ELECTRON TUBES OF THE MULTI REFLEXION TYPE

Original Filed April 29, 1952

3 Sheets-Sheet 1

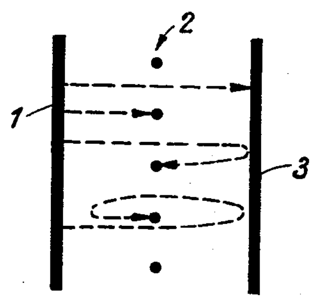

Fig.1

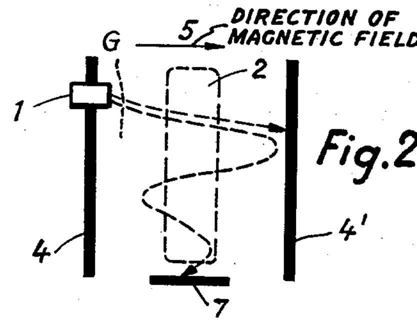

Fig.2a

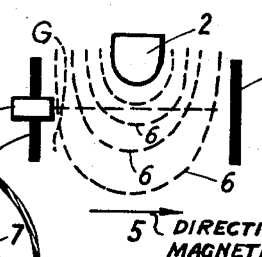

Fig2b

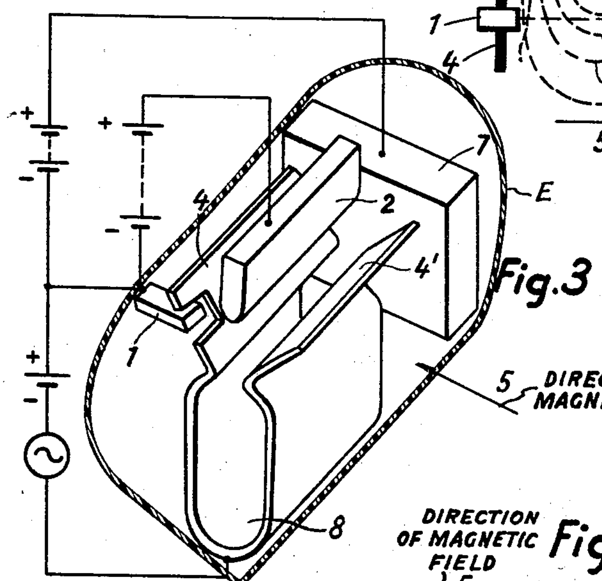

Fig.3

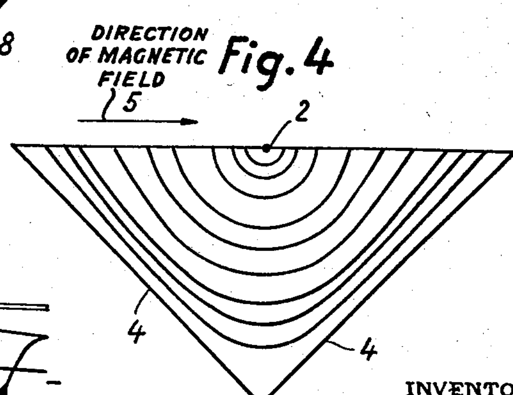

Fig.4

Fig.12a

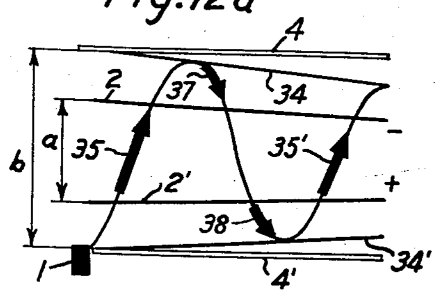

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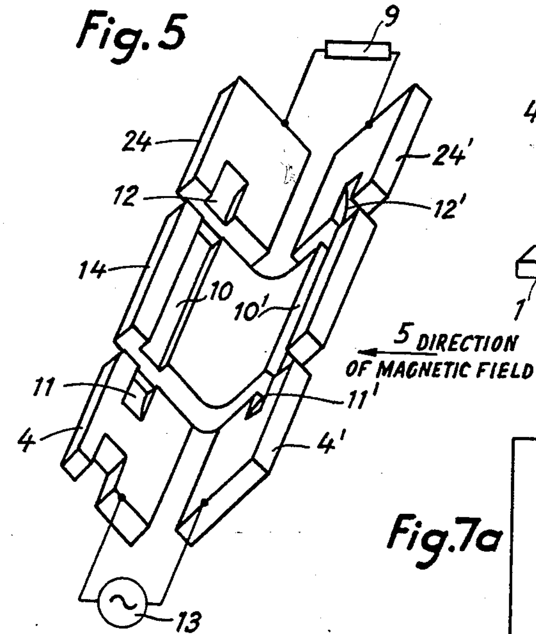
Fig. 5



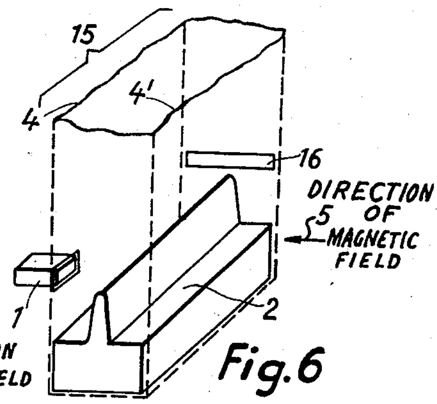


Fig. 6

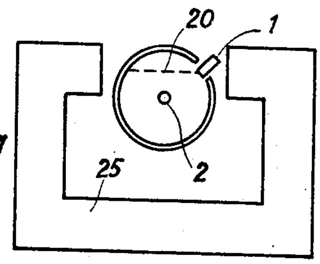
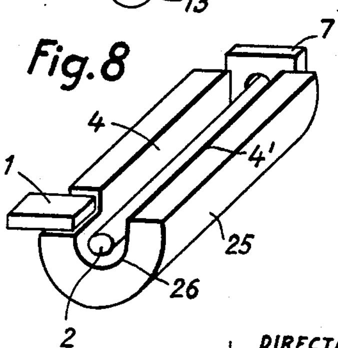


