Aug. 9, 1949. R. H. VARIAN 2,478,216

THERMIONIC VACUUM TUBE AND CIRCUIT

Original Filed Dec. 30, 1943 3 Sheets-Sheet 1

Fig. 1.

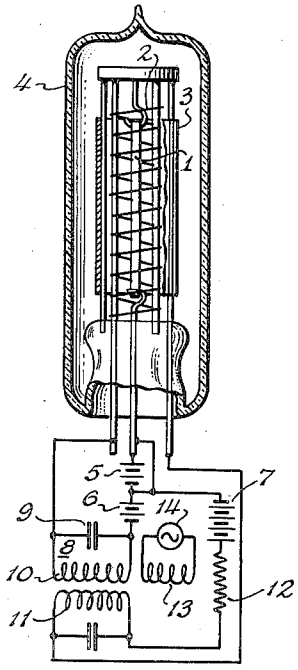
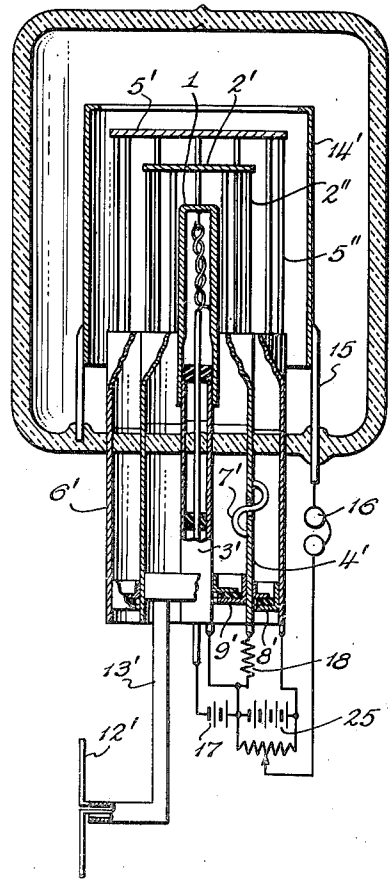


Fig. 2.



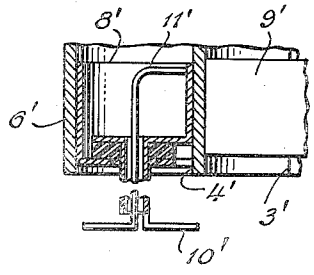


Fig. 2A.

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Fig. 3.

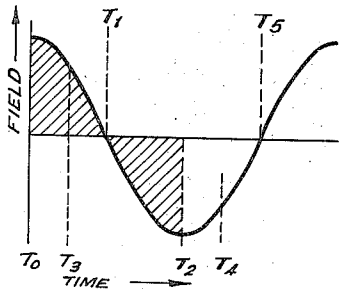


Fig. 4.

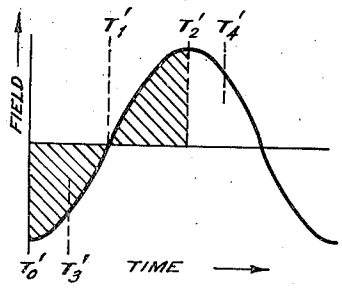


Fig. 5.

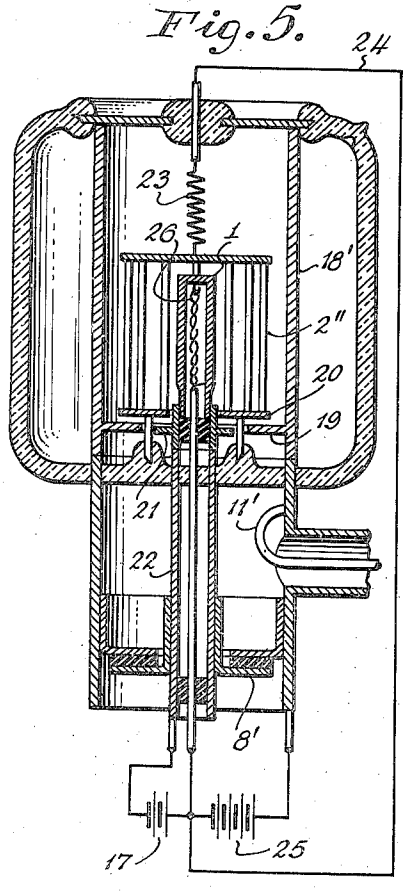
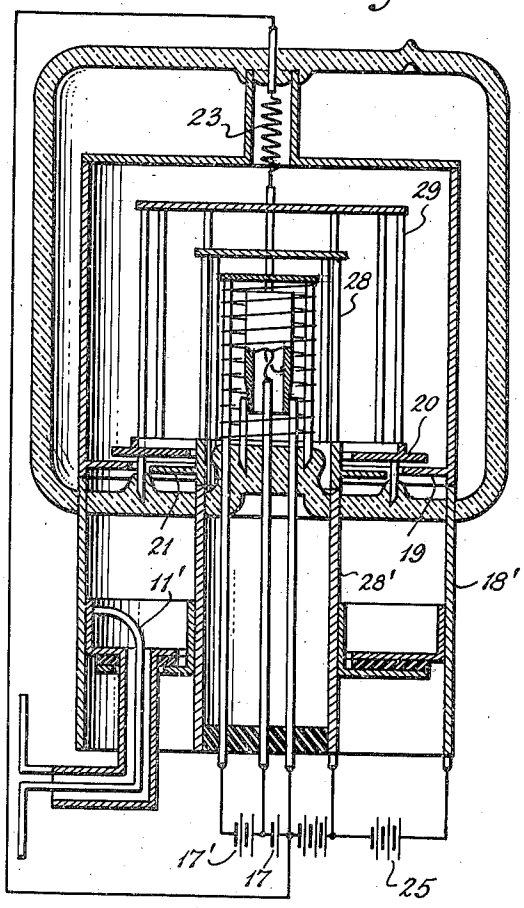


Fig. 8.



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Fig. 6.

