ELECTRON DISCHARGE APPARATUS

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FIG. 1

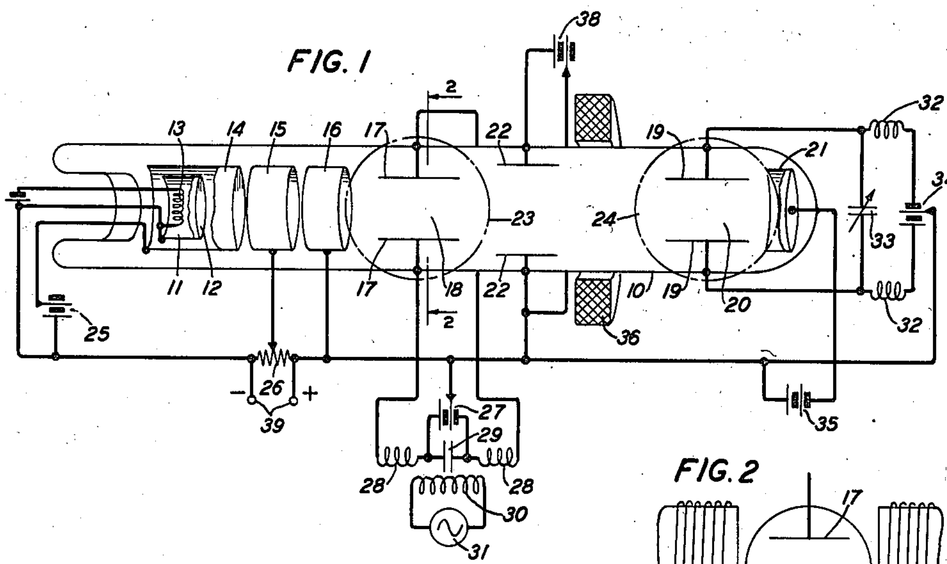

FIG. 2

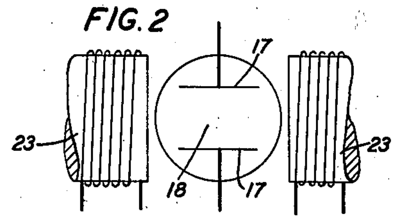

FIG. 3

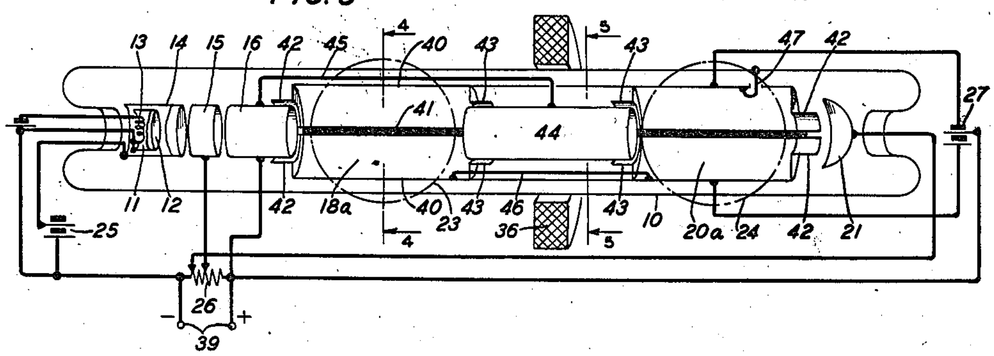

FIG. 4

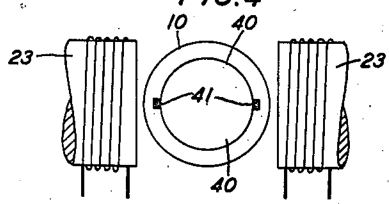

FIG. 5

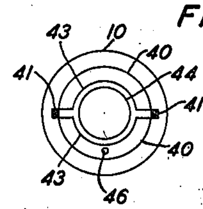

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FIG. 6

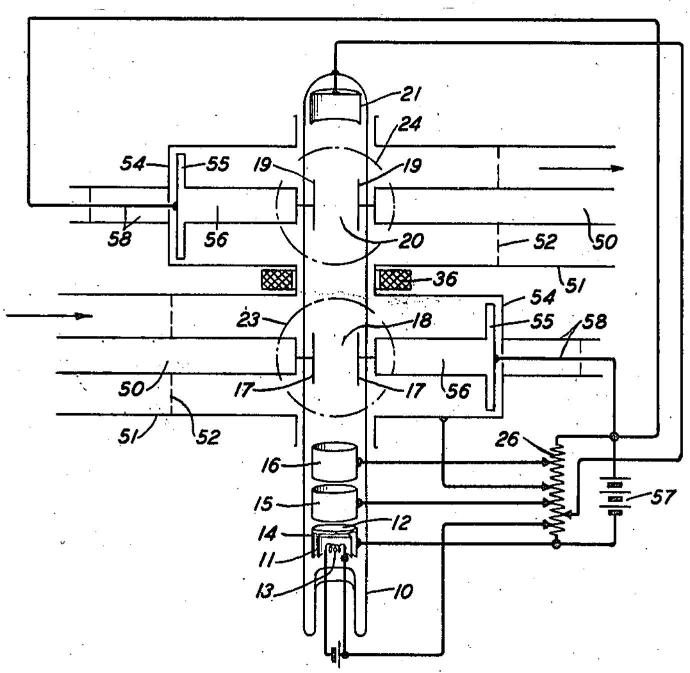
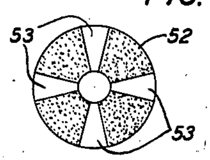


FIG. 7



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2,313,819

ELECTRON DISCHARGE APPARATUS

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Application April 4, 1941, Serial No. 386,783

9 Claims. (Cl. 250—27)

This invention relates to electron discharge apparatus operable at ultra-high frequencies and more particularly to such apparatus including devices of the velocity variation beam type.

Electron beam discharge devices of the velocity variation type comprise, in general, an electrode or electrode system for producing a concentrated electron beam and one or more elements, such as a cavity resonator or other resonant system, defining an input space or gap traversed by the beam and which, when suitably energized to produce an alternating current field at the input space or gap, effects velocity variation of the beam. Necessarily, such elements of known design are of such construction that the alternating current field is compressed within the limits of the input space or gap and, inasmuch as at the high frequencies involved the requisite dimensions of the input space or gap are very small, the fabrication of such elements entails considerable difficulty. Furthermore, the mechanical difficulties involved in the fabrication of elements defining input spaces or gaps are reflected in variations in the operating characteristics of devices embodying such elements and, together with the smallness of the dimensions involved, result in relatively low efficiency for the input space or gap.

One broad object of this invention is to facilitate the efficient production of velocity varied beams in ultra-high frequency electron discharge devices. More specifically, objects of this invention are to enable the production of velocity varied electron beams by the use of input systems of relatively large dimensions, to improve the efficiency of the input space in electron beam discharge devices of the velocity variation type, and to obtain substantially constant operating characteristics for the input space in such devices.

