June 8, 1943. D. A. BELL ET AL 2,321,354

ELECTRICAL APPARATUS

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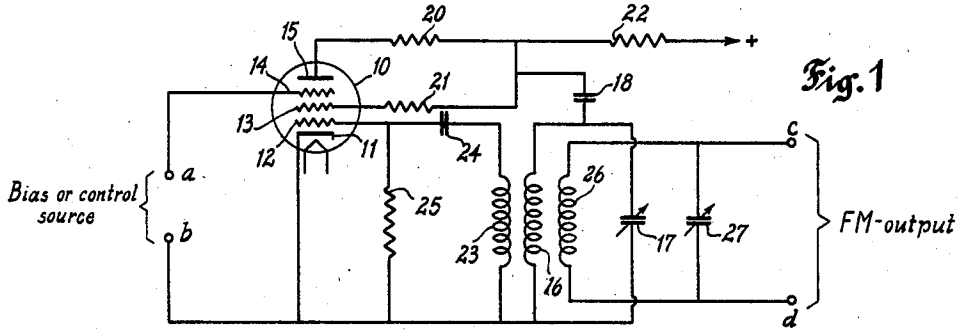


Fig. 1

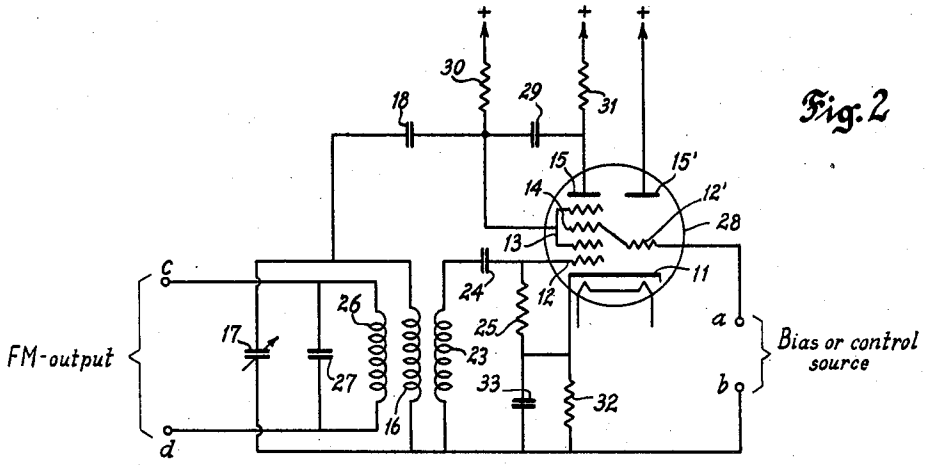


Fig. 2

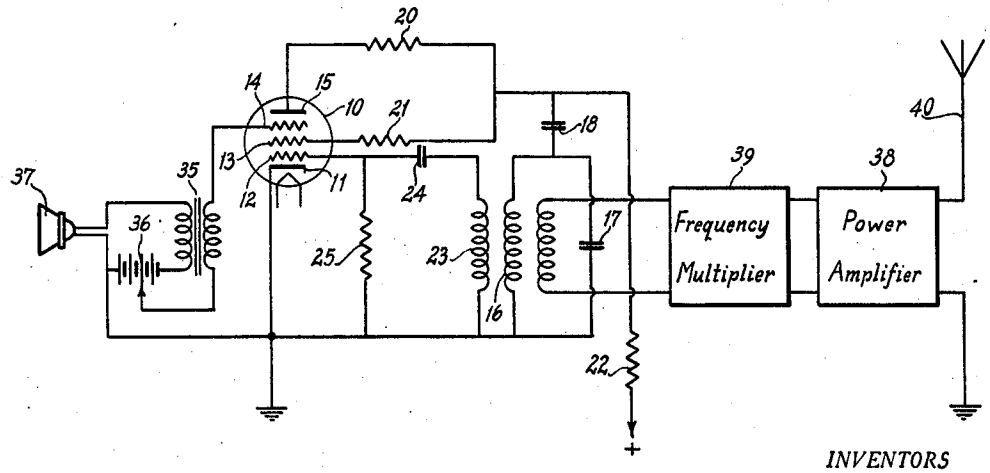


Fig. 3

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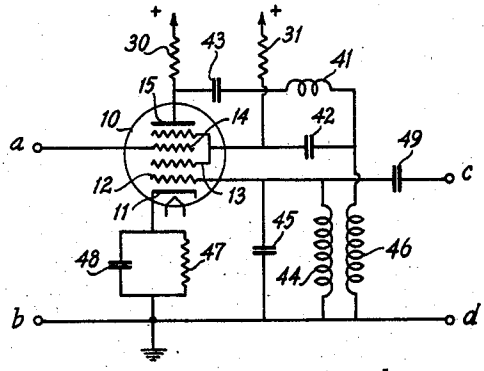