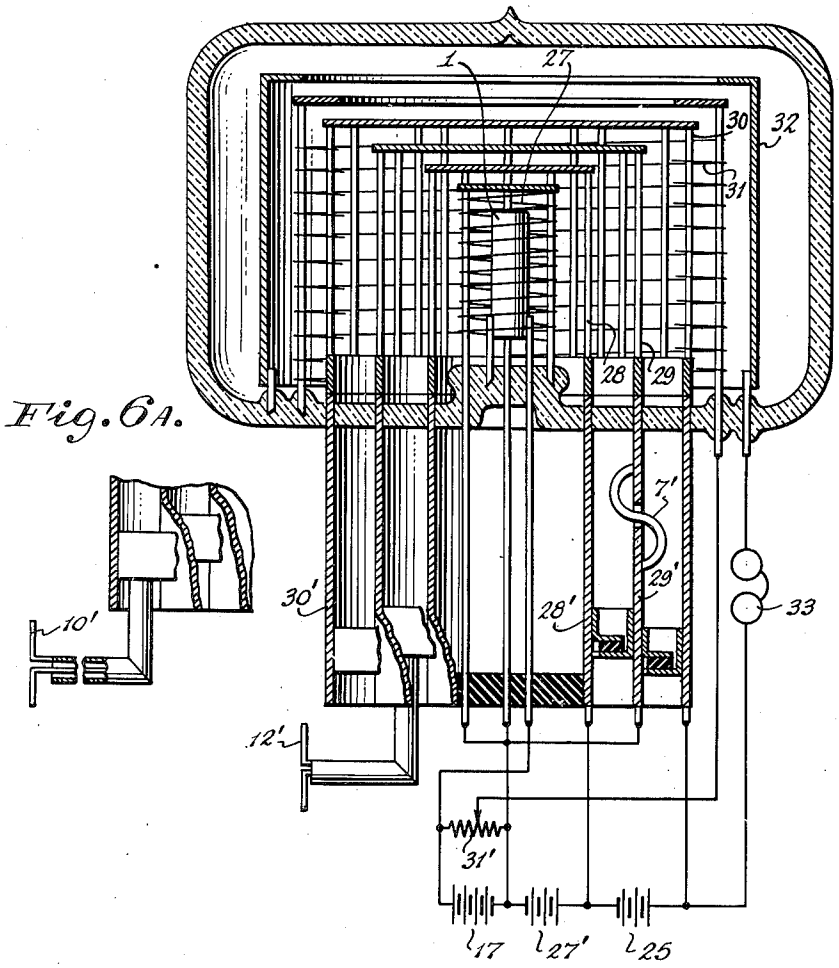


Fig. 6A.

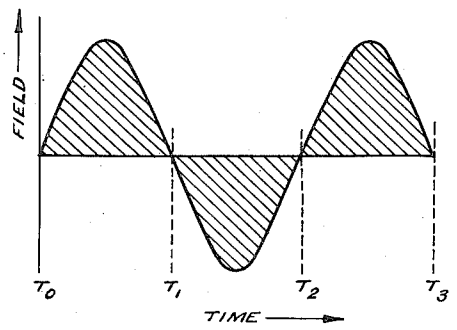


Fig. 7.

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Patented Aug. 9, 1949

2,478,216

UNITED STATES PATENT OFFICE

2,478,216

THERMIONIC VACUUM TUBE AND CIRCUIT

Russell H. Varian, Cupertino, Calif., assignor to The Board of Trustees of the Leland Stanford Junior University, Stanford University, Calif., a legal entity of California

Original application March 8, 1939, Serial No. 260,546. Divided and application March 24, 1942, Serial No. 435,953. Divided and application December 30, 1943, Serial No. 516,147. Again divided and this application October 2, 1948, Serial No. 52,483

14 Claims. (Cl. 315—5)

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The present invention relates, generally, to means and methods for converting direct or low frequency current into alternating current, and particularly to alternating currents of frequencies of 10^8 cycles or more per second, and the invention has reference, more particularly, to novel thermionic vacuum tube and circuit construction operable as electrical converters, including oscillators, amplifiers, and detectors employing control grids in connection with cathodes and anodes connected to resonant circuits. The present application is a division of copending application Serial No. 516,147 filed December 30, 1943 as a division of application Serial No. 435,953, which in turn is a division of application Serial No. 260,546, filed March 8, 1939, now Patent No. 2,287,845.

The principal object of the present invention is to remove limitations inherent in the known types of thermionic three-electrode tubes and circuits, namely, the limitation dependent on "active grid loss," and the limitation imposed by the flow of current to the control grid whenever it becomes positive with respect to the cathode. Removal of the first limitation renders it possible to operate three-electrode tubes at frequencies beyond the range heretofore obtainable, while removal of the second limitation contributes to the same end as well as to improving the efficiency and flexibility of vacuum tube circuits.

Another object of the invention is to provide a control grid arrangement in the class of tubes generally included in the "three-electrode" classification, i. e., triodes, pentodes, and other conventional forms, which arrangement permits the grid impedance to be, as may be desired, positive, negative or effectively nearly infinite.

Still another object of the invention is to render it feasible to make three-electrode vacuum tubes for operation at high frequencies without extremely small spacings between the electrodes, thereby also facilitating the manufacture of vacuum tubes for high frequency and large power rating.

Still another object of the invention is to provide vacuum tubes of the three-electrode type that constitute an integral part of the resonant circuits of which they are a part, and are thoroughly shielded against undesired escape of radiation from said circuits.

A further object of the invention is to provide means for allowing the escape of radiation from said circuits under accurately controllable conditions, or for the induction of energy into any

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of said circuits under accurately controllable conditions.

Yet another object of the invention is to provide a combination of circuit and three-electrode tube in which the resistance losses are less than is the case in arrangement of the customary type.

Yet another object of the invention is to provide a tube and circuit in which the high frequency electron current drawn by the control grid adds to the energy delivered to the electron circuits by the electron stream.