In one illustrative embodiment of this invention, an electron beam discharge device comprises an electron gun for producing a concentrated electron beam, an input element defining a space or gap at which velocity variation of the beam is effected, means for converting the velocity varied beam into a density varied beam, and an output element energized or excited by the density varied beam.

In accordance with one feature of this invention, the input element comprises means for producing in the input space or gap, which may be of considerable length, crossed magnetic and electric fields, the magnetic field being normal to the direction of projection of the beam into the input space or gap and the electric field being normal to the magnetic field, and means for establishing in the gap or space an alternating current field normal to the magnetic field. The magnetic and electric fields are so correlated in intensity that the electrons constituting the beam traverse cycloidal paths in passing through the space or gap and, at the region where they emanate from the space or gap, are traveling in the direction in which they were projected into the space or gap but with velocities differing from their initial velocities to an extent dependent upon the magnitude and phase angle of the alternating current field.

The invention and the above-noted and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawings, in which:

Fig. 1 is in part a longitudinal view of an electron discharge device illustrative of one embodiment of this invention and particularly suitable for use as an ultra-high frequency amplifier, and in part a circuit diagram illustrating one way in which the device may be operated;

Fig. 2 is a view in section along line 2—2 of Fig. 1;

Fig. 3 is a view similar to Fig. 1 of electron discharge apparatus illustrative of another embodiment of this invention and especially suitable for the generation of ultra-high frequency oscillations;

Fig. 4 is a view in section along line 4—4 of Fig. 3;

Fig. 5 is a view in section along line 5—5 of Fig. 3;

Fig. 6 is a view of electron discharge apparatus illustrative of still another embodiment of this invention, including an electron discharge device of the construction shown in Fig. 1 and operated as a repeater associated with input and output circuits of the coaxial line type; and

Fig. 7 is a detail view of the diaphragm included in the coaxial input line shown in Fig. 6.