Fig. 4

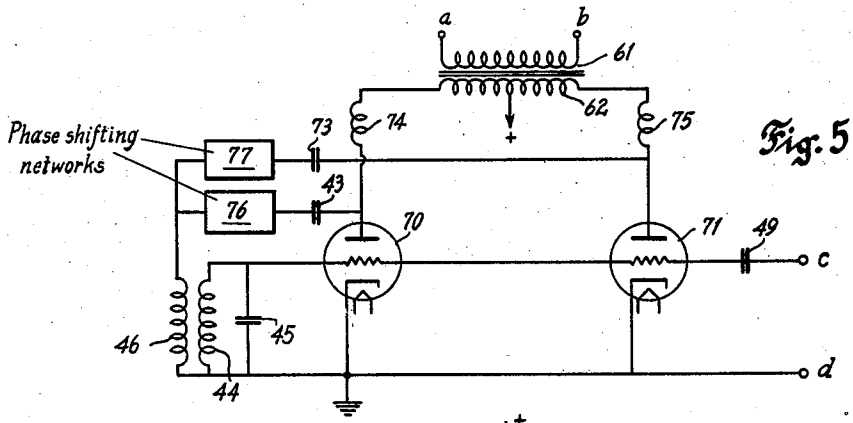


Fig. 5

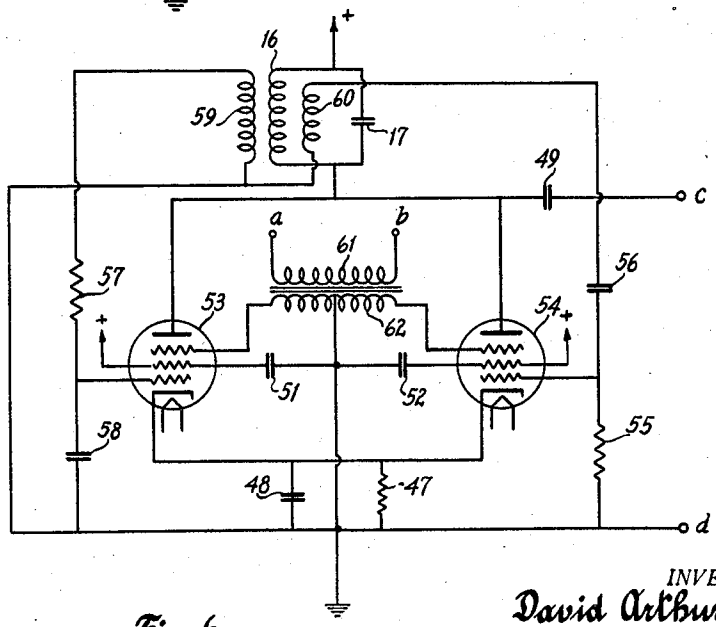


Fig. 6

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ELECTRICAL APPARATUS

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10 Claims. (Cl. 250—36)

The present invention relates to vacuum tube oscillators and has for its main object the provision of an oscillator the output frequency of which may be adjusted or controlled in an easy and efficient manner by means of a source of control potential.

Another object of the invention is to provide a single tube frequency modulated oscillator which will supply frequency modulated oscillations of substantially constant amplitude.

A further object is the provision of a simplified, single tube frequency modulated oscillator suitable for producing wide frequency swings without distortion as required in wide band frequency modulated transmitters and servicing oscillators.

The above and further objects of the invention will become more apparent from the following detailed description taken with reference to the acompanying drawings forming part of this specification and wherein: Figures 1 and 2 of the accompanying drawings are circuit diagrams of oscillators embodying the principles of the invention each employing a single valve; Figure 3 represents, partly in blocked diagram form, a complete frequency modulated transmitter embodying an improved oscillator according to the invention; Figure 4 is a circuit diagram of another oscillator embodying the invention and employing a single valve; Figures 5 and 6 are circuit diagrams of further oscillators embodying the invention each employing two valves.

