

June 27, 1939.

F. B. LLEWELLYN

2,163,756

HIGH FREQUENCY OSCILLATOR

Filed Dec. 20, 1935

2 Sheets-Sheet 1

FIG. 1

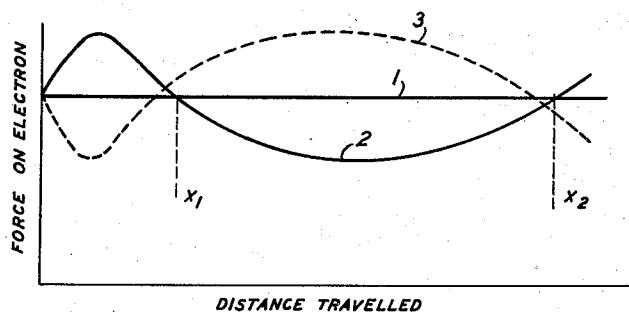


FIG. 1A

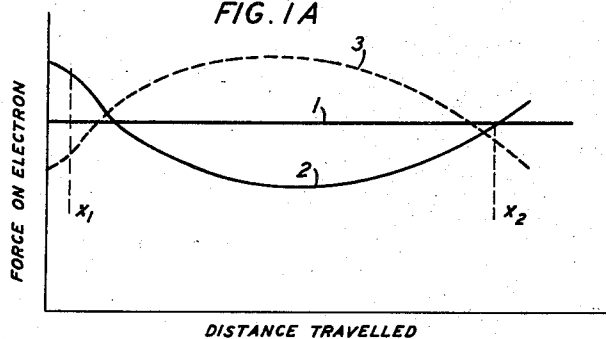
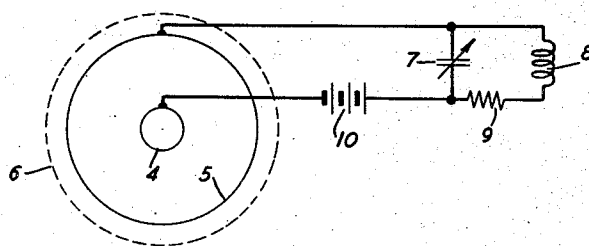


FIG. 2



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FIG. 3

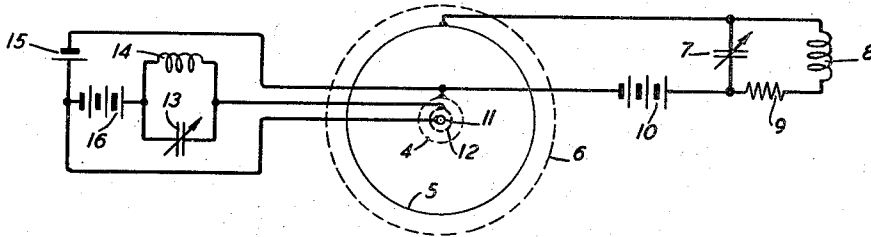


FIG. 4

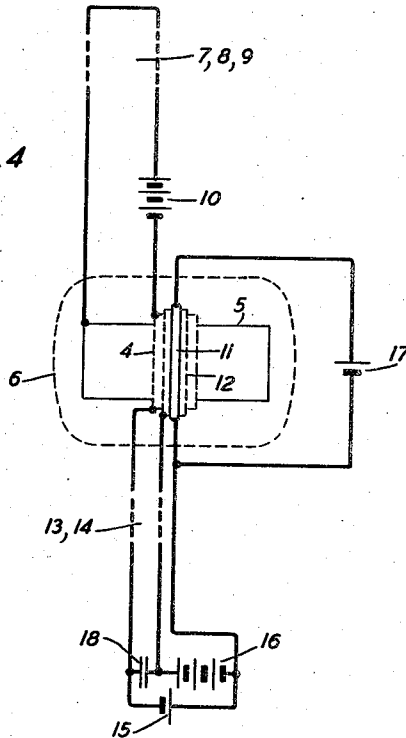
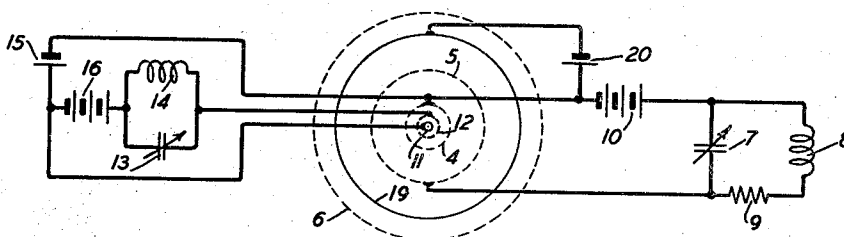


