

July 14, 1942.

A. G. CLAVIER ET AL

2,289,756

ELECTRON TUBE AND CIRCUITS EMPLOYING IT

Original Filed May 27, 1938

3 Sheets-Sheet 1

Fig. 1.

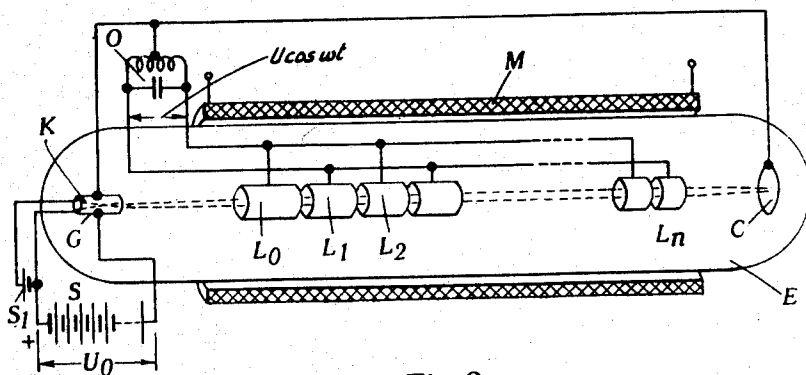


Fig. 2.

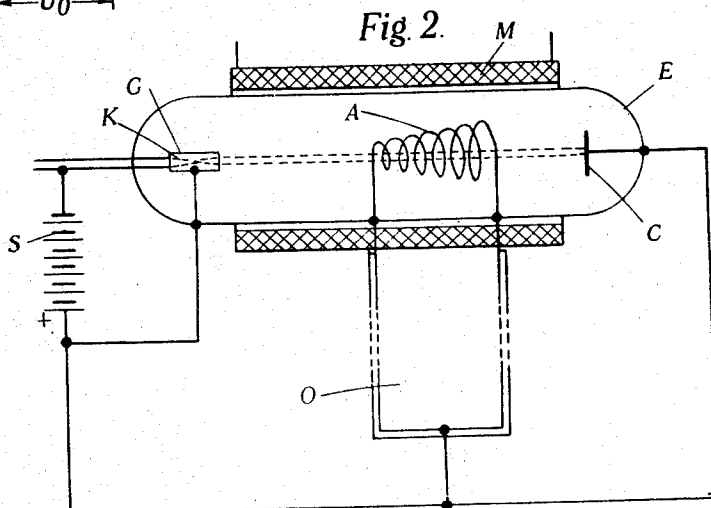
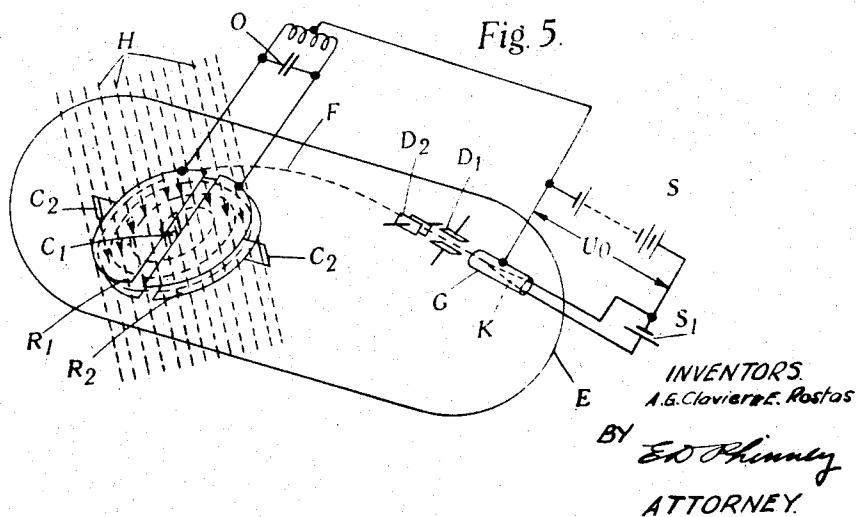


Fig. 5.