Like reference numerals identify like parts in the several figures of the drawings.

A feedback oscillator comprises essentially (*a*) a resonant circuit and (*b*) a circulation path including an amplifier, an input circuit to the amplifier from the resonant circuit, and a feedback path from the output of the amplifier to the resonant circuit. If the oscillator is to maintain oscillations of a frequency which is displaced from the true resonant frequency determined by the inductance and capacitance of the resonant circuit, it is necessary that the phase angle of the circulation path shall compensate for the phase angle exhibited by the resonant circuit at that frequency.

The present invention contemplates a feed back oscillator having a plurality of circulation paths of different electrical characteristics, each arranged to feed back regenerative energy, and means to vary the ratio of the energies fed back through said paths in accordance with an applied bias or modulating potential.

In a preferred arrangement, parts of said circulation paths are in common while other parts, which are therefore in parallel, have different phase angles.

In order to maintain reasonable constancy of amplitude when the frequency is varied by varying the applied potential, the said phase angles should be so selected that the sum of the purely regenerative components of the energies fed back in the whole of the circulation paths will remain fairly constant. If there are two circulation paths, this implies that the rates of change with modulating potential of the purely regenerative components of the energies fed back in the two paths shall be substantially equal and opposite.

In one method of carrying the invention into effect, separate thermionic valves are included in the different circulation paths and the ratio of the energies fed back through said paths is varied by variation of control potentials applied to said thermionic valves.

In another arrangement for carrying the invention into effect, a single valve of the pentode or similar type is employed. By a valve of pentode or similar type in this specification is meant a valve provided with at least two output electrodes and a modulation control grid having negligible control over the cathode current but which is adapted to control the distribution of current between said output electrodes, in addition to having a further control grid for controlling the cathode current. In a pentode such as those of the 6AC7 type commercially available, the output electrodes may be the screen grid and the anode while the modulation grid may be the suppressor grid. In a hexode, such as the 6K8 type, the modulation grid may be the third grid while the output electrodes are the coupled second and fourth grids on the one hand and the anode on the other hand.

When a pentode or similar type of valve is employed, one of the circulation paths is arranged to include the feedback circuit of one output electrode and another of the circulation paths is arranged to include the feedback circuit of the other output electrode. The energy fed back along one path will then be increased while that fed back along the other path is decreased when a change is made in the potential applied to the modulation control grid. The circuits of the output electrodes may have substantially different phase angles. Alternatively, they may have the same phase angle, provided that this is not zero; and as one form of this a single net-

work may form a feedback circuit common to both output electrodes.

The anode current of a thermionic valve depends jointly on the anode voltage and the grid voltage, the relative importance of these two factors depending upon the amplification factor. If the amplification factor is very large, the anode voltage has little effect, and the anode current is then substantially in phase with the grid voltage regardless of the nature of the anode circuit. If, however, the amplification factor is sufficiently small for the anode voltage to have appreciable effect, then the phase of the anode current will depend upon the phase angle of the anode load. If the anode circuit contains reactance, the phase of the anode current will then differ appreciably from that of the grid voltage.

In a valve of pentode or similar type, the amplification factor between the first output electrode (screen grid) and the control grid which controls the cathode current (inner control grid) is relatively low; while the amplification factor between the second output electrode (anode) and that control grid is very high. It follows that, if the feedback networks have the same phase angle, or if a single feedback network is employed in common, the phase angle of the total feedback current relative to the inner control voltage will be dependent upon the distribution of current between the two output electrodes, and will thus be dependent upon the control potential applied to the modulation control grid.

In order to maintain reasonable constancy of amplitude with change of amplification factor, it is necessary to arrange that the purely regenerative component of the total energy fed back shall not vary substantially.

The distribution of current between the two output electrodes is influenced, not only by the potential of the modulation control grid, but also by the potentials of the output electrodes themselves. By proper choice of the impedances of the output circuits, this effect can be made to secure substantial constancy of output for all potentials of the modulation control grid within the modulation range, in spite of the different characteristics of the valve with respect to the outputs from the two electrodes.

Alternatively, the feedback networks shall include different amounts of attenuation so that, although the anode voltages are unequal, the regenerative energies delivered to the tuned circuits are substantially equal.