Fig. 7a

Fig. 8



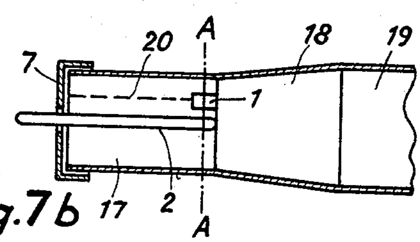


Fig. 7b

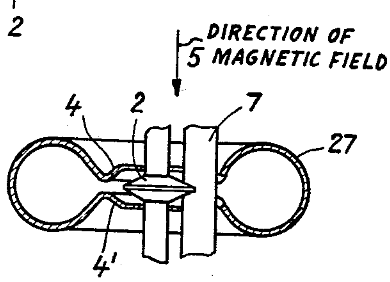


Fig. 9a

Fig. 9b

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March 15, 1960 H. O. G. ALFVÉN ET AL 2,928,992

ELECTRON TUBES OF THE MULTI REFLEXION TYPE

Original Filed April 29, 1952 3 Sheets-Sheet 3

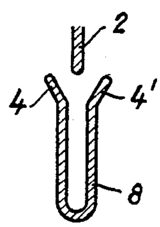


Fig. 10a

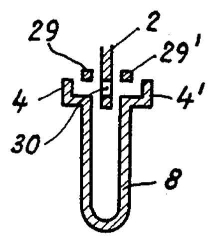


Fig. 10b

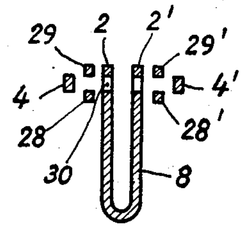
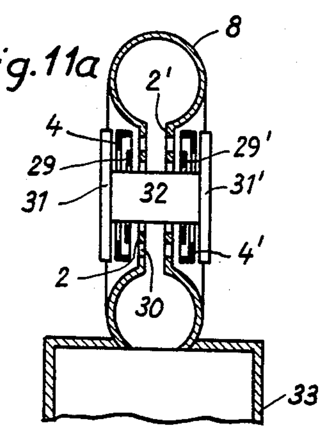


Fig. 10c

Fig. 11a



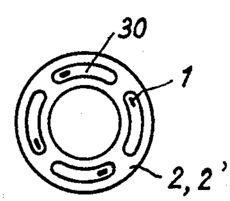


Fig. 11b

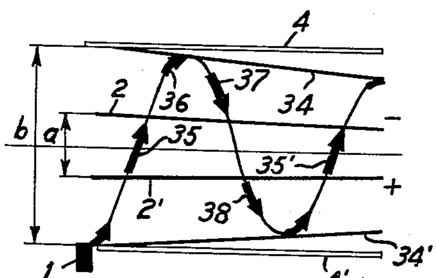


Fig. 12b

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United States Patent Office

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ELECTRON TUBES OF THE MULTI REFLEXION TYPE

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Continuation of application Serial No. 284,978, April 29, 1952. This application March 14, 1957, Serial No. 646,169

Claims priority, application Sweden June 30, 1951

29 Claims. (Cl. 313—157)

One of the oldest methods of generating electromagnetic waves in the centimeter and decimeter wave range is by means of so-called Barkhausen-Kurz oscillations. A simple generator of this kind is obtained, if, in an ordinary triode, the grid is made positive and the anode slightly negative in relation to the cathode. Electrons emitted from the cathode will oscillate about the wires of the grid with a frequency of the order of 1000 mc./second and can be made to do work on a circuit connected between anode and cathode.

A disadvantage of this generator is the fact that the electrons oscillate but a small number of times before striking the grid. Hence, the efficiency is low. Also the grid will be considerably heated and the difficulty of dissipating this heat limits the maximum power of the tube.

These disadvantages may be eliminated by guiding the electrons by means of a magnetic field, which is parallel to the electric field, in which they oscillate. The Swedish Patent 117,735 gives an example of such an arrangement. This device, however, has the disadvantage that electrons, which have delivered their energy to the high frequency alternating field, remains for a considerable time in the electron beam, where their space charge will disturb the electrostatic field and where they will tend to be accelerated by the alternating electric field, the energy of which will thus be dissipated.

It is the purpose of this invention to eliminate these disadvantages by causing the electrons to oscillate in a non-homogeneous magnetic field or in a magnetic field perpendicular to a component of the static electric field. This device will give the electrons, besides the oscillating motion parallel to the magnetic field and to the high frequency electric field (and in addition to a rotating motion about the magnetic lines of force), a translational or drift motion perpendicular to the magnetic field, by means of which the electrons may be removed after having delivered their energy to the high frequency field. Also, the possibility arises of developing the tube into an amplifier as will be described in the following. Finally it is possible by this method to make the electrons deliver all of their residual energy to an electrode, which can easily be designed in such a manner that it may easily dissipate large amounts of heat.