FIG. 5



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HIGH FREQUENCY OSCILLATOR

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Application December 20, 1935, Serial No. 55,314

3 Claims. (Cl. 250—36)

This invention relates to ultra-high frequency vacuum tube oscillator circuits and more particularly to such circuits as conditioned to achieve a high efficiency and power output, as compared with prior art alternatives, in the production of

The efficiency of any vacuum tube circuit, including amplifiers and oscillators, may be improved by allowing the anode electron current to flow for only a part of the alternating current cycle. The principle is exemplified at low frequencies in the so-called shock excited circuit, the benefits being measured by the resultant decreased losses as compared with the alternative where the anode electron current flow is continuous. In the practice of this principle in the past, it has been customary to achieve this interrupted anode electron flow by correspondingly conditioning the cathode-anode path so as to effectively intermittently inhibit the flow of electrons therethrough, as by effectively intermittently introducing a space charge in this path by the use of a negative grid or control electrode.

The present invention concerns the extension of this intermittent electron flow idea to ultra-high frequency oscillators. A physical explanation of the operation of ultra-high frequency oscillators may be obtained from the energy relations existing between the anode supply, the external oscillatory circuit, and the electron stream within the tube. In such an oscillator, of either the diode or triode type, it can be shown that each electron that leaves the cathode during one half of the alternating current cycle will deliver energy to the oscillating circuit, while each electron that leaves during the other half of the cycle will absorb approximately the same amount of energy from the circuit as was delivered by an electron a half cycle earlier. When more electrons leave during the former half of the cycle than during the latter half of the cycle a net amount of energy may be transferred from the anode source to the oscillating circuit for a complete cycle. If the cathode emitted no electrons during the latter half cycle, a greater portion of the direct current energy from the anode source would be transferred to the oscillating circuit. The problem therefore is to suppress the emission of electrons from the cathode during one half of the high frequency cycle, without the necessity for lengthening the transit time by the use of negative grids between cathode and anode.

It has been noted that the electron current to the slightly negative plate or third electrode of a Barkhausen oscillator has exactly this desired

property, namely, that it flows for only a fraction of the cycle. During the remainder of the cycle electrons are turned back at what amounts to a virtual cathode positioned just inside the plate and are returned toward the positively biased grid. Accordingly, a Barkhausen oscillator may be made a component of an effective diode oscillator, or negative or positive grid triode oscillator, by the use of electrodes additional to those specific to the Barkhausen oscillator component, the Barkhausen oscillator component therefore being treated as a cathode, to be substituted for the cathode of conventional diode or triode oscillators, and as being valuable in such an environment because of its ability to emit electrons in groups rather than continuously. For ultra-high frequencies the use of a positive grid, as compared with a negative grid, triode oscillator is to be preferred. Although other circuit means could conceivably be used to achieve the effect that this Barkhausen oscillator component achieves, the use of the Barkhausen oscillator principle is effective particularly in the extremely high frequency range for which it is contemplated being used. As so used the resultant oscillator is much more effective in producing electrons in groups than its nearest alternatives in the prior art, and so makes possible the development of a greater power output from the tube. This favorable comparison has in mind not only prior art diode or negative grid oscillators, but the Barkhausen oscillator itself. In the particular oscillator to be described in this specification, the energy developed by the Barkhausen component is not used usefully externally to the tube and is of minor extent as compared with the eventual oscillation developed by the effective over-all oscillator.