In Figure 1 of the accompanying drawings, there is shown a pentode **10** provided in the manner known with a cathode **11**, an inner control grid **12**, a screen grid **13**, a suppressor or outer control grid **14**, and an anode or plate **15**, all arranged substantially in the order named with respect to said cathode. An oscillatory tank circuit comprising, in the example shown, an inductance coil **16** shunted by a variable condenser **17** is coupled for high frequency currents to both the screen grid **13** and plate **15** used as the output electrodes through a coupling condenser **18**. There are further provided suitable impedances such as high ohmic resistors **20** and **21** arranged in the anode and screen grid circuits, respectively, and these circuits are further parallelled and connected through a common impedance **22** to the positive terminal of a suitable source of space current supply such as a battery or the output of a rectifier indicated in a customary manner by the plus symbol in the drawing. Feedback to the control grid **12** from the oscillatory circuit **16, 17** is effected by way of a coupling inductance **23** arranged in inductive relation with the tank circuit inductance **16** and coupled to the control grid and cathode through grid coupling condenser **24**. The control grid is provided with a grid leak **25** in the manner and for the purpose well understood by those skilled in the art. Any other known type of regenerative circuit arrangement may be employed for the maintenance of sustained oscillations in the circuit **16, 17** as will become obvious from the following:

The outer control or suppressor grid **14** is biased through a suitable modulation source connected to terminals *a, b* by means of a fixed potential sufficiently negative (see Figure 3) to enable the tube to work on the linear portion of the suppressor grid characteristic and to prevent the potential on the suppressor grid from rising above cathode potential.

The frequency at which the circuit aforedescribed will oscillate is dependent on the potential of the suppressor grid and bears a linear relationship to the latter over a considerable band of operating frequencies. The amplitudes of the screen grid oscillatory current and of the anode oscillatory current are also each dependent upon the suppressor grid potential, but it is possible to arrange that the sum of their purely regenerative components will be substantially independent of the suppressor grid potential by suitable choice of the impedances **20, 21**, and **22**. Amplitude variations of the oscillatory voltage across the circuit **16, 17** are thus substantially eliminated, while retaining dependence of the frequency of oscillation upon the suppressor grid potential. Thus, by coupling a control or modulation source of any suitable wave form to terminals *a, b* such as for example a sine wave or saw-tooth oscillator, or an audio frequency voltage, the frequency of the generated oscillations may be modulated in a corresponding manner.

The variation of the oscillating frequency may be due, not only to the effects above described but also in part to a change of the cathode-to-plate capacity of the tube which is effectively shunted across the oscillatory circuit **16, 17**, the capacity variations being in turn the result of the changing space charge distribution in the cathode-anode space caused by potential changes on the outer control grid **14**.

In order to avoid disturbance of the parameters of the oscillatory circuit, the output of the tube is preferably derived by means of a tuned circuit of low "Q" comprising an inductance **26** shunted by a condenser **27** and being in coupling relation to the tank circuit inductance **16**.

If the amplitude of the oscillatory voltage developed across the tank circuit **16, 17** is found to be not quite sufficiently constant when the frequency is modulated, compensation of the amplitude variations may be effected by tuning the output circuit **26, 27** to a frequency at the end of a frequency modulation band at which the amplitude is low.

The tuning of the tank circuit may be varied over a range by varying the capacitance of the condenser **17**.

Figure 2 shows a circuit diagram of a modified oscillator circuit according to the invention utilizing a tube **28** of the triode-hexode type. In this embodiment, the anode **15** is directly coupled through condenser **29** to the second and fourth grids forming the screen **13** enclosing the outer control grid **14**, the impedances corresponding to **20** and **21**, Figure 1, being omitted. The necessary

relative adjustment of the currents in the output circuit in this case is obtained by the adjustment of series impedances **30** and **31** connected in the leads to the space current supply source of the screen grid and plate electrodes, respectively.

In order to obtain a wide frequency modulation band it is necessary that the tuned circuit **16**, **17** shall be fairly heavily damped. If the impedance of the network **29**, **30**, **31** is too high for this purpose an additional resistance (not shown) may be connected in parallel with the oscillatory circuit **16**, **17**.