Yet another object of the invention is to provide a three-electrode tube having a positive space charge grid which at high frequency increases the action of the control grid upon the electron stream.

Yet another object of the invention is to provide a new and useful method of detecting a radio signal.

A further object of the present invention is to provide a novel thermionic tube that is adapted to provide one stage of radio frequency amplification in addition to serving as a detector and which is useful at both high and low frequencies.

Other objects and advantages will become apparent from the specification, taken in connection with the accompanying drawings wherein the invention is embodied in concrete form.

In the drawings,

Fig. 1 illustrates in section an ordinary three-electrode tube shown for purposes of explanation.

Fig. 2 illustrates in section a preferred embodiment of the present invention.

Fig. 2A shows a modified detail of construction in section.

Figs. 3 and 4 are explanatory graphs.

Fig. 5 shows in section an alternative form of the structure of Fig. 2.

Fig. 6 is a sectional view of another embodiment which operates somewhat differently from Fig. 2.

Fig. 6A shows a modified construction detail.

Fig. 7 is an explanatory graph.

Fig. 8 shows an alternative form of the structure of Fig. 6 in section.

Similar characters of reference are used in all of the above figures to indicate corresponding parts.

The phenomenon of active grid loss which is overcome by the present invention may be explained in connection with the conventional three-electrode tube of Fig. 1. In this figure there is shown an electron emitting filament 1, a control grid 2, and a plate or anode 3 in an

evacuated container 4. The filament 1 is heated by a battery 5; the grid 2 is biased by a battery 6, and the plate 3 is energized by a battery 7. A resonant circuit 8 comprising a condenser 9 and an inductance 10 impresses an alternating difference of potential on the grid 2. An inductance 11 in series with the plate circuit is inductively coupled to inductance 10 for feedback control. A resistor 12 represents the load to which the system delivers energy, and an inductance 13 is connected to a generator 14 and inductively coupled to inductance 10 represents the source of alternating current excitation for the system. The system as shown is capable of operating as an oscillator, as an amplifier or as a detector depending on factors of design and adjustment. The general theory of operation is well known in the prior art and will in the following be assumed without explanation except in so far as the effect of active grid loss is concerned.

In the operation of the tube of Fig. 1 at low frequencies the time required for an electron to travel from the filament 1 to the plate 3 is small compared with the period, that is to the time interval corresponding to a cycle of operation. The grid 2 has its potential varied with respect to the filament 1 potential at the frequency of the system, and the impedance of the space between filament 1 and plate 3 is varied in accordance with the potential during the time the electron is passing from filament 1 to plate 3. Under these conditions energy is not transferred between the grid 2 and the electrons which pass through the grid. This statement should not be confused with the fact that a positively charged grid carries current. To avoid possible confusion, however, the subject of grid loss will be explained with reference to a grid which is negative with respect to the filament at all times, and thus does not collect electrons from the surrounding space.

It is well known in the art that so long as grid 2 remains at a constant potential, it may control the number of electrons passing from electron emitter 1 to plate 3, but it cannot influence the energy with which electrons strike plate 3. This follows because whatever the potential of grid 2 may be, the electrons in passing the grid are merely passing a potential valley or hill as the case may be, and the energy lost by the electrons in ascending the hill is all regained in going down the other side. If the grid represents a potential valley, the same is true with the signs reversed. The same is true also if the potential of the grid is changing slowly, and it is easily seen that it will remain true as long as the grid does not change its potential appreciably while the electron is in transit between filament 1 and plate 3.

If on the other hand the grid 2 does appreciably change its potential while an electron is in transit between filament 1 and plate 3, the electron may strike the plate with either increased or diminished energy, for if the height of the potential hill, or the depth of the potential valley, at grid 2 changes while the electron is in transit, the energy lost on the ascent side will in general not equal the energy gained on the descent side. The matter of whether the electron gains or loses energy as a result of the change in the potential hill or valley at grid 2 depends on the phase of the change when the electron passed through the field of grid 2.

If a stream of electrons uniformly distributed in time crosses the cyclically varying potential hill or valley at grid 2 there will be as many electrons

gain energy as lose energy, and if the gain or loss is small compared with total energy, the cyclic variations in the barrier, that is, the potential of grid 2 will not increase or decrease the average energy with which the electrons strike the plate 3. However, in a three-electrode tube the electron stream is not uniformly distributed in time, and it therefore becomes necessary to investigate the phase relations existing between the maximum electron emission and the grid potentials to determine whether the electron stream on an average gains energy from, or loses energy to, the grid circuit. The greatest number of electrons will leave the filament 1 when the grid 2 is most positive, and these electrons will gain energy from the grid circuit in traveling from the filament 1 to the grid 2, and since the grid 2 will be more negative while the electrons complete their journey from the grid 2 to the plate 3, these electrons will not lose the energy they gained in traveling from the filament 1 to the grid 2. Hence, the grid 2 will lose energy to the electron stream. This is known as active grid loss.

With the tube shown in Fig. 1 operating at high frequencies, the time required for an electron to travel from the filament 1 to the plate 3 may become comparable with a period of oscillation of the system. In tubes of ordinary dimensions, the transit time in the tube becomes comparable with the period at frequencies of the order of 10^8 cycles per second or less, the larger the tube in general the lower the frequency where transit time becomes appreciable. When the transit time of the electron traveling from filament 1 to plate 3 is an appreciable fraction of the oscillation period, the potential of grid 2 with respect to filament 1 changes materially during the time of transit of the electron from the filament 1 to plate 3, and the tube is thus subject to active grid loss.

The active grid loss is understood in the prior art. Some attempts to overcome this loss have been made, and in particular attempts to reduce the transit time of electrons in the tube by reducing the spacing between the electrodes, but none of the attempts known prior to Patent No. 2,244,747, issued June 10, 1941 in the names of Russell H. Varian and Arnold J. Siegert, and the present invention did more than reduce the effect by dimensional design.

