Dec. 27, 1949 A. E. BOWEN 2,492,680

RESONATOR

Original Filed May 4, 1943 4 Sheets-Sheet 1

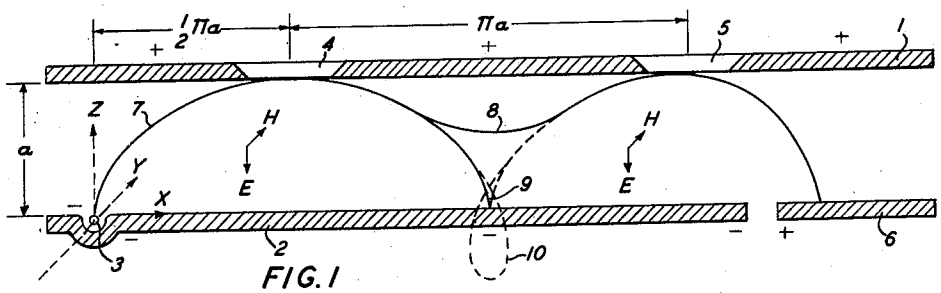


FIG. 1

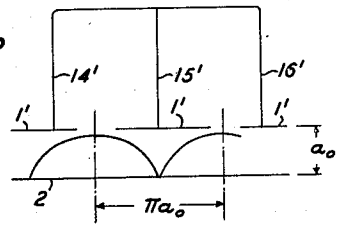


FIG. 2

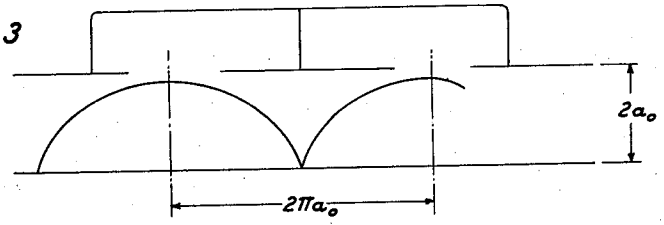


FIG. 3

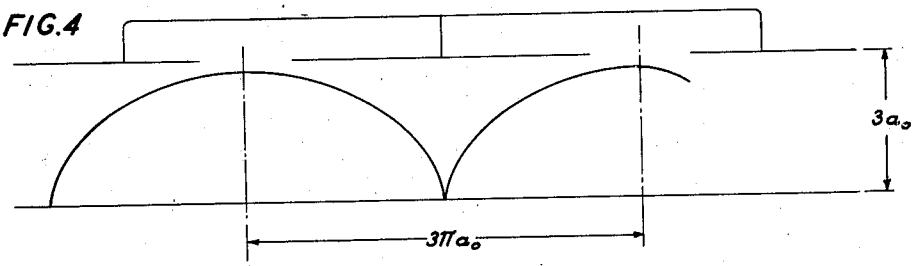


FIG. 4

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Dec. 27, 1949 A. E. BOWEN 2,492,680