The circuit according to Figure 2 is otherwise similar to that shown in Figure 1 but has certain additional features. The hexodes, at present commercially available such as the popular **6K8** type, are nearly all triode-hexodes, and in the exemplification of Figure 2 which shows a tube of this type the triode section comprising the common cathode **11**, the control grid **12'**, directly internally connected to the outer control grid **14** of the hexode section, and the plate **15'**, is employed to provide negative feedback which has been found to widen the band of linear modulation obtainable. This is effected by including a resistance **32** in the cathode lead of the tube shunted by a condenser **33** of such capacity as to offer low impedance to currents of the oscillatory frequency generated and high impedance to the currents of the modulation frequency or band of modulation frequencies impressed upon the triode control grid **12'**. Alternatively, the triode section of the tube may be connected in a separate feedback oscillator circuit to generate an oscillatory voltage of any desired frequency for modulating the frequency of the oscillatory circuit connected to the hexode section.

If an exceptionally wide frequency modulation band is required, this may be obtained by heterodyning the outputs of two oscillators of the character hereinbefore described, in which case the outer control grids of these oscillators are modulated in phase opposition. If a triode-hexode is employed in one of these oscillators, its triode section may be used to provide the necessary change of the phase of the modulation voltage for application to the valve of the other oscillator.

Referring to Figure 3, there is shown a complete frequency modulated transmitter embodying a master oscillator of the type proposed by the invention. The oscillator circuit shown is similar to that according to Figure 1 with the exception that the outer control grid **14** is excited by the secondary of an audio frequency transformer **35**, the primary of which is connected in a modulating circuit including a current source **36** and a microphone **37** in series. The source **36** which may be a battery or any other suitable voltage supply, also serves to bias the grid **14** to a potential sufficiently negative with respect to the cathode for the purpose pointed out above. The frequency modulated output voltage developed across the tank circuit **16**, **17** is impressed upon a suitable power amplifier **38**, if desirable, by way of a frequency multiplier **39** to increase both the frequency and the power sufficiently for energizing the antenna **40**. The same system may be used for producing a phase modulated output by the provision of a suitable corrective network or integrating circuit such as a series resistance and shunting condenser inserted between the microphone and outer control grid circuits in a manner well understood by those skilled in the art. Furthermore, means for maintaining constant or stablizing the centre frequency may be provided in accordance with known practice comprising a standard frequency (crystal) oscillator beating with oscillations derived from the power amplifier or antenna circuit to produce a control frequency which is impressed upon a frequency discriminator producing a control voltage varying in sign and magnitude in accordance with the departure of the oscillator centre frequency from its assigned value. This control voltage which may be due to oscillator drifts and other causes is applied to the outer control grid **14** together with the modulation voltage in such phase as to counteract any initial centre frequency deviation in a manner well known in the art.

The oscillator shown in Figure 4 is shown as comprising a single hexode valve **10** having like elements as the hexode portion of the valve in Figure 2.

The tuned circuit consists of inductance **44** in parallel with condenser **45** and is connected in the control grid circuit of the valve.

The high tension supplies to anode and screen grid are made through separate resistors **30** and **31** of high value.

In the feed back path from the anode a blocking condenser **43** is introduced, but the phase angle of this path is substantially determined by the inductance **41**. The phase angle of the feed back path from the screen grid is substantially determined by the condenser **42**, which may have a reactance at oscillation frequency substantially equal in magnitude to that of inductance **41**. The feed back is effected through inductance **46**, common to both feed back paths, coupled with inductance **44** of the tuned circuit.

The output voltage developed between terminals *c* and *d* is derived through coupling condenser **49** directly from the voltage appearing across the tuned circuit. Its frequency is modulated by varying the potential applied between terminals *a* and *b* to the modulation control grid and thereby varying the distribution of current between screen grid and anode of the valve. Bias for both control grids is produced in conventional manner by resistance **47** shunted by condenser **48** which exhibits low reactance at both oscillation and modulation frequencies.

In Figure 5, two triode oscillator valves **70** and **71** are provided, and the tuned circuit comprising inductance **44** and condenser **45** is connected in common in the grid circuits of these valves. Separate feed back circuits from the anodes are connected through blocking condensers **43**, **73** and phase shifting networks **76**, **77** to a common coupling coil **46** which is coupled to inductance **44** of the tuned circuit. The ratio of the energies fed back in the two paths is controlled by varying the relative anode potentials of valves **70** and **71**. The high tension source for these anodes is connected to the midpoint of the secondary winding **62** of a transformer, the primary winding **61** of which is connected between the terminals *a* *b* of the modulation source. The anodes of the valves **70**, **71** are connected to the opposite extremities of secondary winding **62** through choke coils **74**, **75** respectively which offer high impedance to currents of oscillation frequency.

