May 20, 1952 M. J. O. STRUTT ET AL 2,597,542

ULTRAHIGH FREQUENCY GENERATING TUBE

Filed April 18, 1946 2 SHEETS—SHEET 1

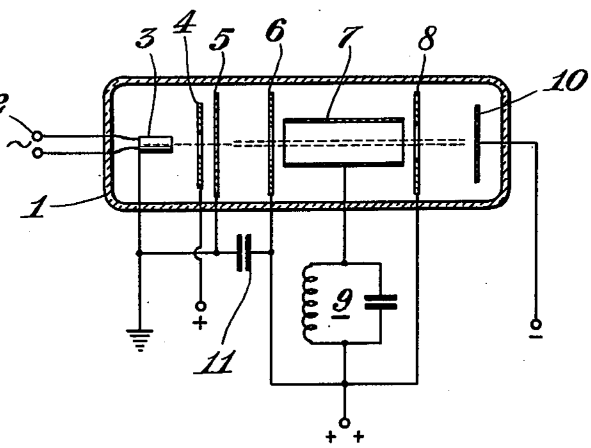

Fig. 1.

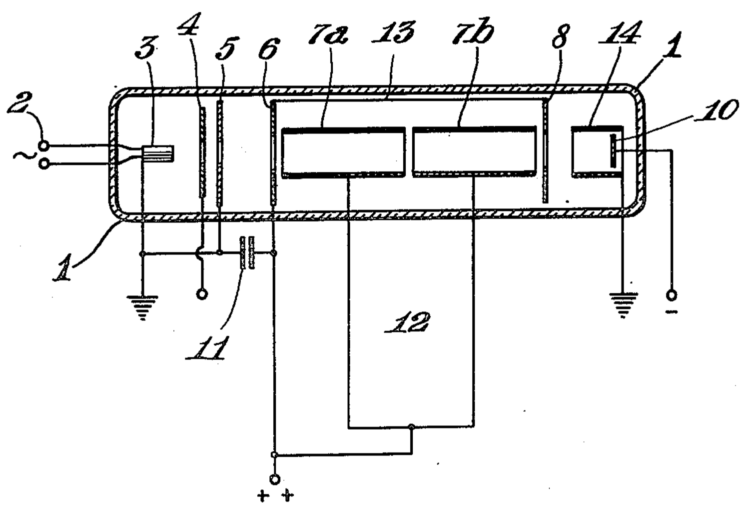

Fig. 2.

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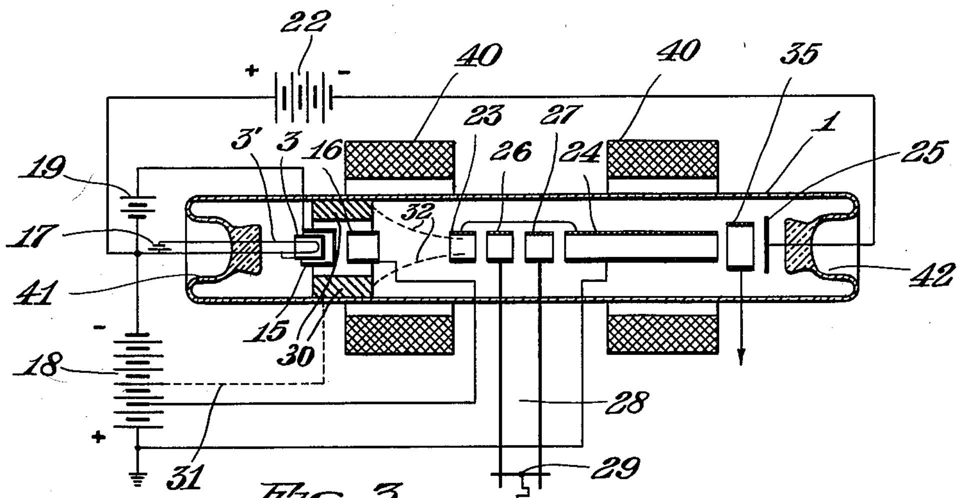

Fig. 3.