It is an object of the invention to generate ultra-high frequency oscillations in a vacuum tube oscillator circuit without the sacrifice of efficiency and of power output attendant on the use of prior art devices and circuits.

A more specific object of the invention is to extend the beneficent effect of the shock excitation or interrupted anode current principle to the art of ultra-high frequency vacuum tube oscillator circuits.

In order to use the property of the Barkhausen oscillator as above described as an incident in the operation of an ultra-high frequency vacuum tube oscillator which includes the Barkhausen oscillator as the effective cathode element, it is only necessary to perforate the Barkhausen oscillator plate so that electrons may pass there-

through and to surround this plate with an anode operated at a high positive potential so that the electrons which have once penetrated through the Barkhausen oscillator plate will be drawn to the anode by this potential. The higher this potential is made the greater will be the available energy output, the limit being imposed when the screening of the perforated plate is insufficient to prevent the high potential anode from reacting unfavorably on the Barkhausen oscillator. An output oscillatory circuit may then be connected to the anode. Another oscillatory circuit, or other oscillatory circuits, may be used with specific relation to the Barkhausen oscillator component without affecting the basic principles of operation of the invention and such oscillatory circuit, as well as the output oscillatory circuit, may take the form of a tuned Lecher system or the like. Analogously additional electrodes may be inserted in the tube to perform the auxiliary functions characteristic of them generally in the prior art without compromising the tube or circuit as a whole with relation to the particular function of this invention.

The invention will be more fully explained in the following detailed description taken in connection with the accompanying drawings in which:

Figs. 1 and 1—A are graphs for facilitating explanation of the invention;

Fig. 2 is a schematic drawing showing an embodiment of the invention but for clearness in explanation omitting details which are shown in Figs. 3 and 4;

Fig. 3 is a circuit diagram showing one embodiment of the invention and is drawn to show an end view of the space discharge device;

Fig. 4 is a circuit diagram showing another embodiment of the invention and illustrating the space discharge device by a side view; and

Fig. 5 is a circuit drawing showing still another embodiment of the invention in which the space discharge device is modified by the addition of an electrode to obtain greater output and efficiency.

In Figs. 1 and 1—A the axis of abscissae represents the distance which a typical electron has travelled from the cathode of a space discharge device. The axis of ordinates represents the force which acts on the electron as it moves along toward an anode, the said force arising from two sources, first, a biasing potential of constant value to accelerate the electron and second, the presence of an alternating current in a circuit attached to the electrodes of the space discharge device. The cyclical variation of force exhibited in these graphs corresponds in frequency to the desired frequency of the wave to be ultimately derived from the circuit as an oscillation generator. This frequency is the frequency of the spurts of electrons from the cathode.

As drawn, Figs. 1 and 1—A strictly represent conditions which would be obtained if both cathode and anode were arranged in the form of parallel planes of infinite extent, with no appreciable space charge between them. As used in practice, the two electrodes are more usually arranged in the form of concentric cylinders, the inner one forming the cathode. The effect of this arrangement would be to increase the ordinates at the left hand end of the figures and to decrease those at the right, the amount of this modification becoming more pronounced as the ratio of diameter of the outer cylinder to that of the inner cylinder is made greater. On the other hand, space charge tends to decrease all

ordinates, but affects the left hand ones to a greater extent than the right hand ones. Thus in a measure space charge tends to compensate for the effect of the cylindrical shape. As the description of this invention progresses it will be seen that the effect of the cylindrical electrodes with inner cathode is undesirable and that the principle of the invention is not consistent with complete space charge. It is therefore desirable to construct cylindrical vacuum tubes so that the ratio of diameters is a small number when the cathode constitutes the inner cylinder. From the following description of the proposed means of obtaining the desired cathode characteristics it will become evident that a small diameter ratio is consistent with facility of mechanical construction and electrical operation.

