Nov. 16, 1948. A. H. ROSENTHAL 2,454,094

ELECTRON DISCHARGE DEVICE FOR PRODUCING ELECTRIC OSCILLATIONS

Filed Jan. 21, 1944 5 Sheets-Sheet 1

Fig. 1.

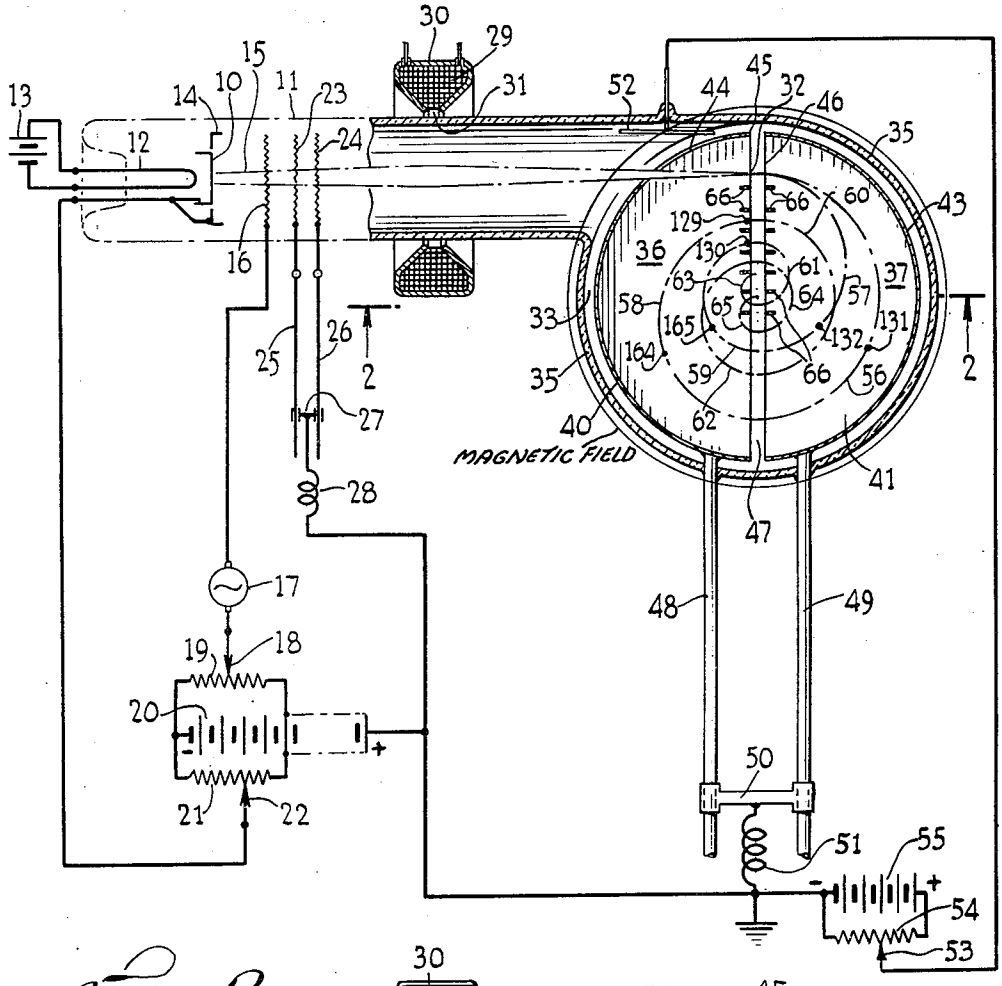
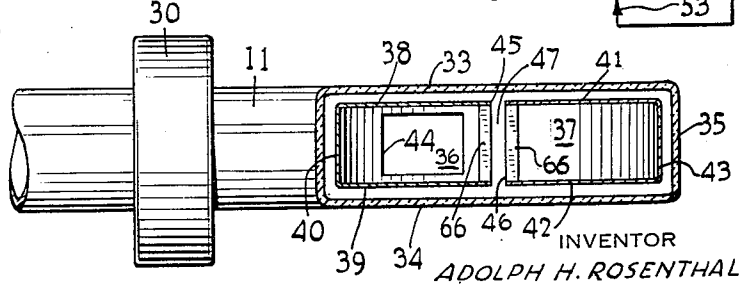


Fig. 2.



INVENTOR
ADOLPH H. ROSENTHAL
BY J. D. Allen,
ATTORNEY

Nov. 16, 1948. A. H. ROSENTHAL 2,454,094

ELECTRON DISCHARGE DEVICE FOR PRODUCING ELECTRIC OSCILLATIONS

Filed Jan. 21, 1944 5 Sheets-Sheet 2

Fig. 3.

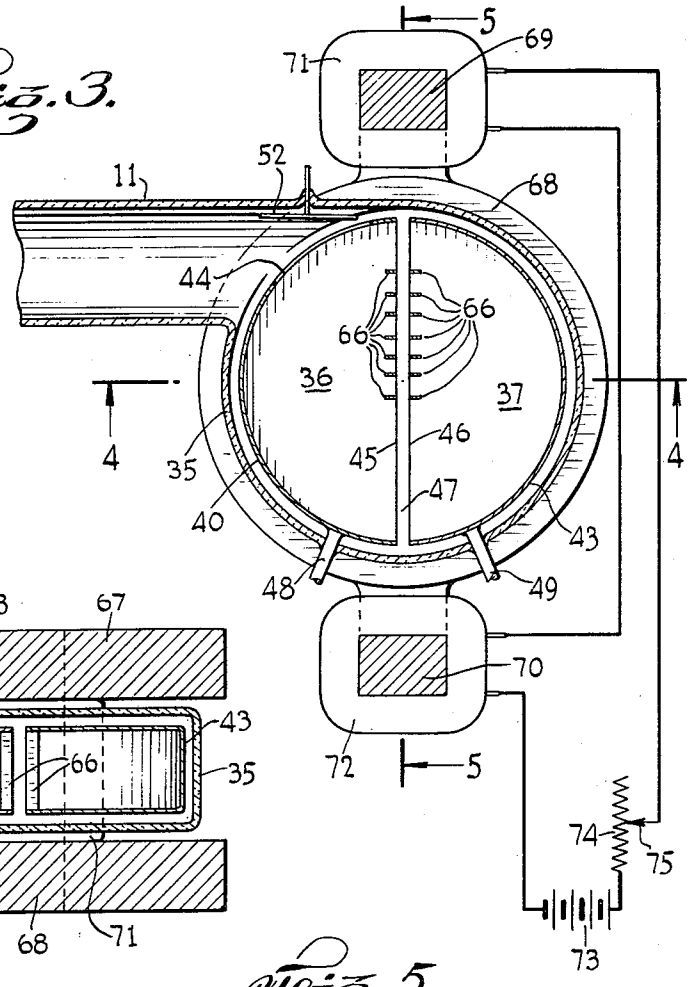


Fig. 4.

