

May 8, 1956

A. E. BOWEN

2,745,039

ULTRA-HIGH FREQUENCY ELECTRONIC DEVICE

Original Filed May 4, 1943

6 Sheets-Sheet 1

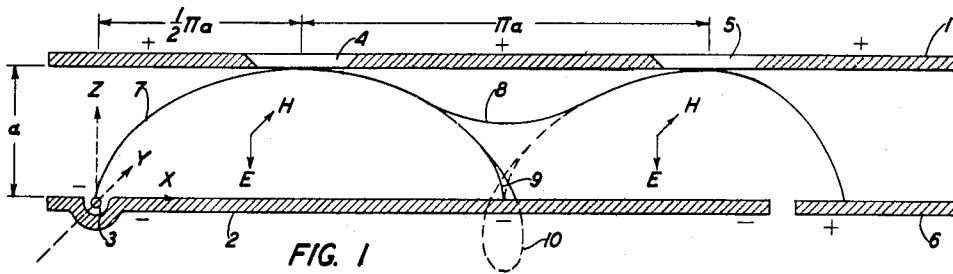


FIG. 2

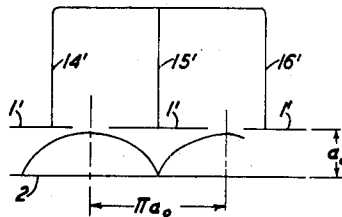


FIG. 3

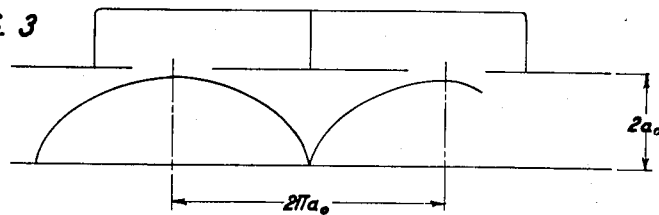
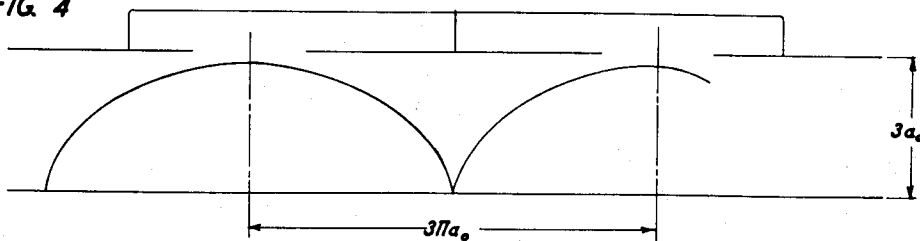


FIG. 4



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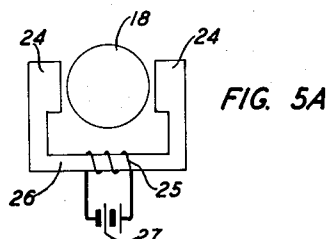
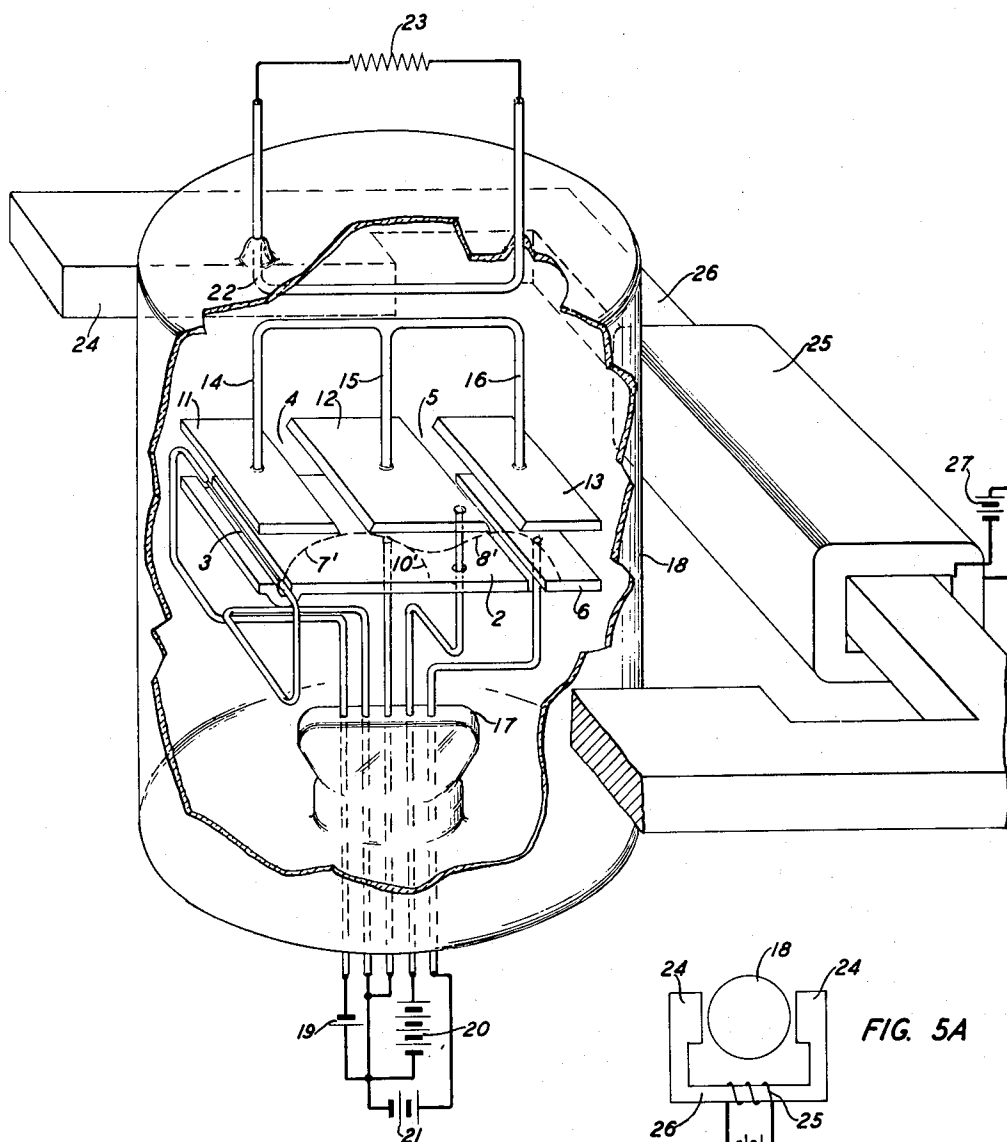
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FIG. 5



