Feb. 9, 1960 H. O. G. ALFVÉN 2,924,741

HIGH FREQUENCY ELECTRON TUBE DEVICE

Filed Nov. 25, 1955 4 Sheets-Sheet 1

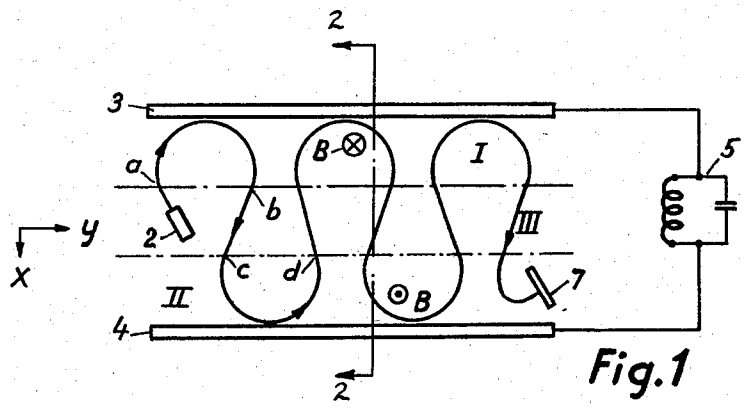


Fig. 1

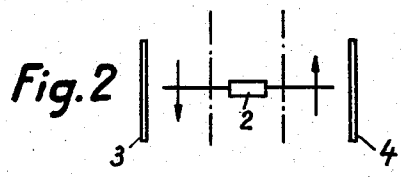


Fig. 2

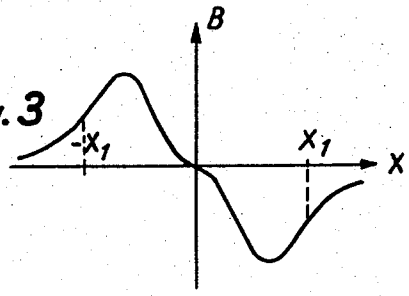
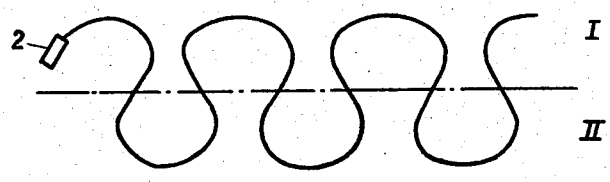


Fig. 3

Fig. 4



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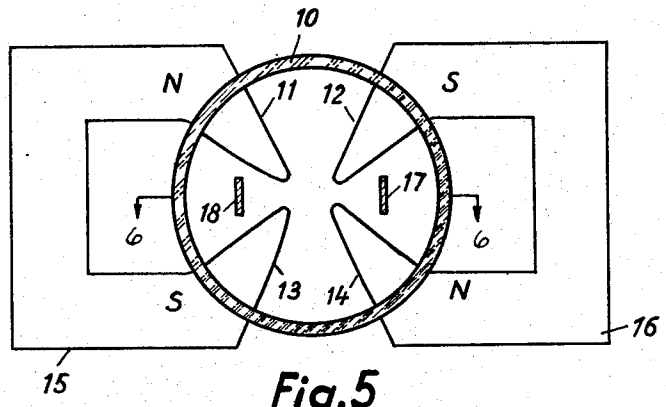