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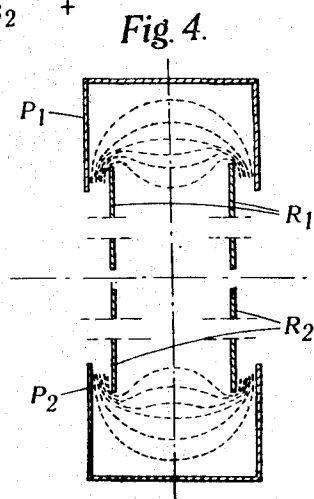
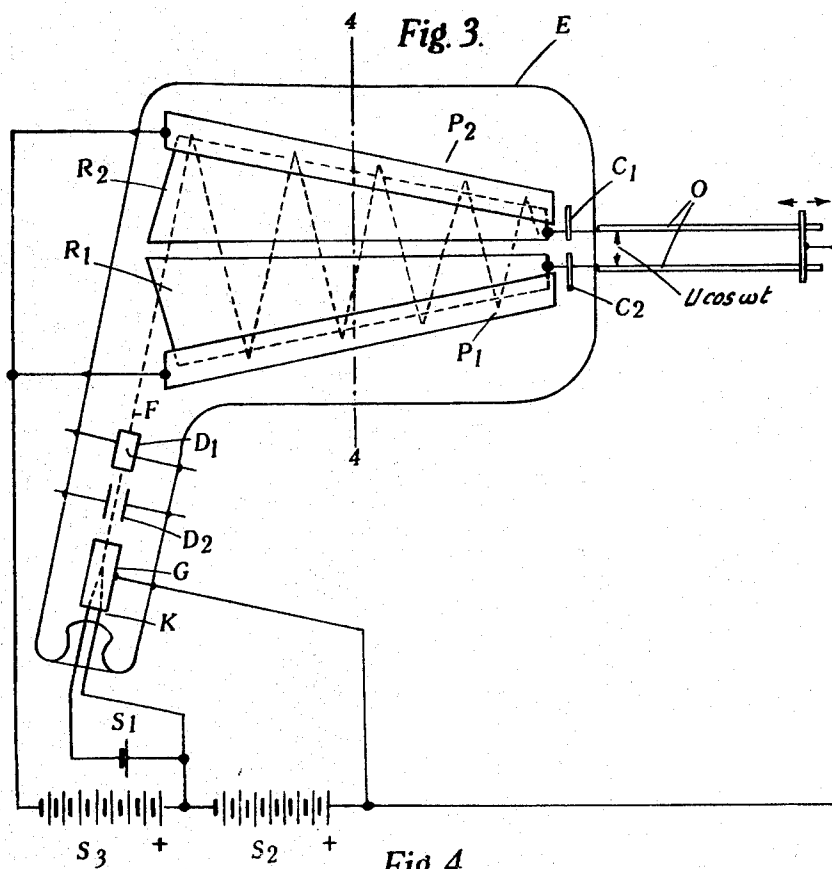
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3 Sheets-Sheet 2



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3 Sheets-Sheet 3

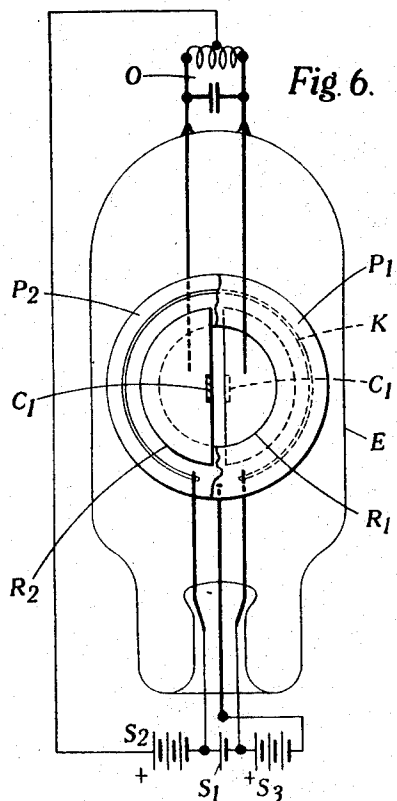


Fig. 6.