In the present invention, as in the above mentioned patent, the factors which determine active grid loss are controlled in such a way that the active grid loss may be eliminated entirely or reversed in sign so that the control grid may be caused to gain energy from the electron stream instead of imparting energy thereto. The methods whereby these results are accomplished in the present invention are somewhat simpler and more easily carried out in practice than those described in the specification above referred to.

As has been shown in the foregoing analysis of active grid loss, when a three-electrode tube, having conventional spacings, is connected in the ordinary way and operated at high frequency, there will be an active grid loss. This does not, however, apply to all possible element spacings and connections of a three-electrode tube. One such exception is shown in Fig. 2. In the operation of a three-electrode tube, as shown in Fig. 2, a radical departure is made from conventional practice, namely, that instead of the anode and grid potentials being in opposite phase with respect to each other these potentials are approximately in the same phase. It will now be shown

qualitatively that energy will be delivered to a resonant circuit by a stream of electrons passing between cathode and anode.

Two resonant circuits are shown in Fig. 2 which circuits consist of a concentric pair of concentric lines, the inner pair consisting of cathode 1 and grid 2'' having closely spaced conducting grid wires and a conducting top plate 2', and conductors 3' and 4', which are electrical continuations of cathode 1 and grid 2''. The second consists of grid 2' and electron permeable 5'' (in the form of a grid) also having a conducting top plate 5' and conductors 4' and 6', which are electrical continuations of grid 2'' and anode 5'' respectively. A coupling conductor 7' links some of the field in both resonators, and serves to couple the two resonant circuits together, if such coupling is desired in a particular case. An annular member 8' is employed for closing the end of the outer concentric line and for tuning the same by sliding this annular member in and out. It consists of two metal plates separated by a thin layer of insulating material which makes it possible to maintain conductors 4' and 6' at different unidirectional potentials and at the same time provides a free path for passage of high frequency currents between the two conductors. A similar annular member 9' serves the same purposes for the inner concentric line. A radiating dipole 10 (see Fig. 2A) may be connected by concentric line 11' to the outer of the concentric line resonators for linking the flux therein at 11' for removing energy therefrom. A dipole 12' is connected to the inner resonator by concentric line 13' for delivering energy thereto. The two dipoles 10' and 12' are not intended to be used simultaneously, but are shown as alternative arrangements, 10' being used if the device is serving as a transmitter, and 12' being used if the device is serving as a receiver. If the device is used as a receiver the cylindrical plate 14' may be used as a detector and the detected signal is removed through a wire 15, and energizes phones 16 as will further appear.

The cathode 1 is heated by battery 17. Grid 2'' is shown as being connected to the cathode through resistor 18, which is the usual arrangement in standard oscillators. If the device is to be used as a receiver, resistance 18 will ordinarily be replaced by a biasing battery or other source of potential. If the spacing between cathode 1 and grid 2'' and the potential gradient between cathode 1 and grid 2'' is such that an electron leaving cathode 1 takes approximately one-half cycle to travel from cathode 1 to grid 2'', the electron stream as a whole will do work on the grid 2'' as is shown in Fig. 3.

In Fig. 3 positive values of the sine curve represent gradients between cathode 1 and grid 2'' which tend to accelerate electrons traveling between cathode 1 and grid 2'' while negative values represent gradients tending to decelerate electrons traveling between cathode 1 and grid 2''. The greatest electron current will leave cathode 1 approximately when grid 2'' is most positive, or at the time marked T_0. Due to the presence of the space charge barrier at the cathode and to the fact that electrons leaving the cathode have initially only their thermal velocities, actually the greatest number of electrons will leave the virtual cathode slightly in front of the cathode 1 at the time the grid is most positive. This involves a correction which may appreciably shift the phase of the electron groups at very high frequencies, but at frequencies of the

order of 3×10^8 cycles and lower it may be neglected. This greatest electron current will do work on the grid if it remains in transit between cathode 1 and grid 2'' for the time interval T_2-T_0, as shown in Fig. 3. This allows these electrons to be accelerated for a quarter-cycle and decelerated for a quarter-cycle.

According to the convention adopted in this figure, the shaded area above the axis represents velocity gained from the grid circuit by this most numerous group of electrons that leaves the cathode when most negative during the first quarter of a cycle, while the shaded area below the axis represents the velocity lost by the electrons in the next ensuing quarter-cycle.

This is so because the curve is a graphical representation of the force acting on the electrons as a function of time, and

$$\text{velocity}=k\int_{T_2}^{T_0} f\,dt$$

where f=force and t=time. Since the area below the axis is as great as the area above, these electrons lose as much velocity as they gain in traveling from cathode 1 to grid 2''.

The energy gained or lost by the electrons in traveling from cathode 1 to grid 2'' is

$$\int_{\text{grid }2''}^{\text{cathode}} f\,d\mathrm{D}$$

where D is the distance. Since the electrons are continuously gaining velocity from the direct current field in their flight from the cathode to grid 2'', the electrons travel farther per unit time in the last half of their flight than they did in the first half, and hence there is a preponderance of energy lost over energy gained by the electrons.

In Fig. 4 the velocity changes are shown for electrons 180° out of phase with those shown in Fig. 3. It can be seen that this group of electrons gain as much velocity per electrons from the grid circuit as was lost per electron by the previous and larger group of electrons, but since this is the least numerous group of electrons, they will not extract as much energy from the grid circuit as the most numerous group of electrons added to it.