Fig.5

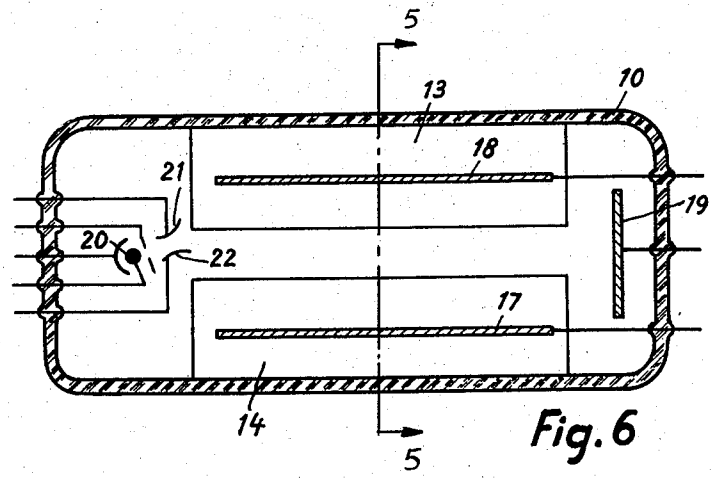


Fig.6

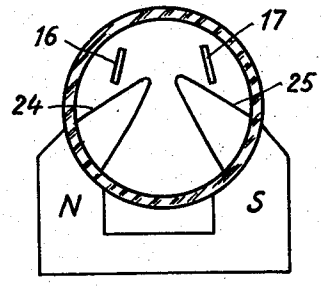


Fig.7

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Fig. 8

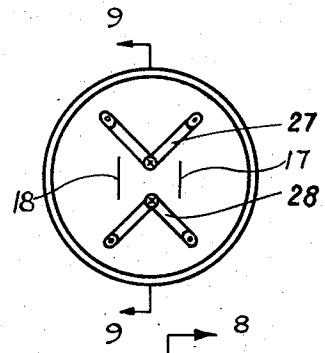
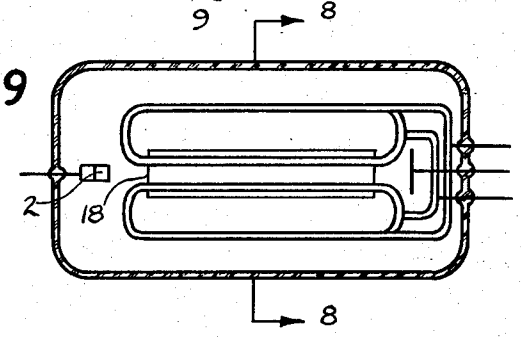