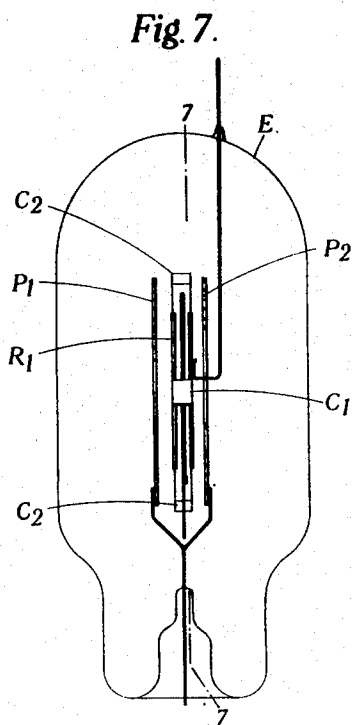


Fig. 7.

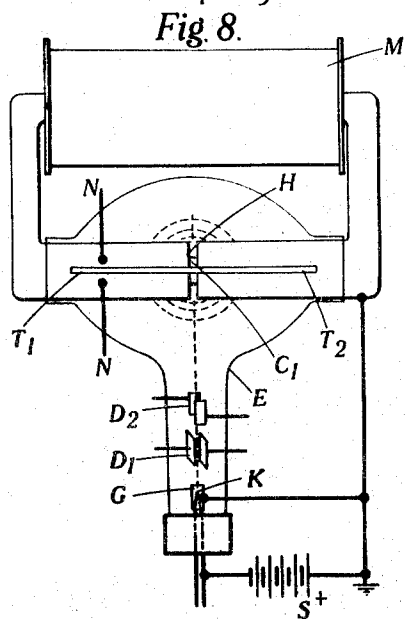


Fig. 8.

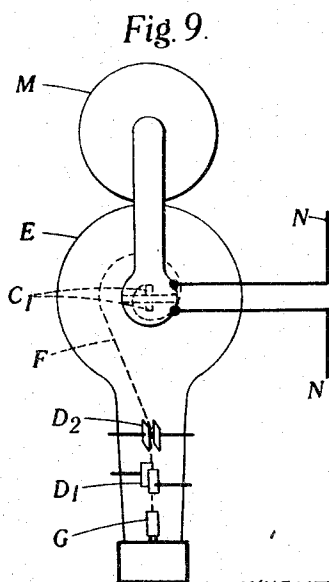


Fig. 9.

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UNITED STATES PATENT OFFICE

2,289,756

ELECTRON TUBE AND CIRCUITS EMPLOYING IT

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Original application May 27, 1938, Serial No. 210,332. Divided and this application June 9, 1939, Serial No. 278,207. In France May 29, 1937

1 Claim. (Cl. 250—157)

The present invention relates to new electron tubes and their utilisation and to circuits employed with such tubes.

The present application is a division of my copending application Ser. No. 210,332, filed May 27, 1938, for "Electron tubes and circuits employing them."

One of the objects of the invention is to improve the output and operation of ultra-high frequency systems, for example, employing frequencies corresponding to wave lengths of the order of the decimeter, the centimeter or even of values considerably lower as well as frequencies of higher wavelength.

In order to understand the nature of the present invention, it seems well to make some remarks with regard to the output of the electron tubes employed in particular as oscillators.

The output of the normal oscillator or amplifier tubes, that is to say, those in which the time of transit of the electrons remains short with respect to the period of the oscillation, is all the greater if the alternating tension between electrodes is a fraction higher than the direct tension in the source of supply (the output impedance being assumed to be ohmic).

By applying this reasoning to tubes in which the time of transit of the electrons is comparable to the period, there will be found a double limitation of the output of these tubes. The first is the difficulty in achieving output circuits of a sufficient impedance to obtain these high tensions. This limitation is not directly bound up with the use of electronic oscillators. It is simply due to the high frequencies which it is attempted to use.