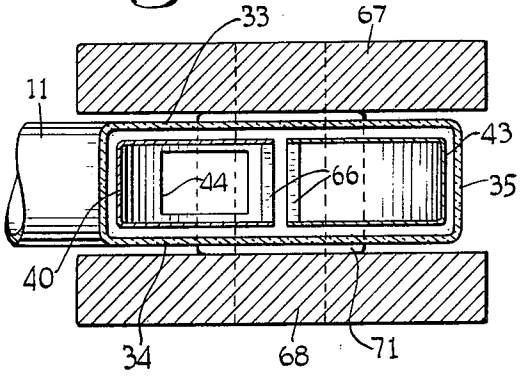
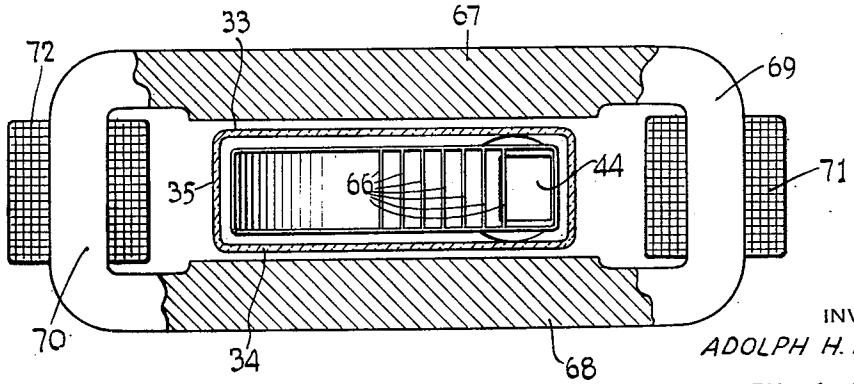


Fig. 5.



INVENTOR
ADOLPH H. ROSENTHAL
BY J. O. Allen,
ATTORNEY

Nov. 16, 1948. A. H. ROSENTHAL 2,454,094

ELECTRON DISCHARGE DEVICE FOR PRODUCING ELECTRIC OSCILLATIONS

Filed Jan. 21, 1944 5 Sheets-Sheet 3

Fig. 6.

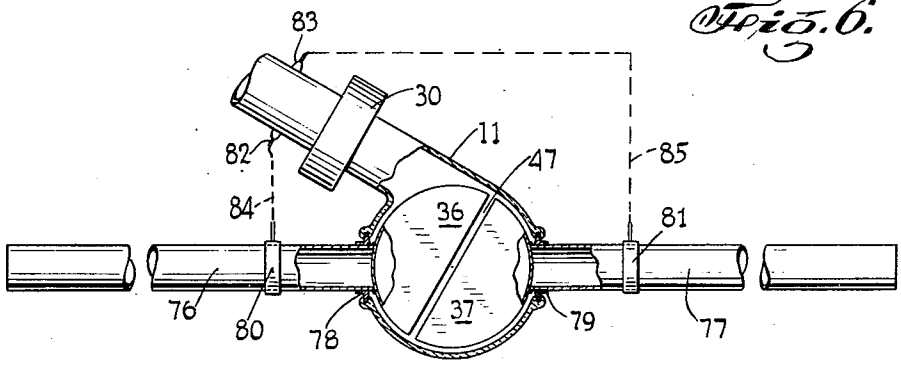


Fig. 7.

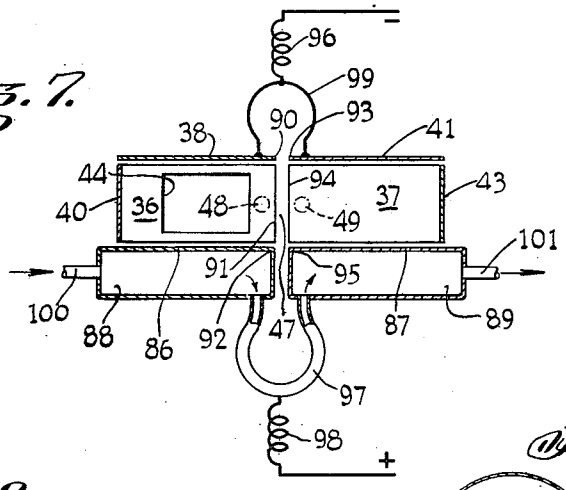


Fig. 8.

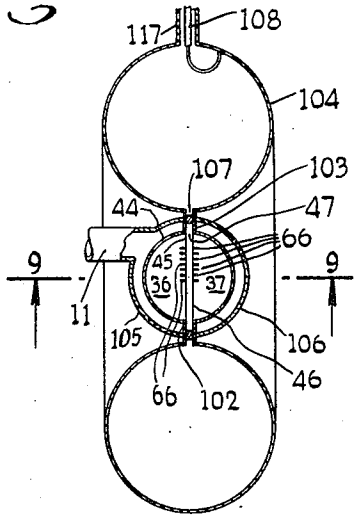
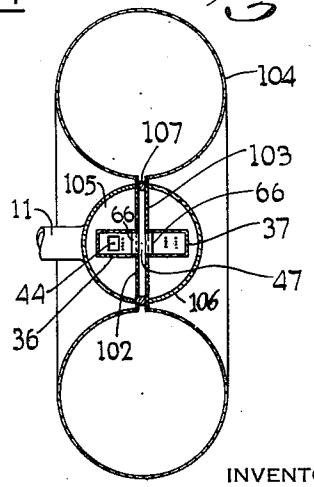


Fig. 9.



INVENTOR
ADOLPH H. ROSENTHAL
BY J. D. Allen,
ATTORNEY

Nov. 16, 1948. A. H. ROSENTHAL 2,454,094

ELECTRON DISCHARGE DEVICE FOR PRODUCING ELECTRIC OSCILLATIONS

Filed Jan. 21, 1944 5 Sheets-Sheet 4

Fig. 10.

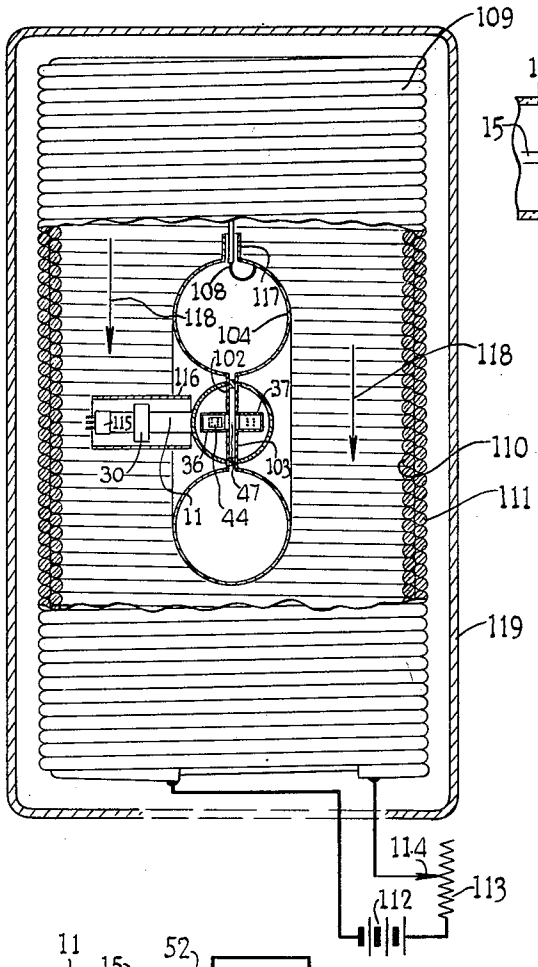


Fig. 11.