Fig. 9



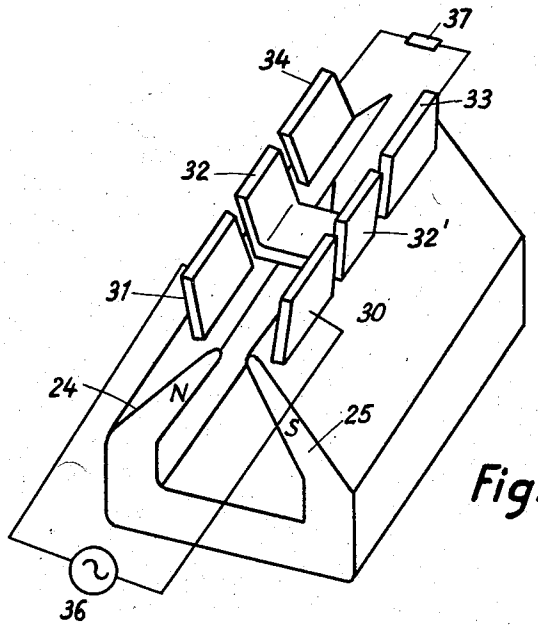


Fig. 10

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Fig. 11

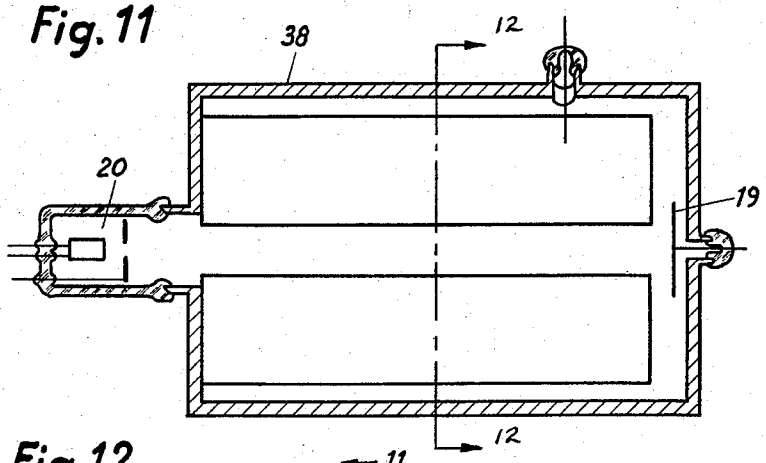


Fig. 12

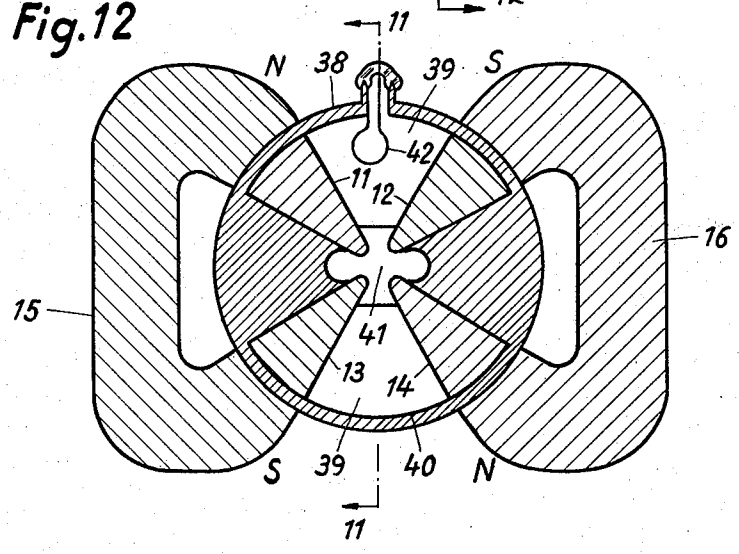
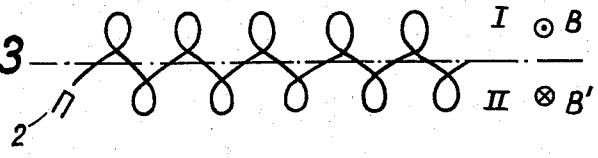


Fig. 13



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HIGH FREQUENCY ELECTRON TUBE DEVICE

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Application November 25, 1955, Serial No. 549,065
Claims priority, application Sweden November 27, 1954
12 Claims. (Cl. 315—5.26)

This invention relates to electron tubes for generating and amplifying high frequency electron oscillations.

Generally electron tubes, in which electrons are caused to oscillate, are used for generating high frequency oscillations. In the hitherto known devices of this kind the electron oscillations are generated by means of electric fields which sometimes are combined with magnetic fields as in the magnetrons and the so-called strophotrons. In electron tubes utilizing combined electric and magnetic fields the magnetic field may be made inhomogeneous for the purpose of effecting a continuous drift motion of the electrons in a certain direction rather to produce oscillations of the electrons.

In an electron tube device according to the invention the electrons are by means of an electron gun injected into a discharge space having no static electric fields and the oscillations of the electrons are obtained exclusively by means of an inhomogeneous magnetic field. In this way a maximum efficiency is obtained as the electrons can deliver a high percentage of their energy to a high frequency circuit coupled to the electron beam without simultaneously taking up energy from a D.-C. electric field.

An electron tube device according to the invention comprises a source for emitting electrons which are subjected to a drift motion along a discharge space simultaneously with an oscillatory motion perpendicularly to the median path of the drift motion, electrode means for setting up an alternating electric field exchanging energy with the oscillating electrons, and a collector electrode. The drift and the oscillatory motion of the electrons are caused by a non-homogeneous magnetic field. This field has in the projection upon a plane perpendicular of the median path of the drift motion in which the electrons move, a maximum value on either side of the median path and extends in opposite directions on either side of said average path.

The invention will be described more in detail in connection with the accompanying drawings.

Fig. 1 is a diagrammatic plan view of the electrode system in an electron tube according to the invention.

Fig. 2 is an end view seen in the direction of the y-axis of the electrode system according to Fig. 1.

Fig. 3 is a graph showing the required distribution of the magnetic field seen in a plane perpendicular to the y-axis in Fig. 1.

Fig. 4 is a diagram of a modified electron path in an electron tube according to Fig. 1.

Fig. 5 is a cross-section taken on line 5—5 of Fig. 6 and shows a tube according to the invention disclosing one arrangement for generating the magnetic field.

Fig. 6 is a longitudinal section taken on line 6—6 of Fig. 5.

Fig. 7 is a cross-section of an electron tube similar to that of Figs. 5 and 6, but having different means for generating the magnetic field.

Fig. 8 is a cross-section taken on line 8—8 of Fig. 9 and showing an electron tube in which the magnetic field is generated by suitably shaped coils.

Fig. 9 is a longitudinal section taken on line 9—9 of Fig. 8.

Fig. 10 is an isometric view of an amplifier system according to the invention.

Fig. 11 is a longitudinal section taken on line 11—11 of Fig. 12 and showing a further embodiment of an electron tube device according to the invention.

Fig. 12 is a cross-section taken on line 12—12 of Fig. 11, and

Fig. 13 shows a further graph of an electron path.