Following the same procedure we may take any other group of electrons as for instance the one leaving cathode 1 at time T_3 and arriving at grid 2'' at time T_4. This group of electrons loses more energy per electron than the group leaving at T_0, but there is a corresponding group leaving cathode 1 at time T_3', Fig. 4, and arriving at grid 2'' at the time T_4' which gains as much energy per electron from the grid circuit as the other group lost to it, but it will be noticed that the first mentioned group left the cathode when the grid was more positive than its mean value whereas the second group left the cathode when the grid was less positive than its mean value, and hence the first group will be more numerous than the second group and the combined effect of both groups will be to give up energy to the grid circuit. Similarly, other corresponding pairs of electron groups may be chosen till the whole cycle is covered, and it will be found that over much the greater part of the cycle the electron groups that deliver a given energy per electron to the grid circuit contain more electrons than the corresponding group that extracts the same energy per electron from the grid circuit. Of course the limited region in Figs. 3 and 4 in which the electrons that gain energy from the grid are more numerous than those that lose the same amount of energy to the grid, while representing an actual

loss of energy by the grid circuit, yet the amount of energy loss is proportional to the amount of energy lost per electron of the energy losing group, multiplied by the difference between the number of electrons in the energy losing group and the number in the energy gaining group, and by inspecting the diagrams it may be seen that this product is rather small and hence does not detract from the energy gained by the grid circuit over the entire cycle.

This is valid proof that the electron stream as a whole will deliver energy to the grid circuit, and hence the so-called active grid loss under these conditions will be negative in sign. This analysis does not, however, prove that the flight time above considered of the electrons passing from cathode to grid gives the maximum gain of energy from the electrons, and as a matter of fact it does not. However it constitutes a usable flight time, and in some cases a desirable one. The active grid gain in this case is not large, but in an amplifier an active grid gain large enough to cancel all other losses, and cause the circuit to oscillate may be desirable.

The largest active grid gain occurs when the flight time of the electrons between cathode and grid is somewhat greater than one-half cycle.

Due to the fact that the group of electrons, having the maximum gain of energy per electron, is not the most numerous group of electrons, and that the velocity of electrons increases from cathode 1 to grid 2'', and is influenced by space charge, an exact analysis is difficult to make.

Hence, the foregoing qualitative analysis is given in the belief that it is more understandable than an exact analysis would be if it were made.

This analysis neglects certain factors which should be noted here; firstly, it neglects the influence of space charge; secondly, it neglects the fact that the tubes shown have cylindrical symmetry, and therefore the field strength increases toward the cathode. The field strength in a space charge field between parallel plates increases approximately as $D^{1/3}$. These two neglected terms have opposite effects, and can be made to approximately cancel each other by choice of suitable ratios for the diameter of the cathode and the control grid. Another neglected factor is the grouping of electrons in the electron stream by the effect of fast electrons from the cathode tending to catch up on slow electrons that left the cathode at a slightly earlier time.

We will now consider the conditions which must exist between the grid and anode in order that the electron stream may deliver a maximum of energy to a resonant circuit of which the grid and the anode are a part.

Obviously, the greatest energy will be delivered to the grid-anode circuit when the line integral of fdD taken from grid to anode for the average electron has its greatest value, and this can always be made a maximum for a particular grid to anode spacing and potential difference by adjusting the phase relation between the grid-filament and the grid-anode circuit.

In the case just described, the most numerous group of electrons pass the grid when it is most negative with respect to the filament, and hence, if the electron flight time from grid to anode is short compared to a half cycle of the oscillating frequency, the grid-anode circuit should be substantially in phase with the grid-filament circuit, for under these conditions the motion of the most numerous group of electrons will be opposed by the strongest field, and hence retarded the most. If the flight time from grid to anode is an appreciable part of a half cycle, the phase in the grid-anode circuit should be somewhat retarded with respect to the grid-filament circuit, so that the most numerous group of electrons will enter the grid-anode interspace a little before the opposing field has reached its maximum, and will reach the anode a little after it has passed its maximum. Since the electrons are normally gaining velocity from the direct current field in the grid-anode interspace, and as has been said before, the work done on the electrons is the line integral of fdD taken from grid to anode, the field should reach its maximum somewhat after the middle of the time interval during which the most numerous group of electrons is passing from grid to anode.

In the above mentioned previous Patent No. 2,244,747, an arrangement was disclosed in which the electron transit time between cathode and grid was about ¾ cycle, and the flight time between grid and anode was preferably enough to bring the total flight time between cathode and anode to roughly 1¼ cycles. In that case the alternating fields between cathode and grid, and cathode and anode, were substantially 180° apart in phase. This gives substantially a maximum active grid gain. By reference to Fig. 3, it may be seen that a continuous transition from the case described in the present specification to the case described in Patent No. 2,244,747, is possible. At the time T_0—T_2 is lengthened, the phase of the grid-anode circuit should be shifted by the same fraction of a cycle that the flight time between cathode and grid is lengthened.

It is therefore apparent that if the flight time between cathode and grid lies between T_0—T_2 and a point beyond T_0—T_5, the active grid loss will be negative, and that for any flight time between or beyond these limits, a proper phasing of the electric field in the anode circuit, with respect to that in the grid circuit, will cause the electron stream to deliver maximum power to the grid-anode circuits.

In Fig. 2, suitable means are shown for obtaining all possible phase differences between the cathode-grid and grid-anode circuits. In this figure the cathode 1 and the conductor 3' form the inner member of a concentric line resonator, while grid 2'' and conducting tube 4' form the outer member of the concentric line resonator. Also, grid 2'' and conducting tube 4' form the inner member of a second concentric line resonator, of which grid-anode 5'' and conducting tube 6' form the outer member. If the mesh of the grid 2'' is fine, as would ordinarily be the case, and no other coupling means is supplied, the two resonators are independent of each other. If a coupling member, such as coupling conductor 7', is inserted between the two resonators, any desired degree of coupling may be obtained, and since members 8' and 9' which short the concentric lines for alternating current are adjustable, each concentric line resonator is separately tunable. As is well known in the art, the phase angle between the oscillations in two coupled resonant circuits may be varied by detuning one resonator slightly with respect to the other.

In a device such as has just been described, the energy with which an electron impinges on a conductor has no necessary relation to the potential of the conductor at the instant when the electron impinges. This is because the electric fields through which the electron passes change markedly while the electron is in transit. An-

other feature of the device shown in Fig. 2 is that the alternating electric fields are substantially completely confined within their respective concentric lines, and the electrons passing from the cathode through grid 2'' and anode 5'' pass completely out of the alternating electric field at anode 5'', and hence the alternating field will produce no further changes in electron velocity. The electrons therefore emerge from anode 5'' with varying velocity, and do not have these variations canceled in traveling from anode 5'' to detector plate 14', as would be the case with an ordinary permeable electrode excited in the ordinary way. It is therefore possible, for either of these reasons, to use a form of detector in the present invention which is inoperative in the usual type of tubes and circuits.