Electrode systems in electron tubes according to the invention are preferably constructed in such a manner as to cause the electrons to move in a channel limited by positive and negative electrodes, which, together with the magnetic field penetrating the electrode system, will guide the electrons in such a manner that they are caused to oscillate perpendicularly to the channel while drifting along it. In order to achieve this it is required that the electrostatic field between the electrodes shall have, firstly, a component perpendicular to the magnetic field and to the longitudinal direction of the channel, which component together with the magnetic field will give the electrons a drift velocity along the channel equal to E/B meters/second (if E is measured in volts/meter and B in voltseconds/m.^{2}), and secondly, components parallel and anti-parallel to the magnetic field and increasing towards the sides of the channel, which components serve to reflect the oscillating electrons before they reach the electrodes limiting the channel.

The negative electrodes, which serve to shape the electrostatic field in such a manner as to reflect the electrons, will be called reflectors. The electrodes, which serve chiefly to supply the component of the electrostatic field which is perpendicular to the magnetic field, will be called guiding-field electrodes. These electrodes, generally, do not carry high frequency potential. Some of the electrodes limiting the channel may be connected to resonators or other high frequency circuits and so shaped that the high frequency electric field between them will have a main direction parallel to the oscillating motion of the electrons. Transfer of energy will thus be possible between the field and this component of the electron motion. Such electrodes may be either positive or negative. The positive electrodes, which mostly contribute to that component of the electrostatic field, which accelerates the elecrons emitted from the cathode, are called anodes.

The various electrode functions mentioned above may be combined in various manners in the same electrode. Thus the anodes may serve as guiding-field electrodes and carry high frequency potentials as well.

After the electrons have drifted through the whole length of the channel or a major part of it, they are captured by one or more of the electrodes mentioned above, or by a special collector electrode.

The channel mentioned above may be straight or curved and may have a cross-section, which is constant or varies along the length of the channel.

The frequency of oscillation of the electrons is mainly determined by the highest electrostatic potential in the electron path and the distance between the reflectors according to the relation

$$f=k\cdot\frac{\sqrt{V}}{b}$$

where V is the highest potential, through which the electrons oscillate, b is the effective width of the electrode system between the reflectors in the plane of the oscillating electrons, and k is a constant, which in the MKSA-system of units has the value

$$\left(\frac{1}{\pi}\sqrt{\frac{2e}{m}}\right)=0.189\cdot10^6$$

This expression holds true, if the potential distribution is parabolic between the reflectors, i.e. such, that all the electrons, irrespective of amplitude, have the same frequency of oscillation.

The effective width b of the electrode system is, at the most, equal to the geometrical distance between the reflectors in the plane of the electron path. It may be diminished by making the reflectors negative in relation to the cathode, thus causing the frequency of oscillation of the electrons and hence the operating frequency of the tube to increase. This offers a simple means of frequency modulation and frequency control.

In order for the electron beam to work on the field of a circuit connected to the reflectors or to a pair of anodes the beam must be intensity modulated.

This modulation may be effected by three different mechanisms or a combination thereof: (1) by modulation of the cathode emission current, (2) by removal at the reflector surfaces of electrons having such a phase relationship to the applied high frequency field as to be accelerated by it, (3) by so arranging the retarding fields of the reflectors as to cause bunching of the electrons.

The magnetic field through the electrode system must be strong enough to cause the electron paths to be curved to such a degree that they are not able to reach anodes or guiding-field electrodes while drifting through the electrode system. Above this critical value the magnetic field may be increased within wide limits without the function of the tube being much affected.

Under certain conditions a strong noise will arise in systems, where free electrons exist in magnetic fields. The noise will not be appreciable (in comparison to shot noise) unless the electron current exceeds a certain limit, given by the dimensions of the electrode system and by the magnitudes of the static electric and magnetic fields.

Electron tubes according to the invention are preferably designed and operated in such a manner that this limit will not be exceded. For an electrode system of simple geometry this limit is given by the following approximate formula:

$$I<I^{*}\cdot b\cdot 2d/l$$

where

$$I^{*}=\frac{\epsilon_0}{2}\cdot\frac{E^2}{B}$$

and where

I is the electron current,
E the mean value in the electron beam of that component of the electrostatic field which is perpendicular to the beam and to the magnetic field,
B the mean magnetic field density in the electron beam,
b the average distance between the reflectors,
d the minimum distance from the center of the electron beam to the nearest electrode, and
l the distance along the electrode system between the cathode and the collector.

It should be noted that the current I can never exceed the value of the order of $I^{*}\cdot b$, due to space charge effects.

These considerations are especially important in the case of amplifier tubes. According to the invention amplification of a high frequency signal may be obtained in an electrode system comprising e.g. a common anode and three pairs of reflectors arranged along the anode. The first pair of reflectors (situated nearest to the cathode) is connected to the signal voltage and serves to give the electron current a velocity modulation. This is converted into an intensity modulation in the field of the second pair of electrodes, which is shaped in such a manner as to cause fast electrons to be delayed in relation to slower electrons (or to catch up with them). Finally the intensity-modulated electron beam will induce an (amplified) voltage in the last pair of reflectors, which may be utilized in a load connected to their pair of electrodes. In a similar manner an amplifier tube may be constructed with pairs of anodes, between which signal voltages are applied and induced respectively.

In amplifiers, constructed in this manner, the problem may arise of preventing self-excited-oscillation of the input section. This may be avoided, if the electrodes are arranged in such a manner that the current emitted by the cathode will be intensity modulated to a certain degree by the voltage across the input section and that after leaving the cathode, the electrons will be so much delayed that, on entering the high frequency field, by which they are to be modulated, they draw energy from this field. Under these conditions sustained oscillations cannot exist.

The electrodes carrying high frequency potentials have hitherto been presumed to act as equipotential surfaces also from the high frequency point of view. However, embodiments of the invention are also conceivable, in which an electromagnetic wave traveling along the electrodes interacts with the oscillating electrons, the electrodes being shaped into a delay line and the drift velocity of the electrons being chosen so as to approach the velocity of propagation of the wave.