RESONATOR

Original Filed May 4, 1943 4 Sheets-Sheet 2

FIG. 5

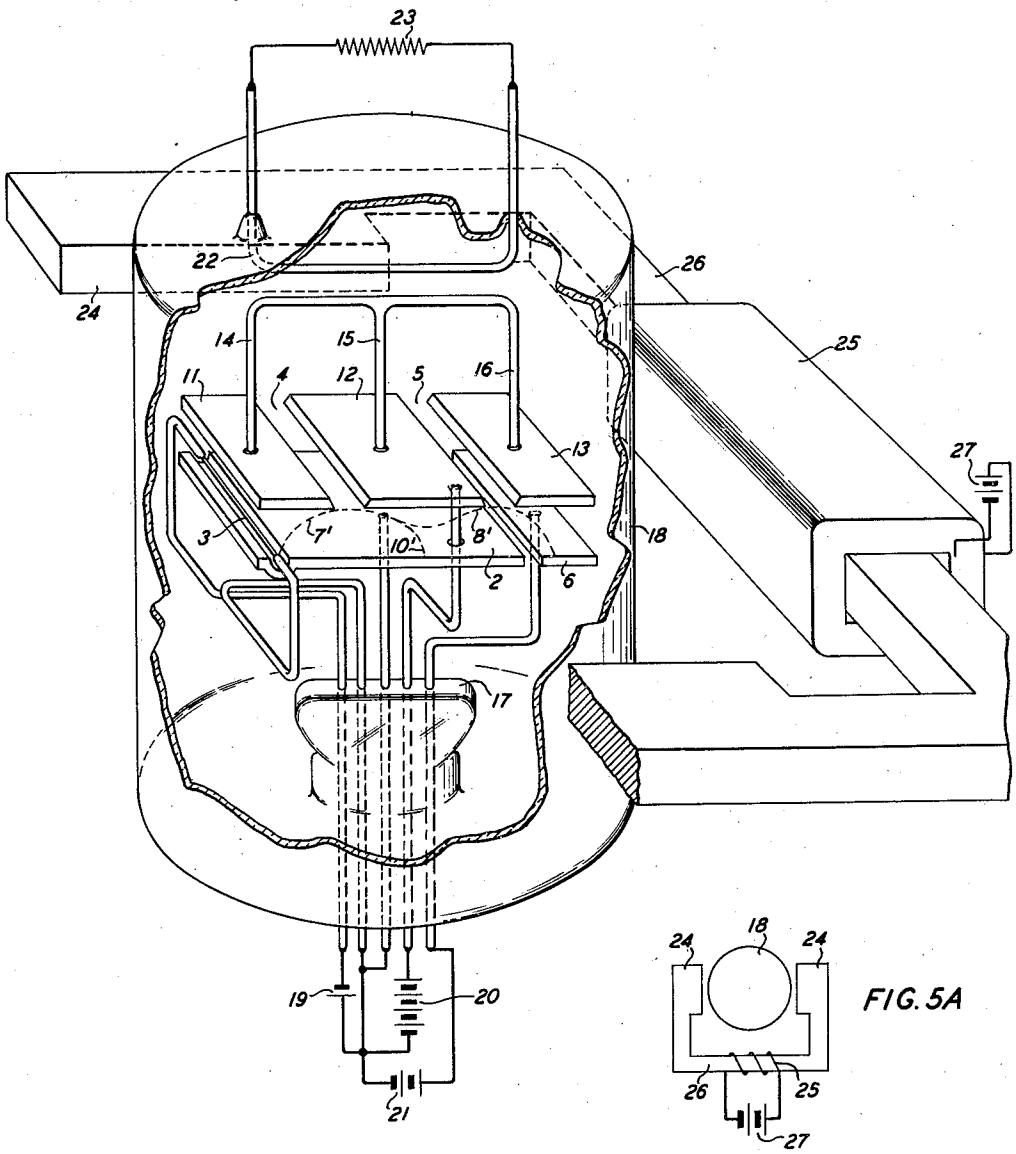


FIG. 5A

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Dec. 27, 1949 A. E. BOWEN 2,492,680