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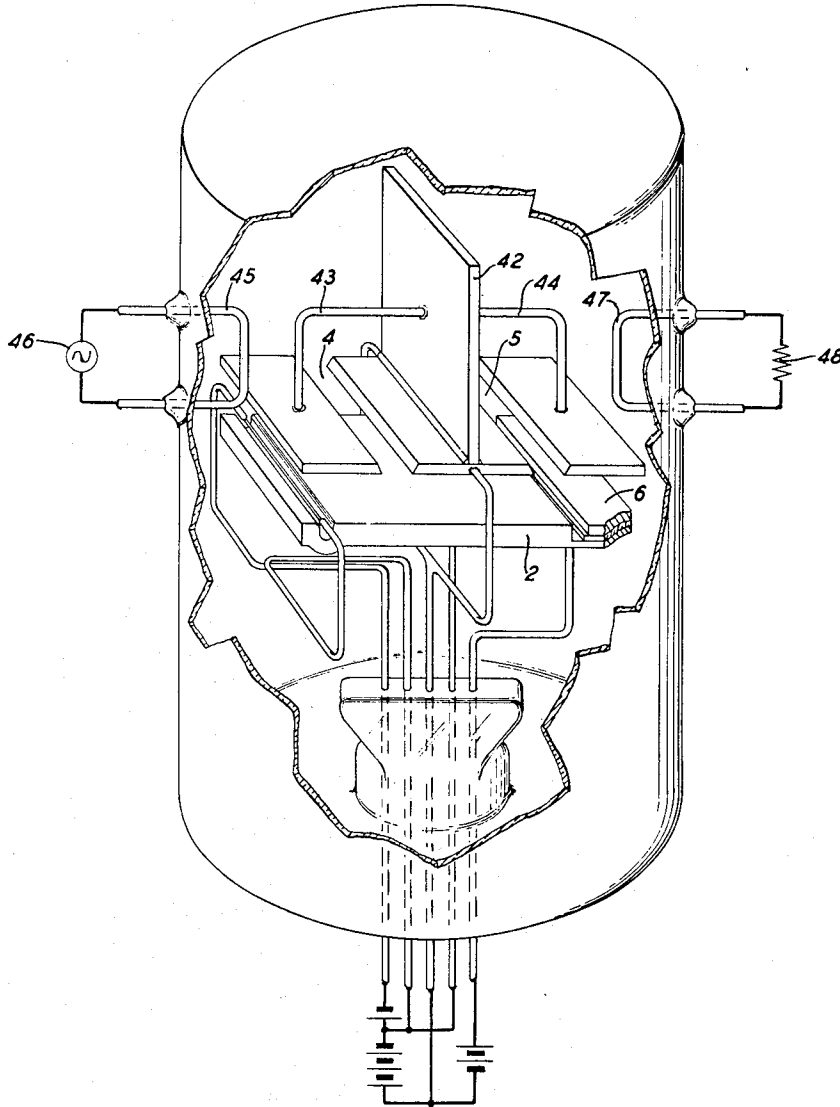
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ULTRA-HIGH FREQUENCY ELECTRONIC DEVICE

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FIG. 6



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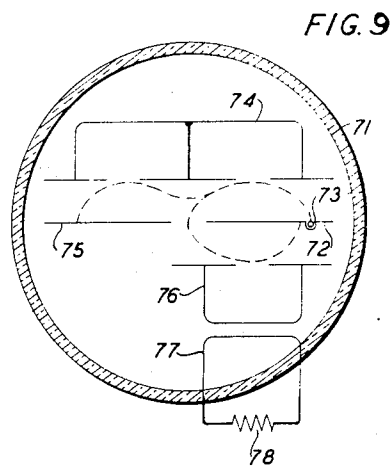
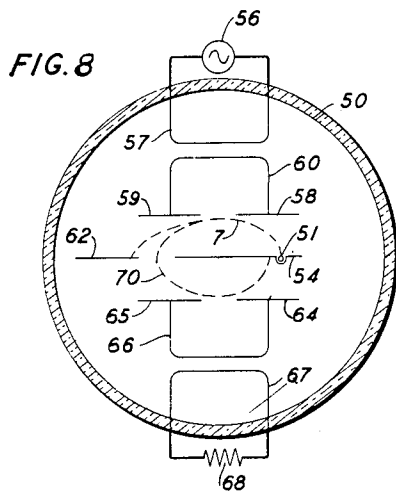
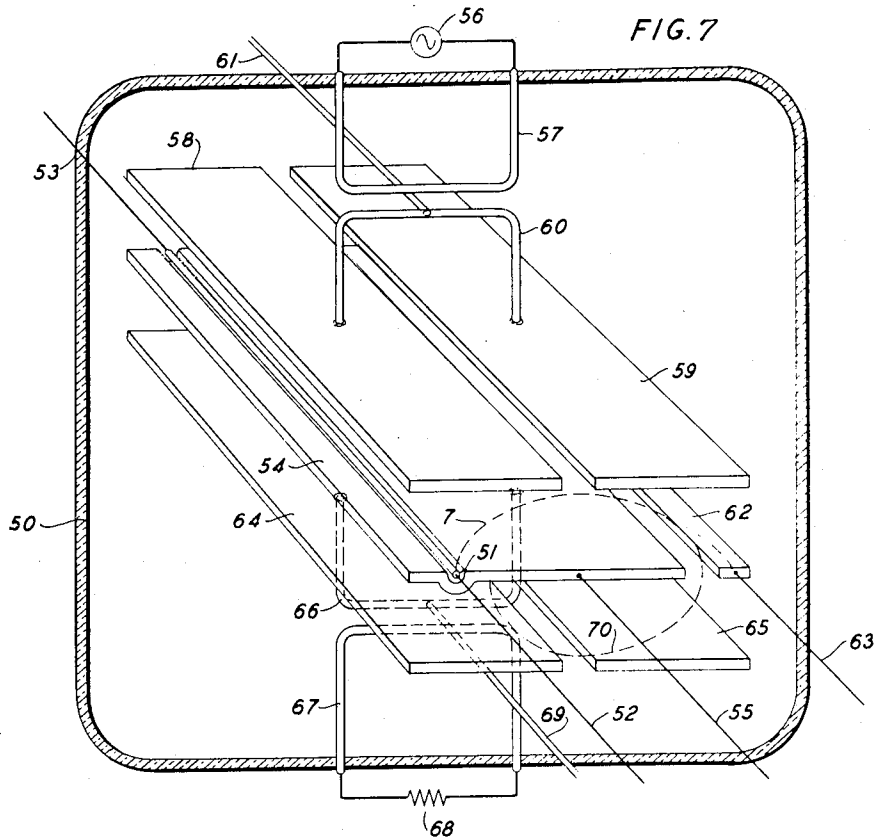
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ULTRA-HIGH FREQUENCY ELECTRONIC DEVICE