Referring now to the drawings, the electron discharge device illustrated in Fig. 1 comprises an elongated evacuated enclosing vessel 10 at one end of which there is positioned an electron gun for producing a concentrated electron beam projected along and parallel to the longitudinal axis of the enclosing vessel 10. The electron gun includes a cathode 11 having a surface 12 coated with a material of good thermionic emission characteristics, a heater element 13, and a plurality of coaxial cylindrical electrodes 14, 15 and 16 for concentrating the electrons emanating from the cathode into a beam. Opposite the electrode 16 and equally spaced from the longitudinal axis of the vessel 10 are a pair of elongated parallel plates 17 which define an input space or gap 18.

A pair of elongated parallel plates 19 equally spaced from the longitudinal axis of the vessel 10 are mounted adjacent the other end of the vessel and define an output space or gap 20 which is followed, with respect to the direction of flow of the electron beam, by a collector electrode 21.

Mounted between the input and output spaces or gaps 18 and 20 respectively and equally spaced from the longitudinal axis of the vessel 10 are a pair of parallel plates 22 the function of which will be pointed out hereinafter.

A pair of electromagnets 23 and 24 are provided externally of the vessel 10, each of these electromagnets having its poles opposite one of the input or output spaces or gaps 18 and 20 and in such position as to produce a magnetic field normal to the longitudinal axis of the vessel 10, e. g. perpendicular to the plane of the drawing in Fig. 1.

As shown in Fig. 1, the electrodes 14, 15 and 16 are maintained at suitable positive potentials with respect to the cathode 11 by a source, such as a battery 25 in association with a resistance 26 and another source, not shown, connected across the resistance 26 and, as will be apparent, the plates 17 also are maintained at a positive potential with respect to the cathode 11. An electric field is produced between the plates 17, normal to the magnetic field in the space or gap 18, by a source, such as a battery 27, the plates having connected therebetween inductances 28 and a condenser 29. The inductances 28 and the condenser 29 in combination with the capacity of the plates 17 constitute a resonant circuit. This circuit is coupled to an input element comprising an inductance 30 and high frequency source 31, whereby there is impressed upon the input space or cavity 18 a high frequency electric field normal to the magnetic field therein.

The output space or gap 20 is associated with a resonant circuit including the plates 19, inductances 32 and a condenser 33, an electric field being produced between the plates 19, normal to the magnetic field in the space or gap 20, by a battery 34.

The collector electrode 21 is maintained at a potential somewhat lower than that of the electrode 16 with respect to the cathode 11, as by a battery 35.

It will be noted that the electron beam produced by the electron gun is projected with a certain velocity into the input space or gap 18 in which crossed magnetic and electric fields, that is fields normal to each other, exist. The effect of this space or gap upon the beam will be understood from the following considerations. Using rectangular coordinates, the beam may be considered as projected in the X direction into the input space or gap 18 in which there is an electric field E in the Y direction and a magnetic field H in the Z direction. When the electric and magnetic fields are constant, that is when no high frequency field is impressed between the plates 17, it can be shown that, considering the point of injection of the electron beam into the space or gap 18 as having coordinates $x=0$ and $y=0$, the solution for the electron motion is given by the equations

$$x-\mu t=\gamma_0 \sin \omega_0 t \qquad (1)$$

$$y-\gamma_0=-\gamma_0 \cos \omega_0 t \qquad (2)$$

where t is time, taken as zero at the point of entry of the electrons into the space or gap 18, ω_0 is 2π times the frequency of motion and equal to 2.22×10^7H, μ is the velocity of the center of motion and equal to

$$7.96\times10^7\frac{E}{H}$$

and γ_0 is the radius of the circular motion. It is also the distance of the center of circular motion from the x axis and equal to

$$\frac{\dot{x}_0-\mu}{\omega_0}$$

where $\dot{x}_0$ is the velocity of the electrons in the x direction at the point of entry into the input space or gap 18. From this it will be seen that in flowing through the input space or gap 18, an electron follows a cycloidal path, i. e. its motion is equivalent to revolution around a circular path of radius γ_0 the center of which moves at a uniform velocity μ in a straight line parallel to the x axis. The shape of the actual cycloidal path is dependent upon the relative magnitudes of the initial electron velocity $\dot{x}_0$ and the velocity μ. When $\dot{x}_0$ is greater than 2μ, the cycloidal path is a series of loops along a line parallel to the x axis. When $\dot{x}_0$ is less than 2μ, the path is of wave form. In a device such as shown in Fig. 1, a ratio of $\mu/\dot{x}_0$ somewhat less than one-tenth is preferable.