With this restriction on the diameter ratio, the principles involved in the invention may be explained for cylindrical as well as for planar electrodes by reference to Fig. 1 where the force component resulting from the constant biasing potential is shown by the horizontal line 1 and the total force arising both from the constant biasing potential and from the alternating current is shown by the solid curving line 2. The difference between the ordinates of lines 2 and 1 therefore gives the component of the force on the electron which arises from the alternating current.

It is well known in the science of mechanics that the area lying between a curve representing force versus distance and the distance axis is a measure of the work done by the force. In Fig. 1 therefore the area lying beneath curve 2 measures the work done by the total force acting on the electron and the area lying beneath curve 1 measures the work done by the source of energy which supplies the constant biasing potential. The difference between these two areas is the area enclosed between curves 2 and 1 and measures the work done by the forces arising from a flow of alternating current in an attached circuit. When this difference is positive, the force has done work on the electron, which work must come from the energy associated with the alternating current. The alternating current therefore tends to die out unless maintained by an additional source of alternating energy. On the other hand, when the area between curves 2 and 1 is negative, the electron has done work on the attached circuit, thus building up or maintaining the alternating current.

From the foregoing it is apparent that if the flight of the typical electron subject to the conditions illustrated by curve 2 were terminated at an electrode located at X_1 , then work would have been done on the electron by the alternating forces and accordingly the alternating current would tend to die out.

If, however, the flight of the typical electron were terminated at an electrode located at X_2 in Fig. 1, then the net work done on it would be the algebraic sum of the two areas enclosed between curves 1 and 2, taken from the origin up to X_2 . Now the constant biasing potential causes the electron to travel much faster during the latter part of its path than during the initial part, so that even though the time required by the electron in reaching X_1 is approximately the same as that required in going from X_1 to X_2 , nevertheless the distance traversed in the latter time is much greater than in the former. Accordingly, the negative area between X_1 and X_2 which is enclosed by curves 2 and 1 is much greater than the positive area enclosed by the same two curves

before X_1 . The electron therefore does work against the alternating force and hence transfers energy to the alternating current producing a tendency for it to build up.

It is thus evident that the particular electron whose action is illustrated by curve 2 in Fig. 1 can be made either to absorb energy or to deliver energy depending on whether it requires a half or a whole cycle of the alternating current to move from cathode to a positive anode.

In the case of ordinary space discharge devices there is a continuous emission of electrons from the cathode. It therefore follows that the force diagram of another typical electron which is emitted just a half cycle later than the one described above may be traced on Fig. 1. The total force acting on this second electron is shown by the dotted curve 3, and the work done by the alternating force on this second electron is measured by the area enclosed between curves 3 and 1. But the latter area tends to be positive where the area between curves 2 and 1 is negative and vice versa. It therefore results that work done by the second electron is nearly cancelled by the work done on the first electron so that the net effect of the two is very small and differs from zero only because the energy required or delivered by the two electrons is different in different parts of the cycle so that curves 2 and 3 do not intersect curve 1 at exactly the same point.

It therefore becomes apparent that if either one of the two typical electrons whose force diagrams are shown at 2 and 3 respectively could be eliminated, then the net work obtainable from the remaining electron would greatly exceed that which could be procured when both are allowed to be present. Thus, if only electrons of the type shown by curve 2 were present, alternating energy would be obtained if the anode were located at a distance X_2 from the cathode which the electron took approximately a whole cycle to traverse. Again by extending the curves of Fig. 1 it is evident that energy would again be available when the electron took any even number of half cycles to move from cathode to anode. On the other hand, if only electrons of the type shown by curve 3 were present, alternating energy would be obtained if the anode were located at a distance from the cathode which is less than X_1 corresponding to a transit time of a half cycle or less between cathode and anode. By extending the curves of Fig. 1 it is evident that energy would be available whenever the electron took an odd number of half cycles to move from cathode to anode.