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FIG. 10

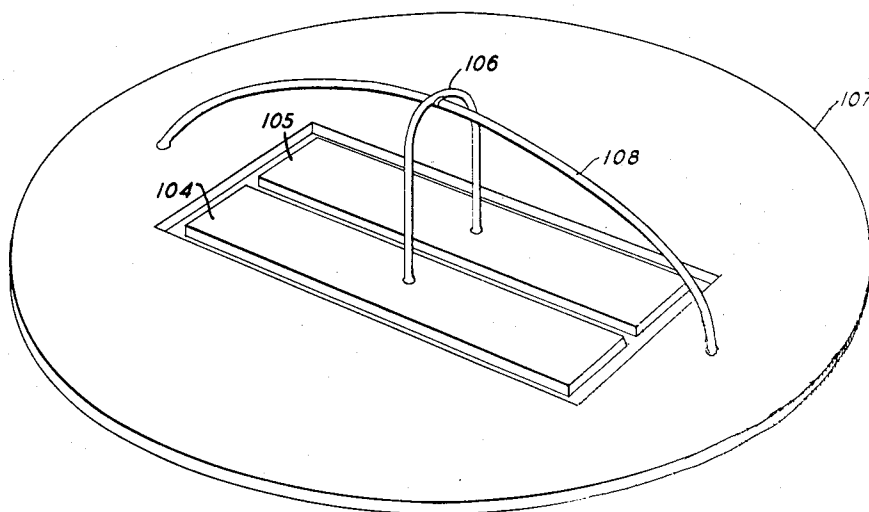
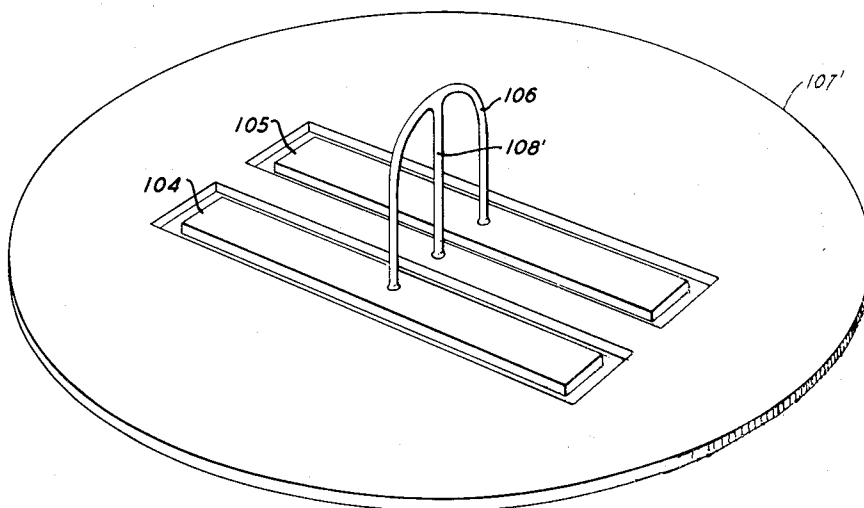


FIG. 11



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ULTRA-HIGH FREQUENCY ELECTRONIC DEVICE

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FIG. 12

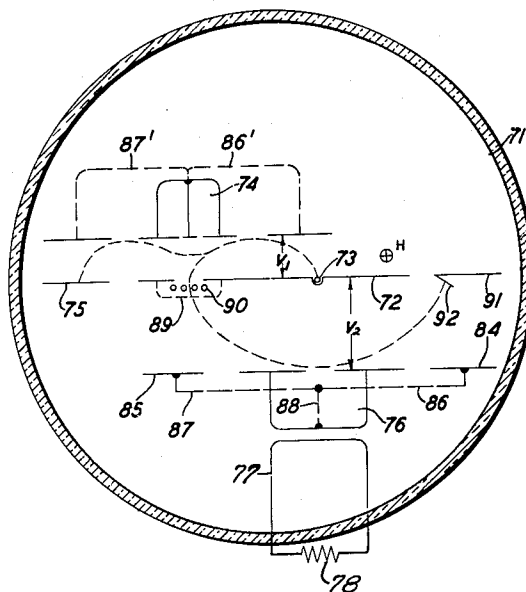
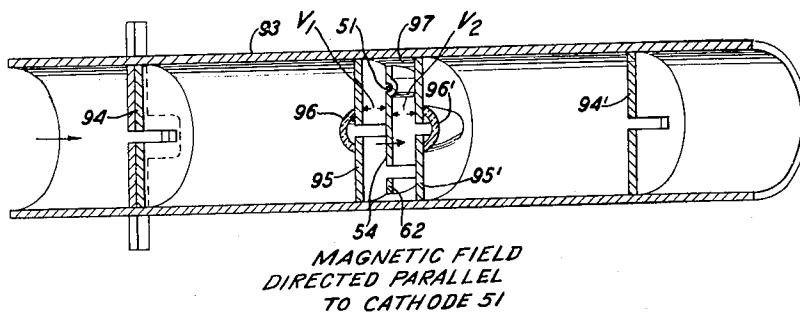


FIG. 13



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ULTRA-HIGH FREQUENCY ELECTRONIC DEVICE

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Original application May 4, 1943, Serial No. 485,579, now Patent No. 2,530,373, dated November 21, 1950. Divided and this application September 20, 1950, Serial No. 185,850

2 Claims. (Cl. 315—39.51)

This invention relates to arrangements for effecting energy interchanges in high frequency electromagnetic systems, particularly between a stream of moving charged particles such as electrons, and electromagnetic waves guided or enclosed by electrical conductors.

In devices of this type, it is common practice to determine the trajectories of the charged particles either by means of an electric field alone or by a combination of electric and magnetic field components. Devices in which the combined type of trajectory control is employed are commonly called magnetrons. In one known class of magnetrons, an electric field is maintained by impressing a potential between parallel plane plates, while at the same time a magnetic field is maintained parallel to the plates and hence perpendicular to the electric field. It is known that electrically charged particles, upon being exposed to the action of mutually perpendicular electric and magnetic fields and having initial velocities confined to the direction perpendicular to both the electric and magnetic field intensity vectors, move in cycloidal and trochoidal paths. In magnetrons with cycloidal or trochoidal electron trajectories, use has been made, as far as I am aware, only of that part of the energy residing in the transverse component of the electron velocity. In other words, the energy utilized has been taken from the electron during the part of its motion perpendicular to the planes between which it moves.

It is a feature of the present invention that energy is abstracted from the electron when it is traveling parallel to the planes between which it moves. The invention may be embodied in oscillators, amplifiers, repeaters, and the like, particularly for high frequency and microwave applications wherever generation, repetition, control, or amplification of electromagnetic waves is an object.