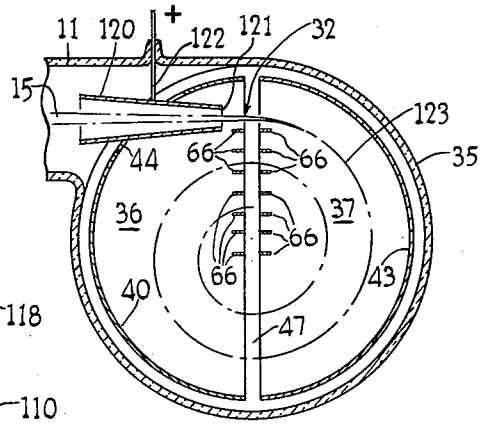


Fig. 13.

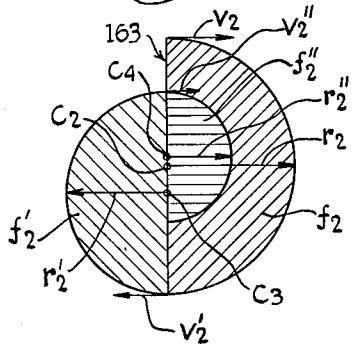
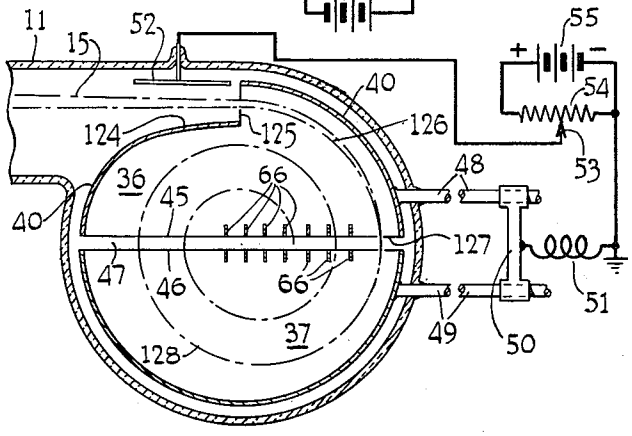


Fig. 12.



INVENTOR
ADOLPH H. ROSENTHAL
BY J. O. Allier,
ATTORNEY

Nov. 16, 1948. A. H. ROSENTHAL 2,454,094

ELECTRON DISCHARGE DEVICE FOR PRODUCING ELECTRIC OSCILLATIONS

Filed Jan. 21, 1944 5 Sheets-Sheet 5

Fig. 14.

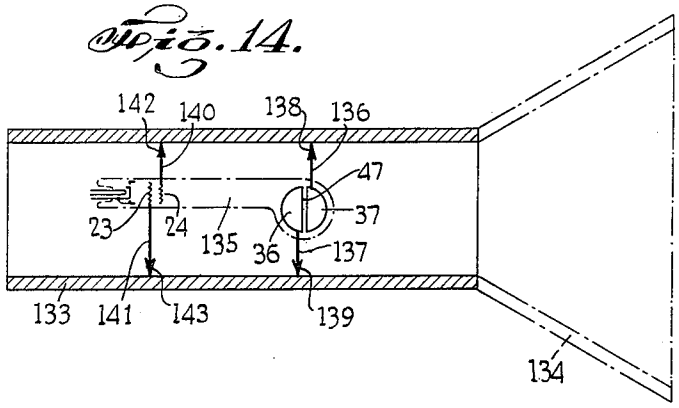


Fig. 15.

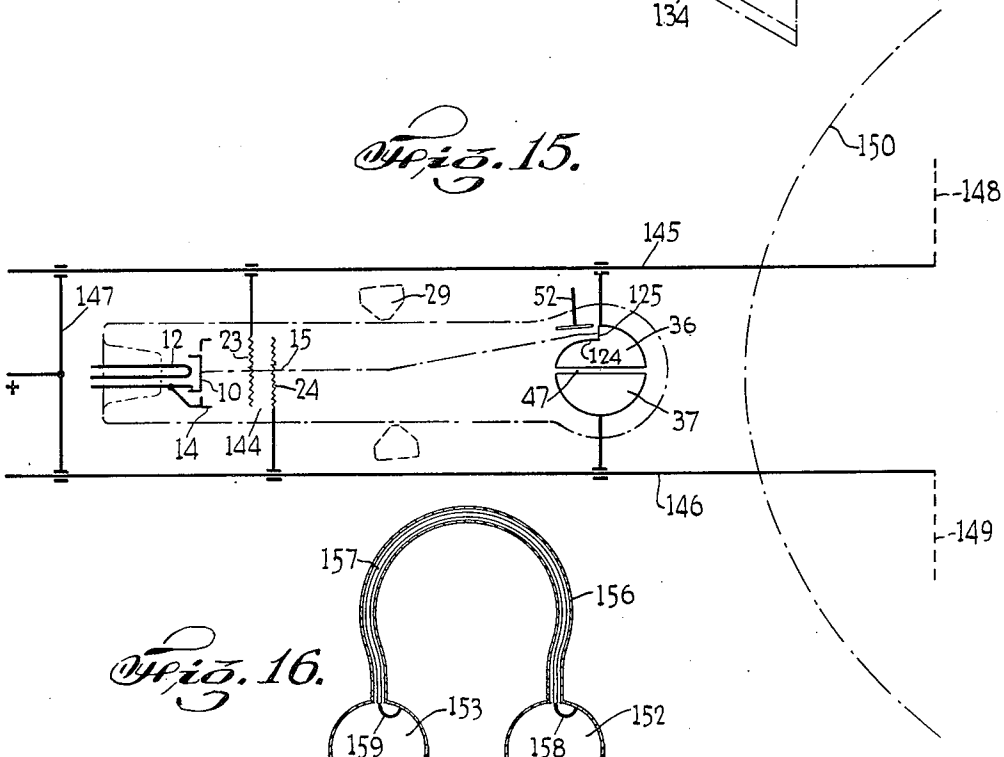
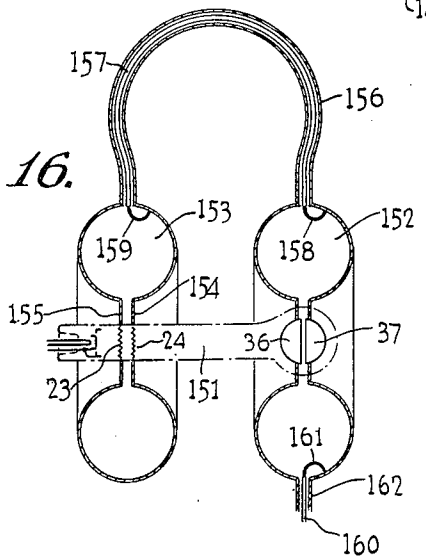


Fig. 16.



INVENTOR
ADOLPH H. ROSENTHAL
BY J. O. Allen,
ATTORNEY

Patented Nov. 16, 1948 2,454,094

UNITED STATES PATENT OFFICE

2,454,094

ELECTRON DISCHARGE DEVICE FOR PRODUCING ELECTRIC OSCILLATIONS

Adolph H. Rosenthal, New York, N. Y., assignor to Scophony Corporation of America, New York, N. Y., a corporation of Delaware

Application January 21, 1944, Serial No. 519,130

8 Claims. (Cl. 250—36)

1

This invention relates to a method and electronic device for generating, varying (modulating or demodulating), indicating (detecting) and shaping electric oscillations of high and ultra-high frequency.