The second on the other hand is directly connected with the method of operation of the tubes. One of the conditions necessary for the operation of the present tubes is that the time of transit of the electrons should not depart too much from a mean suitable value related in a fixed manner to the period. Now, this type of transit depends upon the value of the alternating tension superposed on the direct tension. Inasmuch as the high frequency tension is small with respect to the direct tension, the above condition is fulfilled. If it becomes comparable with the direct tension it considerably modifies the time of transit of the electrons which leave at different moments in the period, and thus limits the amplitude of the oscillation. It will consequently be seen that the high frequency tension must always remain small in proportion to the direct tension. In accordance with this

reasoning the output of the electron tubes will thus seem theoretically limited to low values.

It is found, however, that the condition offered by normal tubes of only being able to lead to a good output if the alternating high frequency tension becomes comparable with the direct tension is not inevitable in the case of electronic oscillators. This will be seen by considering not the output but the losses in the tubes and by seeking for the condition which leads to the minimum losses, that is to maximum output.

In the case of tubes in which the time of transit is negligible, the losses are defined at any moment by the product of the tension and of the instantaneous current, or more exactly by the product of instantaneous current multiplied by the speed of the electrons (expressed in volts) arriving at any moment on the positive electrode. Inasmuch as the time of transit of the electrons is negligible the two expressions are equivalent since in this case the speed of the electrons arriving on the positive electrode is equal to the tension of this electrode.

In the case in which the time of transit is comparable with the period the speed of the electrons arriving on an electrode is not always that corresponding to the potential of this electrode. This speed may be higher or lower than the speed corresponding to the tension of this electrode. The difference of speed in proportion to the case of a negligible time of transit may become great, in spite of a low high frequency tension, in the case in which the electrons oscillate several times in the high frequency fields before arriving on the electrode. It will be seen that the instantaneous losses in such a tube are no longer given by the product of the instantaneous current by the instantaneous tension. They may be greater or smaller. This difference is supplied or absorbed by the oscillatory circuit. The output of the tube thus no longer depends in the same way on the high frequency tension on the terminals of the load. The output is increased if the speed of the electrons on arrival on the electrode is smaller than that corresponding to the potential electrode; it is reduced if the speed is increased.

The present invention provides arrangements in which the electrons are systematically slowed down by one or more feeds of high frequency, and thus supply energy in one or more oscillatory circuits, losing it themselves.

The present invention in accordance with one of its aspects thus permits the said limitations to be overcome; among others it provides an

electron tube particularly adapted to the generation of ultra-high frequency waves, employing one or more electronic bundles associated with such means that the average speed of the electrons of each bundle upon their arrival on a target-electrode is less than the speed which corresponds to the difference of potential between the source of electrons and the target.

In accordance with one feature of the invention these arrangements are such that the retardation of the electrons is produced in the system repeatedly under the action of the same high frequency field, or fields, so as to increase the total energy given by the electrons concerned to the oscillatory circuit.

In accordance with another feature of the arrangement under consideration, the retardation of the mean speed of the electrons is produced by the magnetic or electro-magnetic high frequency field sustained by the energy given up by the slowing down of the average speed of the electrons.

The invention is not limited to the generation of ultra-high frequency waves and the tubes described here may be adapted to be employed for the generation amplification or detection as well as for various other applications, such for example, as in oscillographic systems or television systems, or for measuring apparatus.

The invention will be explained in detail in the case of the generation of ultra-high frequency waves, and indications will be given with regard to its employ in other fields.

The present invention will be better understood by means of the following description based on the attached drawings in which:

Fig. 1 represents an example of a tube incorporating the features of the invention in which the retardation of the electrons is ensured by means of auxiliary cylindrical electrodes;

Fig. 2 is a modification of the device of Fig. 1 in which the retardation of the electrons is obtained by means of a wire wound in a conical spiral;

Fig. 3 shows a particular embodiment of the invention in which the electronic bundle advances in a zig-zag path; and

Fig. 4 is a section of the guide electrode structure of the device of Fig. 3, along the line 4-4;

Fig. 5 shows a device in accordance with certain features of the invention employed in the magnetic field to guide the bundle along the spiral;

Figs. 6 and 7 show a modification of the arrangement of Fig. 5 in which the electron emission takes place in one plane; and

Figs. 8 and 9 represent another modification of the device of Fig. 5 employing pole pieces of a magnet as electrodes for retarding the electrons.