It can be shown that the presence of space charge tends to result in the production of more electrons of the type shown by curve 2 than of the type shown by curve 3 so that even when both types of electrons illustrated by curves 2 and 3 are present there may be a net production of electrical energy. At very high frequencies, however, the appreciable transit times of the electrons with accompanying phase shifts causes a given alternating potential on the electrodes to have less control on the flow of electrons than is the case at low frequencies, and hence makes desirable the expedient, above suggested, of eliminating one of the two types of electrons so that the electrons leave the cathode at a variable rate, the alternations occurring at the same frequency as the alternating current. The most desirable cathode would be one which emitted electrons by intermittent spurts instead of in a continuous manner.

Fig. 2 shows how to employ such a cathode for the efficient production of ultra-high frequency oscillations. The cathode is shown without detail as a cylinder at 4 and the concentric anode at 5, the space between them being free from electrodes which disturb a uniform and swift flow of electrons, and being enclosed in an evacuated envelope 6. Between the cathode 4 and anode 5 is connected, externally, a source of constant biasing potential 10 and a circuit consisting of the condenser 7, inductor 8 and load resistor 9. The size of the condenser 7 is adjusted so that the system 7, 8, 9 together with the capacitance between the tube electrodes 4 and 5 is tuned to the frequency of the electron spurts which the cathode emits.

Similar results are obtained whether the potential of biasing source 10 is adjusted so that the electrons take either a whole cycle or a half cycle to move from cathode 4 to anode 5. In the former case operation occurs at X_2 in Fig. 1 in accord with curve 2, while in the latter case operation occurs at X_1 in accord with curve 3.

The above relations have been explained on the basis that the pulse of electrons starts from the cathode at the instant when the variable part of the force is zero. This phase relation is by no means necessary, and Fig. 1—A illustrates conditions when the pulse starts from the cathode at the instant when the variable force is nearly at its maximum value. The constant component of force is shown at 1. When the variable component follows the course of curve 2, then energy is available when the anode is located at X_2 . On the other hand, if the variable component of the force follows the curve 3, then energy is available when the anode is located at X_1 .

In operation, with a fixed position of the anode and a given anode supply voltage, the phasing of the variable force component always adjusts itself to extract the greatest energy from the electron stream. The reason for this is that any transients which start in the circuit in the wrong phase will die out, while the one that starts in the proper phase, as explained, will build up. The output circuit 7, 8, 9 should always be adjusted so that the whole system including the inter-electron capacitance of the vacuum tube is tuned to the frequency of the electron spurts, and the biasing potential should be adjusted to as high a value as is available in order to decrease the transit time as much as possible and thus obtain increased energy output by the avoidance of positive portions of the work diagrams in Figs. 1 and 1—A.

In Fig. 3 is shown a method of obtaining the desired characteristics of a cathode that emits electrons in ultra-high frequency spurts. An ordinary thermionic emitter is placed at 11 within an evacuated envelope 6. Fig. 3 shows an end view of the wire constituting the emitter so that the heating means is hidden, but heating may be accomplished by sending current through the emitting wire by means of a battery as shown in Fig. 4 where 11 is the thermionic emitter and 17 is a battery supplying the heating current, the thermionic emitter and battery being similar in both Fig. 3 and Fig. 4, the latter figure differing from the former in showing a side view instead of an end view of the emitter and in employing certain modifications in the remainder of the circuit which will be described later.

Surrounding the thermionic emitter 11 in Fig. 3 is a cylindrical grid 12 biased to a positive potential with respect to the emitter by means of 75

the constant potential source 16 which is connected to the grid 12 through a tuned circuit consisting of a coil 14 and condenser 13. Surrounding the positively polarized grid 12 is a perforated cylinder 4 which is biased by the constant potential source 15 to a potential slightly negative with respect to the thermionic emitter 11.