In Fig. 1 showing the principle of an electron tube device according to the invention an electron gun of conventional design is designated by 2, said electron gun being arranged to generate a narrow or concentrated electron beam which is directed into the region or zone designated by I. This space is transverse by a perpendicular magnetic field B′ which is directed towards the plane of the paper. Another region or zone II is traversed by a magnetic field, the field lines of which are also directed perpendicular of the plane of the paper but upwards. Between the regions I and II there is a region or zone III substantially free of the field. Two electrodes 3 and 4 are connected to a resonance circuit 5.

Let it be assumed that no high frequency field is applied to the electrodes 3 and 4, then the electron beam will be deviated to the right when it is entering the magnetic field region I at a, and if the velocity of the electron beam and the strength of the magnetic field are properly selected the electron beam will leave said magnetic field region at b and pass into the field free region III. The electron beam is then entering the magnetic field of the region II where it is deviated to the left in such a way that it is again entering the field free region. In this way the electron beam is performing a continuous motion along a mean path and an oscillatory motion perpendicularly to said mean path.

The electron tube device is operating as generator, for example in the following manner. The high frequency circuit 5 is tuned in such a way, that the resonant frequency is equal to the period of oscillation of the electrons or to some of its odd multiples or submultiples. A necessary condition for an energy exchange between the electron beam and the high frequency field between the electrodes 3 and 4 emanating from the tuned circuit is, as in other tubes in which the generation of oscillations is obtained by means of oscillating electrons, that the electron beam is intensity modulated. The beam can be intensity modulated already in the electron gun before entering the magnetic field. The electron beam can also be automatically intensity modulated as a continuous electron beam entering a magnetic field already is automatically phase focused after a few oscillations so that intensity maxima and minima are formed in the beam. This focusing has been found to be very stable which contributes to the good efficiency of the device. When the electrons have given up the main part of their energy they are suitably collected by a collector electrode 7 for preventing disturbing space discharges in the tube.

The electrons may deviate a certain distance upwards or downwards from the plane of the paper, but if they deviate too much from this plane they must be returned to the vicinity of this plane. This can be accomplished, for example by means of giving the magnetic field a falling characteristic at the apsides of the electrons, seen in a plane perpendicular to the mean path of the drift motion. This is illustrated in Fig. 3 which shows a diagram of the magnetic flux density B as a function of the distance from said mean path. As is seen from this diagram the flux density must be zero in the mean path and have maxima of different polarity on either side of the mean path. The apsides should be located outside the maxima, seen from the mean path, for example at the points x_1 and x_2.

The electron beam can also be stabilized by means of an electrostatic field which returns the electrons to the vicinity of the plane of oscillation.

If the magnetic field is shaped as shown in Fig. 3 the electron path will be more complicated than that shown in Fig. 1 and an example of such a path is shown in Fig. 4. The character of the path can easily be changed by adjusting the angle at which the electron beam is directed into the inhomogeneous magnetic field. As the distance travelled by the electrons during a period of oscillation is varying with the angle at which the electron beam enters the magnetic field it is obviously very easy to change or modulate the frequency of the electron oscillations simply by varying the angle of entry by means of an electrostatic or magnetic deflection system located in or adjacent to the electron gun.

Figs. 5 and 6 show an electron tube comprising an evacuated envelope **10** in which four magnetic pole shoes **11, 12, 13, 14** which are so located that the vertical component of the magnetic field has the same distribution along a horizontal diameter as is shown in Fig. 3. The pole shoes are magnetized by means of external magnets **15** and **16** in such a way that the pole shoes **11** and **14** become north poles and the pole shoes **12** and **13** become south poles. Two electrodes **17** and **18** are located within the tube envelope and connected to a tuned circuit in the same manner as shown in Fig. 1. A collector electrode **19** is arranged for collecting the electrons. In Fig. 6, there is shown an electron gun **20** and a system **21, 22** of deflection electrodes, by means of which the angle can on entry of the beam be varied. The electrons are suitably iniected into the envelope in such a way that they will oscillate along the horizontal diameter along which the resulting field strength is zero.

Fig. 7 shows a section perpendicular of the drift or longitudinal direction, that is of the *y*-axis as defined in Fig. 1, of an electron tube similar to that shown in Figs. 5 and 6 except for the magnet arrangement. According to Fig. 7, the non-homogeneous magnetic field is generated by only two pole shoes **23, 24**. Owing to the horizontal component of the magnetic field, which appears in this arrangement, the electrons will also oscillate in a vertical direction in a more or less pronounced trochoidal path. The oscillation energy can for example be taken out between the electrodes **17** and **18** or between these electrodes interconnected and the magnet. In the latter case the oscillation frequency is preferably equal to twice the frequency of the electrons.