Referring to Fig. 1, an envelope E in which vacuum is made contains an electron gun G of the usual type which supplies a bundle of electrons passing through a succession of cylindrical electrodes L_0 , L_1 , L_2 etc., of decreasing lengths and whose axis coincides with that of the bundle. These electrodes are alternately connected to the two poles of an oscillatory circuit O which can alternatively be composed of a line having a length of approximately a quarter wavelength, or a whole multiple of a quarter wavelength. At the end of the cylindrical electrode structure is a target electrode C. The electron gun G and the cathode K which co-operates therewith are respectively fed by sources of tension S, S_1 . The gun G, the middle point of the oscillatory cir-

cuit O and the target C are connected and brought to the same direct potential. A longitudinal magnetic field produced by the coil M will be employed to assist in the concentration of the bundle.

Assuming that the oscillatory circuit has already a certain tension $U \cos \omega t$ let us consider an electron passing from the inside of the electrode L_0 to the inside of the electrode L_1 at the moment of the maximum of the high frequency tension and at the instant when the first electrode is positive with respect to the second. The electron will be retarded by a value corresponding in volts to the tension U. If the length of the electrode L_1 is such that the electron thus retarded passes through it in a half period it will again be retarded by the same value U in electron-volts, passing from the electrode L_1 to the electrode L_2 and so on. Finally, after having undergone a certain number of times the same retardation it will fall on a plate C and be eliminated.

It will be seen that the length of the electrodes should decrease in accordance with the following law:

$$L = L_0 \sqrt{\frac{U_0 - nU}{U_0}}$$

The linear speed of the electron is:

$$v = \sqrt{\frac{2e}{m}} U_0$$

or, taking into consideration the constants: $v = 0.6 \times 10^8 \sqrt{U}$ volts cm./sec. It is desired that the electron should pass through the electrode L_1 in a half period, hence:

$$L_0 = 0.6 \times 10^8 \sqrt{\frac{U_0}{2f}}$$

and

$$L_n = \frac{0.6 \times 10^8}{2f} \sqrt{U_0 - nU}$$

It will be seen that for the construction of the tube it is already necessary to choose in advance the tension U in the terminals of the oscillatory circuit, or rather the ratio between the supply tension U_0 and the tension U. This ratio determines the law in accordance with which the lengths of the successive electrodes must decrease.

If all the electrons clear the interval between the electrodes L_0 and L_1 at the moment of the maximum of the retarding tension, they will finally be retarded in n times the value U. The output of the tube would be

$$= \frac{nU}{U_0}$$

Actually, the passage of the electrons takes place in a continuous manner. If we take $\omega t = \varphi$, the retardation undergone by an electron passing from the electrode n to the electrode $n+1$ at the moment corresponding to the phase φ we get:

$$\Delta v^2 = \frac{2e}{m} U \cos(\varphi_n - n\pi) = (0.6 \times 10^8)^2 \Delta U$$

The mean retardation of the electrons passing the first interval is zero. The number of electrons having undergone a certain retardation is equal to the number which have undergone an acceleration of the same value.

At the second interval, however, the electron current is no longer uniformly distributed in time. The electrons having undergone a retardation equal to U volts take a half period to pass through the electrode L_1 and will be retarded by U in passing L_1 to L_2 . The electrons which have

undergone an acceleration of U volts take less than a half period to pass through the same electrode and will, consequently, undergo an acceleration smaller than U volts in passing from L_1 — L_2 . It will be seen that on the average a retardation is found.

The complete calculation of the operation of the tube shows that even for a tension of the oscillatory circuit different from that for which the lengths of electrodes have been established, the electronic bundle supplied energy to the oscillatory circuit. In particular, the bundle supplies energy for as small high frequency tensions as desired which indicates that the tube can be started like an oscillator.