It will now be recognized that the electrodes 11, 12 and 4 in conjunction with the external circuit 13, 14, 15, 16 constitute an oscillator of the type commonly associated with the name Barkhausen. Moreover, in accordance with the characteristic mode of operation of this type of oscillator, electrons impinge on its slightly negative plate 4 during substantially one half of the high frequency cycle only, and are returned toward the positive grid 12 during the remainder of the cycle. Hence it follows that if the plate 4 be perforated as specified above, electrons will pass through the perforations during substantially one half of the cycle only and are thus emitted in spurts by the perforated cylinder 4. The cylinder 4 may consequently be employed as a cathode for the oscillator described in conjunction with Fig. 2 where the cathode is required to emit electrons in spurts or from another point of view, the Barkhausen oscillator as a whole may be thought of as constituting said cathode. Inasmuch as it is undesirable that the Barkhausen oscillations be influenced by stray fields reaching through the perforations of the cathode 4, and thus coupling to the electron stream within it, the perforations should preferably affect only a relatively small part of the surface of the cathode and, besides, should individually be small.

The only requirement imposed on the Barkhausen oscillator is that it be capable of delivering electrons in spurts through the perforations in cylinder 4. The Barkhausen oscillator therefore may be operated with a small expenditure of power. On the other hand, the power developed in the load resistor 9 depends upon the energy obtainable from the electrons in their transit from cathode 4 to anode 5 and thus depends upon the potential of source 10. By increasing this potential, the power delivered to the load 9 may be made much greater than that supplied by the Barkhausen oscillator, and the over-all efficiency becomes very high because no work is expended in moving useless electrons from 4 to 5.

Fig. 4 shows an embodiment of the invention similar to that disclosed in Fig. 3 in which however the inductances, capacitances and resistances required in the attached circuits are distributed in the form of Lecher wires instead of being concentrated individually in the form of coils, condensers, and resistors. The figure is a side view of the space discharge device which comprises a concentric system of electrodes including a thermionic emitter 11, a grid 12 surrounding the emitter 11, a perforated plate 4 surrounding the grid 11 and an anode 5 surrounding the perforated cylinder 4, the ensemble of electrodes being enclosed in an evacuated envelope 6. Heating current is supplied to the thermionic emitter 11 by the energy source 17 which may be a battery. The grid 12 is biased to a positive potential by the energy source 16, which may be a battery, and the perforated cylinder 4 is biased to a slightly negative potential by the source or battery 15. A tuned circuit comprising distributed inductance and capacitance is formed by the Lecher wire system 13, 14 and is

connected between the grid 12 and perforated plate 4, the tuning adjustment of the Lecher system being accomplished by adjusting the position of a shunting condenser 18. The combination of electrodes 11, 12 and 4 together with the attached circuits and energy sources 13, 14, 15, 16, 17 form an oscillator of the Barkhausen type and constitute a cathode which delivers electrons in regular spurts to the space outside of the perforated cylinder 4. The anode 5 is connected to the effective cathode 4 through an energy source of high voltage 10 which may be a battery or a direct-current generator, and a tuned circuit 7, 8, 9 consisting of distributed capacitance, inductance, and resistance, arranged to form a Lecher wire system. The resistance component of the impedance of the Lecher wire constitutes the load for absorbing the high frequency power output from the vacuum tube and may consist in part of radiation resistance for transferring the high frequency oscillations into radio waves. The length of the Lecher system 7, 8, 9 is adjusted until the impedance presented to the electrodes 4 and 5 is of an inductive nature with a resistive component and tunes with the interelectrode capacitance between them. The potential source 10 is adjusted to a high value.