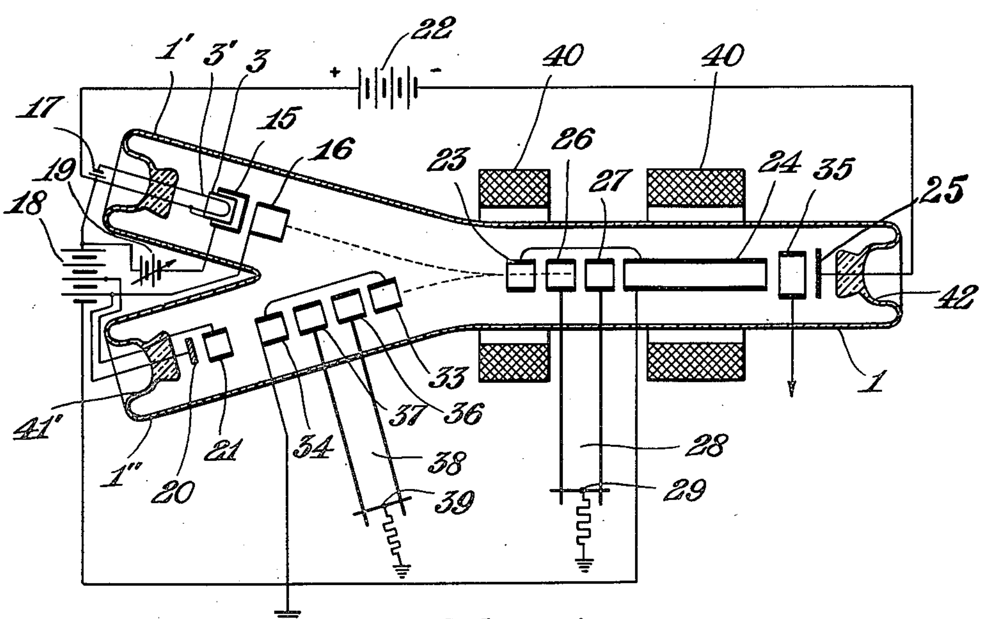

Fig. 4.

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ULTRAHIGH FREQUENCY GENERATING TUBE

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Section 1, Public Law 690, August 8, 1946
Patent expires December 2, 1960

2 Claims. (Cl. 313—82)

1

This invention relates to a device comprising a discharge tube in which an electron beam is generated and the velocity of the electrons in the beam is controlled by an ultra-high frequency oscillation by means of an electrode system, the velocity variations being then converted into intensity variations and it being possible to derive an output voltage from the beam varied in intensity. Such a device may be used for example for generating, modulating or amplifying electric oscillations of ultra-high frequencies.

In the devices of this kind suggested before the velocity control is effected by the beam of electrons being passed through a control space bounded by two electrodes and containing one or more electrodes surrounding the electron path and having a controlling ultra high-frequency oscillation supplied to them. The velocity variations of the electrons in the beam are then converted into intensity variations and this is preferably effected by the beam being passed through a so-called drift-space in which the slow electrons are overtaken by the more rapid ones so that successive maxima and minima of the electron density are set up. Next, energy may be withdrawn from the beam modulated in intensity, for example by the beam being passed through an energy abstracting space bounded by two bounding electrodes and having placed in it one or more output electrodes that surround the electron path. For the purpose of generating electric oscillations part of the energy abstracted from the output electrodes may be fed to the electrodes for controlling the velocity of the electrons in the beam.

However, devices of the kind above-described have the disadvantage that the required electron valves are comparatively involved and have a great length.

The invention has for its object to provide an ultra-high-frequency device by means of which the above-mentioned difficulties are obviated.

The device according to the invention comprises a discharge tube in which an electron beam is generated and the velocity of the electrons is controlled by an ultra-high-frequency oscillation by means of an electrode system, the velocity variations being then converted into intensity variations and provision being made for means by which the electrons varied in velocity are caused to reverse their direction of movement during or after the conversion of the velocity variations into intensity variations so that the electrons pass a second time through the

2

control electrode system and induce an oscillation therein.

The reversal is preferably brought about by means of a repelling electrode placed on that side of the control electrode system which is remote from the electrode system for generating the electron beam.