In the particular case of a tube in which the length of the electrodes has been established for a ratio $U/U_0=1/12$ and having seven cylindrical electrodes, the output is 13% if the efficient output tension is equal to $U/\sqrt{2}$. If the output tension is equal to $2U/\sqrt{2}$, the output is 18%, and if the output tension is $U/2\sqrt{2}$, the output is 3%. If we bring the number of electrodes to thirteen, that is to say, to the maximum possible for $U/U_0=1/12$, the respective outputs become 13%, 35% and 25%.

It is clear that in the case in which the total length of the tube is comparable with the wave length of the oscillation the law given previously for the calculation of the lengths of the successive electrodes must be modified taking into consideration the distribution of the tension along the tube.

In the tube shown in Fig. 1 in which the spaces between the electrodes are short with respect to the length of the electrodes the electrons are only in the high frequency field during a small portion of their journey. If the wave length to be produced is very short such tubes are difficult to carry out. In this case it is preferable to make use of the electric field of a stronger wave on a tuned line. An embodiment employing this means is shown in Fig. 2.

In this figure the electron gun G , target C and the middle point of the tuned line O are connected to the same source S so as to have the same direct potential as in the case of Fig. 1. An auxiliary concentrating magnetic field can also be provided.

The tuned line is composed of a wire wound in a conical spiral and associated with an outside circuit O . By means of this outside circuit stronger waves are created on this spiral. As the nodes (or tension loops) are at equal distances along the wire forming the spiral the axial distance of these nodes (or loops) decreases from left to right in the example shown. We thus get a high frequency stationary axial field whose tension loops are more and more close to each other going from left to right, and the electron bundle will undergo a retardation similar to that which it undergoes in the tube, Fig. 1.

Fig. 3 represents another embodiment of a device for the systematic retardation of the electrons comprising an evacuated envelope E in which are arranged an electron gun G , two pairs of deflecting plates D_1 , D_2 operating in the ordinary way to produce and define an electron bundle and two pairs of metal retarding plates R_1 , R_2 respectively associated with metallic reflecting electrodes P_1 and P_2 . Fig. 4 shows a section of this figure along the line 4—4, Fig. 3. The oscillatory output circuit O composed, for example, of a Lecher line is connected to each pair

of retarding electrodes, and its middle point is connected to the electron gun G . The reflecting electrodes are connected to a source S_2 of potential negative with respect to the cathode. Targets C_1 , C_2 are placed on the two Lecher wires at the end of the structures.

The bundle of electrons F passes between the electrodes R_1 parallel to the surface of these electrodes, passes through the interval between the electrodes R_1 and the electrodes R_2 at a certain angle different from 90° , then passes between the electrodes R_2 . On its approach to the reflecting electrode P_2 at the outer edges of the electrodes R_2 the bundle is returned to the space between R_2 as shown, again passes between the plates R_1 and is returned by the electrode P_1 . The bundle thus advances in zig-zag along the structure in order finally to strike one of the targets C_1 or C_2 .

A tension $U \cos \omega t$ is assumed to exist between the pairs of electrodes R_1 and R_2 . If the time between the two successive passages through the interval between the electrodes R_1 and R_2 is a half period the electrode will be retarded on each journey if it has been retarded on the first journey. If the form of the electrodes is suitably chosen we then find in consequence of considerations similar to those given for the tube of Fig. 1 that the electrons will be retarded on the average and will consequently supply energy to the oscillatory circuit composed of the tuned transmission line O .

If the form of the reflecting electrode P_1 or P_2 is suitably chosen the electro-static field between the main electrode and the reflecting electrode is such that it forms an electronic lens assisting to maintain the concentration of the electron bundle. This field is represented schematically in Fig. 4 by means of its equipotential lines.

Fig. 5 to which we will now refer gives an embodiment of an electron retarding tube with a magnetic deflecting field.

In this drawing an envelope E in which vacuum is made contains an electron gun G associated with the pairs of ordinary deflectors D_1 and D_2 , and retarding electrodes F_1 and R_2 . An oscillatory output circuit O connected to the plates R_1 and R_2 has its middle point in the same potential as the electron gun G .

Each retarding electrode is formed of two plane parallel half discs close together, connected at the middle of their rectilinear edges by a small plate serving as target C_1 . The half discs also support by radial connections a target C_2 at one point of their periphery. As will be seen later on, these latter targets are not indispensable.