In electron tubes according to the invention the cathode will sometimes take up a not negligible part of the eight of the reflectors (in a direction perpendicular to the plane of oscillation). This will cause electrons emitted from different parts of the cathode to have different oscillation frequencies unless special precautions are taken. According to what has been previously mentioned the oscillation frequency is determined by the quotient between the square root of the highest electric potential on the magnetic line of force, along which the electron is oscillating and the distance between the reflectors. Since, in some embodiments the anode is unsymmetrically situated in relation to the plane of oscillation, this potential will increase towards one side of the electron beam, and so the frequency of oscillation will be higher nearer the anode. This may be compensated for at least approximately by shaping the reflectors in such a manner, that the quotient $\sqrt{V/b}$ remains constant for all parts of the electron beam.

Electron tubes according to the invention are preferably operated with such values of the electric and magnetic fields, that the operating frequency of the tube is remote from the cyclotron frequency, i.e. the frequency, by which the electrons rotate around the magnetic lines of force. This frequency is:

$$\frac{1}{2\pi}\cdot\frac{eB}{m}$$

where B is the magnetic field density in the electron path and e and m are the charge and mass of the electron. Applications are possible, however, where the operating frequency of the tube coincides with the gyro-frequency or one of its multiples or submultiples.

Embodiments of the invention will be described in the following with reference to the accompanying drawing, in which

Fig. 1 shows schematically the electrode system of a Barkhausen-Kurz type oscillator;

Figs. 2*a* and 2*b* show schematically the electrode system of a simple oscillator according to the invention;

Fig. 3 shows in perspective an electrode system according to the invention;

Fig. 4 shows a section through the equipotential surfaces of an electrostatic field in a theoretical case similar to certain embodiments of the invention;

Fig. 5 shows another embodiment of the reflectors;

Fig. 6 shows an electrode system built together with a wave guide;

Figs. 7*a* and 7*b* show an electrode system built together with another type of wave guide;

Fig. 8 shows another embodiment of the electrode system;

Figs. 9*a* and 9*b* show a further embodiment of the electrode system;

Figs. 10*a*, 10*b* and 10*c* show schematically, other embodiments of electrode systems of tubes according to the invention;

Figs. 11*a* and 11*b* show a further embodiment of the tube according to the invention; and

Figs. 12*a* and 12*b* show, schematically, details of the electronic motion in certain embodiments of the invention.

Fig. 1 shows schematically the electrode system of an oscillator of the Barkhausen-Kurz type, where **1** indicates the cathode or electron gun, **2** the anode, consisting of a wire grid, which has a high positive potential in relation to the cathode, and **3** indicates a reflector, which has a negative potential in relation to the cathode.

The resonant circuit (not shown) of the oscillator is assumed to be connected to the electrodes **1** and **3** (cathode and reflector). The electrons emitted by the cathode will move in various paths, some of which are indicated by the arrows. Oscillations are maintained by either or a combination of the following effects: (1) electron bunching in the retarding fields, due to differences in transit time for electrons of different velocities, (2) sorting-out of out-of-phase electrons at the reflector surface, the remaining electrons doing work on the high-frequency field.

Figs. 2*a* and 2*b* show schematically in two sections the electrode system of an oscillator according to the invention where **1** indicates the cathode, **2** the anode, which has a high positive potential in relation to the cathode, and **4** and **4'** a pair of reflectors, which have a negative potential in relation to the cathode. The arrow **5** indicates the direction of the magnetic field through the electrode system. The lines **6** indicate some of the equipotential surfaces of the electrostatic field between anode and reflectors.

The resonant circuit (not shown) of the oscillator may be connected between the two electrodes **4** and **4'**. The electrons emitted by the cathode will be accelerated by the electrostatic field of the anode, but are prevented from reaching this electrode by the strong magnetic field indicated by the arrow **5**. By the combined action of the crossed electric and magnetic fields the electrons will obtain a translational (drift) velocity perpendicular to the two fields. In addition, the electrons will usually get a rotation superimposed on the translational motion. Oscillations, in this simple embodiment of the invention, are maintained by much the same mechanism as in the case of Barkhausen-Kurz oscillations. The electrons will follow the paths indicated by the arrows. Those electrons, which have done work on the high frequency field will reach the collector **7**, which has a potential between the potentials of the anode and cathode. Where it is desirable to intensity modulate the electron beam a control electrode such as shown at G in Figs. 2*a* and 2*b* may be provided in front of or near the cathode **1**.

Fig. 4 shows a cross-section through the equipotential surfaces of an electrostatic field between the positive electrode **2** and the negative electrode **4**, which approximately fulfills the following two conditions. (1) Electrons, guided by a horizontal magnetic field **5**, will oscillate with a frequency, which is very nearly independent of their amplitude. (2) Electrons oscillating in different horizontal planes will all oscillate with nearly the same frequency.

The field is that which is obtained between an infinite line charge and two planes, which are perpendicular to each other, parallel to the line charge and symmetrically situated in relation to it. The two conditions mentioned above may also be fulfilled with more or less accuracy by other fields.

Fig. 3 shows schematically in perspective the fundamental construction of one type of electrode system according to the invention which as in all of the other embodiments is enclosed in a more or less conventional evacuated envelope E. **1** indicates a cathode or electron gun situated in a notch in one of the reflectors **4**. The other reflector is indicated by **4'**. The anode **2** is symmetrically arranged between the recectors. The collector **7** terminates the channel formed by the anode **2** and the reflectors **4** and **4'**, in which the electrons emitted by the cathode oscillate, guided by the electric field between the positive anode and the negative reflectors and the magnetic field indicated by the arrow through the electrode system. The loop **8**, together with the reflectors **4** and **4'** forms the resonant circuit.