The velocity, in the x direction, of an electron in the input space or gap is given by the relation

$$\dot{x}=\dot{x}_0-\omega_0 y \qquad (3)$$

From the foregoing, it will be seen that an electron in traversing the input space or gap 18 follows a cycloidal path and at recurrent points in its path and on the x axis it is moving in its original direction, i. e. in the x direction, and with its initial velocity. The locations of these points along the x axis are determinable from the relation

$$x=Kn\frac{E}{H^2} \qquad (4)$$

where

$$K=2\pi\left(\frac{\mu}{\omega_0}\right)=22.6$$

and n has successive integral values. From Equation 4, it will be noted that the location of the points is independent of the initial electron velocity $\dot{x}_0$ and inasmuch as the velocity μ of the center of motion and the frequency of motion ω_0 also are independent of the initial electron velocity, electrons with different initial velocities will travel from the origin to these points in the same period of time.

When an alternating current field is superimposed upon the input space 18, the electron trajectories will be varied in a manner which will be understood from the following. As an illustrative case, the superimposed field may be considered as in the x direction and of intensity E_a $\cos(\omega t+\delta)$, δ being the phase angle of the superimposed field at the time $t=0$, where t for any electron is measured from the instant of entry into the crossed magnetic and electric fields. For such case, and where the superimposed field is either in or near resonance with the frequency of the normal electron motion, i. e. the motion when no superimposed field is present, and the electron transit time is small as compared to

$$\left(\frac{\pi}{\omega-\omega_0}\right)$$

the electron path through the input space or gap is given by the relations

$$x-\mu t=\gamma_0 \sin \omega_0 t-\frac{Ft}{2\omega_0}\sin(\omega_0 t+\delta) \quad (5)$$

$$y-\gamma_0=-\gamma_0 \cos \omega_0 t+\frac{Ft}{2\omega_0}\cos(\omega_0 t+\delta) \quad (6)$$

where

$$F=-\frac{e}{m}10^7 E_a$$

e being the electron charge and m the electron mass, and the electron velocity in the x direction is given by the equation

$$\dot{x}=\dot{x}_0-\omega_0 y+\frac{F}{\omega}[\sin(\omega t+\delta)-\sin\delta] \quad (7)$$

For the case under consideration, just as in the normal case, the origin $x=0$, $y=0$ is taken at the plane where the electron enters into the input space or gap 18, at which plane it has an initial velocity $\dot{x}_0$ and the time t is zero.

From Equations 5 and 6 it will be noted that for the case under consideration the motion of an electron is, as in the normal case, equivalent to rotation around a moving circular path, but with the radius of the circular path changing with time in a manner depending upon the phase angle δ of the superimposed field.

It can be shown that if the velocity μ of the center of motion is small compared to the initial electron velocity $\dot{x}_0$, for example where $\mu/\dot{x}_0$ is somewhat less than $\frac{1}{10}$, and if the total change in the radius of the circular motion is relatively small compared to the initial radius γ_0, for example 20 per cent of the initial radius γ_0, at recurrent points along the x axis all of the electrons projected into the input space or gap 18 in the x direction will be traveling substantially in the x direction and that the location of these points along the x axis will be the same as in the normal case, i. e. with no superimposed field, as given by Equation 4. However, as will be apparent from a comparison of Equations 3 and 7, the electron velocities at these points for the case of the superimposed field will be different, greater or lesser depending upon the magnitude of the superimposed field, than the electron velocities at these same points in the normal case. Hence, the superimposed field effects a velocity variation of the electron stream projected into the input space or gap 18. If the input space or gap 18 is terminated at a plane corresponding to one of these points, the beam, as it issues from the input space, will be traveling in the same direction as when it was projected into the input space or gap, i. e. in the direction of the longitudinal axis of the vessel 10, and will be velocity varied in character.