The output voltage appearing between terminals *c* and *d* is derived through coupling condenser **49** directly from the tuned circuit; its frequency is modulated in accordance with the voltage variations of the modulation source connected between terminals *a* and *b*.

The phase shifting networks 76 and 77 can produce any desired angles of phase shift, provided that these angles are different and that the feed back through each is regenerative. Preferably these phase angles should be of equal magnitude and opposite sign. If desired, however, one of these networks may be omitted while the other may, for example, have a phase angle of about 45°. Over the extreme modulation range, as the feed back is substantially wholly transferred from one valve to the other, there will then be a change in the proportion of the in-phase component of the voltage fed back of the order of $\sqrt{2}$ to 1, assuming the attenuation in both feed back networks to be the same. The actual change in amplitude of the oscillation generated will be less than this owing to the curvature of the valve characteristics, and for many purposes an amplitude variation of this order will not be objectionable.

In Figure 6 the tuned circuit comprising inductance 16 in parallel with condenser 17 is connected in common in the anode circuits of pentode valves 53, 54 between the anodes and the high tension source. Separate coils 59 and 60 are coupled to inductance 16 to supply separate feed back paths to the control grids to the two pentode valves. Between coil 59 and the control grid of valve 53 a substantially 45° lagging phase shift is introduced by the network comprising resistance 57 and condenser 58; the reactance of condenser 58 being substantially equal at oscillation frequency to the value of resistance 57. Similarly a substantially 45° leading phase shifting is introduced between coil 60 and the control grid of valve 54 by a network comprising condenser 56 and resistance 55, the reactance of condenser 56 at oscillation frequency being substantially equal to the value of resistance 55. The screen grids of both pentode valves are maintained at constant potential. The energies handled by the valves are varied oppositely by connecting suppressor grids to opposite ends of the secondary winding 62 of the transformer, the primary winding 61 of which is connected to the terminals *a b* of the modulation voltage source. The centre point of the secondary winding 62 is maintained at earth potential. Bias for both control grids of each valve is obtained in conventional manner by resistance 47 shunted by condenser 48, which exhibits low reactance at both modulation and oscillation frequencies. The output voltage developed between terminals *c* and *d* is derived through coupling condenser 49 from the anodes of the valves; its frequency is modulated in accordance with the voltage variations of the modulation source applied between terminals *a* and *b*.

It will be evident from the foregoing that the invention is not limited to the specific details and circuits shown herein for illustration, but that the underlying basic principle is susceptible of variations, 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 limiting sense.

We claim:

1. In an oscillator, an electron discharge tube comprising 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 operatively connected to said first grid and to both said output electrodes substantially in parallel relation for the oscillating output currents to generate sustained electrical oscillations, the non-common circuit portions from said output electrodes to said oscillatory circuit having substantially the same phase angle characteristics, and a source of variable control potential connected to said second control grid and cathode for varying the frequency of the oscillations produced.

2. In an oscillator, an electron discharge tube comprising 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 operatively connected to said first grid and to both said output electrodes substantially in parallel relation for the oscillating output currents to generate sustained electrical oscillations, impedance means in the non-common connecting leads from said oscillatory circuit to said output electrodes to adjust the normal ratio of the oscillating current components supplied by said output electrodes to substantially compensate amplitude variations of the total oscillating current in said circuit in response to potential variations on said second grid, said impedance means having substantially the same phase angle characteristics, and a source of variable control potential connected to said second control grid and cathode for varying the frequency of the oscillations produced.

3. In an oscillator, an electron discharge tube comprising 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, a tuned oscillatory circuit coupled to both said output electrodes and said cathode in substantially parallel relation for the oscillating output currents, a further coupling connection between said oscillatory circuit and said first grid to generate sustained electrical oscillations in said circuit, impedance means in the non-common circuit portions to said output electrodes to adjust the normal ratio of the oscillating current components supplied by said output electrodes to substantially compensate amplitude variations of the total oscillating current in said circuit in response to control potential variations of said second grid, said impedance means having substantially the same phase angle characteristics, and a source of variable control potential connected to said second grid and cathode for varying the frequency of the oscillations produced.