In one convenient embodiment of the invention the conversion of velocity variations into intensity variations is effected by means of a drift space through which the electrons pass before and after the reversal.

In order that the invention may be clearly understood and readily carried into effect it will now be described more fully with reference to the accompanying drawings in which convenient embodiments of the invention are diagrammatically shown and in which,

Figs. 1 and 2 show devices according to the invention comprising one and two control electrodes respectively, the reversal of the direction of movement of the electrodes being effected by means of a repelling electrode which also serves for converting velocity variations into intensity variations.

Figs. 3 and 4 illustrate two embodiments of the invention in which the reversal of the electrons and the conversion of velocity modulation into intensity modulation is effected by means of a drift space traversed both before and after the reversal of the electrons.

Referring to Fig. 1, 1 designates a tube in which provision is made of an electrode system for generating an electron beam, said system being constituted in succession by a cathode 3 heated indirectly by a filament to which terminals 2 connect and an accelerating electrode 4 and an electrode 5 serving to concentrate the electron beam. The cathode 3 and the electrode 5 are earthed and the accelerating electrode 4 has a comparatively low positive potential (+) relatively to the cathode.

In addition, the tube contains a control electrode system comprising two plate-shaped bounding electrodes 6 and 8 and in between a cylindrical control electrode 7, all of these electrodes having an identical and high direct-current potential (++) relatively to the cathode. The control electrode 7 is connected to one terminal of an oscillatory circuit 9 whose other terminal is connected to the bounding electrodes 6 and 8.

On that side of the control electrode 7 which is remote from the cathode is arranged an electrode 10 having such a negative potential (—)

relatively to the control electrode that electrons accelerated by the first-mentioned electrode cannot reach this electrode and thus reverse their direction of movement in its proximity. The electrode 10 is therefore referred to as the repelling electrode. Similarly, electrode 5 functions to reverse the direction of electrons leaving the velocity modulation electrode system 7 in the direction of the cathode. Accordingly, electrode 5 will hereinafter be referred to as the "first" repelling electrode since it is a first repelling electrode with respect to the cathode and electrode 10 will be referred to as the "second" repelling electrode.

It is presumed that the operation of the device shown in Fig. 1 may be explained as follows:

For the present it is assumed that in the circuit 9 oscillations occur whose frequency corresponds at least substantially to the natural frequency of the circuit. Thus, between the control electrode 7 and the bounding electrodes 6 and 8 respectively, there are set up two electric alternating fields by which the velocity of the electrons received from the cathode and accelerated by the bounding electrode 6 will be controlled in the space between the bounding electrodes.

By a suitable choice of the mean velocity at which the electrons enter the control-electrode system with relation to the length of the control electrode it can be ensured, as is known per se, that the electrons traverse the control space in such a time that they are accelerated or retarded by the said two alternating fields in dependence on the time when the electrons reach the control space. Thus, the electron beam, on leaving the control space, exhibits a velocity modulation.

The electrons leaving the control space arrive in the field which is set up between the electrode 10 and causes the electrons varied in velocity to reverse their direction of movement. Electrons accelerated in the control space by the two alternating fields will, however, penetrate into the repelling field to a further extent than electrons that are retarded by the two alternating fields. Due to this, the path traversed by the accelerated electrons in the repelling field will be larger than the path traversed therein by the retarded electrons and the accelerated electrons are therefore for a longer time in the repelling field than the retarded ones. This, however, means that in the electron beam that leaves the repelling field successive maxima and minima of the electron density occur or in other words that the velocity variations of the electron beam are converted by the field at least partly into intensity variations.

According to the invention, the electron beam modulated in intensity and leaving the field traverses the control electrode system a second time but on this occasion in opposite direction and then reaches the field existing between the bounding electrode 6 and the electrode 5 which latter electrode functions as a repelling electrode. The direction of movement of the electrons is thereby reversed again and the velocity variations of the beam are similarly converted into intensity variations. The electrons then traverse the control-electrode system a third time and again arrive in the field set up by the electrode 10 and so forth.

As is clear from the above electrons in the device shown in Fig. 1 perform an oscillating movement in the axial direction of the control electrode 7, as is designated in the figure by dotted lines.