Methods and electronic devices have been suggested for this purpose which operate on the principle of transit time phenomena of electrons and in particular of modulating the velocities of electrons comprised in a beam and permitting them to drift over a straight path of predetermined length at the end of which they concentrate periodically in the frequency of their modulation into bunches or charges of greater density. Kinetic energy was withdrawn at that end from the electron beam of periodically varying density by load circuits, particularly resonators tuned to the frequency in which the electron velocities of the beam were modulated, and the electrons were thereby decelerated and thereafter collected by an electrode at suitable potential.

Velocity modulation was effected by subjecting the beam or stream of electrons arising continuously from an electron emitter, to a periodically varying field which changes the linear velocities of the individual electrons just passing it. Thereby, for instance, the linear velocity of electrons passing that field in one instant is increased, the velocity of other electrons passing the field in the next instant is not affected, and the velocity of still other electrons passing the field in a subsequent instant is decreased. During the transit of successive electrons of thus modulated individual velocities over a drift path of sufficient length, the faster electrons overtake the slower ones at a certain point of the path and an instantaneous bunching or as sharp as desired concentration of an electron charge results. By proper choice of the modulating field strength and frequency with respect to the initially equal individual velocities of the electrons emerging from the emitter or electron gun, high densities of these periodically recurring bunches or concentrated charges can be obtained. Relatively large electric currents can be induced by these recurrent concentrated charges in parts of a load circuit or resonator arranged in the vicinity of their bunching point and tuned to the frequency at which the electron beam is modulated, or a harmonic of that frequency; thus electric oscillations are built up and maintained in that circuit or resonator. Thereby kinetic energy is withdrawn from the successive concentrated or bunched electron charges of the passing beam, and the electrons comprised by those charges continue their travel at their different though reduced velocities, and de-bunching of the electrons or loss of high charge concentration results. The electrons of the velocity modulated beam cannot be decelerated completely, however, because each bunched or concentrated charge is comprised of electrons of different individual velocities, and consequently there remains a considerable residual kinetic energy in the beam which is converted into heat when the electrons are eventually caught in the collector electrode. Since the bunched electrons pass always in the same direction the parts of the load circuit which withdraw kinetic energy from them, an asymmetric wave form is induced in that circuit. As a result, the efficiency of these known methods and devices is limited and cannot exceed a theoretical maximum of 58%, and is far lower with practical devices.

2

It is therefore an object of the invention to increase the efficiency of methods and electronic devices which utilise transit time phenomena of electron beams.

It is another object of the invention to utilise a velocity modulated stream of electrons of periodically varying space charge density, for energising a tuned load circuit as symmetrically as desired.

It is a further object of the invention to utilise the effects of periodically varying space charge densities or bunches of a stream or beam of electrons at two or more distant places or points along its transit path.

It is still another object of the invention to produce and repeatedly utilize space charge concentrations in a stream or beam of electrons at spaced places of its transit path until or before practically all of the electrons comprised by a concentration or bunch have given up most of their energies to the load circuit and are collected.

It is still another object of the invention to produce along a transit path of a velocity modulated beam or stream of electrons a number, two as a minimum, of space charge concentrations spaced from one another, and to utilize each of them for inducing electric currents in a load circuit.

It is still a further object of the invention to produce a number, two as a minimum, space charge concentrations in a beam or stream of electrons at spaced places along its path, and to withdraw electric energy from a number, two as a minimum, of these charge concentrations into the same load circuit, until or before practically all the electrons of the beam or stream are decelerated and collected.

It is still another object of the invention to produce in a velocity modulated beam or stream of electrons a number, two as a minimum, of space charge concentrations at spaced places of its transit path, to withdraw at a number, two as a minimum, of those places electric energy from a charge concentration and to decelerate the electrons comprised by such charge concentration by means of an opposing electric field, and to collect the electrons after their velocities are sufficiently decelerated, in order to minimize losses by heating of the collector electrode or electrodes and to increase the overall efficiency of the device.

It is another object of the invention to cause and utilize periodically recurring space charge concentrations in the transit path of a continuously produced stream or beam of electrons and to utilize them in a load circuit, by means of a new and compact electronic device of relatively high efficiency.

These and other objects of the invention will be more clearly understood when the specification proceeds with reference to the drawings in which by way of exemplification, Fig. 1 shows in cross section, with some parts in elevation, and rather schematically, an electronic device according to the invention and a diagram of its principal operation circuit, Fig. 2 a cross section along line 2—2 in Fig. 1 through a part of that device, Fig. 3 a cross section, with parts in elevation, through that part of an electronic device and means for exciting therein a magnetic field, Fig. 4 a cross section, with parts in elevation, along line 4—4 in Fig. 3, Fig. 5 a cross section, with parts in elevation, along lines 5—5 in Fig. 3, Fig. 6 rather schematically in cross section, with parts in elevation, a modified embodiment of the invention, Fig. 7 schematically and in cross section operative parts of another modification of the invention, Fig. 8 in cross section and schematically parts of a new device according to the invention combined with a cavity resonator, Fig. 9 a cross section, with parts in elevation, along line 9—9 in Fig. 8, Fig. 10 schematically in cross section, with parts in elevation, the arrangement of a device as exemplified in Fig. 9 within a magnetic field, Fig. 11 in cross section a further modification of essential parts of a new device according to the invention, Fig. 12 in cross section, with parts in elevation, still another modification of operative parts of the new device and in diagram a part of its circuit, Fig. 13 a diagrammatic illustration of the theory of the invention, Fig. 14 schematically the arrangement of an embodiment of the invention within a wave guide and with a horn radiator, Fig. 15 a connection of a modified device according to the invention with a Lecher wire system and radiating dipole and reflector, and Fig. 16 diagrammatically a generator for ultra-high frequency oscillations using the principle and a device according to the invention.

According to the invention a stream or beam of velocity modulated electrons is discharged or injected into a substantially homogeneous magnetic field the direction of which is perpendicular or inclined to the mean path of the beam or stream. The electrons entering the magnetic field retain their individual linear velocities but are deflected to follow circular paths the radii of which are the larger, the larger the individual linear velocities of the deflected electrons (tangential to their now circular paths) are. However, the angular velocity of travel over those circular paths is the same for all the electrons and

independent of their individual linear (tangential) velocities.

Assuming a plane through the line where the electrons are subjected first to the deflecting action of the magnetic field and perpendicular to their instantaneous mean direction of flight, the virtual or momentary centers of the circular orbits travelled thereafter by all the electrons lie in that plane although the radii of those orbits differ. Consequently, and as will be shown hereinafter in more detail, all the electrons of each bunch or space charge concentration will cross and re-cross substantially simultaneously the above assumed plane after each half-circle of their individual paths. In other words, the instantaneous phase relation of the electrons of a bunch or charge concentration entering the magnetic field is restored or reappears after each half-circle of their individual orbits, independent of the velocity reductions of the individual electrons.