In Fig. 2, anode 5'' functions as efficiently in extracting energy from the electrons in transit between grid 2'' and anode 5'' as though it were an impervious cylinder of metal which stopped all the electrons striking it; hence, if oscillating fields exist in the tube, electrons will emerge into the space between anode 5'' and metal detector cylinder 14' with velocities different from those which they would have had if there had been no oscillating fields. If the oscillations are weak, as would be the case if the oscillations were caused by a weak signal picked up by antenna 12', there will be nearly as many electrons speeded up as are slowed down, and hence detection of the oscillations is most efficient when detector plate 14' is biased so that the difference in number of electrons caught by detector cylinder 14' when there are oscillations present, and the number caught when there are no oscillations present, is a maximum. There are two bias points that will meet these conditions, one when cylinder 14' is biased so most, but not all, of the electrons can strike it, and one when most but not all of the electrons cannot strike it. Cylinder 14' may detect either by stopping all the electrons striking it and allowing them to be conducted away by conductor 15, or by emitting an excess of secondary electrons when struck by primaries. If it is to operate by the first method, it should be made to emit as few secondary electrons as possible as by coating it with carbon, or by any other method of preventing emission of secondary electrons. If it is to operate by the second method, the more secondary electrons cylinder 14' can be made to emit the better.

The importance of the fact just mentioned that it makes no difference in the amount of work done on the field of the circuit by the electrons in a resonator whether the electrons, after passing through the field, are allowed to strike the wall of the resonator, i. e., anode 5'', or are caused to pass through small apertures in the wall or anode, cannot be over-emphasized, for this fact frees us from the well known requirement that a control grid must be negatively biased to prevent it from extracting energy from the grid circuit due to an alternating current produced by electrons striking the grid. In the device of Fig. 2, the grid-cathode resonator consists of the space within the concentric line of which cathode 1 and grid 2'' form part of the boundary, and it makes no difference whatever to the standing waves within this space what becomes of an electron after it has left the field contained in this space. Since this is true, it does not change the losses in the grid-cathode circuit to make grid 2'' positive and allow electrons to strike it.

We will now consider the effect produced by grid 2'' in removing some of the electrons upon the power delivered to the resonant circuit of which grid 2'' and anode 5'' are a part. In the first place, it is obvious that, if grid 2'' is positive, it will leave fewer electrons to excite the anode circuit. If grid 2'' removed an equal percentage of electrons throughout the cycle, the result would be a proportional reduction in the power delivered to the anode circuit. This would not be at all serious, but as a matter of fact the power reduction in the anode circuit will be less than this, and in some cases may even be reversed in sign. This is because there is a larger proportion of the electrons removed from the electron stream by grid 2'' when this grid is positive with respect to cathode 1, and it will be noted that electrons passing grid 2'' in this phase relation extract energy from the anode circuit instead of adding energy to it, and hence the more electrons of this phase relation removed by the grid the better. Hence, since the direct current conductance of grid 2'' is a measure of the electron current removed by grid 2'' over the whole cycle, and the alternating current conductance is a measure of the current removed as a result of the alternating potential on grid 2'', the removal of electrons by grid 2'' will benefit the anode circuit if the alternating current conductance exceeds the direct current conductance. This is not likely to be true in general, but the alternating current conductance may be counted on to minimize the loss in power caused by the direct current conductance of grid 2''.

In Fig. 5 is shown an alternative method of producing an oscillator. The basic mode of operation is the same as in Fig. 2. In Fig. 5, cathode 1 and grid 2'' are used as in Fig. 2. Element 18' is a cylinder serving the same purpose as anode 5'' in Fig. 2. In this figure the flight time of electrons between cathode 1 and grid 2'' is preferably arranged to be about a half-cycle, and the flight time between grid 2'' and cylinder 18' is preferably less than a quarter-cycle. An annular inwardly projecting flange 19 is provided on cylinder 18', and serves to form a condenser with an annular ring 20, which is attached to the low ends of the grid wires of grid 2''. Annular ring 20 in turn forms a condenser with an annular ring 21, which latter ring is attached to the cathode 1. By means of these two condensers, the alternating current potential is divided so that the potential between cathode 1 and grid 2'' is a certain fraction of the potential between cathode 1 and cylinder 18', and is substantially in phase with it. Cylinder 18' and cathode 1 and the lower cylinder 22, which is a continuation of cathode 1, form a resonant concentric line which is closed by member 8', which serves the same purpose as members 8' and 9' in Fig. 2. A resistor 23 connected between grid and cathode acts as the grid leak resistance generally used in a conventional oscillator. Resistor 23 is connected to cathode 1 through a wire 24, and cylinder 18' is connected to the positive terminal of a battery 25. Cathode 1 is heated in the usual way by an indirect heater 26 which is energized by a battery 17. Since the phase relations between the various elements of the tube shown in Fig. 5 correspond to those in Fig. 2, it will be clear that the electrons will deliver energy to the fields in the same way as in Fig. 2. Energy can be re-

moved from the concentric line 22—18' as by loop 11'.

In Fig. 6 there is shown a somewhat different type of oscillator which makes use in a novel way of the well known so-called space-charge grid. In this figure, 1 is the thermionic cathode as before. Element 27 is a grid, which may be omitted if desired. Its function is to limit the electron emission from the cathode, but it does not develop alternating current potentials with respect to the cathode. In the drawing it is shown as electrically connected to the cathode, but in use it may be given any convenient fixed potential with respect to the cathode, as by a battery 17' as shown in Fig. 8. An accelerating grid 28, concentric with grid 27, may be given any desired positive bias by battery 27', and the electron space current in the tube can be fixed independently of the bias on grid 28 by properly biasing grid 27. Grid 28 is positively biased with respect to cathode 1, but in the proper functioning of the tube there is no alternating current potential between grid 28 and the cathode 1.