Figs. 8 and 9 show a further embodiment of the invention, where the magnet poles within the tube are replaced by conductors passed by current. In this figure **27** and **28** designate two elongated coils passed by a current flow which conductors are so located, that adjacent parts of the two coils are passed by currents having the same direction. The electron beam of the electron gun **2** is injected substantially in the symmetry plane of the two coils, and the electrons will oscillate in a surface in the space between the coils.

The magnetic field may be shaped in such a way that the field strength increases or decreases along the direction of the translational motion or in such a way that the gradient is varying along the path of the translational motion. In this way it is possible to vary the period of the electron oscillations or to keep it constant although the amplitude is changed. Thus it is possible to keep the oscillation frequency constant in spite of the decrease of the amplitude which is obtained along the direction of the translational motion when the tuned circuit is loaded. This arrangement will give the device maximum efficiency.

Fig. 10 shows schematically the electrode arrangement of an amplifier tube according to the invention. This tube is built up principally in the same way as shown in Fig. 7. The electron gun and the collector electrode are for the sake of simplicity deleted in the figure, but they may be arranged in the same way as shown in Fig. 6. The electrodes **17** and **18** of Fig. 6 are in Fig. 10 divided into three groups **30, 31, 32, 32'** and **33, 34**. The electrodes **30, 31** form an input section and they are connected to the source **36** of the voltage to be amplified. The intermediate electrodes **32, 32'** are directly interconnected and form a screening section between the input section and the third sectiond formed by the electrodes **33, 34**, which serves as output section and is connected to a load **37**.

Electrons emitted from the electron gun will, if no signal is impressed on the input section **30, 31**, oscillate with the same amplitude and frequency and no bunching of the electrons will take place. The electrons will pass all the three sections in a sequence and finally they will be caught by the collector electrode evenly distributed at all times. If, however, an input signal is impressed on the input section, the frequency of which is corresponding to the oscillation frequency of the electrons, a bunching of the electrons takes place and the bunching is more accentuated the stronger the applied signal is. This bunching is sustained during the screening section **32** and at the entry into the output section the electron bunches will induce an amplified signal in the electrode system **33, 34** of the output circuit, which signal is taken out to the load **37**.

Figs. 11 and 12 show two sections of an electron tube device where the electrode system and the magnetic pole shoes together form a resonator. The evacuated envelope **38** consists of an elongated cylindric metallic housing provided with two inner wedge-shaped projections projecting into the space between the pole shoes **11** and **13** and between **12** and **14**, respectively. The spaces **39** formed between the pole shoes **11** and **12** and between the pole shoes **13** and **14**, respectively, together with the space **41** between the radially inner ends of the wedge-shaped projections form the resonant chamber which is tuned to the desired oscillation frequency. In order to obtain a resonant chamber having low losses the inner walls **40** of the resonant chamber, i.e. the surfaces of the magnetic pole shoes **11, 12, 13, 14** and the parts of the metallic envelope limiting said chamber are plated with a suitable low loss metal suitable for use in vacuum, for example gold. The electron beam emanates from the electron gun **20**, which is only schematically shown but this gun can be of any convenient kind known in the prior art. The electrons are oscillating horizontally in the space **41** in the electric field of the high frequency electromagnetic field of the resonator which electric field is concentrated to the space **41**. The frequency of the electron oscillations may be varied or modulated by means of changing the angle of the entry of the electron beam, the velocity of the electron beam or the strength of the magnetic field in analogy with the earlier described embodiments. The high frequency energy is taken out by means of an inductive loop **42** projecting into the cavity **39** of the resonator. The electrons, which have passed the discharge space and given up their energy to the high frequency field, are as in the other embodiments caught by a collector electrode **19**. The magnetic flux to the pole shoes **11, 12, 13** and **14** is as before described supplied by external magnets **15** and **16**, so that the pole shoes **11** and **14** become north poles and the pole shoes **12** and **13** become south poles.

Fig. 13 shows a further type of electron paths possible in an electron device according to the invention. In this case the magnetic field is somewhat stronger than in the above embodiments, whereby the radius of curvature is smaller. It is to be observed that the magnetic fields within the regions I and II, respectively, have directions opposite to those shown in Fig. 4. If the directions of the fields were the same as in Fig. 4 the electrons would obviously move backwards, i. e. to the left in the figure.

