance elements, feedback coupling means between said screen grid and said circuit to apply substantially in-phase feedback energy to said circuit to generate sustained electrical oscillations, and a further feedback path substantially free of phase rotating circuit elements between said anode and the junction point of said non-reactive impedance and the reactance element in series therewith.

5. In an oscillator, an electron discharge tube having at least a cathode, a first control grid, a screen grid, a second control grid and an anode all arranged substantially in the order named, a parallel tuned oscillatory circuit comprising inductive and capacitative reactance elements in shunt relat'on, said circuit being connected between said first control grid and cathode, a non-reactive impedance in series with one of said reactance elements, feedback coupling means between said screen grid and said circuit to apply substantially in-phase feedback energy to said circuit to generate sustained electrical oscillations, a further feedback path substantially free of phase rotating circuit elements between said anode and the junction point of said non-reactive impedance and the reactance element in series therewith, means for applying a variable bias potential to said second control grid for controlling the frequency of the oscillations produced, and means to prevent variations of the in-phase feedback energy responsive to said bias potential.

6. In an oscillator, an electron discharge tube comprising an oscillation generating control and an output electrode, an oscillatory circuit coupled to said control electrode, regenerative feedback means connecting said output electrode to said circuit to apply in-phase feedback energy to said circuit, whereby to generate sustained electrical oscillations, a further electron receiving output electrode coupled to the oscillation generating electrodes by the electron stream of the tube, phase shifting impedance means coupling said further output electrode to said oscillatory circuit for feeding thereto energy of the generated frequency displaced in phase with respect to the generated frequency, and means substantially decoupled from the oscillation generating electrodes for varying the amount of phase-shifted feedback energy supplied by said further output electrode to thereby control the frequency of the oscillations produced.

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