In Fig. 5 is shown a space discharge device having concentric electrodes 11, 12, 4, 5 and 19 enclosed in an evacuated envelope 6. Electrodes 11, 12 and 4 are similar in construction and operation to those bearing the same numbers in Figs. 3 and 4. Electrode 5 is also similar in position and operation, but as employed in Fig. 5 it must be perforated to allow the passage of electrons through it. Electrode 19 is a concentric cylinder located outside of the other electrodes and biased to a slightly negative potential with respect to the cathode 4 by the source or battery 20. An output circuit 7, 8, 9 and source 10 is connected between the anode 5 and cathode 4.

In operation, the Barkhausen oscillator 11, 12, 13, 14, 15, 16, 4 causes the cathode 4 to emit electrons in spurts. These are attracted toward the positive perforated anode 5, and deliver energy to the oscillatory current in the tuned output circuit 7, 8, 9 by virtue of the fact that the bias potential of source 10 is adjusted to cause the transit time between 4 and 5 to be approximately a half cycle. On reaching the perforated anode 5 some of the electrons penetrate through the perforations and proceed toward the negative plate 19, which is positioned so that approximately a half cycle is required for the transit from 5 to 19. Thus, as the electrons pass through 5, the phase of the voltage reverses because the half cycle point X_1 in Fig. 1 is being passed, but also the direction of the force on the electrons reverses because the actuating electrode 5 now lies behind the electron spurt instead of ahead of it. The result is that the component of force on the electrons which is set up by the alternating current acts in a direction opposite to the electron motion and hence abstracts additional energy from them. Again, the electrons stop just before reaching the plate 19 and start to move back toward the anode 5. The phase of the voltage on 5 reverses however at the same time so that the variational force component again opposes the electron motion and yet more energy is transferred to the alternating current.

It will be seen that the action of electrodes 4, 5 and 19 in conjunction with the circuit elements 75

7, 8, 9, 10 is similar to that in the Barkhausen type of oscillator ("The Barkhausen Oscillator", Bell Laboratories Record, August, 1935) but possesses the great advantage that the useless electrons which are emitted by an ordinary thermionic cathode during half of the high frequency cycle, and which absorb energy and decrease efficiency and output of the Barkhausen oscillator are eliminated by the special cathode of Fig. 5 which emits electrons only when they are employed to increase output and efficiency.

What is claimed is:

1. An electron discharge tube circuit comprising, an electron emitting means, an anode, means for impressing a positive potential on said anode relatively to said emitting means, an electrode external to said anode, circuit means relating said emitting means, anode and external electrode in such manner as to constitute therewith a braking field type of oscillator, and means for causing an intermittent flow of electrons from said emitting means to said anode comprising additional electrodes and connecting circuits so related to said emitting means as to constitute therewith a self-contained positive grid triode oscillator, said positive potential being such that the oscillatory energy derivable from said braking field oscillator is large as compared with the energy derivable from said self-contained oscillator.

2. An electron discharge tube circuit comprising an electron emitting means, an anode separated from said emitting means only by etheric space, means for impressing a positive potential on said anode relatively to said emitting means, an

electrode external to said anode, circuit means relating said emitting means, anode and external electrode in such manner as to constitute the whole a braking field type of oscillator, and means for causing an intermittent flow of electrons from said emitting means to said anode comprising additional electrodes and connecting circuits so related to said emitting means as to constitute therewith a self-contained positive grid triode oscillator, said positive potential being such that the oscillatory energy derivable from said braking field oscillator is large as compared with the energy derivable from said self-contained oscillator.

3. An electron discharge tube circuit comprising, an electron emitting means, an anode, means for impressing a positive potential on said anode relatively to said emitting means, an electrode external to said anode together with circuit means connecting said emitting means, anode and external electrode in such manner as to constitute the whole a braking field type of oscillator, and means for causing an intermittent flow of electrons from said emitting means to said anode comprising additional electrodes and connecting circuits so related to said emitting means as to constitute therewith a second braking field type of oscillator, said positive potential being such that the oscillatory energy available between said anode and said emitting means is large as compared with said second braking field oscillator energy.

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