The electron tube operates as an oscillator in the following manner: The anode voltage is chosen in such a manner as to cause the oscillation frequency of the electrons to be nearly equal to the resonance frequency of the circuit **4—8—4'**. electrons have such a phase as to be accelerated by the high frequency electric field, will reach the reflector **4'** or **4** and thus be removed. The remaining electrons will do work on the field, thus keeping up the oscillations in the resonant circuit. The magnetic field (and hence the translational velocity) and the loading impedance across the resonant circuit are preferably chosen in such a manner as to cause the electrons to reach the collector **7** in the moment, when the amplitude of their oscillations is approaching zero.

The same figure may serve to illustrate another mode of operation. In this case the reflectors **4** and **4'** are made so strongly negative that not even electrons that have been accelerated by the high-frequency field can reach them. The electrostatic field between the electrodes in this case is shaped in such a way as to cause bunching of the electrons. The bunched beam will then do work on the high-frequency field.

The operating frequency of the electron tube is strongly influenced by the magnitude of the negative voltage applied to the reflectors. If an audio frequency voltage is applied between cathode and reflectors, the signal generated by the tube will therefore be frequency modulated.

Fig. 5 shows schematically in perspective an example of the construction of the reflectors of an amplifier tube according to the invention. The cathode, anode and collector are assumed to be arranged as in Fig. 1. The arrow **5** indicates the direction of the magnetic field through the electrode system. The pair of reflectors, indicated by **4** and **4'**, and situated nearest to the cathode is connected to a high-frequency signal source **13**. The middle pair of electrodes indicated by **14** consists of only one part thus being short-circuited. The third pair of electrodes indicated by **24** and **24'** is connected to a load impedance **9**.

The first and the third pair of electrodes are shaped in such a manner that, together with the anode (not shown), they will give an electrostatic field of the character shown in Fig. 4. The middle pair of electrodes is modified (e.g. by the grooves **10, 10'**) in such a manner, that the field along the line, where the electrodes are intersected by the plane of the oscillating electrons, will follow a suitable function of distance from the plane of symmetry. In order to reduce the effect of the discontinuities at the transition between the different sections, notches indicated by **11, 11'** and **12, 12'** may be arranged in the first and the third pairs of electrodes.

If no signal is applied to the input section, the electrons emitted by the cathode will all oscillate with the same amplitude and frequency. They will pass through the three sections and finally reach the collector (not shown), evenly distributed in all phases. If a signal is applied to the input section, the frequency of said signal being equal to the oscillation frequency of the electrons, the energies of the electrons will be distributed. In the middle section those electrons, which have large amplitudes will be delayed in comparison to those, which have a smaller amplitude, causing a bunching of the electrons so that, when they enter the third section, they will induce an amplified signal in the third pair of electrodes, which may be utilized in the load impedance **9**.

Fig. 6 shows schematically in perspective the construction of an electrode system according to the invention, which is built into a rectangular wave guide. The wave guide is indicated by **15**, the cathode by **1** and the anode, which ends the wave guide but is insulated from it, by **2**. The sides **4, 4'** of the wave guide, parallel to the anode, serve as reflectors. The magnetic field through the electrode system is indicated by **5**. A slot in the wall of the wave guide is indicated by **16**. If the electron tube is to act as an oscillator, a collector is placed in that slot. The electrode system may also serve as the input section of an amplifier, in which case the slot remains open, so that the electrons may pass out of the wave guide into the next section of the amplifier. The electrode system may also serve as an output section, in which case the cathode is omitted and substituted by a slot, corresponding to the slot **16**, in the opposite short end of the wave guide. A collector is placed in the slot **16**. The wave guide is preferably operated in the mode $H_{0,1}$.

Figs. 7*a* and 7*b* show schematically in two projections the construction of the electrode system of an electron tube according to the invention, which system is built into a circular wave guide. The wave guide has a narrow part **17**, which encloses the electrode system proper, a transitional part **18**, and a wide part **19**. The diameter of the narrow part is chosen so as to only slightly exceed 1.22 λ, where λ indicates the wave length, at which the tube is operating. By this means it is achieved that the electromagnetic wave in this wave guide section will have very nearly the same phase in all of the space occupied, by the electrode system. The electron tube will preferably operate with a wave of the $H_{0,1}$ -mode, but the $H_{0,2}$ and perhaps other modes may also be possible, in which cases the factor 1.22 mentioned above should be modified, so that the condition of equality of phases will be satisfied.

In the electrode system, **1** indicates the cathode, **2** the anode and **7** the collector, which ends the wave guide but is insulated from it and from the anode. The magnet **25** maintains a magnetic field through the electrode system. The dotted lines **20** indicate the plane in which the electrons oscillate.

Fig. 8 shows schematically in perspective the fundamental construction of an electrode system according to the invention intended for direct radiation of energy of very high frequency. The cathode is indicated by **1**, the anode by **2** and the collector by **7**, **25** indicates a permanent magnet giving the magnetic field necessary for the function of the electron tube, the magnet being coated on the inside with a good conductor **26**, such as silver. This layer forms a resonator for the frequency, at which the tube is operating and serves at the same time as reflectors **4** and **4'**.

Figs. 9*a* and 9*b* show schematically in two projections a further embodiment of the electrode system according to the invention. The cathode or the electron gun is indicated by **1**, the anode by **2** and the collector by **7**. The reflectors **4** and **4'** together with the hollow, troidal body **27** form a resonant circuit with a high Q. The arrow **5** indicates the direction of the magnetic field through the electrode system.