A grid 29, exterior of and concentric with grid 28, is connected so as to be at substantially cathode potential so that a large part of the electrons passing through grid 28 are brought to rest and repelled back toward this grid. The distance between grids 28 and 29, and the average velocity of the electrons between grids 28 and 29, determine the flight time of the electrons between those grids. The average velocity of the electrons between grids 28 and 29 is determined by the potential difference between cathode 1 and grid 28. For the best functioning of the oscillator shown in Fig. 6 this flight time between 28 and 29 should be substantially a half-cycle of the resonant frequency of the circuit connecting grids 28 and 29, although a considerable departure from this value is possible

The electrons will emerge into the interspace between grids 28 and 29 evenly distributed in time, and since the changes in electron velocity in this space caused by the alternating current field existing in the concentric structure existing between grids 28 and 29 is generally small compared to the average velocity of the electrons, the electrons will remain substantially uniformly distributed in time throughout this space except in the vicinity of the region where electrons are stopped and turned back, and this region is so close to grid 29 that the work done on the electrons from this point to grid 29 may be neglected. Hence, we can say that of the electrons traveling from grid 28 to grid 29, there are as many accelerated as retarded by the alternating current field between grids 28 and 29, and hence the average work done by the alternating current field is negligible. But the electrons which have been accelerated between grids 28 and 29 have a better chance of penetrating beyond grid 29 than the electrons that have been decelerated, and hence there will be fewer of these electrons returning from grid 29 to grid 28 than there are of the electrons that have been decelerated. Therefore, the electrons returning from grid 29 to grid 28 will not be uniformly distributed in time.

In Fig. 7, these conditions are illustrated graphically. The electrons that left grid 28 at time T_0 are the ones most accelerated, and the area under the sine curve between T_0 and T_1 is a measure of the velocity gained by this group of electrons in traversing the distance between grids 28 and 29. The velocity lost by the electrons most decelerated is represented by the area under the sine curve between times T_1 and T_2. Since there will be fewer of those electrons that left grid 28 at time T_0 returning to grid 28 from grid 29, and more nearly the full number of those electrons that left grid 28 at time T_1 returning to grid 28 from grid 29, there is a sinusoidal component of electron current density returning to grid 28 from grid 29. The maximum of this current of electrons will leave grid 29 at approximately T_2, and they will arrive at grid 28 at time T_3, and since grid 28 has been more positive than its mean value during the interval T_3—T_2, the electrons of this group will lose energy to the grid control circuit between grids 28 and 29; moreover, the energy they will lose will be a maximum.

If the electrons passing through grid 29 were merely thrown away, energy would be derived from the electron flow by the circuit of which grid 28 and 29 are a part, and this circuit would with a suitable current break into oscillation. However, the electrons that pass through grid 29 are not thrown away, but are caused to do further useful work.

This will be apparent when the operation of an electron-permeable anode or anode-grid 30 exterior of grid 29 is understood. As is shown in Fig. 6, the concentric line resonator consisting of grids 28 and 29 and the conducting cylinders 28' and 29'' connecting them is independent so far as currents of its resonant frequency are concerned, from the adjoining concentric line resonator consisting of grid 29 and anode 30, and the conducting cylinders 29'' and 30' connecting them. Hence, if an alternating current of the frequency of the last mentioned resonator flows from grid 29 to anode 30, oscillations will spontaneously develop in the resonator of such phase as to extract a maximum of energy from the alternating current flowing from grid 29 to anode 30. If the tube in Fig. 6 is operated in this way, it is equivalent to an oscillator operating a power amplifier which is electron-coupled to the oscillator. If desired, a coupling may be inserted between the two concentric line resonators as is also shown in Fig. 2. This may be required if it is desired to produce oscillations with a current smaller than that necessary to cause the circuit of which grids 28 and 29 are a part to oscillate without help. If the device shown in Fig. 6 is used as an oscillator, the energy may be radiated by antenna 10, as shown in Fig. 6A, exactly as in the cases of the device of Fig. 2A. If it is to be used as a receiver, the signal may be received on antenna 12'. It is not intended that the receiving and transmitting antenna be used on the same device.

If the device is used as a receiver, it may be used either as a regenerative detector or as an oscillator-detector. It is probably more sensitive as an oscillator-detector. The circuit consisting of grids 28 and 29 and the connecting conductors is allowed to oscillate, and a signal of a slightly different frequency is introduced from antenna 12'. The beats between these two frequencies cause the amplitude of oscillation to periodically vary, and this periodically varying oscillation will be amplified in the resonator consisting of grid 29 and anode 30 and their connecting conductors. The electrons after losing energy to the aforementioned resonant circuit will pass through

anode 30, and encounter an opposing unidirectional field between anode 30 and a grid 31. Grid 31 is supplied with a relatively low direct potential by potentiometer 31 connected across battery 17. The unidirectional field between anode 30 and grid 31 is of such strength that many of the electrons that are slowed down between grid 29 and anode 30 will be turned back, and since the number of electrons turned back will be dependent on the amplitude of oscillation in the circuit of which grids 28 and 29 are a part, the current flowing from cylinder 32 through a pair of connected earphones 33 will be a function of the amplitude of oscillation in the circuit of which grids 28 and 29 are a part. Thus, the incoming signal is detected.

The detector shown in Fig. 6 is different from the one shown in Fig. 2, but it operates on the same principle, namely that of discriminating between electrons according to the velocity with which they penetrate the respective preceding grids. It may be here emphasized that this type of detection is not used in existing three-electrode tube practice, nor is it usable in such practice without special circuit design.

It should be mentioned at this point that, in all the figures, the grids or other permeable electrodes have been shown with wires widely spaced so as to minimize confusion in the drawings. In actual tubes, the electrodes would in general contain considerably more wires.