The operation of such a tube is as follows:

The two formulae relating to the movement of the electrons in a plane perpendicular to a uniform magnetic field H and in a space devoid of electric field are as follows:

1. The path of the electrons is the radius of a circle:

$$\rho = \frac{m v}{e H}$$

in which

$$\rho = 3.37 \sqrt{\frac{t}{P}} \text{ cm.}$$

U being the speed of the electrons in electron volts and H the magnetic field in gauss.

2. Their angular velocity is:

$$\omega = 1.76 \times 10^7 H \text{ sec}^{-1}.$$

It is independent of the speed of the electrons employed.

The two electrodes R_1 and R_2 are placed in a uniform magnetic field H perpendicular to the plane of the electrodes. The frequency proper f of the oscillatory circuit O is equal to:

$$f = \frac{\omega}{2\pi} = \frac{1}{2\pi} 1.76 \times 10^7 H$$

An electron bundle F is thrown perpendicularly into the magnetic field and tangentially with respect to the circle formed by the two electrodes. The speed of the electrons of the bundle is given in electron-volts by:

$$U_0 = \left(\frac{rH^2}{3.37} \right)$$

r being the external radius of the electrodes.

Let us recall the term: $\omega = 1.76 H \times 10^7$. The electrons will describe a semi-circle in the period

$$\pi = \frac{1}{2f}$$

independent of their period. If an electron has crossed the separation between one side of the two electrodes at the moment t_1 , it will pass a second time through the separation of the other side of the electrodes one half period later and so on, that is to say, it will pass the separations at the same portion of the period.

If the electron passes the first time from one electrode to the other at the moment when it is retarded, it will be retarded in all the successive journeys. As moreover, its speed decreases on each journey the radius of its path also decreases and it will describe a spiral which will get nearer to the centre of the electrodes.

If, on the other hand, the electron passes the separation the first time at the moment when it is accelerated it will be accelerated each time it passes by the same value, in volts; it will describe a spiral which gets further and further from the centre of the electrodes. This acceleration takes place at the expense of the energy of the oscillatory circuit in the same way that the retardation takes place to the benefit of the energy in the oscillatory circuit.

It is sufficient to limit the diameter of the paths of the electrons in order to limit the energy taken up by the accelerated electrons. This limitation takes place automatically by the limited diameter of the electrodes, but it can also be obtained by placing targets in the path of the accelerated electrodes. It is also possible to fix a lower limit to the speed of the electrons by means of targets C_1 in the path of the retarded electrons.

This latter target C_1 thus determines the smallest radius of curvature of the paths in the retarded electrons. The ratio between the speed of the electrons before entering the retarding system and the speed of the electrons on the arrival at the internal target C_1 is given by:

$$\frac{U_0}{U_{\min}} = \frac{r^2}{r_{\min}^2}$$

$r_{\min}$ being the distance at the centre of the retarding system to the edge of the target C_1 .

In the same way the maximum speed of the accelerated electrons is given by:

$$\frac{U_0}{U_{\max}} = \frac{r^2}{r_{\max}^2}$$

$r_{\max}$ being the distance from the centre to the internal edges of the targets C_2 .

As half the electrons are accelerated and the other half retarded the theoretical output of this tube is given by the expression:

$$\pi = 1 - \frac{r_{\min}^2 + r_{\max}^2}{2r^2}$$

In order that this may be upheld it is necessary that:

$$r_{\min}^2 + r_{\max}^2 < 2r^2$$

which is easily realised.

If this latter condition is fulfilled as well as the conditions which relate the intensity of the field to the proper frequency of the oscillatory circuit, and the feed tension to the magnetic field and to the external radius of the retarding electrodes, the electrons supply energy to the oscillatory circuit.

Figs. 6 and 7 represent another embodiment incorporating features of the invention.