4. In an oscillator, an electron discharge tube comprising 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, a tuned oscillatory circuit connected to both said output electrodes in substantially parallel relation for the oscillating output currents, further coupling means between said oscillatory circuit and said first grid to generate sustained electrical oscillations in said circuit, impedance means in the non-common circuit portions to said output electrodes from said oscillatory circuit to adjust the normal ratio of the oscillating current components supplied by said output electrodes to substantially compensate amplitude variations of the total oscillating current in said circuit in response to control potential variations of said second grid,

means for applying a steady negative bias potential to said second control grid of such magnitude as to prevent said control grid potential from rising above the cathode potential, the non-common circuit portions between said oscillatory circuit and said output electrodes having substantially the same phase characteristics, and a source of variable control potential connected to said second grid and cathode for varying the frequency of the oscillations produced.

5. In an oscillator, an electron discharge tube comprising a cathode, a control grid and a pair of output electrodes, means to provide a relatively low amplification factor between said control grid and one of said output electrodes and to provide a relatively high amplification factor between said control grid and the other output electrode, an oscillatory circuit operatively connected to said grid and to both said output electrodes substantially in parallel relation for the oscillating output currents to generate sustained electrical oscillations, the non-common circuit portions from said output electrodes to said oscillatory circuit having substantially the same phase angle characteristics, and means to control the relative oscillating current supplied by said output electrodes to correspondingly vary the frequency of the oscillations produced.

6. In an oscillator, an electron discharge tube comprising a cathode, a control grid, and a pair of output electrodes, means to provide a relatively low amplification factor between said control grid and one of said output electrodes and to provide a relatively high amplification factor between said control grid and the other output electrode, an oscillatory circuit operatively connected to said first grid and to both said output electrodes substantially in parallel relation for the oscillating output currents to generate sustained electrical oscillations, the non-common circuit portions from said output electrodes to said oscillatory circuit having substantially the same phase angle characteristics, and a current distribution control grid between said output electrodes for controlling the ratio of the oscillating currents supplied by said output electrodes to said circuit to correspondingly vary the frequency of the oscillations produced.

7. In an oscillator, an electron discharge tube comprising a cathode, a control grid, a screen grid forming a first output electrode and a second output electrode all arranged substantially in the order named, an oscillatory circuit operatively connected to said control grid and to both said output electrodes substantially in parallel relation for the oscillating output currents to generate sustained electrical oscillations, the non-common portions from said output electrodes to said oscillatory circuit having substantially the same phase angle characteristics, and means to control the relative oscillating current supplied by said output electrodes to said circuit to correspondingly vary the frequency of the oscillations produced.

8. In an oscillator, an electron discharge tube comprising 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 operatively connected to said first grid and to both of said output electrodes substantially in parallel relation for the oscillating output currents to generate sustained electrical oscillations, ohmic resistance means in the non-common connecting leads from said output electrodes to said oscillatory circuit to adjust the normal ratio of the oscillating current components supplied by said output electrodes, and means to apply variable control potential of said second grid to correspondingly vary the frequency of the oscillations produced.

9. In an oscillator, an oscillatory circuit, electron space discharge means comprising input means and a pair of output electrodes, circuit means between said oscillatory circuit to said input means, further circuit means operatively connecting said oscillatory circuit to both said output electrodes substantially in parallel relation for the oscillating output currents to generate sustained electrical oscillations, means to provide a relatively high amplification factor between said input means and one of said output electrodes and to provide a relatively low amplification factor between said input means and the other output electrode, the non-common circuit portions from said output electrodes to said oscillatory circuit having substantially the same phase angle characteristics, and means to control the relative output current supplied by said output electrodes to said circuit to correspondingly vary the frequency of the oscillations produced.

10. In an oscillator, an oscillatory circuit, electron space charge means comprising input means and a pair of output electrodes, circuit connections between said oscillatory circuit and said input means, further connections between said oscillatory circuit and both said output electrodes substantially in parallel relation for the oscillating output currents to generate sustained electrical oscillations in said circuit, means to provide a relatively high amplification factor between said input means and one of said output electrodes and to provide a relatively low amplification factor between said input means and the other output electrode, non-reactive impedance means inserted in the non-common connecting leads from said output electrodes to said oscillatory circuit to adjust the normal ratio of the output current components, and means to control the ratio of the output current components in respect to said normal ratio to correspondingly vary the frequency of the oscillations produced.

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