The invention utilizes this phenomenon by creating an electric field of a direction opposed to that of the travel of the electrons comprised by an initial bunch or charge concentration, at the places and the instants where and when these electrons first cross and then re-cross the above assumed plane after each half-circle of their travel. Each time these electrons pass that opposing electric field, their individual linear velocities tangential to their orbits are decreased and consequently the radii of the half-circles they travel thereafter are reduced; but their angular velocities remain the same, and the virtual or momentary centers of those successively reduced half-circles continue to lie substantially in that above assumed plane. Thus the electrons comprised by any charge concentration once formed in that plane, will practically simultaneously re-cross that plane thereafter and, in this sense, concentrate again in that plane. The paths of the electrons of different individual velocities are comprised of successive half-circles of successively decreased radii and resemble spirals. Each time the essentially equiphased electrons pass the opposing electric field, a portion of their kinetic energy is withdrawn from them and utilized in a properly arranged load circuit tuned to a frequency a cycle of which substantially equals twice the time required by all the electrons of a bunch or concentrated charge to travel over a half-circle of their orbits. In this manner electric energy can be withdrawn repeatedly from each bunch or concentrated charge, and in particular symmetrically energize the load circuit at each half-wave of its oscillations. The individual electrons are decelerated to correspondingly great extent by repeated crossings of the plane and their residual kinetic energy reduced to desired small value until they are collected. Hence the efficiency of the method and device according to the invention considerably exceeds that of known devices utilizing the principle of electron transit time phenomena.

With conventional magnetron and positive grid generators, the efficiency or figure of merit is limited by the initial random distribution in time of the electrons with respect to the phase of the high frequency field which produces the sorting of the electrons; in other words, the high frequency field both decelerates and accelerates electrons admitted into it at random. With the present invention, an efficient pre-sorting of the electrons admitted or shot into the magnetic field is accomplished so that only electrons in

correct phase relationship, i. e. when instantaneously bunched or concentrated in space charges of high density, enter the magnetic field whereby considerably increased efficiency is secured.

Referring to Fig. 1, an electron emitter 10, such as a flat cathode is arranged within an evacuated envelope 11, such as of glass; the cathode is heated by a heating element 12 connected with an adjustable source 13 of electric heating current. An electron-optical element 14 on the same potential with emitter 10 serves to direct the electrons continuously emanating from emitter 10 in the form of a straight beam or stream 15 through a number of modulating fields produced by proper electromagnetic or electrostatic means, such as electrodes.

Thus, for instance, a grid 16 or like control electrode is arranged in the path of the beam if it is desired to impress upon it or modulate its intensity by any signal frequency other than the carrier frequency to be produced or generated; such frequency may be derived from an external source of alternating voltage, indicated by a modulator 17. A steady potential adjustable relative to that of cathode 10, is put on electrode 16 by tap 18 adjustable along potentiometer 19 across potential source 20; from another potentiometer 21 across that source a desired potential for cathode 10 is derived by tap 22.

Two grids 23, 24 or like control electrodes serve to modulate the velocities of the electrons in well known manner and are connected with conductors 25, 26 pertaining to a tunable Lecher wire system, the adjustable bridge 27 of which is connected at its center through self-induction coil (high-frequency choke) 28 with a steady positive, preferably adjustable potential derived from source 20. An alternating potential of the desired high or ultra-high frequency to which the Lecher wire system resonates, is applied between electrodes 23 and 24 from an external source, such as a signal to be amplified or derived by feed-back from the generated oscillatory energy in order to maintain self-sustained high frequency oscillations. Thereby the velocities of the electrons successively passing the grids 23, 24 are modulated in well known manner, so that beam or stream 15 past electrode 24 is comprised of successive electrons the velocity of which is respectively increased, not affected or reduced. In travelling over the transit path past grid 24, subsequent faster electrons overtake slower ones ahead of them at a certain distance from grid 24, and space charge concentrations or bunches recur there in the frequency of the velocity modulation. A beam focusing device enhances this effect by axially concentrating or focusing the electrons and is exemplified by an electromagnetic focusing coil 29 provided with an iron cover 30 open at the inner edge 31 arranged around envelope 11 and energized in adjustable, well known manner (not shown); it acts as a so-called electron-lens which focuses the electrons at or near point 32 where they are bunched or concentrated recurrently to maximum space charge density at the frequency of their velocity modulation.

Tubular envelope 11 continues into a preferably cylindrical portion comprised of two circular and flat front walls 33, 34 and a cylindrical side wall 35. Within this cylindrical portion, two members hereinafter termed "duants" or "dees" 36, 37 of copper, aluminum or other non-magnetizable metal or alloy are arranged; duant 36 comprises two half-circular front walls 38, 39 and a half-cylindrical side wall 40, and duant 37 two half-circular front walls 41, 42 and a half-cylindrical side wall 43. Duant 36 is further provided with an aperture or window 44 wide enough to permit beam 15 to enter. The edges 45, 46 of the duants are parallel and spaced from one another to leave a narrow gap 47 between them. Each of the duants is connected with and supported by conductors 48, 49, respectively, which air-tightly pass wall 35 and pertain to a tunable Lecher wire system the adjustable bridge 50 of which is connected at its center through self-induction coil (high-frequency choke) 51 with an adjustable steady potential which is positive relative to emitter 10 and may be the same on which Lecher wire system 25, 26, 27 is held.

A homogeneous magnetic field, as indicated in Fig. 1, traverses the duants 36, 37, in this example perpendicularly to the plane of the drawing and directed toward the latter, i. e. with a north pole above and a south pole below the plane of the drawing, and tends to convert the straight path of the electrons injected through aperture 44 into the equipotential space within duant 36 into a circular one. In order to prevent the electron beam from being bent before reaching point 32, a suitably shaped electrode 52 is arranged near and outside window 44 and a potential which is slightly positive relative to that of duant 36, is applied to it through tap 53 adjustable along potentiometer 54 across a source of voltage 55; the electric field locally produced by electrode 52 counteracts the magnetic field and straightens the path of the electrons until they reach point 32 in a plane between edges 45 and 46 and perpendicular to that of the drawing, where instantaneous maximum concentrations or bunching of electrons of different velocities recur in the frequency of their velocity modulation.

When a bunch or space charge concentration passes gap 47 near point 32, duant 36 is at its instantaneous highest positive potential and duant 37 at its instantaneous lowest potential, and an electric field results of a direction from edge 45 to edge 46 across gap 47; hence the linear velocities (measured in electron volts) of all the electrons comprised by that bunch are reduced by an amount equalling the instantaneous potential difference between the duants.

The electrons of that bunch now enter the equi-potential space within duant 37 where they are subjected only to the action of the magnetic field. The electrons of the bunch of reduced though still relatively highest linear (tangential) velocity will therefore travel over a half-circular path 56 of largest radius while the electrons of reduced and relatively lowest linear velocity pass over a half-circle 57 of smallest radius. Since the angular velocity of all the electrons of that bunch is however the same, they complete their half-circular paths at the same instant and therefore arrive simultaneously again at gap 47. By this time the potentials of duants 36, 37 have changed to the opposite, i. e. duant 37 is at its peak positive potential while duant 36 is at its lowest potential, and consequently an electric field is produced between their edges 46, 45 across gap 47 of a direction from edge 46 to edge 45, which again opposes the flight of all the electrons substantially simultaneously arrived at and now crossing gap 47 for a second time. Therefrom results a second deceleration of those electrons by an amount equalling the maximum alternating potential difference between the duants, and also a second reduction of the radii of the orbits

of all those electrons but their angular velocity still remains the same. Consequently path 56 is continued past gap 47 by a half-circular path 58 the radius of which is smaller than that of path 56 but still larger than that of the half-circular path 59 into which path 57 of the slowest electrons continues, and eventually all the electrons of that initial bunch arrive substantially simultaneously again, and now for a third time, in front of gap 47. At that instant a full oscillation period or cycle is completed and duants 36, 37 have returned to the same potential as prevailed when this bunch of electrons arrived at gap 47 for the first time, and an electric field is produced across the gap of a direction from edges 45 to edges 46, whereby again the linear velocities are reduced of all the electrons crossing gap 47 now for the third time by an amount equivalent to the maximum voltage amplitude between the duants. Consequently, a half-circular path 60 of the still fastest electrons and a half-circular path 61 of the slowest electrons of that initial bunch results, and so forth. Pursuing the total path of a fastest electron contained in an individual bunch passing point 32, it will be seen that it comprises successive half-circles 56, 58, 60, 62, 64 and 65; the successive radii of these successive half-circles considerably decrease, and a kind of contracting spiral results. Electrons of that bunch of smallest linear velocity successively pursue half-circular orbits 57, 59, 61 and 63, resulting in a spiral of successively far more decreasing radii than of the spiral travelled by the fastest electrons, as will be seen from subsequent mathematical considerations.