In accordance with the invention, a stream of charged particles is constrained to move in a trajectory comprising a series of cycloidal or trochoidal hops, progressing along a predetermined axis. The motion is characterized by the alternate intervals of relatively high forward axial speed and relatively low or reversed axial speed peculiar to cycloidal or trochoidal motion under substantially constant forces. The regions of relatively high axial speed may conveniently be designated as loops and the intervals of relatively low or reversed axial speed as nodes, in partial analogy to the alternate loops and nodes of a vibrating air column. The stream of charged particles is subjected to a cyclical velocity variation followed by a separation of accelerated and decelerated electrons to form a density varied stream which may be used to excite oscillations in a resonator of suitable form. In accordance with the invention, the velocity variation and oscillation excitation operations are carried out at loops in the cycloidal path, while the stream is density varied by withdrawing some of the electrons from the stream in a region near a nodal point of the path.

It has already been proposed to perform upon a stream of charged particles the operations of velocity variation,

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velocity sorting, and energy abstraction in that order and at successive points along the path of the stream. It is also known that velocity sorting may be effected by variably curving or deflecting the stream. The arrangements of the present invention, however, have an advantage not found in prior devices, namely, that the path of the stream is kept away from the vicinity of the deflecting or controlling electrodes except at those points where the operations of velocity variation, removal of unwanted particles, and abstraction of energy are to be effected. As a result, energy losses and noise currents caused by charged particles striking the deflecting or controlling electrodes are largely avoided. Other features and advantages of the invention will be evident from the following description.

This application is a division of the copending application, Serial No. 485,579, filed May 4, 1943, now Patent No. 2,530,373, issued November 21, 1950, and assigned to the same assignee as the present application.

Several illustrative embodiments of the invention are described in detail hereinafter with reference to the accompanying drawings, in which:

Fig. 1 is a somewhat diagrammatical cross-sectional view of a typical mechanism for controlling the trajectories of a succession of charged particles in accordance with the invention;

Figs. 2, 3, and 4 are diagrams showing a variety of proportionings of the essential parts of the trajectory control mechanism;

Fig. 5 is a perspective view, partially broken away, showing an embodiment of the invention in an oscillator;

Fig. 5A is a plan view of the device of Fig. 5;

Fig. 6 is a perspective view, partially broken away showing an embodiment of the invention in an amplifier;

Fig. 7 is a perspective view, partly diagrammatic, of an embodiment in an electron coupled amplifier;

Fig. 8 is a schematic diagram corresponding to Fig. 7;

Fig. 9 is a schematic diagram of an electron coupled oscillator-amplifier arrangement;

Figs. 10 and 11 are perspective views of tuned circuit structures adapted for use in various embodiments of the invention;

Fig. 12 is a schematic diagram of another form of electron coupled oscillator-amplifier; and

Fig. 13 is a perspective view in longitudinal section showing a repeater in a wave-guide transmission line.

The principles underlying the invention are conveniently explained with reference to Fig. 1, wherein are represented diagrammatically two parallel plane plates 1 and 2 separated a distance a and maintained at a substantially constant potential difference V_0 , plate 1 being positive with respect to plate 2. The resultant electric field intensity

$$E = \frac{V_0}{a}$$

acts downward in the plane of the drawing, as indicated by arrows in the figure. A cathode 3 is located in the plane of plate 2 and may be insulated from the plate so that the cathode may be a directly heated filament if desired. Slots or gaps 4 and 5 are made in plate 1 on centers spaced apart a distance πa , the slot 4 being located a horizontal distance

$$\frac{1}{2}\pi a$$

from the cathode 3. A collector plate 6 is located in the plane of plate 2, insulated therefrom, and preferably maintained at a potential somewhat positive with respect to plate 2. A substantially uniform magnetic field of intensity H is maintained with its lines of force directed perpendicular to the plane of the drawing in the sense

away from the reader. It is assumed for the purpose of the explanation that the uniformity of the fields E and H is not materially disturbed by any edge effects or by the presence of the cathode 3, the collector 6, or the slots 4 and 5. Assuming further that electrons are released with zero velocity at the cathode 3, then, according to known principles, the electrons will travel in trajectories such as that shown in the curve 7, which is a common cycloid. The assumed conditions may readily be approximated in practice.

The equations of motion of an electron in the system of Fig. 1 are readily set up and the equations of the electron paths under given boundary conditions derived therefrom by conventional analytical methods. It is therefore deemed unnecessary to present a detailed solution, and only the basic equations and final results are set down here.

Assuming a set of mutually perpendicular rectangular coordinate axis X, Y, Z , directed as indicated in Fig. 1, the equations of motion for an electron of charge e and of mass m are

$$\frac{d^2x}{dt^2} = \frac{eH}{mc} \frac{dz}{dt} \quad (1)$$

$$\frac{d^2y}{dt^2} = 0 \quad (2)$$

$$\frac{d^2z}{dt^2} = \frac{eE}{m} - \frac{eH}{mc} \frac{dx}{dt} \quad (3)$$

where c is the velocity of light, and e, E , and H are to be taken as positive numbers. As the problem is fundamentally one of two dimensions only, it will not be necessary to consider further the y -coordinate nor Equation 2. Additional simplification of the analysis may be had by introducing the following abbreviations:

$$\frac{eH}{mc} = p \quad (4)$$

$$\frac{cE}{H} = s_0 \quad (5)$$

the use of which makes

$$\frac{eE}{m} = ps_0 \quad (6)$$

The equations to be solved then reduce to

$$\frac{d^2x}{dt^2} = p \frac{dz}{dt} \quad (7)$$

$$\frac{d^2z}{dt^2} = p \left(s_0 - \frac{dx}{dt} \right) \quad (8)$$

The complete solution of the simultaneous Equations 7 and 8 is

$$x = C_1 \sin pt - C_2 \cos pt + s_0 t + C_3 \quad (9)$$

$$z = C_2 \sin pt + C_1 \cos pt + \frac{s_0}{p} - \frac{C_4}{p} \quad (10)$$

from which the following may be derived by differentiation:

$$\frac{dx}{dt} = p(C_1 \cos pt + C_2 \sin pt) + s_0 \quad (11)$$

$$\frac{dz}{dt} = p(C_2 \cos pt - C_1 \sin pt) \quad (12)$$

$$\frac{d^2x}{dt^2} = -p^2(C_1 \sin pt - C_2 \cos pt) \quad (13)$$

$$\frac{d^2z}{dt^2} = -p^2(C_2 \sin pt + C_1 \cos pt) \quad (14)$$

In (9) to (14), inclusive, C_1, C_2, C_3 , and C_4 stand for the constants of integration.