Of course it is possible to modify the invention in a

plurality of different ways. For example the inhomogeneous magnetic field may be generated in different ways, and the shape and arrangement of the electrodes may vary.

I claim:

1. An electron tube device for generating high frequency electron oscillations, comprising an evacuated elongated envelope having a longitudinal extending plane of symmetry, electron reflecting electrode means disposed in said envelope symmetrically of said plane, terminal bias means for applying to said electrode means a substantially equal bias potential, said electrode means defining within the envelope a longitudinally extending discharge space substantially free of electrostatic fields, a source of electrons generating a concentrated electron beam directed into said discharge space at one end thereof, the electrons in said beam being contained in an oscillation plane perpendicular of said plane of symmetry and parallel to the longitudinal direction of said discharge space, electron collecting electrode means at the other end of said discharge space, and means for generating a magnetic field in said discharge space, said field having at least a major component perpendicular of said oscillation plane, said major component having a zero value in said symmetry plane and opposite directions on opposite sides of said symmetry plane, the magnetic field having at least one maximum of different polarity on each of said opposite sides of the symmetry plane whereby the electrons are caused to oscillate substantially in said oscillation plane between the reflecting electrode means while progressing along the discharge space.

2. An electron tube device for generating high frequency electron oscillations, comprising an evacuated elongated envelope having a longitudinal extending plane of symmetry, electron reflecting electrode means disposed in said envelope symmetrically of said plane, terminal means for applying to said electrode means a substantially equal bias potential, said electrode means defining within the envelope a longitudinally extending discharge space substantially free of electrostatic fields, a source of electrons generating a concentrated electron beam directed into said discharge space at one end thereof, electron collecting electrode means disposed at the other end of said discharge space, and means for generating a magnetic field having at least one major component directed perpendicular of said plane of symmetry, said major component having a zero value in said plane of symmetry and maxima of different polarities on opposite sides of said plane of symmetry whereby the electrons in said beam are caused to travel along a path oscillating about said plane of symmetry and progressing along the discharge space toward said collector electrode means.

3. Electron tube device according to claim 2, characterized in that the output energy of the electrons and the strength of magnetic field are such that the turnover points of the electrons in the oscillation path are located at a greater distance from said plane than said field strength maxima.

4. Electron tube device as claimed in claim 2, characterized by means for varying the angle of entry of said beam into said envelope.

5. Electron tube device as claimed in claim 2, characterized therein, that the strength of the magnetic field is varying in such a way that the oscillation frequency is constant along the discharge space in spite of the decreasing energy of the oscillating electrons along said space.

6. Electron tube device as claimed in claim 2, comprising magnetic pole shoes projecting into the discharge space, characterized therein, that said pole shoes and parts of the envelope form a resonator in which the electrons oscillate and interchange energy with the electric field within said resonator.

7. An electron tube device according to claim 2, wherein said means for generating the magnetic field comprise two magnets having pole pieces protruding into said discharge space and extending longitudinally therein, like poles of said magnets facing each other in diametrical arrangement across said plane of symmetry.

8. An electron tube device according to claim 2, wherein said means for generating the magnetic field comprise a magnet having pole pieces disposed within the envelope in a position in which the magnetic field has a component parallel of said plane of symmetry, said parallel component causing the electrons to oscillate in perpendicular direction along a generally trochoidal path.

9. An electron tube device according to claim 2, wherein said means for generating the magnetic field comprise coiled conductors extending within said envelope in generally longitudinal direction, adjacent parts of said conductors being disposed to be traversed by a flow of current in the same direction.

10. An electron tube device according to claim 2 for amplifying a voltage, wherein said reflecting electrode means comprise three pairs of electrodes disposed in longitudinal alignment within the envelope, the pair next adjacent to said source of electrons constituting the input section adapted to be connected to a voltage to be amplified, the electrodes of the intermediate pair being interconnected and constituting a screening section, and the electrodes of the third pair constituting the output section adapted to be connected to a load.

11. An electron tube device according to claim 2, wherein said means for generating the magnetic field comprise two pairs of magnets having pole pieces extending into the envelope, like poles facing each other in diametrical arrangement, said pole pieces in conjunction with said electrodes defining a resonance chamber within said chamber, said chamber being tuned to the selected oscillation frequency.

12. An electron tube device according to claim 11, wherein said envelope is in the form of a metallic cylindrical housing having two radially inwardly extending protrusions, each of said protrusions being disposed between the two pole pieces of one of the magnets to define the resonance chamber in conjunction with said pole pieces.

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