RESONATOR

Original Filed May 4, 1943 4 Sheets-Sheet 3

FIG. 6

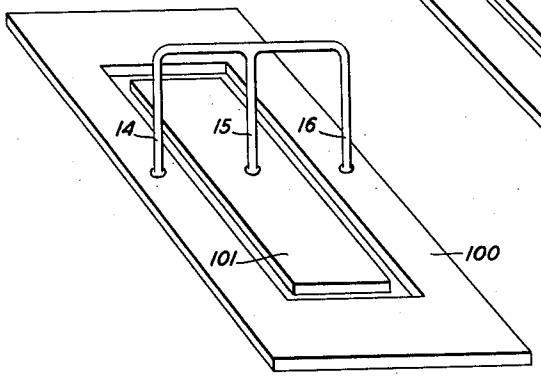


FIG. 7

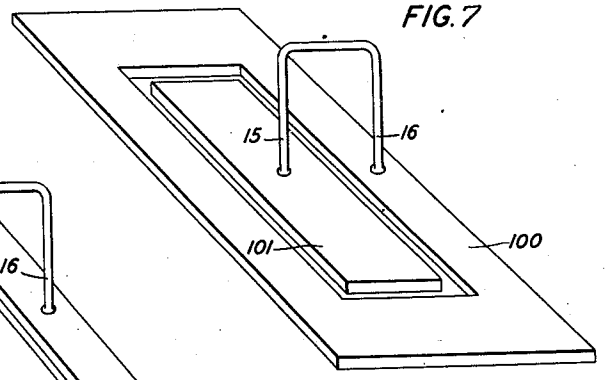


FIG. 8

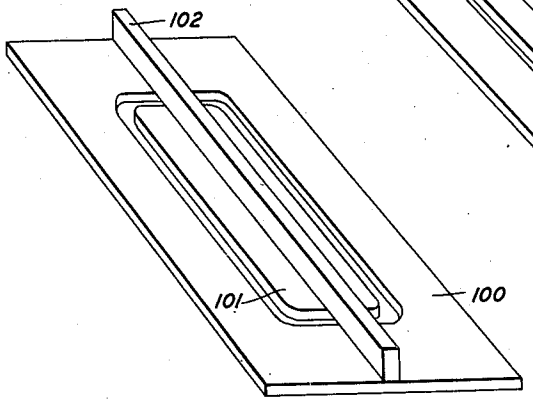
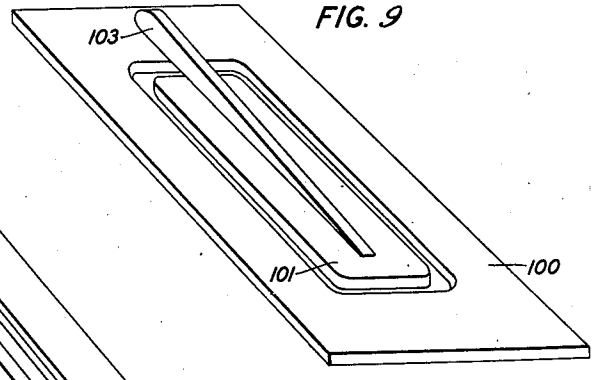


FIG. 9



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Dec. 27, 1949 A. E. BOWEN 2,492,680

RESONATOR

Original Filed May 4, 1943 4 Sheets-Sheet 4

FIG. 10

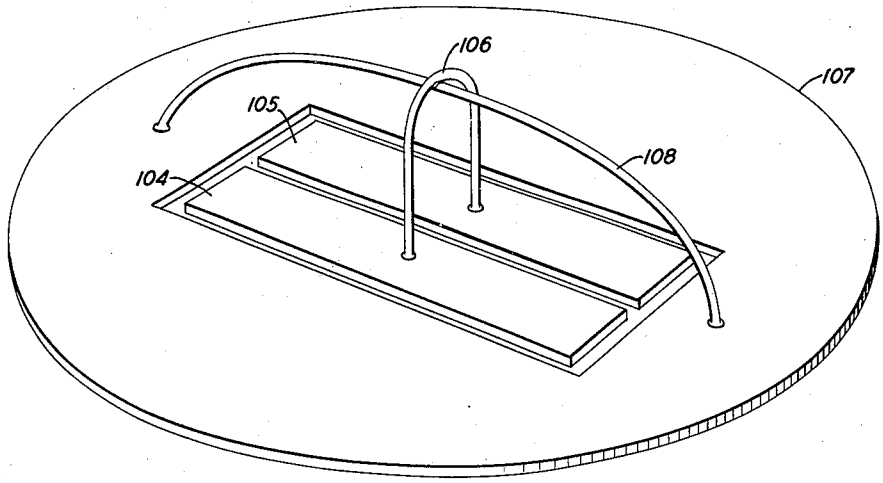
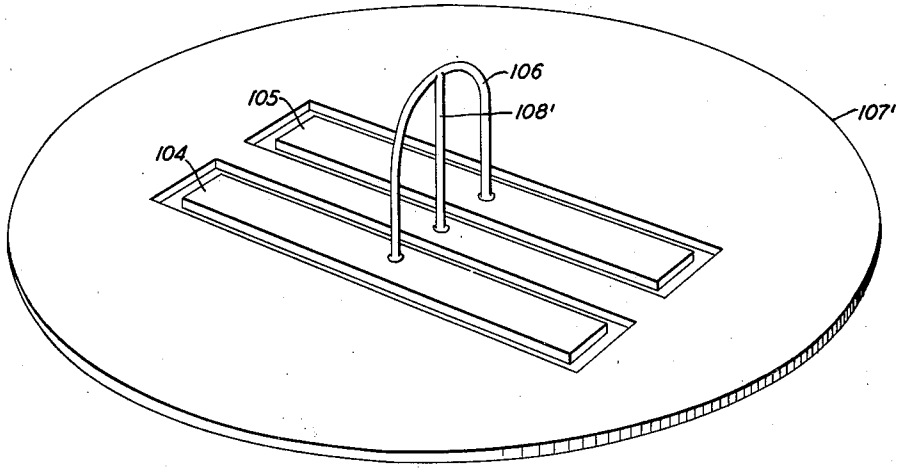