From the general solutions (9) and (10), a particular

solution may be had for the case of particles starting from rest at the origin at the time when t is zero by using the initial conditions represented by

$$x = z = \frac{dx}{dt} = \frac{dz}{dt} = 0 \quad (15)$$

to determine the constants of integration. The result is readily found to be

$$x = \frac{s_0}{p}(pt - \sin pt) \quad (16)$$

$$z = \frac{s_0}{p}(1 - \cos pt) \quad (17)$$

the standard equations of a common cycloid.

Referring to the curve 7 in Fig. 1, the left-hand portion of the curve represents the common cycloid of Equations 16 and 17. The curve will have a maximum value of z for the condition

$$pt = \pi \quad (18)$$

and at this point it will be found that

$$x = \frac{\pi s_0}{p} \quad (19)$$

$$z = \frac{2s_0}{p} \quad (20)$$

$$\frac{dx}{dt} = 2s_0 \quad (21)$$

$$\frac{dz}{dt} = 0 \quad (22)$$

Assuming that the spacing a has been so chosen that the cycloidal trajectory 7 will just graze the plate 1, it will be evident that the maximum z -coordinate of the trajectory will be equal to a , and it will be found that at $pt = \pi$,

$$x = \frac{1}{2}\pi a \quad (23)$$

and

$$z = a \quad (24)$$

where

$$a = \frac{2s_0}{p} = \frac{2mc^2 E}{eH^2} \quad (25)$$

In accordance with the invention, a velocity variation is impressed upon the particles as they pass the first point of maximum z -coordinate by means of a variable potential difference across the slot 4, which will be suitably superposed upon the initial potential V_0 of the plate 1 as a whole. Then the potential which acts upon a given electron causing it to pass the gap 4 may be expressed as

$$V = V_0 + \delta V_0 \quad (26)$$

where δ is a small factor which in ordinary practice will usually lie within limits between -1 and $+1$. If we assume that a given electron leaves the gap 4 with a speed s determined by the potential V , as given in (26), then the equation

$$Ve = \frac{1}{2}ms^2 \quad (27)$$

represents the relationship between V and s based upon the conversion of potential energy into kinetic energy. Solving (27) for s and using (26) gives

$$s = \sqrt{\frac{2(V_0 + \delta V_0)e}{m}} \quad (28)$$

Using

$$V_0 = aE \quad (29)$$

together with (25) and (4), we have

$$s = 2s_0\sqrt{1 + \delta} \quad (30)$$

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The trajectory of an electron after it leaves the gap 4 must be such as to satisfy the equations of motion (1), (2), and (3) as well as the new initial conditions produced by the velocity variation. The latter conditions are such that when

$$pt = \pi \quad (31)$$

then

$$x = \frac{1}{2}\pi a \quad (32)$$

$$z = a \quad (33)$$

$$\frac{dx}{dt} = 2s_0\sqrt{1+\delta} = ap\sqrt{1+\delta} \quad (34)$$

and

$$\frac{dz}{dt} = 0 \quad (35)$$

Under these conditions, it is readily found that

$$x = \frac{a}{2}[pt - (2\sqrt{1+\delta}-1) \sin pt] \quad (36)$$

$$z - a(1-\sqrt{1+\delta}) = \frac{a}{2}[1 - (2\sqrt{1+\delta}-1) \cos pt] \quad (37)$$

Equations 36 and 37 will be recognized as the equations of a family of trochoids generated by a movable point, distant

$$b = \frac{a}{2}(2\sqrt{1+\delta}-1) \quad (38)$$

from the center of a circle of diameter a , which is rolling upon and above the line

$$z = a(1-\sqrt{1+\delta}) \quad (39)$$

The x -component of velocity is

$$\frac{dx}{dt} = s_0[1 - (2\sqrt{1+\delta}-1) \cos pt] \quad (40)$$

The trochoids corresponding, respectively, to the values $\delta = -0.5$, $\delta = 0$, and $\delta = +0.5$ are plotted in Fig. 1 as curves 8, 9, and 10. Curve 9 is a common cycloid, which is a special case of a trochoid.

Two important characteristics of the trajectories are to be deduced from the above analysis. The first is that all the trajectories regardless of the δ -value pass through a common point near the gap 5. The second important deduction is that the average value of the x -velocity of each particle is equal to s_0 , independently of the δ -value. In particular, the result is found that the transit time between the gaps 4 and 5 is the same for all the particles regardless of the length and shape of trajectory. Both these characteristics may be verified by substituting $pt = 3\pi$ in (36) and (37), which gives

$$x = \frac{3\pi a}{2} \quad (41)$$

$$z = a \quad (42)$$

which expressions are independent of δ and determine the above-mentioned common point at the gap 5. The average speed of any particle while traversing the distance between the gaps 4 and 5 is the intergap distance πa divided by the transit time from $pt = \pi$ to $pt = 3\pi$, which speed amounts to

$$\frac{1}{2}ap, \text{ or } s_0$$

In accordance with the invention, the passage of charged particles across the gap 5 in a density varied stream causes an alternating current to be induced in the plate 1. The stream is given a density variation by the action of the plate 2, which is so placed as to intercept particles in a group of trajectories represented by curve 10, while particles in a group of trajectories represented by curve 8 pass on unintercepted. The velocity variation

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impressed upon the stream at the gap 4 produces a cyclical variation in the trajectories of successive particles ranging in turn through trajectories of the type of curve 8, the cycloidal type 9, the type of curve 10, the cycloidal type again and back to the type of curve 8, etc. Only the particles following trajectories of the type 8 reach the gap 5, and these form a density varied or intermittent stream at the gap 5. Plate 6 serves to collect the spent particles after they leave the gap 5. The parts of the curves 9 and 10 which are unoccupied by particles because of interception by plate 2 are shown dotted in Fig. 1.

It will be noted that the mechanism described is one for transforming a steady stream of charged particles into an intermittent or density varied stream. It will be noted further that the grouping of the particles is not dependent upon the principle of fast moving particles overtaking slower moving particles. The principle employed is one of segregating those particles which exceed a certain critical velocity.

It will be noted further that the charged particles approaching the gap 4 are moving with substantially a uniform velocity and in a direction parallel to the plate 1. This condition might be brought about in various ways other than by locating the cathode 3 in the plane of the plate 2 and using the mechanism described for producing the cycloidal trajectory 7. For example, the stream of charged particles might be made to approach the gap 4 along a straight path parallel to the plate 1 under the influence of an electric field in the absence of the magnetic field H. The mechanism shown and the use of the cycloidal trajectory 7 will ordinarily be simplest and most expedient, but it will be understood that it is within the scope of the invention to employ any suitable means to provide a stream of charged particles which approaches the gap 4 with substantially uniform velocity and charge density.