Although the foregoing analysis has been for the case wherein the superimposed field is in the direction of initial electron velocity, i. e. in the x direction, it can be shown that a similar velocity variation effect is produced when the superimposed field is in other directions and normal to the magnetic field. In Fig. 1 this superimposed field is between the plates 17, i. e. normal to the longitudinal axis of the vessel 10.

In an idealized space for producing velocity variations as above described, the uniform electric and magnetic fields would be sharply bounded by two parallel planes normal to the initial electron velocity, that is normal to the x axis. The fields, then, could be so adjusted with respect to the length of the space that the ratio E/H^2 would be such, in accordance with Equation 4, that at the terminal plane of the field the electrons would leave the space traveling in their initial direction, i. e. in the direction of the x axis. For example, if operation of the device at 3000 megacycles were desired, the magnetic field as determined by the expression

$$f_0=\frac{\omega_0}{2\pi}=3.54\times10^6 H$$

would be about 1200 ampere centimeters and, for a ratio of $\mu/\dot{x}_0$ of one-tenth, the electric field E for a beam having an initial velocity of 2500 volts would be about 300 volts per centimeter. In actual spaces, however, the fields do not have such extremely sharp boundaries and at the ends of the input space 18, therefore, some fringes are present. However, the velocity variation in such fringes is so small as to be negligible for practical purposes so that the actual space or gap produces effectively the same result as the idealized space.

It may be noted also that as the beam emerges from the input space or gap, there may be a spurious angular dispersion thereof. However, when the velocity μ of the center of motion is small as compared with the initial electron velocity $\dot{x}_0$ as noted heretofore, this dispersion is substantially negligible. Furthermore, any such dispersion may be counteracted by focusing means, such as a magnetic coil 36 shown in Fig. 1 which produces an electron lens effect whereby an image of the beam at the exit plane of the input space 18 is focused upon the output space or gap 20.

The velocity varied beam produced at the input space or gap 18 is projected into a drift space, extending between the input and output spaces or gaps 18 and 20 respectively whereby a bunching of the slow moving and fast moving electrons in the beam is effected and the velocity variations are converted into density variations. A pair of parallel plates 22, between which a potential is impressed as by a battery 38, are provided in the drift space to allow correction for any misalignment of the beam as it leaves the drift space.

The density varied beam then enters the output space or gap 20 in which there are crossed electric and magnetic fields due to the battery 34 and electromagnet 24 so that the electron bunches in the density varied beam, by their cycloidal oscillations in the output space 20, act upon the output circuit through the plates 19 and deliver high frequency energy to this circuit, the high frequency output being greatest when the circuit is tuned to the frequency of the cycloidal oscillations.

After leaving the output space 20, the electrons are collected by the electrode 21, which is at a potential less than the initial voltage of the electrons so that the heat generated in the device is small.

The electron beam produced by the electron gun may be controlled in intensity or otherwise modulated by impressing an appropriate potential between the electrode 16 and the cathode 11, as by way of terminals 39.

It will be appreciated that the input space or gap 18 may be made relatively long so that an input gap in accordance with this invention may be produced without any particular difficulties. Furthermore, such a gap enables the attainment of a relatively high velocity variation factor and, hence, a high efficiency.

In the oscillator illustrated in Fig. 3, which includes an electron gun of the construction shown in Fig. 1 and described hereinabove, the input and output spaces or gaps are of the cavity resonator type. Specifically, the device disclosed in Fig. 3 comprises a pair of complementary semicylindrical metallic members 40 separated at their edges, in a plane passing through the longitudinal axis of the enclosing vessel 10, by insulators 41, as shown in Fig. 3, and provided with semicircular end flanges 42 and intermediate flanges 43, one set of end flanges 42 encompassing the cylindrical electrode 16. Between and extending to within the flanges 43 is a cylindrical conductor 44 which defines a drift space and is maintained at the potential of the electrode 16 through a conductor 45.

The semicylindrical members 40, it will be apparent, define a pair of resonant cavities 18*a* and 20*a* separated by and coaxial with a drift space and are designed to be resonant at the same predetermined frequency, that is the operating frequency of the device. The two cavities may be connected by a conductor 46 whereby some of the energy in the cavity 20*a*, when this cavity is excited in the manner described hereinafter, is fed back to the cavity 18*a*. Energy may be withdrawn from the cavity 20*a* through a loop 47.