It has been found that the electrons which pass through the centre of the control electrode 7 a second time, a third time and so on, induce an oscillation in the oscillatory circuit connected to the said electrode. For the purpose of obtaining the maximum efficiency it is desirable that the direct voltage of the field or fields should be chosen with relation to the relative distance of a repelling electrode and the control electrode system in such manner that the electrons pass through the center of the control electrode 7 a second, a third or more times after a time which is about equal to or a whole multiple of the oscillation period of the oscillatory circuit 9 connected to the electrode 7, 6 and 8. The length of time of one oscillation therefore approximately amounts to an even whole multiple of the oscillation period of the oscillatory circuit.

The oscillation induced in the circuit 9 brings about a velocity control of the electrons in the electron beam as above described and this enables the device described to generate self-maintaining oscillations.

Due to the fact that the electrons that pass through the control electrode system a second, a third or more times induce an oscillation in the circuit 9, energy is abstracted from the oscillating electrons of the beam so that their velocity becomes less than the velocity originally brought about by the potential difference between the cathode and the neighbouring accelerating electrode. Due to this and also due to the mutual repulsion of the electrons in the beam the electrons, after having performed one or more oscillations, will impinge on a bounding or a control electrode.

It has been found that it is favourable as regards the efficiency of the device according to the invention to take measures for increasing the average number of oscillations performed by the electrons before impinging on a bounding or control electrode.

For this purpose use may be made of a magnetic field directed in the axial direction of the control electrode 7. This field can be set up by means of one or more coils or else by means of a permanent magnet and concentrates the electrons to form a beam.

A further measure for achieving the said object which may be used in conjunction with that just mentioned consists in choosing the period of an oscillation performed by the electrons so as to be a minimum.

It has been found that for the purpose of obtaining optimum efficiency with relation to the length of the control electrode 7 in the axial direction the mean velocity at which the electrons enter the control electrode system should be chosen in such manner that the electrons traverse the control electrode in a time which corresponds to or is an uneven whole multiple of half the oscillation period of the oscillatory circuit 9.

In order to reduce the duration of one oscillation of the electrons as far as possible the mean velocity at which the electrons enter the control electrode 7 is preferably chosen in such manner that the electrons traverse the control electrode in a time corresponding to half the oscillation period of the circuit 9.

It has been found in addition that for the purpose of obtaining optimum efficiency it is necessary that the direct voltage applied between the control electrode 7 and the repelling electrode should be chosen in such manner with relation to the distance between the repelling electrode and the neighbouring bounding electrode which is nearer thereto that the interval of time between the moment when the electrons pass through the said bounding electrode in the direction of the neighbouring repelling electrode and the moment when the same electrons pass through this electrode in the reverse direction corresponds to or is an uneven whole multiple of half the oscillation period of the oscillatory circuit.

The said interval of time is therefore a minimum if it corresponds to half the oscillation period of the circuit 9.

It follows from the foregoing that the optimum efficiency will be obtained by means of the device shown in Fig. 1 if the duration of one oscillation performed by the electrons amounts to double the oscillation period of the circuit 9.

Fig. 2 shows a device according to the invention in which in contradistinction to Fig. 1 the control electrode system comprises two control electrodes 7*a* and 7*b*. The parts corresponding to the device shown in Fig. 1 are designated by similar reference numerals.

The control electrodes 7*a* and 7*b* are connected respectively to the terminals of an oscillatory circuit 12 comprising two parallel conductors and provided with a central tapping earthed for high-frequency currents. This central tapping and the bounding electrodes 6 and 8 which are interconnected by a conductor 13 have supplied to them a high positive direct-current potential (++) relatively to the cathode 3.

The operation of the device shown in Fig. 2 is similar to that described with reference to Fig. 1. As before, the mean velocity at which the electrons enter the control electrode system is preferably chosen in such manner in relation with the length of the control electrodes 7*a* and 7*b* that the electrons traverse each of the control electrodes in a time corresponding to half the oscillation period of the oscillatory circuit 12. Since two control electrodes are used the minimum and, as regards the efficiency of the device, optimum duration of one oscillation of the electrons is triple the oscillation period of the circuit 12.