In any case, after leaving the gap 4, the motion of the particles is characterized by a periodic component of motion in the direction of the electric field superposed upon a general progression or drift in the direction perpendicular to the plane common to the electric and magnetic vectors. In the neighborhoods of gap 4 and gap 5, the periodic component of motion in the direction of the electric force produces a maximum displacement in compliance with the electric field. In the region where certain of the trajectories meet the ground plate 2, the particles are moving in opposition to the electric field. In the case of trajectories of the type of curve 10, there is superposed upon the drift motion an incidental periodic component which could be utilized if circumstances warranted.

The velocity variation at the gap 4 effects a control over the periodic motion in the direction of the electric force, namely, a control of the amplitude of such periodic motion. Under the variable amplitude condition, however, all the variation is confined to the region in which the particles move against the force of the electric field, as described, the excursion of the particles in compliance with the electric force being limited to the uniform maximum value a by the combined effect of the electric and magnetic fields.

In the operation of the device as an amplifier, the potential of the gap 4 is varied by means of the wave to be amplified, and the output resonator is connected across the gap 5. The spacing πa , between the gaps 4 and 5, as seen from (25), is a function of both E and H , varying directly as E and inversely as the square of H . The transit time between the gaps is

$$\frac{2\pi}{p}$$

and varies inversely with H , independently of E . There is, moreover, no critical transit time required in the amplifier case.

In the operation of the device as an oscillator, the available values of H are limited once the frequency of the desired oscillation is determined. It has been shown above that the particles which pass the gap 5 when the plate 2 is in place are those which are decelerated at the gap 4. In order for these particles to contribute energy to the field at the gap 5, the particles must pass gap 5, while the field is opposing their motion. In a case where the gaps 4 and 5 are excited in such manner that the fields at the two gaps are poled in the same direction, an integral number of periods of the oscillation should elapse between the passage of a particle across the gap 4 and its subsequent passage across the gap 5.

In terms of the frequency f , the relation

$$\frac{n}{f} = \frac{2\pi}{p} = \frac{2\pi mc}{eH} \quad (43)$$

must hold, where n is any integer or, in terms of the free space wavelength λ ,

$$\frac{n\lambda}{c} = \frac{2\pi mc}{eH} \quad (44)$$

It will be noted that in a given device of this type, m , c , and e are natural constants, and the product λH is dependent upon these constants as well as upon the value of n which may be chosen. Thus,

$$\lambda H = \frac{2\pi mc^2}{ne} \quad (45)$$

in which formula λ is to be expressed in centimeters and H and

$$\frac{m}{e}$$

in electromagnetic units. The same thing with H in oersteds is

$$\lambda H = \frac{2\pi mc}{ne} \quad (46)$$

which, when the charged particles are electrons becomes approximately

$$\lambda H = \frac{10650}{n} \quad (47)$$

It will be evident from Equation 47 that the larger the value of n selected, the smaller the value of H required for oscillations of a given wavelength.

The value of the spacing a between the plates as given by 25 may be expressed in terms of V_0 as follows:

$$a = \frac{c}{H} \sqrt{\frac{2mV_0}{e}} \quad (48)$$

which formula is applicable either to an amplifier or an oscillator. Since, in the case of the electron oscillator, λH is given by 45, the spacing will be

$$a = \frac{n\lambda}{\pi c} \sqrt{\frac{V_0 e}{2m}} \text{ centimeters} \quad (49)$$

where V_0 and

$$\frac{e}{m}$$

are in electromagnetic units, λ is in centimeters, and $e = 3 \times 10^{10}$ centimeter/seconds, or

$$a = \frac{n\lambda \sqrt{V_0}}{3160} \text{ centimeters} \quad (50)$$

where λ is in centimeters and V_0 in volts.

A number of examples coming out of Formula 50 have been computed and are shown diagrammatically in Figs. 2, 3, and 4. It will be noted that for given values of λ and V_0 , the spacing a is proportional to n . Thus, if, as in Fig. 2, a has the value a_0 corresponding to $n=1$, then, for the same wavelength and same voltage, the spacing is $2a_0$ for $n=2$, which case is shown in Fig. 3; and $3a_0$ for $n=3$, as shown in Fig. 4. The spacing of the gaps is equal to πa in every case. For a wavelength of 10 centimeters and a voltage V_0 of 1000 volts, the value of a_0 comes out approximately 1 millimeter.

Various changes in the values of V_0 and H may be made, at the same time changing n so that the required spacing remains the same. For example, in Fig. 2, if n is made 2 and the wavelength and spacing remain unchanged, the voltage must be reduced to one fourth its former value. The change in n also requires that H be reduced to one half its former value in order that 47 may be satisfied.

Several possible combinations of values for a 10-centimeter wavelength in the diagram of Fig. 2 are tabulated in Table I.

Table I

a , cm.	n	V_0 , volts	H , oersteds	λ , cm.
0.1	1	1,000	1,065	10
0.1	2	250	532	10
0.1	3	111	355	10

Several possible combinations for a 10-centimeter wavelength in the diagram of Fig. 3 are given in Table II.

Table II

a , cm.	n	V_0 , volts	H , oersteds	λ , cm.
0.2	1	4,000	1,065	10
0.2	2	1,000	532	10
0.2	3	445	355	10
0.2	4	250	267	10

Combinations for the diagram of Fig. 4 are given in Table III.

Table III

a , cm.	n	V_0 , volts	H , oersteds	λ , cm.
0.3	1	9,000	1,065	10
0.3	2	2,250	532	10
0.3	3	1,000	355	10

Conductors 14', 15', and 16' of a resonant circuit are shown schematically connecting the plate segments 1' in Fig. 2. To indicate resonance at the same wavelength in Figs. 3 and 4 as in Fig. 2, the areas enclosed by the conductors are shown approximately equal in all three figures.

Fig. 5 represents an embodiment of the invention in an oscillator complete with a resonating circuit, an output coupling device, and means for supplying the requisite electric and magnetic field intensities. The equivalent of the plate 1 of Fig. 1 is represented in Fig. 5 by a three-segment anode having segments 11, 12, and 13 connected together by conductors 14, 15, and 16, the latter, together with the anode segments, comprising a resonant circuit. The inductance of the resonant circuit resides mainly in the conductors 14, 15, and 16, while the capacitance is mainly between segments 11 and 12 at the gap 4 and between segments 12 and 13 at the gap 5. The negative or ground plate 2 has a depression in which the cathode 3 is insulatingly mounted. These parts, together with the collector plate 6, are supported by rods

held in a press 17 of conventional type formed in the wall of a vacuum-tight container 18, which wall may, for example, be of glass. The supporting rods may serve also as electrical connections from the plates to the sources of electromotive force. The latter sources may constitute batteries or other suitable devices, of which 19 serves to heat the cathode, 20 to polarize the anode segments 11, 12, 13 positively with respect to the ground plate 2, and 21 serves to maintain the collector 6 preferably at a somewhat positive potential with respect to the plate 2. Coupled to the conductors 14 and 16 is a coupling loop 22, the ends of which may project through the envelope 18 and be connected to any suitable load device for transmitting or utilizing the generated oscillations, the load circuit here being represented by a resistor 23. An electromagnet comprising pole-pieces 24, winding 25, a yoke 26 and energized by suitable means, such as a battery 27, is provided, preferably external to the envelope 18, and is set up in such a position (Fig. 5A) as to provide a magnetic field having lines of force substantially parallel to the cathode 3 and the several plates.