The electrons emitted by the cathode **1** will oscillate between the reflectors at the same time as they drift along a cylindrical surface parallel to the magnetic lines of force and finally reach the collector **7**.

Figs. 10*a*, 10*b* and 10*c* show schematically sections of three different electrode systems, illustrating a line of development from the simplest form of the electron tube according to the invention to more complicated types. In the figures, **2** indicates anodes, **4** reflectors, **8** resontors, **28** negative and **29** positive guiding-field electrodes. **30** indicates slots in the anodes. In all three cases the electrons oscillate in a horizontal plane, limited by the reflectors.

In the device according to Fig. 10*a* the highest potential attained by the electrons will be a fraction of the potential of the anode because the equipotential surfaces are concentrated near the anode. In practice this fraction will be about ⅓. The coupling between the electrons and the resonant circuit **8** will be relatively weak.

In the device according to Fig. 10*b* the electrons pass through a highest potential only slightly below that of the anode, thus causing the voltage of the anode supply to be more effectively utilized. In this arrangement, however, the contribution of the anode to that component of the electrostatic field, which together with the magnetic field is to give the electrons their drift velocity along the system, is insignificant. Instead, the two positive guiding-field electrodes **29**, **29'** will supply this component here. The horizontal parts of the reflectors **4**, **4'** may be regarded as negative guiding-field electrodes. In this device the coupling between the electrons and the circuit **8** is still relatively weak.

In the device according to Fig. 10*c* the anode has been divided into two, **2** and **2'**, and the resonant circuit **8** has been connected between these (instead of being connected between the reflectors). By this means the following advantages are obtained: firstly, the coupling between the electrons and the circuit is stronger, secondly, the tube will operate with good efficiency on an (odd) harmonic of the electron oscillation frequency.

Fig. 11*a* shows schematically a section through the main parts of an electrode system of the same fundamental type as in Fig. 10*c*. The anodes are indicated by **2**, **2'**, the reflectors by **4**, **4'**, the resonator by **8**, the positive guiding-field electrodes by **29**, **29'** and the anode slots by **30**. **31** and **31'** indicate a pair of pole pieces of a soft magnetic material, and **32** indicates a permanent magnet. **33** indicates a wave guide, to which the resonator **8** is coupled. The cathodes, not shown, lie in the plane of the reflectors.

Fig. 11*b* shows a detail of the anodes **2** and **2'** with their slots **30** and the location of the cathodes, indicated by **1**.

As has been mentioned previously the intensity modulation of the electron beam may be obtained, either by the removal of electrons of the wrong phase by means of bunching in the retarding fields of the reflectors, or by modulating the emission current of the cathode. The latter case is of special interest in electrode systems of the general type shown in Fig. 10*c* and when the electron tube is operating at a frequency, which is an (odd) harmonic of the electron oscillation frequency. With reference to Figs. 12*a* and 12*b* it will now be described how criterions may be found for the most favourable design, when the tube is to operate on a certain harmonic, and how it is possible to diminish or eliminate phase differences of the emitted electron clouds in relation to the phase, which would give the highest efficiency.

In the Figures 12*a* and 12*b*, **1** indicates the cathode, **2** and **2'** the planes of the anodes, **4** and **4'** the planes of the reflectors and **34** and **34'** the envelopes of the curves, along which the electrons oscillate. The arrows **35—38** indicate the positions of some electron bunches in a certain moment. For the sake of simplicity the electrons are assumed to follow a sinusoidal curve in time and a damped sinusodial curve in space. When the electron bunches have the positions shown in the drawings, the high frequency field between the anodes is assumed to have its maximum with signs according to the figures. The electrode structure is assumed to be such, that the potential of the nearest anode will have an essential influence on the emission of the cathode.

In Fig. 12*a* the tube operates on the third harmonic of the electron oscillation frequency and in Fig. 12*b* on the fifth harmonic of said frequency. It may be shown that in order to obtain the greatest possible coupling between the electron bunches and the high frequency field, the ratio between the anode distance a and the electron amplitude b should be, in the first case 0.500 and in the latter case 0.308 or, in general

$$a/b = \sin\frac{\pi}{2n}$$

where n is the ordinal number of said harmonic.

It may also be shown, that if the cathode is placed as in Figs. 12*a* and 12*b* and has the same potential as the reflectors, the maximum emission will occur at phase angles, differing from the most favourable phase by a value α, where in the first case α is equal to 30° (too early) and in the latter case −18° (too late) or, in general

$$(\alpha) = \frac{\pi}{2n}$$

(alternatively positive and negative). This is with reference to the period of the oscillating electrons. With reference to the period of the high frequency field, the phase differences will be + or −90°, irrespective of n.

In practice the electron motion may differ from the idealized conditions, which have been presumed here, in which case the values (a/b and α) obtained from the formulas above must be corrected.

The phase differences α may be decreased or eliminated by displacing the cathode outwards or inwards from the position shown in Figs. 12*a* and 12*b*, causing the transit time from the cathode to the nearest anode (2′) to attain the correct value. Thus in Fig. 12*a* the cathode ought to be moved outwards from the anode and in Fig. 12*b* it ought to be moved closer to the anode.

The device according to the invention may be modified in various manners and is not limited to the embodiments shown. Thus, for the sake of simplicity only one cathode has been shown in most cases. However, it is often advantageous to arrange a cathode in each reflector.

There is further the possibility of a larger part or possibly the whole surface of the reflector being occupied by the cathode, or the reflectors being wholly substituted by cathodes.

The resonant circuit may be connected to other electrodes than reflectors or anodes, e.g. between anode and cathode, between reflectors and cathodes, between a reflector and an anode or between anode and cathode.