An evacuating envelope E contains a hot circular cathode K of any known suitable type, placed between two annular plane reflecting electrodes P_1 and P_2 concentric with the cathode. Between the plane of the cathode and the reflecting electrodes are arranged two electrodes R_1 and R_2 similar to those of Fig. 5, and provided with central targets C_1 and peripheral targets C_2 . The oscillatory circuit O is connected to the half-discs R_1 and R_2 and its middle point is connected to the positive side of the direct source S_2 . The source S_3 maintains the electrodes P_1 and P_2 at a negative potential with respect to the cathode. The whole of the device is placed in a uniform magnetic field of suitable intensity perpendicular to the plane of the electrodes.

The operation of the device is similar to that of the device of Fig. 5 with the exception that the cathodic emission takes place in the plane of the cathode towards the centre. The electrodes P_1 and P_2 serve to prevent the emission of the electrons outside the plane of the cathode.

Figs. 8 and 9 show another modification of the tube structure shown in Fig. 5.

The electron gun G and the pairs of deflecting plates D_1 and D_2 supply a thermionic bundle which may be exactly directed towards and to one side of a gap between two pole-pieces with preferably circular section T_1 and T_2 of a magnetic substance covered with a layer of good conducting metal such as copper, silver etc.; these pieces are of such shape that at the same time they constitute the retarding electrodes corresponding to the electrodes R_1 and R_2 of Fig. 5 and two tuned transmission lines forming an output oscillatory circuit. For this purpose the pieces T_1 and T_2 are longitudinally split as shown. The length of these splits is approximately equal to a quarter or to a whole multiple of a quarter of the operative wave length. Targets C_1 preferably of non-magnetic material, are provided near the centre of the air-gap. Targets similar to the targets C_2 in Fig. 5 can also be provided outside the air gap. The pole pieces T_1 and T_2 pass in vacuum tight fashion through the walls of the envelope E . A magnetic field is produced in the air gap either by means of an electro-magnet M , or by means of permanent magnets. The source S is connected between the cathode K and the electron gun G which is directly connected to the body of the two pole pieces.

The coupling with a loading circuit, such for example as a dipole antenna, can be carried out by connections N , N in any position along the tuned oscillatory circuit T_1 or T_2 which permits a

choice of the loading impedance and of the oscillatory circuit by simple adjustment of said position.

The path of the bundle of electrons is indicated at F. The operation of the device is similar to that of the device of Fig. 5.

In the systems employing a magnetic field for the guiding of the bundle the retarding electrodes shown are constituted by discs cut along a diameter, but it is clear that such electrodes can be provided according to the requirements in the form of a certain number of identical sectors, preferably even in number. These sectors may, of course, be such that once assembled they give a polygonal figure instead of a circumference. These sectors must be alternately connected to the two poles of the oscillatory circuit. The relation between the frequency of the oscillatory circuit and the intensity of the magnetic field is changed, the intensity of the field decreasing in inverse ratio to the number of pairs of electrodes.

When we produce an oscillator device by the means which have just been described we have at our disposal a negative resistance effect which can be utilised in the amplification of electrical oscillations, for example, of the same order of magnitude as that of the oscillations which can be produced by the tube, when the conditions of operation are adjusted to be outside the range of conditions in which self-oscillation occurs.

In the case in which it is desired to employ such tubes as modulated oscillation generators it

is possible to provide inside the tubes which have just been described electrodes having an influence on either the intensity or the direction of the electronic bundle or bundles employed.

Other arrangements within the spirit of the invention and within the scope of the appended claim will be apparent to those versed in the art.

What is claimed is:

10 An electron tube including a source of electrons, means for directing said electrons in a flat spiral path and applying a retarding field thereto, said means including a pair of aligned magnetic pole pieces arranged in spaced relation, the opposed spaced ends of said pole pieces having generally circular surfaces and serving as opposed electrodes, said pole pieces having longitudinally and diametrically extending gaps formed as by cutting said pole pieces longitudinally along
15 a given diameter thus providing diametrically extending uniform gaps in the electrode surfaces of said pole pieces, the longitudinal lengths of said pole-piece gaps being substantially equal to an integer multiple of one quarter the wave length
20 of the desired operating frequency, whereby said electrode structures may simultaneously serve to direct electrons between said circular surfaces in a flat spiral path and also resonate of themselves as transmission lines.

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