The cycloidal path of a typical electron leaving the cathode 3 and approaching the gap 4 is shown at 7'. The path of this electron, should it be decelerated at the gap 4, is indicated at 8' showing that its trajectory continues past the gap 5 and preferably ends upon the collector plate 6. Should the same electron instead be accelerated at the gap 4, its path is indicated at 10', ending upon the ground plate 2 and not reaching the gap 5.

The spacing between the ground plate and the anode is determined as described hereinbefore in connection with Fig. 1 for a desired operating wavelength at a given voltage and for a chosen value of n according to (50). The resonator is proportioned to be resonant to the operating wavelength. Further details of the operation of the system of Fig. 5 will be evident from the explanation given hereinabove in connection with Fig. 1.

Fig. 6 illustrates an embodiment of the invention in an amplifier. In the arrangement of Fig. 6, the conductor 15 used in Fig. 5 is replaced by a conductive plate 42. The conductors 14 and 16 are replaced, respectively, by conductors 43 and 44 connected to opposite sides of the plate 42. An input coupling loop 45 is arranged adjacent the conductor 43. The collector plate 6 may be insulatingly mounted upon a shoulder cut in the ground plate 2, as shown. Waves to be amplified may be supplied by a source 46 connected to the loop 45. The impressed oscillations serve to set up alternating potentials across the gap 4. The amplified oscillations are set up in the resonant circuit including the conductor 44. A coupling loop 47 is mounted adjacent the conductor 44 and is connected to a load device 48. The detailed operation of the system of Fig. 6 as an amplifier will be readily understood from the description hereinabove given in connection with Fig. 1.

In an alternative mode of operation of devices in accordance with the invention, the faster group of electrons may be utilized in the excitation of the output circuit in place of the slower group. This mode of operation may be used with a small accompanying reorganization of the apparatus. Fig. 7 shows an amplifier arranged to effect excitation of the output circuit by means of the faster group of electrons. The chief modification comprises the placing of the input and output circuits on opposite sides of the ground plate in the form of separate anodes. Each anode may comprise two segments defining a single gap. It may be necessary in some cases to provide increased separation between the ground plate and the collector in order to accommodate the passage of accelerated electrons therebetween in a variety of trajectories.

In the arrangement of Fig. 7, a vacuum container is represented schematically by a broken line 50. The leads by which the energizing and biasing potentials are applied to the various electrodes within the vacuum compartment are shown for simplicity by solid lines crossing

the boundary 50. For simplicity, also, the energizing sources of electromotive force have been omitted, since they may be readily supplied, as shown in Figs. 5 and 6. A cathode 51 is represented as supplied by heating leads 52 and 53. A ground plate 54 is provided with a groove for accommodating the cathode 51. External connection to the ground plate is provided by means of a lead 55. A source of high frequency waves to be amplified is represented by a generator 56, coupled by means of a loop 57 to an input tuned circuit comprising two anode segments 58, 59 joined by a conductor 60. A suitable positive potential may be impressed upon the system 58, 59, 60 by means of a lead 61 preferably symmetrically disposed, as shown. A collector 62 is provided in the same plane as the ground plate 54 and is connected to a lead 63. On the opposite side of the ground plate from the system 58—60 is provided an output tuned circuit comprising two anode segments 64, 65 joined by a conductor 66. An output loop 67 is provided in inductive relation to the conductor 66 and has its ends led out to a load circuit which is represented by a resistor 68. A suitable positive potential may be impressed upon the anode system 64—66 through a lead 69.

In the operation of the system of Fig. 7, the typical electron leaving the cathode 51 travels in a cycloidal trajectory 7 and in passing the vicinity of the gap 58, 59, the electron receives a velocity variation due to the impressed waves from the generator 56 acting through the coupling system 57 to 60, inclusive. The accelerated electrons pass through the gap between plates 54 and 62, and, as they emerge, they come into the field between the ground plate and the output anode system 64, 65, 66. An accelerated electron thus emerging follows a generally cycloidal trajectory 70, which carries it to the vicinity of the gap between the anode segments 64, 65 and finally causes the electron to strike the lower side of the plate 54, as shown. The decelerated electrons are carried past the gap 54 to 62, inclusive, to the collector 62. The accelerated electrons, thus separated from the decelerated electrons, form an intermittent or density varied stream which serves to excite the output tuned circuit as the stream passes the vicinity of the gap 64, 65.

Fig. 8 is a simplified schematic representation of the arrangement of Fig. 7, the elements being correspondingly numbered in the two figures.

Other modifications of the structures hereinabove described enable the system to be adapted for use as a master oscillator-amplifier combination in which the coupling between the oscillator and the amplifier is effected by means of the electron stream. There is thus provided what is commonly termed an electron-coupled oscillator. Examples of this are shown in Figs. 9 and 12 by means of simplified schematic representations.

In Fig. 9, there is shown within a vacuum container 71 a ground plate 72 having on one side thereof a cathode 73 and a tuned circuit 74 of the three-segment anode type disclosed in Fig. 5. Coplanar with the ground plate 72 is a collector plate 75. On the reverse side of the ground plate 72 from the cathode 73 is an output tuned circuit 76 like the system 64, 65, 66 shown in Fig. 8. A coupling loop 77 is provided in inductive relation to the circuit 76 and is connected to a load 78.

In the operation of the arrangement of Fig. 9, the oscillator section is excited by the slower group of electrons, as in the arrangement of Fig. 5, and the spent electrons of the slower group are collected on the plate 75. The electrons of the faster group pass through the space between the plates 72 and 75, as in the arrangement of Figs. 7 and 8, where they serve to excite the tuned circuit 76, which in turn supplies oscillations to the load 78 through the coupling loop 77. The load 78 may be varied without disturbing to any appreciable extent the operating conditions of the oscillator section. Therefore, the load has a minimum of disturbing effect upon the frequency of the oscillator.