FIG. 11



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Patented Dec. 27, 1949 2,492,680

UNITED STATES PATENT OFFICE

2,492,680

RESONATOR

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Original application May 4, 1943, Serial No. 485,579. Divided and this application April 13, 1945, Serial No. 588,199. In Canada April 12, 1944

1 Claim. (Cl. 178—44)

1

This invention relates to a resonator or resonating structure particularly designed for microwaves, as for example in the region of a 10-centimeter wavelength, more or less.

This application is a division of my copending application Serial No. 485,579, filed May 4, 1943, and assigned to the same assignee as the present application. The parent application discloses and claims systems and arrangements with which the resonator of the present application may be employed.

The resonators of the invention are adapted for but not limited to use in high frequency electromagnetic systems for effecting energy interchanges between a stream of moving charged particles such as electrons, and electromagnetic waves guided or enclosed by electrical conductors.

The invention will be described as a component part of a high frequency electronic device of the type disclosed in the parent application.

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 type of device disclosed in the parent application that energy is abstracted from the electron when it is traveling parallel to the planes between which it moves. A device of this type may be embodied in an oscillator, an amplifier, a repeater, and the like, particularly for high frequency and microwave applications, wherever generation, repetition, control or amplification of electromagnetic waves is an object. The resonator of the present invention may be used with the devices disclosed in the parent application or in various other applications for ultra-high frequencies and microwaves.

2

In the particular system disclosed herein and in the parent application, 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. 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, 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 disclosed 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 that 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.

In the drawing, 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 disclosure in the parent application;

Figs. 2, 3 and 4 are diagrams showing a variety of proportionings, the essential parts of the trajectory control mechanism, including resonators in accordance with the present invention;

Fig. 3 is a perspective view, partly broken away

showing an oscillator employing a resonator in accordance with the invention;

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

Figs. 6 to 11, inclusive, are perspective views of various forms of resonators in accordance with the invention.

The principles underlying the invention disclosed in the parent application 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 axes X, Y, Z, directed as indicated in Fig. 1, the equations of motion for an electron of charge e and of mass m are

$$\frac{d^2x}{dt^2}=\frac{eH}{mc}\frac{dz}{dt} \tag{1}$$

$$\frac{d^2y}{dt^2}=0 \tag{2}$$

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

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:

$$\frac{eH}{mc}=p \tag{4}$$

$$\frac{cE}{H}=s_0 \tag{5}$$

the use of which makes

$$\frac{eE}{m}=ps_0 \tag{6}$$

The equations to be solved then reduce to

$$\frac{d^2x}{dt^2}=p\frac{dz}{dt} \tag{7}$$

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

The complete solution of the simultaneous Equations 7 and 8 is

$$x=C_1\sin pt-C_2\cos pt+s_0t+C_3 \tag{9}$$

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

from which the following may be derived by differentiation:

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

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

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

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

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

$$x=z=\frac{dx}{dt}=\frac{dz}{dt}=0 \tag{15}$$

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

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

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

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

$$pt=\pi \tag{18}$$

and at this point it will be found that

$$x=\frac{\pi s_0}{p} \tag{19}$$

$$z=\frac{2s_0}{p} \tag{20}$$

$$\frac{dx}{dt}=2s_0 \tag{21}$$

$$\frac{dz}{dt}=0 \tag{22}$$

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 $pt=\pi$,

$$x=\tfrac{1}{2}\pi a \tag{23}$$

and

$$z=a \tag{24}$$

where

$$a=\frac{2s_0}{p}=\frac{2mc^2E}{eH^2} \tag{25}$$

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

$$V=V_0+\delta V_0 \tag{26}$$

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

$$Ve=\tfrac{1}{2}ms^2 \tag{27}$$

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

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

Using

$$V_0=aE \tag{29}$$

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

$$s=2s_0\sqrt{1+\delta} \tag{30}$$

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

$$pt=\pi \tag{31}$$

then

$$x=\tfrac{1}{2}\pi a \tag{32}$$

$$z=a \tag{33}$$

$$\frac{dx}{dt}=2s_0\sqrt{1+\delta}=\sqrt{1+\delta} \tag{34}$$

and

$$\frac{dz}{dt}=0 \tag{35}$$

Under these conditions it is readily found that

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

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

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

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

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

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

The x-component of velocity is

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

The trochoids corresponding respectively to the values $\delta=-0.5$, $\delta=0$, and $\delta=+0.5$ are plotted 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

$$x=\frac{3\pi a}{2} \tag{41}$$

$$z=a \tag{42}$$

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

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 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 of 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

$$\frac{n}{f}=\frac{2\pi}{p}=\frac{2\pi mc}{eH} \tag{43}$$

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

$$\frac{n\lambda}{c}=\frac{2\pi mc}{eH} \tag{44}$$

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,

$$\lambda H=\frac{2\pi mc^2}{ne} \tag{45}$$

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

$$\lambda H=\frac{2\pi mc}{ne} \tag{46}$$

which, when the charged particles are electrons becomes approximately

$$\lambda H=\frac{10650}{n} \tag{47}$$

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:

$$a=\frac{c}{H}\frac{\sqrt{2mV_0}}{e} \tag{48}$$

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

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

where V_0 and

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

are in electromagnetic units, λ is in centimeters, and $c=3\times10^{10}$ centimeter/seconds, or

$$a=\frac{n\lambda\sqrt{V_0}}{3160}\text{ centimeters} \tag{50}$$

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 1,000 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 shows a modification of the tuned circuit of Fig. 5. The anode segments 11 and 13 of Fig. 5 are merged into a single segment 100 which may surround a middle segment 101 as shown. The inductive connection between the segments 100 and 101 comprises the conductors 14, 15 and 16 corresponding to those similarly numbered in Fig. 5.

Fig. 7 shows a tuned circuit similar to that of Fig. 6 but with the inductive connection between the plates 100 and 101 simplified so as to eliminate the conductor 14.

Figs. 8 and 9 show tuned circuits similar in principle respectively to the tuned circuits of Figs. 6 and 7.

In the arrangement of Fig. 8, a conductive bar 102 takes the place of the conductors 14, 15, 16, inclusive, of Fig. 6. In this kind of structure there is less inductance in the connector 102 and resonance is determined to a greater extent by distributed inductance in the segments 100 and 101.

In the arrangement of Fig. 9 the inductive connection 15, 16 is replaced by a bar 103. Here again the inductance relied upon for resonance resides mainly in the distributed inductance of the segments 100 and 101.

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.

What is claimed is:

A resonator comprising a conductive guard plate having a closed slot therein, a pair of conductive plates mounted coplanarly with each other and with said guard plate within the slot

in said guard plate, a first inductive conductor connecting said pair of conductive plates and lying in a plane perpendicular to the plane of said guard plate, and a second inductive conductor lying in a plane perpendicular to the plane of said guard plate, said second inductive conductor connecting said first inductive conductor to said guard plate and thereby supporting said pair of conductive plates within the slot in said guard plate.

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