During operation of the device shown in Fig. 3, a potential is impressed between the semicyclindrical members 40, as by the battery 27, so that an electric field, normal to the longitudinal axis of the enclosing vessel 10 is produced in both the cavities 18*a* and 20*a*. The magnets 23 and 24 produce in these cavities magnetic fields normal to the electric fields therein and normal also to the longitudinal axis of the enclosing vessel 10, the magnetic and electric fields being made of such intensity, as described hereinabove in connection with Fig. 1, that the electrons in the beam traverse cycloidal paths and at the plane where they enter the drift space are traveling parallel or substantially parallel to the longitudinal axis of the cylindrical electrode 44.

The input cavity 18*a* is excited at its resonance frequency by the energy fed back along the conductor 46, so that it oscillates with its alternating current electric vector parallel to its axis and it acts throughout its length on the cycloidal motion of the electrons traversing it whereby the beam is velocity varied in the manner described heretofore in connection with Fig. 1. The velocity varied beam passes through the drift space wherein the velocity variations are converted into density variations. The density varied beam then traverses the output cavity 20*a*, wherein crossed magnetic and electric fields are extant, and by its cycloidal oscillations drives the output cavity resonator to cause it to oscillate. A fraction of the power thus developed in the output cavity 20*a* is fed back to the input cavity, by the conductor 46, and the two cavities thus constitute an ultra-high frequency oscillation generator capable of supplying power, through the loop 47, to a load circuit.

In the apparatus illustrated in Fig. 3, a magnetic focusing coil 36 may be employed, as in the device shown in Fig. 1 and described hereinabove, to correct for dispersion of the beam and to focus the beam upon the output cavity 20*a*.

In the apparatus illustrated in Fig. 6, the electron discharge device acts as a repeater coupling a pair of coaxial cables and is of substantially the same construction as the device shown in Fig. 1 and described heretofore. The input line comprises a pair of conductors 50 and 51 connected to one another near one end thereof by a diaphragm 52, which, as shown in Fig. 7, is provided with a plurality of radial apertures 53. The outer conductor 51 terminates in a wall 54 adjacent which and forming a high capacity condenser therewith is a metallic disc 55 integral with a conductor 56 of the same diameter as the conductor 50 and coaxial therewith. The coaxial line 50, 51, then, as will be apparent, terminates in a resonant section, which is designed to be resonant at the desired operating frequency of the device.

The inner conductor 50 is connected to one of the plates 17 forming the input gap or space 18 and the outer conductor 51 is connected to an intermediate point on a resistance 26 connected across a source such as a battery 57. The conductor 56 is connected to one end of the resistance 26 so that an electric field, normal to the longitudinal axis of the vessel 10 is produced between the plates 17. As shown in Fig. 6, connection between the resistance 26 and conductor 56 is established through the inner conductor of an antiresonant section of coaxial cable 58 to reduce radiation leaks.

The other coaxial line, which is associated with the output gap 20, is of the same construction as the input coaxial line, as is apparent from the drawing.

Electromagnets 23 and 24 produce magnetic fields in the input and output spaces or gaps 18 and 20 respectively normal to the electric fields therein, the magnetic and electric fields being so correlated, as described with reference to the device shown in Fig. 1, that the electrons in traversing the input gap or space 18 follow cycloidal paths and at the region where they leave this space or region are traveling parallel to the longitudinal axis of the vessel 10.

When a signal is transmitted along the input line 50, 51, the input wave passes into the resonant section, which terminates the input line, through the apertures or slots 53 in the diaphragm 52 and excites this resonant section. Over most of this section the electric field is radial with respect to the axis of the coaxial input line but in the space or gap 18 this field is in the axial direction. The incoming wave, therefore, acts upon the cycloidal oscillations of the beam traversing the input gap or space 18 so that the beam is velocity varied.

The velocity varied beam then passes into the drift space, between the input and output gaps, wherein the velocity variations are converted into density variations. The density varied beam then passes into the output space or gap 20 and excites the resonant section terminating the output coaxial line whereby an amplified wave, corresponding to the input wave, is transmitted out over the output coaxial line.

It will be understood, of course, that the resonant sections terminating the input and output coaxial lines are adjusted so that they are resonant to the incoming wave.

A magnetic coil 36 may be used in the apparatus illustrated in Fig. 6, as described in connection with Fig. 1 to correct for dispersion of the beam and to focus it upon the output space or gap **20**.