Fig. 8 illustrates an alternative arrangement of the device shown in Fig. 6, the only difference being that the control grid 29 is not a part of a concentric line resonator as in Fig. 6, but receives its alternating current potential by capacity coupling through annular rings 19, 20, and 21 as in Fig. 5, where similar parts bearing the same numbers serve the same purpose. Thus it will be apparent that the condenser rings of Fig. 5 may be used in lieu of the concentric lines provided in Figs. 2 and 6. Grid 28 is conductively connected through resistor 23 to a suitable point on the battery. All other parts may be readily identified by reference to Fig. 6 without further explanation.

The type of detection made use of in the device described in Fig. 6 may be used at long wave lengths as well as at very short wave lengths, and without the use of concentric line resonators, if desired. The only requirement to obtain this end is that there must not be a difference of alternating potential between the velocity-discriminating grid, as 31 of Fig. 6 and the grid 30 performing the function of the anode in an ordinary tube, which is the inverse of the alternating potential difference between the cathode and anode 30.

As many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. High frequency apparatus comprising a cathode electrode, an anode electrode, and a grid electrode, all said electrodes being in alignment for passage of an electron stream therebetween, a cavity resonator connected to said cathode electrode, means coupled to said anode electrode for supplying an alternating potential to said grid electrode derived from the potential of said anode

electrode, whereby said grid and anode electrodes have potentials with respect to said cathode electrode which vary in phase, and means for projecting a stream of electrons from said cathode electrode through said grid electrode to said anode electrode.

2. High frequency apparatus comprising a cathode electrode, an anode electrode, and a grid electrode, a cavity resonator connected to said cathode electrode, means coupled to said anode electrode for supplying an alternating potential to said grid electrode derived from the potential of said anode electrode, whereby said grid and anode electrodes have cophasal potentials with respect to said cathode electrode, and means coupled to said electrodes for projecting a stream of electrons from said cathode electrode through said grid electrode to said anode electrode.

3. High frequency apparatus comprising a cathode electrode, a grid electrode and an anode electrode, all said electrodes being in alignment, means defining a cavity resonator connected to said anode electrode, means coupled to said anode electrode for supplying an alternating potential to said grid electrode derived from said anode electrode, whereby the potentials of said grid and anode electrodes with respect to said cathode electrode vary in phase, and means for projecting a stream of electrons from said cathode electrode through said grid electrode to said anode electrode.

4. High frequency apparatus comprising a cathode electrode, a grid electrode and an anode electrode, means defining a cavity resonator connected to said anode electrode, means coupled to said anode electrode for supplying an alternating potential to said grid electrode derived from said anode electrode, whereby the potentials of said grid and anode electrodes with respect to said cathode electrode vary cophasally, and means coupled to said electrodes for projecting a stream of electrons from said cathode electrode through said grid electrode to said anode electrode.

5. High frequency apparatus comprising a cathode electrode, a grid electrode and an anode electrode, all in alignment, means for projecting an electron stream from said cathode through said grid to said anode, and means coupled between said anode and grid electrodes for causing the potentials of said anode and grid electrodes with respect to said cathode to vary in phase.

6. High frequency apparatus comprising a cathode electrode, a grid electrode and an anode electrode, means coupled to said electrodes for projecting an electron stream from said cathode through said grid to said anode, and means coupled between said anode and grid electrodes for causing the potentials of said anode and grid electrodes with respect to said cathode to vary cophasally.

7. High frequency apparatus as in claim 1, wherein said potential-supplying means comprises a capacitative voltage divider including a capacitance connected between said grid and anode electrodes.

8. Apparatus as in claim 3, wherein said potential-supplying means comprises a capacitative voltage divider including a capacitance connected between said grid and anode electrodes.

9. In a thermionic vacuum tube having an evacuated envelope and circuit, a cathode for producing a stream of electrons, an anode, a control grid in said evacuated envelope, a resonant circuit connected between said cathode and said anode for establishing an alternating electric field

in the space between said cathode and anode, a condenser connected between said anode and said grid, and a second condenser connected between said grid and said cathode, the capacity of said condensers being chosen to give said grid a desired alternating potential intermediate the alternating potentials of said anode and cathode, whereby said grid cooperates to effect space charge control of said electron stream to cause the controlled electron stream to give up energy to said resonant circuit.

10. In a thermionic tube having an evacuated envelope and circuit, a cathode, an anode, and a control grid in the evacuated envelope, a concentric line connected between said cathode and said anode and including said cathode and anode as a portion thereof, a condenser connected between said anode and said grid, and another condenser connected between said grid and said cathode, said condensers serving to establish an alternating control potential on said grid that is intermediate the potentials of said anode and cathode, said concentric line serving to establish an oscillating electric field traversing the anode-cathode interspace.

11. In a thermionic tube having an evacuated envelope and circuit, a cathode, an anode, and a control grid in an evacuated envelope, a concentric line connected between said cathode and said anode and projecting beyond the confines of said envelope and including said cathode and anode as a portion thereof, a condenser connected between said anode and said grid, another condenser

connected between said grid and said cathode, said condensers serving to establish an alternating control potential on said grid that is intermediate the potentials of said anode and cathode, said concentric line serving to establish an oscillating electric field traversing the anode-cathode interspace, and tuning means provided in the portion of said concentric line projecting beyond said envelope.

12. An oscillator comprising a cathode, a grid and an anode, means for projecting electrons from said cathode through said grid and said anode, a resonant circuit coupled between said cathode and said anode, and means coupling said grid to said circuit to produce a cathode-grid voltage cophasal with the grid-anode voltage.

13. An oscillator as in claim 12 wherein said electron projecting means provides a cathode-grid electron transit time of about a half-cycle at the operating frequency, and a grid-anode transit time of less than a quarter-cycle at said frequency.

14. An oscillator comprising means for producing a beam of electrons, a grid and an anode along the path of said beam, a resonant circuit coupled to said anode, and means including a coupling connected between said grid and said circuit for producing co-phasal potential gradients on either side of said grid.

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No references cited.