Collector electrodes 66 are arranged between walls 38, 39 and 41, 42 of each duant, and may consist of thin metal strips or wires of the same or different material than that of the duants. If strips are used, their width extends essentially parallel to the path of the electrons so as to cover and obscure the smallest possible area passed by the latter. The spacing and arrangement of electrodes 66 is such that they do not interfere with a bunch of electrons passing point 32 and the adjacent portion of gap 47, and possibly not with electrons re-crossing gap 47 after the first half-circle of their travel, in order to utilise the kinetic energies of the greatest possible number of electrons comprised by each bunch before they are caught by the electrodes 66. After a considerable number of such half-circles and mainly upon reduction of their radius to an order of magnitude approximating the width of the ridges of the electrodes 66, the electrons are collected by those electrodes. Electrons of initially smallest velocity will complete their spiral first and will be caught after a few crossings of gap 47; their initially small velocity will be reduced, however, sufficiently and their energies converted into oscillation energy so as to leave in them little residual kinetic energy. Electrons of initially greatest velocity will obviously cross and recross gap 47 far more frequently until they spiral down to a small radius approximating the ultimate small radius of the slowest electrons and are caught by the collector electrodes; due to their frequent crossing of gap 47, most of their energy will be converted into oscillation energy and their velocity will be sufficiently reduced so as to leave in them little kinetic energy when they are collected by electrodes 66. Hence little loss of energy and little heating of the collector electrodes result, and all the electrons initially concentrated in an individual bunch, cross and

recross repeatedly gap 47 and the retarding electric fields instantly established therein whereby their energy is utilised exhaustively. Hence the figure of merit of a device according to the invention exceeds considerably those of known devices.

The periodic change in the relative potentials of duants 36, 37 is produced conveniently by a tuned load circuit connected with them, in this exemplification formed by a Lecher wire system 48, 49, 50. The frequency of oscillations produced in the circuit and their phase is such that the electric field produced by them between the duants 36, 37 across gap 47 changes periodically and recurrently and is at its maximum, opposed to the direction of flight of the electrons just entering it, each time that a bunch crosses and recrosses the gap, whereby energy is withdrawn from the electrons and converted into high frequency oscillation energy. Consequently a cycle of frequency of that tuned circuit corresponds to the time required for one bunch passing point 32, to complete two successive half-cycles, such as 56, 58 and 57, 59. After each full cycle the instantaneous magnitude and direction of the electric field across gap 47 is the same with reference to point 32, and consequently successive bunches or space charge concentrations formed in the continuously produced beam 15 at a frequency equalling that of circuit 48, 49, 50 and arriving at point 32 will meet identical conditions of the retarding electrical field. The frequencies of that tuned load circuit and of the velocity modulation of beam 15 should therefore be identical, i. e. the Lecher wire systems 48, 49, 50 and 25, 26, 27 be tuned to the same frequency. Their phase relation is to be adjusted so as to take care of the time needed by the electrons for their transit from the place of their velocity modulation to the place 32 of bunching when the decelerating field instantly produced across gap 47 should be essentially at its above described peak. Pursuing now a few bunches or space charge concentrations successively arriving at point 32 at the frequency of the tuned circuit connected with duants 36, 37, it will be appreciated that the first bunch crosses gap 47 a third time when the second bunch or space charge concentration of beam 15 arrives at point 32 and crosses gap 47 a first time; thus the energy withdrawal from the first and second bunch is aggregated. The electrons of the first bunch crossing gap 47 a third time are, however, owing to their two previous decelerations of a smaller average velocity than and spaced from the electrons on the second bunch which cross gap 47 the first time.

Referring to Figs. 3 to 5, there is shown the portion only of the electronic device as described more in detail in Figs. 1, 2, in which a substantially homogeneous magnetic field is produced across the path of the bunched electrons re-currently entering it; identical reference numbers indicate similar parts or elements. The magnetic field substantially perpendicular to the mean path of the entering beam or stream of electrons emerges from pole shoes 67, 68 close to and preferably projecting beyond the circular walls 33, 34 of the "spinning" space inside the duants. The pole shoes are connected through core members 69, 70 of suitable cross section provided with exciting electromagnetic coils 71, 72 which are energized adjustably by a source 73 of direct electric current arranged preferably in series with the coils through a variable resistor 74 and tap 75.

As will be shown hereinafter with reference to mathematical developments, the accurate adjustment of the magnetic field is essential for the proper operation of the device and it can be said that with a given device there is a "magnetic resonance to be established between the strength of the magnetic field and the rotation period which in turn determines the desired output frequency. The invention thus uses what may be termed a "magnetic resonance deceleration."

Fig. 6 exemplifies an embodiment of the invention in which the duants **36, 37** are conductively connected with conducting, preferably metallic rods or tubes **76, 77**, respectively, forming together a radiation dipole. Each rod or tube is provided with a ring **78, 79**, respectively, of metal, e. g. copper, which is airtightly welded or soldered thereto, and to which glass envelope **11** is sealed. The duants may be considered as a part of and co-determining the high frequency of the load circuit formed by parts **76, 77** of the dipole, the equivalent lengths of each of which may correspond to multiples of wave lengths of the high frequency to be produced. Thus simultaneously maximum high frequency potential differences are produced between the duants across gap **47** and between the extreme ends of the parts **76, 77** of the dipole from which electromagnetic waves of the high or ultra-high frequency thus produced are directly radiated into space. In order to conveniently connect the dipole parts **76, 77** with the duants, gap **47** is inclined with respect to the co-axial directions of those parts. In the generator of ultra-high frequency oscillatory wave energy as exemplified in Fig. 6, the means effecting the velocity modulation of the electron beam in that frequency (such as grid electrodes **23, 24** not shown in Fig. 6) obtain their modulation potentials by feed-back from proper and preferably adjustable points of the load circuit formed by the dipole, e. g. through connectors indicated in dotted lines **84, 85** and leading to the terminals **82, 83** of the velocity modulation electrodes. Proper adjustment of both the amplitude and phase relations between the oscillations produced in the duants or parts of the load circuit connected with them, and the pulsating fields securing velocity modulation of the electrons are obtained by proper dimensioning of the feed-back connectors **84, 85**. The same views apply of course to the operation of the other devices hereinbefore and hereinafter described.