Several resonant circuits may further be connected, e.g. in such a manner that one circuit is connected between the reflectors, while another, tuned to twice the frequency or a higher harmonic, is connected between anode and cathode causing the tube to act as a frequency multiplier.

This application is a continuation of our application Serial No. 284,978, now abandoned, filed April 29, 1952.

We claim:

1. In a high frequency electron tube of the retarding field type including in combination elongated anode means, two elongated reflecting surfaces extending substantially parallel to the longitudinal direction of said anode means, and symmetrically arranged relative thereto, cathode means located near one end of the elongated discharge space defined by said anode means and said reflecting surfaces for emitting electrons into said discharge space, collector electrode means located near the end of the discharge space opposite to the cathode means, means for producing a magnetic field, the direction of which is perpendicular to the symmetry plane of said reflecting surfaces, said anode means and said reflecting surfaces being positioned and energized to generate an electrostatic field component for imparting to said electrons oscillations along the field lines of the magnetic field, means for providing a high frequency electric field having at least a main component parallel to the magnetic field and means for generating another electrostatic field component perpendicular to the magnetic field and the longitudinal direction of the discharge space, which component in cooperation with the magnetic field imparts to the electrons a drift motion perpendicular to the magnetic field.

2. In a high frequency electron tube of the retarding field type including in combination, an elongated bar-shaped anode, two elongated surface reflector electrodes, the longitudinal direction of which is substantially parallel to the longitudinal direction of the anode, said reflector electrodes being in any cross-sectional plane located symmetrically in relation to the anode and diverging in the direction towards the anode, cathode means located near one end of the elongated discharge space defined by said anode and said reflector electrodes for emitting electrons into said discharge space, collector electrode means located near the other end of said discharge space, means for producing a magnetic field the direction of which is substantially perpendicular to the symmetry plane of said reflector electrodes, said anode and said reflector electrodes being in position when energized to generate an electrostatic field having a first component for imparting to the said electrons an oscillatory motion along the field lines of the magnetic field and second a component, which in cooperation with the magnetic field imparts to the electrons a drift motion along said discharge space perpendicular to the magnetic field, and means for providing a high frequency electric field having at least a main component parallel with the magnetic field.

3. In a high frequency electron tube of the retarding field type including in combination, a cylindrical anode, a tubular reflector electrode surrounding said anode to form an annular elongated discharge space, cathode means located near one end of said discharge space for emitting electrons into said space transverse to its axis, collector electrode means located near the other end of the discharge space, means for producting a magnetic field perpendicular to the axis of the anode, said anode and said reflector electrode generating an electrostatic field having a first component imparting to the said electrons an oscillatory motion along the field lines of the magnetic field, and a second component which in cooperation with the magnetic field imparts to the electrons a drift motion along said discharge space, and means for providing a high frequency electric field having at least a main component parallel with the magnetic field.

4. In a high frequency electron tube of the retarding field type including in combination elongated anode means, two elongated reflecting surfaces extending substantially parallel to the elongated direction of said anode means, and symmetrically arranged relative thereto, cathode means located near one end of an elongated discharge space between said anode means and said reflecting surfaces for emitting a stream of electrons into said space, collector electrode means located near the end of the discharge space remote from the cathode means and at the end of the anode and reflectors, means for producing a magnetic field the direction of which is substantially perpendicular to the symmetry plane of said reflecting surfaces, said anode means and said reflecting surfaces being positioned so that when positively energized they generate an electrostatic field component for imparting to the electrons oscillations along the field lines of the magnetic field, means for providing a high frequency electric field having at least a main component parallel to the magnetic field and means to impart to the electrons a drift velocity component along said discharge space perpendicular to the magnetic field.

5. An electron tube as defined in claim 4 in which means is provided to collect on the reflecting surfaces electrons phased to be accelerated by the high frequency field whereby the remaining electrons form an intensity-modulated beam.

6. An electron tube as defined in claim 4 in which means is provided to shape the fields of the reflecting surface electrodes to produce areas of retardation therein whereby the electrons of the cathode stream are bunched to provide intensity-modulation stream.

7. The electron tube as defined in claim 4 in which means provides inhomogeneities in the magnetic field whereby drift velocity is imparted to the electron stream.

8. The electron tube as defined in claim 4 in which one of the reflectors is provided with an opening and means is provided to deliver the electrons emitted by the cathode through said opening.

9. The electron tube as defined in claim 4 in which the two reflecting surfaces are transversely divided into three pairs of reflecting surfaces electrically separate from each other.

10. The electron tube as defined in claim 9 in which means connects the first pair of parts of the reflecting surfaces adjacent the cathode to a source of high frequency voltage, means connects the remote pair to a load in which the signal is to be utilized and means connects the intermediate pair electrically for the frequencies which are to

be amplified, said reflecting surfaces being so constructed and arranged that electrons from said stream which have greater amplitude of oscillation will have a larger average transit time than those of lesser amplitude whereby the electrons are bunched at the end of their transit of the intermediate pair of reflecting surfaces.

11. The electron tube as defined in claim 4 having a control electrode adjacent the front of the cathode and means to energize said control electrode to intensity-modulate the electron stream before it enters the high frequency field.

12. The electron tube of claim 4 in which means connect the reflecting surfaces into a circuit resonant at a frequency having a substantially harmonic relation to the frequency of oscillation imparted to the electrons in the tube.

13. The electron tube of claim 4 in which two anodes are arranged parallel to each other and to the reflecting surfaces and means to connect said anodes into a circuit resonant at a frequency having a substantially harmonic relation to the frequency of oscillation imparted to the electrons in the tube.