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Fig. 10 shows a tuned circuit comprising a pair of anode segments 104 and 105 joined by an inductive conductor 106. The arrangement is mounted so that the plates 104 and 105 are coplanar with a guard plate 107 and are positioned in an opening therein. The conductor 106 is conductively connected to and supported by a conductor 108, which is in turn conductively connected to and supported by the plate 107. The conductor 108, while it may represent an appreciable inductance, can still serve as an untuned connection between the conductor 106 and the plate 107. It is only necessary that the system 107, 108 shall not support electromagnetic oscillations at a frequency in the neighborhood of the desired operating frequency. Under this condition, the anode segments 104 and 105 may sustain an alternating potential, while the plate 107 and connector 108 will remain at a substantially unvarying potential.

Fig. 11 shows a tuned circuit which is a modification of that shown in Fig. 10. A guard plate 107' has two openings within which the plates 104 and 105 are positioned, respectively. The conductor 106 connects the plates 104 and 105, as in Fig. 10, and a conductor 108' connects the middle of the conductor 106 to the portion of the plate 107' between the two openings.

In Fig. 12 is shown an arrangement generally similar to that of Fig. 9 and containing several added features. There is shown within the vacuum container 71 a ground plate 72 having on one side thereof a cathode 73 and a tuned circuit 74. Coplanar with the ground plate 72 is a collector plate 75. On the reverse side of the ground plate 72 from the cathode 73 is an output tuned circuit 76. A coupling loop 77 is provided in inductive relation to the circuit 76 and is connected to a load 78. The tuned circuit 74 may be of the type shown in Fig. 11, the broken lines 86' and 87' representing conductive connections effected within the body of plate 107' of Fig. 11. The tuned circuit 76 may be of the type shown in Fig. 10, broken lines 86, 87 and 88 representing the conductor 108 of Fig. 10, and full lines 84 and 85 representing the plate 107 in Fig. 10. The ground plate 72 is in two sections separated by a gap and connected by an untuned conductive connection 89. Opposite the gap in the plate 72 is provided a grid 90 which may be used for modulation or other control purpose. An additional collector 91, 92 is arranged in the plane of the plate 72. The direction of the magnetic field is indicated symbolically by H.

In the operation of the arrangement of Fig. 12, the tuned circuit 74 may be kept at a desired positive potential with respect to the plate 72. The tuned circuit 76 may be kept at a different positive potential with respect to the plate 72. By properly arranging the spacing of the respective plates, the system may be operated with a higher potential in the amplifier section than in the oscillator section, if desired.

Fig. 13 shows in longitudinal section an adaptation of the arrangement of Fig. 8 which enables the device to operate as a repeater in a wave-guide transmission system. The wall of a wave guide is shown at 93. A resonant section of wave guide, preferably constituting a half wavelength resonator, is defined by iris diaphragms represented schematically at 94 and 95. Diaphragm 94 may be variable as to the size of the aperture, and diaphragm 95 may have a fixed aperture hermetically sealed by a window 96 of dielectric material. Similar elements 94', 95', and 96' may be provided to determine another half-wave resonator and a chamber 97 between the diaphragms 95 and 95'. In the chamber 97 may be located a cathode 51, a ground plate 54, and a collector 62, similar to the corresponding elements shown in Fig. 8.

In the operation of the arrangement of Fig. 13, the apertures in the diaphragms 95 and 95' correspond, respectively, to the gaps in the input and output tuned circuits of the arrangement of Fig. 8. A wave transmitted from left to right through the wave guide will be resonated in the chamber between the diaphragms 94 and 95 and will

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impress an alternating potential across the input gap. The output potential will be impressed across the output gap and will act through the window 96' to set up an amplified wave in the resonator between the diaphragms 95' and 94'. The amplified wave will be transmitted through the aperture of the diaphragm 94' and be propagated along to the right through the wave guide.

While means for supplying the necessary steady component of magnetic field are shown only in Fig. 5, it will be understood that suitable means for this purpose are to be supplied in each arrangement illustrated. Mechanical supports for the elements have also been omitted from several of the figures in the interest of focusing attention upon those features which form a part of the present invention.

What is claimed is:

1. An electron coupled oscillator-amplifier combination comprising a ground plate, a cathode on one side only of said ground plate, a resonant system of conductors defining a first gap and a second gap, said system being located generally opposite the ground plate and on the same side thereof as the cathode, means to constrain electrons from said cathode to travel in curved paths which vary in curvature depending upon the velocity of the electrons and which pass through and beyond the neighborhood of said first gap, whereby any alternating electromagnetic field which may be developed in said gap by excitation of said resonant system serves to velocity vary the electron stream to divide the electrons as they pass said gap into first and second density varied streams which follow paths of unequal curvature, said second gap being positioned adjacent the path of said first density varied stream whereby this stream induces an alternating electromagnetic field in said second gap thereby generating self-oscillations in said resonant system, a collecting electrode adjacent to said ground plate and in the path of the said first density varied stream beyond the region of said second gap whereby said first stream strikes said collecting electrode, means including an edge of said ground plate defining an opening located in the path of said second density varied stream through which the said second density varied stream passes into a region on the other side of the ground plate from the cathode, and energy abstracting means positioned along the path of the said second stream in said last-mentioned region spaced from the ground plate in the direction of the thickness of the said plate, whereby self-oscillations of the said resonant system on the cathode side of the ground plate are maintained and transferred by electronic coupling to the system on the other side of the ground plate.

2. An electron coupled oscillator-amplifier combination comprising a ground plate having a gap therein, a cathode on one side only of said ground plate supplying electrons of substantially uniform initial velocity, a resonant system of conductors defining a first gap and a second gap, the aforementioned gap in the ground plate being designated hereinafter as the third gap, said resonant system being located generally opposite the ground plate and on the same side thereof as the cathode, means to constrain electrons from said cathode to travel in curved paths which vary in curvature depending upon the electron velocity and which pass through and beyond the neighborhood of said first gap, whereby any alternating electromagnetic field which may be developed in said gap by excitation of said resonant system serves to velocity vary the electron stream to cause the electrons after they pass said gap to follow paths of unequal curvature, constituting first and second density varied streams respectively, said second gap being positioned adjacent the path of said first density varied stream whereby this stream induces an alternating electromagnetic field in said second gap thereby generating self-oscillations in said resonant system, a collecting electrode adjacent to said ground plate and in the path of the said first density varied stream beyond the region of said second gap whereby said first

stream strikes said collecting electrode, said third gap being positioned in the path of the said second density varied stream beyond the region of said first gap whereby said second stream passes into a region on the other side of the ground plate from the cathode, and energy abstracting means positioned along the path of the said second stream in said last-mentioned region spaced from the ground plate in the direction of the thickness of the said plate, whereby self-oscillations of the said resonant system on the cathode side of the ground plate are main-

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tained and transferred by electronic coupling to the system on the other side of the ground plate.

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