The conversion of the velocity variations of the beam into intensity variations which is brought about by the repelling field may be aided by making sure that the path traversed in the repelling field by the fastest electrons is considerably longer than the path traversed therein by the slowest electrons. This may be ensured by the shape of the repelling electrode 10 being chosen in such manner or, if a repelling electrode assembly is used, by the latter being shaped and/or arranged in such manner that the voltage drop of the repelling field in the part where the direction of movement of the electrons is reversed is considerably lower than in the remaining part of the repelling field.

For this purpose, in the device shown in Fig. 2 in which the second repelling electrode is constituted by a disc-like electrode 10 arranged normally to the axial direction of the control electrodes and having a negative potential relatively to the cathode, and a second electrode 14 is arranged in the proximity and on the side of the electrode 10 facing the neighbouring bounding electrode. This electrode 14 is cylindrical and surrounds the electron path and its potential corresponds to the cathode potential.

As already remarked hereinbefore, the electrons, after giving off part of their energy of movement, eventually impinge on one of the electrodes that surround the control space. Since, however, the electrons which impinge on one of

the control electrodes 7*a*, 7*b* bring about undue damping of the circuit 12 it is desirable that the electrons should impinge substantially on the bounding electrodes 6 and 8.

For this purpose, in the device shown, in which the control electrode or electrodes is or are cylindrical, the bounding electrodes 6 and 8 each of which is constituted by a plane plate, preferably comprise circular openings the diameter of which is smaller than that of the control electrode or electrodes, as shown in the figures.

A feature of the device according to the invention consists in that the oscillations set up in the circuit 9 or 12 can be modulated in amplitude in a very simple manner, viz. by providing the electrode system for generating the electron beam with a control electrode by means of which the intensity of the electron beam can be controlled by a modulation voltage. Such a control electrode may be constituted for example, as is known per se, by a control grid placed intermediate the cathode and the accelerating electrode. In this case, the modulated oscillations may be derived from the circuit 9 or 12, for example by inductive or capacitative coupling of a load impedance with the said circuits.

Obviously, in the device according to the invention as described it is also possible to make use of oscillatory circuits different from those shown. Thus, for example, it is possible to use oscillatory circuits in which the control electrodes constitute not only an essential part of the capacity of the oscillatory circuit but also part of the inductance of the oscillatory circuit. Such is the case, for example, if those ends of the control electrodes 7*a* and 7*b* in the device shown in Fig. 2 which are remote from each other are connected respectively to the ends of a tubular conductor surrounding the control electrodes concentrically.

Figs. 3 and 4 show two embodiments of the invention in which the reversal of the direction of movement of the electrons is brought about by means of a repelling electrode but the conversion of velocity variations into intensity variations is effected by means of a drift space which is traversed before and after the reversal.

The device shown in Fig. 3 comprises a discharge tube formed by an exhausted glass tube 1 having a reentrant stem 41 at one end and a stem 42 at the other end. The tube comprises means for generating an electron beam having substantially constant intensity and electron speed. For this purpose, use may be made of various means and those shown on the drawing are to be regarded as an example only, the device for generating an electron beam comprising a filament 3′ surrounded by a cathode 3, a control electrode 15 and an accelerating anode 16.

During operation of the device the filament 3′ is heated by a current supplied from a battery 17 and the accelerating anode 16 is given a suitable positive voltage relatively to the cathode which is supplied from a source of voltage 18. The control electrode 15 is given a preferably variable bias which is positive relatively to the cathode and may be supplied from the source of voltage 19.

Provision is preferably made of some coils 40 which provide a magnetic field parallel to the beam for the purpose of ensuring a sharp concentration of the electron beam.

The velocity control of the electrons is effected in a control space bounded by two tubular bounding electrodes 23 and 24 which surround the path of the electron beam are earthed in the case shown and receive a high positive voltage relatively to the cathode from the source of voltage 18. In the form of construction shown in Fig. 3 the control electrode system also comprises two control electrodes 26 and 27 which are similarly tubular and surround the electron beam. The control electrodes are connected respectively to the terminals of an oscillatory circuit formed by a Lecher line 28 that can be adjusted to the desired length by an earthed bridge 29.