14. The tube of claim 13 in which slots are arranged in the anodes, and means to cause the electrons in said stream to oscillate through said slots.

15. The electron tube of claim 4 having a wave guide and in which the reflecting surfaces substantially constitute continuations of the sides of said wave guide.

16. The electron tube of claim 4 having a wave guide in which at least a pair of anodes is provided which substantially constitute continuations of the sides of said wave guide.

17. The electron tube of claim 4 in which the reflecting surfaces form a half shell open on one side, nesting the anode means for direct reflection of the energy of the oscillating electrons as electro-magnetic energy radiation into space.

18. The electron tube as defined in claim 17 in which the electrode system is curved in its plane of symmetry about the anode means whereby the said energy radiation into space is concentrated.

19. An electron tube as defined in claim 4 including means for cyclicly varying the voltage applied between the cathode and the reflecting surfaces at a predetermined frequency whereby the oscillation frequency is varied with the amplitude of said voltage to provide a frequency modulated signal.

20. The electron tube as defined in claim 4 in which means is provided to apply to any electrode, absorbing the main part of the electrons which have given up energy to the high frequency field, a potential substantially equal to the highest potential traversed by the electrons.

21. An electron tube according to claim 4, characterized by an arrangement in which the distance between the reflecting surfaces, measured along a line perpendicular to the symmetry plane of the electrode system is proportional to the square root of the electric potential at the intersection of said line with said symmetry plane.

22. The electron tube defined in claim 12 in which the electrode elements are so positioned relative to each other and means provided to energize them to such potentials in respect to the strength of the magnetic field that the electron oscillation frequency

$$\varphi_0 = k \cdot \frac{\sqrt{V}}{b}$$

where $\sqrt{v}$ is the highest potential through which the electrons oscillate, b is the effective width of the electrode system between reflecting surfaces in the plane of the oscillating electrons, and k is

$$\frac{1}{\pi}\sqrt{\frac{2e}{m}}$$

where e and m are the charge and mass, respectively, of the electron, will be remote from the electron rotational frequency around the magnetic lines of force

$$\varphi_2 = \frac{1}{2\pi} \cdot \frac{eB}{m}$$

where B is the magnetic field density.

23. In an electron tube for the generation or amplification of high frequency oscillations including in combination, a cathode for emitting a relatively concentrated stream of electrons, positively charged elongated surface anode means having the elements thereof substantially parallel, a pair of negatively charged reflecting surfaces the elements of which are parallel to said anode elements and collector electrode means beyond the ends of said anode and reflectors, means to produce a magnetic field the axis of which is generally normal to the plane of symmetry of said reflector surface and said anode surface, said cathode being positioned with its stream axis substantially normal to said elements, said charged electrodes being so positioned as to produce an electrostatic field portions of which are substantially parallel to the magnetic field, means to provide a high frequency electric field parts of which are substantially parallel to the magnetic field, and means to impart a drift velocity to said electron stream with a component perpendicular to the magnetic field and longitudinally of said anode elements.

24. Electron tube according to claim 23 wherein two anodes are provided, a resonant circuit for said tube, means connecting said circuit between the anodes, said resonant circuit being tuned to a frequency which is an odd multiple of the electron oscillation frequency, the spacing between said anodes decreasing in the direction of the electron drift velocity, said spacing divided by the distance between the envelopes of the oscillatory electron motion being approximately equal to

$$\sin \frac{\pi}{2n}$$

n being the ordinal number of said harmonic.

25. Electron tube according to claim 24, in which portions of the anode structure, located nearest to the cathode means, are arranged to have an essential acceleration influence on the cathode emission and the distance between said anode portions and said cathode means being so chosen that a majority of the emitted electrons will enter the high frequency field existing adjacent said anode structure with such a phase in relation to said field, that they are caused to deliver energy to it.

26. Electron tube according to claim 4, having means to regulate the magnetic field penetrating said tube to concentrate the electrons into a well-defined plane electron beam, any positive electrode means except the collector electrode means being arranged to have a distance to the limiting planes of said electron beam which is small, but sufficient to limit to a negligible value the current drawn by said positive electrodes.

27. The method of operating an electron tube constructed according to claim 1, comprising adjusting the electron current to a value less than a numerical factor multiplied by the product of the square of the mean value of the field strength of said electrostatic field component perpendicular to the magnetic field and the longitudinal direction of the discharge space, the distance between the reflectors and by the distance between the electron beam and the nearest electrode surface, divided by the product of the magnetic field density and the distance along the electrode system between the cathode and the collector, said numerical factor having the value of ¼ $\epsilon_0 \approx 2 \cdot 10^{-12}$ in the MKSA-system.

28. The electron tube as defined in claim 17, including a trough-like magnet for generating a magnetic field, and a highly conductive coating on the inside of said trough-like magnet constituting the said reflecting surfaces.

29. The electron tube of claim 12 in which means loads the resonant circuit so as to cause the oscillating

electrons to reach the collector electrode after having delivered the major portion of their energy to said resonant circuit, said anode means comprising two anodes arranged parallel to each other and to the reflectors, portions of the anode structure located nearest the cathode means being arranged to have an effective influence on the cathode emission current, the distances between the anode structure and said cathode means being such that a majority of the emitted electrons enter the high frequency field between the anodes with such a phase in relation to the field that they draw energy from it to eliminate the possibility of self-excited oscillations.

References Cited in the file of this patent

UNITED STATES PATENTS

2,707,759	Pierce	May 3, 1955
2,755,403	Hickey	July 17, 1956
2,855,532	Tommer	Oct. 7, 1958

OTHER REFERENCES

I.R.E. Journal, August, 1954—page 1239.