Although specific embodiments of this invention have been shown and described, it will be understood, of course, that they are but illustrative and that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. In electron discharge apparatus, means for producing a velocity varied beam comprising means defining an input space, means for projecting an electron beam into said space parallel to the longitudinal axis thereof, means for producing in said space magnetic and electric fields normal to each other and of such relative strength and so related to the length of said space that electrons in said beam in traversing said space follow cycloidal paths and at the region at which they leave said space are traveling substantially in the direction of said axis, and means for impressing a high frequency field upon said space and normal to said magnetic field.

2. Electron discharge apparatus comprising means defining an input space, means for projecting an electron stream into said space, means for producing in said space a magnetic field normal to the direction of projection of said stream, means for producing in said space an electric field normal to said magnetic field and of such strength relative thereto that the electrons in said stream in traversing said space are directed along cycloidal paths of several periods and at the region where they leave said space are traveling in substantially said direction, means for superimposing on the magnetic and electric fields in said space an alternating electric field substantially in resonance with the cycloidal oscillations of said electrons in said space, and means for withdrawing energy from said stream beyond said region.

3. The method of producing a velocity varied electron beam which comprises projecting a stream of electrons into a region of crossed magnetic and electric fields and normal to the magnetic field whereby the electrons are directed into paths comprising a series of cycloidal sections, varying the amplitude of the electron motion normal to the direction of projection of said stream into said region in resonance with the frequency of said cycloidal sections, and withdrawing said electrons from said region at a point where the electron motion is substantially in the direction of projection thereof.

4. In electron discharge apparatus, means for producing a velocity varied electron beam comprising a pair of opposed plates, an electron gun opposite one end of said plates for projecting an electron stream between said plates parallel to the opposed surfaces thereof, means for producing between said plates a magnetic field normal to the direction of projection of said electron stream and parallel to opposed surfaces of said plates, means for impressing a potential between said plates of such magnitude relative to said magnetic field that the electrons in said stream follow a series of cycloidal hops in passing between said plates and at the other end of said plates are traveling substantially in the direction of their projection between said plates, and means for impressing between said plates an alternating current potential substantially in resonance with the cycloidal hops of said electrons.

5. Electron discharge apparatus comprising means defining a drift space, output means opposite one end of said drift space, and means for projecting a velocity varied beam into said drift space and toward said output means, including means defining an input space, means for projecting an electron stream into said input space, means for producing in said input space a magnetic field normal to the direction of projection of said electron stream, means for producing in said input space an electric field normal to said magnetic field and means for impressing upon said input space a high frequency electric field normal to said magnetic field.

6. Electron discharge apparatus comprising means defining a drift space, means opposite one end of and in alignment with said drift space defining an output element, means for projecting a velocity varied beam into said drift space and toward said output element, said last means including means defining an input gap in axial alignment with said drift space, means for projecting an electron stream into said input gap parallel to the longitudinal axis thereof, means for causing electrons in said stream in traversing said input gap to traverse cycloidal paths including means for producing in said gap a magnetic field normal to said axis, means for producing in said gap an electric field normal to said magnetic field and means for producing in said gap a high frequency electric field normal to said magnetic field, and means for focusing the electrons issuing from said gap upon said output element.

7. Electron discharge apparatus comprising means defining a pair of resonant cavities separated by a drift space, means for withdrawing power from one of said cavities, means for conveying power from said one cavity to the other of said cavities, and means including said other cavity for projecting a velocity varied beam into said drift space and toward said first cavity, said last means including also an electron gun for injecting a stream of electrons into said other cavity and means for producing in said other cavity electric and magnetic fields normal to each other, said magnetic field being normal to the direction of injection of electrons into said other cavity.

8. Electron discharge apparatus in accordance with claim 7 comprising means for focusing the electrons emanating from said other cavity into said first cavity.

9. In electron discharge apparatus, means for producing a velocity varied beam comprising means defining an input space, means for projecting an electron beam into said space parallel to the longitudinal axis thereof, means for producing in said space magnetic and electric fields normal to each other to produce cycloidal oscillations of the electrons in said beam of a predetermined frequency, the magnetic field being normal to the direction of projection of said beam, the length of said space and said magnetic and electric fields being correlated according to the relation

$$x = 2\pi n 3.59 \frac{E}{H^2}$$

where x is the length of said space, n is an integer, E is said electric field and H is said magnetic field, and means for superimposing on said space an electric field normal to said magnetic field and of substantially said predetermined frequency.

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