If it is assumed that in the Lecher system 28 oscillations occur whose frequency corresponds at least substantially to the natural frequency of the Lecher system the velocity of the electrons in the electron beam generated in the tube is so controlled by the alternating voltage supplied to the electrodes 26 and 27 that if the length of the control electrodes is properly chosen with relation to the velocity of the electrons in the electron beam generated by the electrode system 3, 15, 16, the electron beam, which leaves the control space, contains electrons having a higher and electrons having a lower velocity than the mean velocity of the electrons.

The electrons that leave the control space then enter the field-free space enclosed by the electrode 24 and referred to hereinafter as drift space in which the conversion of the said velocity variations into intensity variations is brought about. The conversion is brought about due to the fact that the accelerated electrons tend to overtake the retarded electrons with the result that groups of electrons are formed having a greater electron density than the mean density of the beam.

Before this process has completely come to an end the electrons reach the end of the electrode 24, there being placed at this end in the path of the electrons an electrode 25 which is given a voltage negative relatively to the cathode supplied from the source of voltage 22. The electrons that leave the drift space arrive in the field set up by the potential gradient between the electrons 24 and the so-called repelling electrode 25, said field bringing about the reversal of the direction of movement of the electrons so that the electrons pass through the drift space and the control electrode system a second time. Thus, the conversion of the velocity variations into intensity variations due to the electrons retarded during the control by the electrodes 26 and 27 being overtaken by the accelerated electrons is proceeded with after the reversal of the direction of movement of the electrons, until complete conversion has occurred. The conversion is preferably completed when the electrons pass through the control electrodes 26 and 27 a second time. On the control electrode system being passed through a second time an alternating voltage is induced in the oscillatory circuit connected to the electrodes 26 and 27 by the groups of electrons of which the beam now consists.

The mean velocity of the electrons in the beam is preferably chosen with relation to the length of the electrode 24 in such manner, that the phase of the alternating voltage induced in the Lecher line 28 by the electrons that pass through the electrodes 26 and 27 a second time corresponds to the phase of the control voltage supplied to the electrodes 26 and 27. In this case, the induced alternating voltage itself brings about a velocity control of the electrons in the beam which permits of selfmaintaining oscillations being generated by means of the device described.

Intermediate the control-electrode system and the electrode 25 in the proximity of this electrode is arranged an electrode 35 surrounding the electron beam. This electrode 35 is given a bias suitable for concentrating the returning electrons with the result that the returning electrons, which enter the control space a second time, are concentrated to form a beam.

In the device shown in Fig. 3 the electrons that pass through the control space a second time are collected by the accelerating anode 16, this anode having therefore also the function of collecting electrode.

This double function of the accelerating anode 16 involves the disadvantage that the voltage of this electrode cannot be adjusted to the optimum value for both functions. In addition, difficulties may arise by reason of the intense heating to which the electrode 16 is subjected by the impact with the electrons which have substantially given off their energy. In a modification of the device according to the invention means are therefore provided to ensure that after passing through the control electrode system a second time the returning electrons are deflected and find their way to a collecting electrode deliberately provided for this purpose. In the form of construction shown in Fig. 3 these means are formed by a ring 30 of ferro-magnetic material which is concentrically arranged around the device 3, 15, 16 for generating the electron beam and in the case shown is enclosed within the tube 1. This ring is placed in the magnetic concentrating field provided by the coils 40 and locally brings about such a deformation of this field that the magnetic lines of force between the electrodes 23 and 16 are given the course designated by doted lines 32. The returning electrons, which substantially follow the magnetic lines of force, consequently find their way to the ring 30, which therefore also acts as a collecting electrode and for this purpose is connected via a conductor 31 shown in dotted lines to a suitable positive voltage from the source of voltage 18. If the ring 30 is arranged outside the tube 1 a preferably annular electrode is placed in the path of the lines of force 32 so as to collect the electrons.