Fig. 7 shows schematically a modification of the duants so as to dispense with collector electrodes within the equi-potential "spinning" space of the duants. In this exemplification, each duant **36, 37** comprises half-cylindrical side walls **40, 43** spaced from the associated half-circular front walls **38, 41** and also spaced from the opposite half-circular front walls **86, 87** which form parts of hollow bodies **88, 89**. Edge **90** of front wall **38** is arranged in one plane with edge **91** of side wall **40** and edge **92** of front wall **86**; edge **93** of front wall **41**, edge **94** of side wall **43** and edge **95** of front wall **87** lie in another plane slightly spaced from the first one to form gap **47**. Walls **38, 41** are connected by means of a curved connector **99** representing a high impedance for the generated high frequency and connected at its center through self-induction coil (high-frequency choke) **96** with a steady high potential of the order and the purpose of the high potential at which the duants are held for instance in Fig. 1, The hollow metallic bodies **88, 89** and thereby the front walls **86, 87** are connected by a curved conductive pipe **97** representing a high impedance for the generated high frequency; pipe **97** is connected at its center through self-induction coil (high-frequency choke) **98** with a steady potential slightly more positive and preferably adjustable relative to the other steady potential at connector **99**.

Each duant is also connected with a conductor **48, 49** of the type and purpose hereinbefore described. Consequently an electric field of a direction from edges **90, 91, 92** toward edges **93, 94, 95** will be produced across gap **47** in one instant, and an electric field of opposite direction after a half-circle of rotation of the electrons within duant **37**; the frequency of the changing field equals the frequency of the oscillatory energy produced. The bunch or concentrated space charge of electrons entering through window **44**, is subjected to the action of a homogeneous magnetic field perpendicular to walls **38, 41** and **86, 87**, respectively, and spins accordingly. In addition thereto, a steady electric field is produced in an axial direction within the spinning space between the walls **38, 41** and **86, 87** held on different steady potentials, and directed from walls **86, 87** to walls **38, 41**, respectively. The electrons spinning within the half cylinders **40, 43** will thereby be gradually driven toward walls **86, 87** and eventually impinge upon them and be collected. Hence the members **88, 89** with their end walls **86, 87** act as the collectors for the decelerated electrons.

If very high oscillatory energies are to be produced with the modified device according to Fig. 7, the residual energy is preferably dissipated by using the walls of hollow bodies **88, 89** as collectors and passing a cooling medium through those hollow bodies entering through pipe **100** and leaving through pipe **101**. The hollow bodies **88, 89** can be dispensed with and only half-circular plates **86, 87** retained instead if no such extensive cooling is required, and be connected by a connector **97** of the same type as connector **99**. The high impedance connectors **97** and **99** may be regarded each as a bridged Lecher wire system suitably tuned to maximum impedance for the frequency in question.

Instead of using an auxiliary axial electric field as just described, the effect of driving the electrons spinning within the duants toward collecting plates **86, 87** can also be obtained by slightly inclining the magnetic field relative to the axis of the orbits of the spinning electrons. In such event walls **38, 41** can be made in one piece with the side walls **40, 43**, and the elements **86, 87**, respectively; thereby duants of the type illustrated in Fig. 1 are obtained, and the bottom of one or both of them can be cooled, if desired, in the manner illustrated in Fig. 7.

Figs. 8, 9 exemplify an embodiment of the invention in which the load circuit is formed by a cavity resonator e. g. of doughnut type. The operative parts of the electronic device are indicated schematically, viz. duants **36, 37** with opposite edges **45, 46**, window **44** in one of them and collector electrodes **66**. Edge **45** of duant **36** is conductively connected with an annular disc **102** and edge **46** of duant **37** is similarly connected with an annular disc **103** the outer edge of which are connected with a hollow rotation body **104** of doughnut-like shape of well conductive material the resonance frequency of which equals the high

or ultra-high frequency intended to be generated or amplified.

Disc 102 is air-tightly sealed to the enlarged portion 105 of envelope 11 within which duant 36 is arranged. This enlarged portion is conveniently made half-globular though it may be half cylindrical with flat front halves the same as 33, 34. To the outside of disc 103 another half-globular envelope portion 106 is attached. Portion 106 may be omitted if duant 37 is strong enough to maintain the high vacuum therein. Discs 102, 103 are mechanically connected and the gap 47 between them sealed by means of circular ring 107 of glass or other insulating material, and the discs are electrically connected by the cavity resonator 104.

Oscillatory energy produced in cavity resonator 104 is derived therefrom e. g. by means of magnetic coupling and coaxial line 108, 117.

Fig. 10 shows in cross section the arrangement of a device as described with reference to Figs. 8 and 9 within a magnetic field. This substantially homogeneous magnetic field is produced by a coil 109 e. g. consisting of two coaxial layers 110, 111 which are energized by source 112 of direct current in series with a variable resistor 113 and tap 114 whereby the intensity of the magnetic field within coil 109 can be finely adjusted. The device according to the invention is shown partly in section corresponding to Fig. 9 and comprising the daunts 36, 37 with gap 47 between them, the edges of which are connected by discs 102, 103 with the doughnut rotation body 104 forming a cavity resonator. Tube neck 11 with magnetic focusing device 30 and socket end 115 through which the leads for the various electrodes are introduced, are shielded against the magnetic field of coil 109 by a cylinder 116 of ferro-magnetic material.

Shield 116 as illustrated in this embodiment of the invention is a cylinder but may be of any other suitable shape and in particular encloses resonator means connected with the velocity modulation grids (not shown). Such resonator means, if used, may also form part of a magnetic shield and consequently include ferro-magnetic material where shielding action is required.

As will be shown hereinafter, in many cases only a relatively weak magnetic field is required for producing the effects of the invention. On the other hand, the magnetic field traversing the duants should be as homogeneous as possible, and therefore coil 109 completely surrounds the device and projects considerably above and below it. Assuming that the electrons are shot into the space within the duants through window 44 in the position of the device within coil 109 shown in Fig. 10, the magnetic field produced by and within coil 109 has the direction of arrows 118. The device may be protected against the influence of any outside magnetic fields such as the earth magnetic field, for instance by means of a casing 119 of ferro-magnetic material which encloses coil 109 and the device therein.

As will be evident from the theory of the invention developed hereinafter, the—usually small—strength of the magnetic field should be kept within close tolerances.

Fig. 11 shows in cross section another feature of the part of the device according to the invention in which the bunched electrons are caused to spin and energy is withdrawn from them. In order to shield beam 15 entering the space within duant 36 through window 44 against the magnetic field traversing that duant, a small hollow body 120 of magnetizable material is spacedly arranged within window 44 and projects sufficiently outside duant 36 so as to receive beam 15 at a place where there is no magnetic field; its other end 121 within duant 36 is arranged as close to gap 47 as required for the intended effect.

It will be appreciated that shield 120 can be used simultaneously as an accelerating electrode or the electrons of beam 15 and the same or even a higher positive potential applied to it than is on the duants 36, 37, by means of support 122 of body 120 which is air-tightly sealed into envelope or tube 11.

In order to increase the output of the device, in all embodiments of the invention a beam of the shape of a ribbon or blade can be developed and injected through window 44 in such a manner that its width is perpendicular to the plane of the drawing in Figs. 1, 3, 6, 8, 11, or 12; focus 32 will then designate a line perpendicular to the plane of the drawing. In such case, hollow body 120 may be given a rectangular cross section, with its larger dimension perpendicular to the plane of the drawing. With devices in which an electrode 52 is used instead of shield 120, the width of the electrode should be sufficient so as to straighten out such a ribbon- or blade-like beam.