Fig. 4 shows a further form of construction of a device according to the invention comprising a drift space in which the electrons are deflected before being collected. For this purpose the glass tube 1 has two branches 1′ and 1″ on one side, each of the branches forming a small angle with the extension of the remaining part of the tube 1. The part 1′ contains a device for generating an electron beam which corresponds to the similar device shown in Fig. 3. The branch 1″ of the container encloses an electrode 20 for collecting the deflected electrons and an electrode 21 for collecting or suppressing which serves the secondary electrons that may be emitted by the electrode 20 and has therefore the function of a screen grid or suppressor grid respectively. For this purpose the electrodes 20 and 21 may be given suitable voltages from the source of voltage 18. In addition in the form of construction shown the branch 1″ contains a special electrode system which comprises electrodes 33, 34, 36 and 37 and is substantially similar to the electrode system 23, 24, 26, 27 in the part 1 of the tube shown in Fig. 4.

The electrodes **36** and **37** are connected to a Lecher line **38** comprising a short-circuiting bridge **39** and tuned to the same frequency as the line **28** or, if desired, to a harmonic thereof.

In addition, the space between the electrodes **16**, **33** and **23** preferably contains a magnetic field whose lines of force are normal to the direction of movement of both the forward and the backward electrons and which may be provided by means not shown, for example a horse-shoe magnet. The intensity of this magnetic field is chosen in such manner that after passing through this field the beam which is generated by the electrode system **3**, **15**, **16** and forms a certain angle with the direction of the axis of the control electrode system **23**, **26**, **27**, **24** enters the electrode system **23**, **26**, **27**, **24** in the axial direction. The electrons which after reversal of their movement of direction emerge from the electrode **23** are again deflected due to the magnetic field, viz. towards the side of the branch **1''** of the tube **1** so that they enter the electrode system **34**, **37**, **36**, **33** in the axial direction. If the length of the electrodes and the mean electron velocity are properly chosen the groups of electrons, on passing through the electrodes **36**, **37** induce in the circuit connected to these electrodes an alternating voltage of the same frequency as that of the oscillation induced in the line **28** or a harmonic thereof.

The oscillation induced in the line **38** is preferably fed to a load circuit (not shown) so that the electrodes **26** and **27** merely serve for varying the velocity of the beam, whereas energy is abstracted from the beam by the electrodes **36** and **37**. In addition the mean velocity of the electron beam in this form of construction is chosen in such manner that the conversion of velocity variations into intensity variations due to the retarded electrons being overtaken by the accelerated electrons has not been completed until the electrons reach the electrodes **36** and **37**. The advantage of a special output-electrode system **34**, **37**, **36**, **33** consists in that in the use of such an electrode system it is possible to choose the various auxiliary voltages at will and so as to be optimum for the abtraction of energy from the beam.

What we claim is:

1. A high-frequency electron discharge device of the velocity modulation type, comprising an evacuated envelope and an electron discharge system mounted therein and comprising, successively, a cathode for generating a beam of electrons, a first repelling electrode perforated

to permit the passage of the primary electron beam generated by the cathode for reversing the direction of flow of electrons travelling in a direction toward the cathode, an electron velocity modulating electrode system through which the said electron beam passes, and a repelling electrode system capable of producing a field configuration for returning substantially all electrons leaving the velocity modulating electrode system in a direction away from the cathode, said repelling electrode system comprising a first electrode having a passage for electrons therethrough into the system and a second repelling electrode impervious to electrons and negatively biased with respect to said first electrode of said system for returning substantially all electrons to the said velocity modulation electrode system.

2. A high-frequency electron discharge device of the velocity modulation type, comprising an evacuated envelope and an electron discharge system mounted therein and comprising, successively, a cathode for generating a beam of electrons, a first repelling electrode perforated to permit the passage of the primary electron beam generated by the cathode for reversing the direction of flow of electrons travelling in a direction toward the cathode, an electron velocity modulating electrode system through which the said electron beam passes, and a repelling electrode system capable of producing a field configuration for returning substantially all electrons leaving the velocity modulating electrode system in a direction away from the cathode, said repelling electrode system comprising a disc-like electrode adapted to repel electrons and a hollow cylindrical electrode interposed between the disc-like electrode and the velocity modulating electrode system and axially aligned with the electron beam leaving the said electrode system.

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