Whatever shape of the beam is chosen, the bunched or concentrated space charges will spiral within duants 36, 37, Fig. 11, in the manner hereinbefore described; 123 indicates a mean path of bunches of electrons through the duants. The small and local distorting effect of shield 120 upon the homogeneity of the magnetic field surrounding it and thereby upon the electron orbits, can be eliminated for all practical purposes by a sufficiently large amplitude of the high frequency voltage between the duants which reduces the radii of the electron orbits to such an extent that the electrons are kept outside the slightly distorted magnetic field portion. The slight local non-homogeneity of the magnetic field close to shield 120 can also be corrected by suitable magnetic compensations. As has been previously explained herein with reference to Fig. 1, an auxiliary electrode 52 can be arranged for counteracting the magnetic field at the place where the bunched electrons are shot into the "spinning space" so as to secure a substantially perpendicular crossing of gap 47 by the entering bunched electrons. To this effect the positive potential of electrode 52 should exceed that of duant 36 by an amount sufficient to produce an electric field of proper strength. This field value must exist at the moment when a bunch of electrons enters the interior space of duant 36; at that moment the potential of duant 36 approaches its maximum. Since the negative terminal of source 55 is connected with a point on bridge 50, Fig. 1, which is symmetrically situated with respect to both duants, the value of the potential supplied by source 55 must equal the sum total of the desired compensating potential between electrode 52 and duant 36 and the instantaneous high frequency potential of duant 36 at the moment when a bunch of electrons enters the latter. By adjusting this value many desired characteristics of the tube performance can be obtained; thus, for instance, selected harmonics can be amplified or generated in preference to others, or the shape of the high frequency oscillations can be affected. On the other hand it should be understood, however, that the auxiliary electrode 52 and field produced by it, are not necessary for all performances of the invention. If the amplitude of the high frequency

potential varies greatly, as might be the case e. g. when the device is used as a high frequency amplifier, the arrangement as illustrated with reference to Fig. 12 is preferable. There the duants **36**, **37** are turned by 90 degrees relative to the neck of the tube **11** and the direction of the incoming beam **15** so that gap **47** between them is essentially parallel to that direction. Side wall **40** of duant **36** is tipped at **124** somewhat to the inside and window **125** formed at a step between the inside tipped wall portion **124** and the continuing cylindrical wall portion **40**. The velocity modulated electrons of beam **15** enter through window **125** into duant **36**, and are caused to spin along the path **126**; the overtaking of slower electrons by faster ones will be essentially completed and a space charge concentration of high density formed at point **127** corresponding substantially to point **32** in Fig. 1. The correcting field between electrode **52** and duant **36** adds to the focusing effect of the electron-optical focusing means **30** (Fig. 1) and secures a concentration of the electrons near point **127** where the bunching occurs. The just formed bunch of electrons is faced with the decelerating electric field essentially at its peak at this instant and acting across gap **47** between the juxtaposed edges **45**, **46** of the duants, the potential of edge **45** being the highest positive and the one at edge **46** being the lowest one. Hence the velocities of all the bunched electrons are decreased in passing gap **47** and they continue their spinning path in the manner hereinbefore described, and as indicated for their mean path by dot-dash line **128**.

It will be appreciated that at the moment when the electrons pass from their straight path through tube neck **11** to their bent path in Fig. 12, i. e. when they pass the electric auxiliary field between electrode **52** and duant **36**, the high frequency potential between the duants **36**, **37** is near zero and therefore the potential of duant **36** almost equals that of the middle point of bridge **50**. Thereby the potential supplied by source **55** becomes independent of the amplitude of the high frequency potential and the compensating field impressed by source **55** between electrode **52** and duant **36** will be equally effective for very wide variations of the output high frequency potential.

The theory of the invention has been indicated hereinbefore, in describing several embodiments, and may be briefly elaborated on the basis of a few mathematical considerations.

Electrons continuously emitted from the cathode **10**, Fig. 1, are accelerated to desired velocity determined by the potential difference between an accelerating electrode of highest positive potential and that of the cathode; they are also velocity modulated in well known manner and electrically and/or magnetically focused to a point, line or area of desired cross section where they periodically concentrate into bunches or space charges of relatively highest density. These bunches just formed or forming enter and are decelerated by an opposing electric field and a portion of their kinetic energy is withdrawn and converted into useful electric high frequency energy. Each bunch is also subjected to the action of a magnetic field crossing its path substantially perpendicularly and its electrons are caused to spin in circular orbits of different radii, the smaller radii corresponding to smaller individual (tangential) velocities; the angular velocity of the electrons is however always the same and hence, after a spin over 180 degrees, all the electrons of one bunch are again in phase and cross simultaneously a decelerating electric field then built up in their path. Thereby all the electrons are further decelerated and another portion of their kinetic energy is withdrawn from them a second time, but then continue their individual spin of different radii, and after a third 180 degrees spin come substantially in phase again and cross for the third time an opposing, decelerating electric field built up in their path, and so on. After the electrons have travelled twice 180 electrical degrees, they have completed one circle or cycle, and therefore recross the same opposing, decelerating electric field which they crossed once before. Hence the electrons of one bunch cross the same opposing electric field at their first, third, fifth, and so on crossing, and likewise another opposing electric field at their second, fourth, sixth, and so on, crossing. If the number of cycles thus completed within a second by a bunch is called the "frequency of rotation" of a bunch, the frequency of rotation N_r of an electron of that bunch in a magnetic field of H Gauss is given by the formula:

$$N_r=\frac{1}{2\pi}\cdot e/m\cdot H \qquad (1)$$

wherein e is the charge and m the mass of an electron.

Substituting for e/m the known value $1.77.10^7$ (EMU), I obtain

$$N_r=2.8.10^6.H \qquad (2)$$

Assume that during one rotation cycle of one bunch additional bunches are injected in odd number into the spinning space and magnetic field and enter it at the same place and at equal intervals from one another. The total number of charges entering the field until the first completed one cycle of rotation, is then represented by $(2k-1)$ wherein k is any integer number 1, 2, 3, 4, etc. The output high frequency N can then be expressed by

$$N=N_r(2k-1)=2.8.10^6(2k-1).H \qquad (3)$$

and will form an odd harmonic of the rotation frequency N_r. If, however, an even number of bunches be injected into the spinning space and magnetic field during one rotation cycle of one bunch, it can easily be seen that the effects of the successive bunches simultaneously crossing gap **47** in opposite directions would cancel each other.

For a given high frequency N, the magnetic field (in Gauss) can be calculated therefrom

$$H=\frac{3.6.10^{-7}}{2(k-1)}\cdot N \qquad (4)$$

This value should be closely adjusted by means of tap **114**, Fig. 10, or automatically in a manner as explained hereinbefore.

Applying Formula 3 to Fig. 1, it will be appreciated that for $k=1$, N equals N_r and consequently successive bunches are formed at point **32** at intervals corresponding to a period of time required by each preceding bunch to complete a full cycle or to travel over 360 degrees within the "spinning" space. In other words, electrons of a bunch b_1 which arrives first at point **32**, have completed their paths **56**, **58** and **57**, **59**, respectively to the points **129**, **130** just when the next bunch b_2 is formed at point **32**, and it will be appreciated that the electrons of the successive bunches b_1 and b_2 are decelerated in phase,

i. e. simultaneously in such a manner that their effects upon the load circuit are additive.

For $k=2$, N equals $3N_r$, which means that a subsequent bunch is formed at point **32** when a preceding bunch has completed one third of a cycle or traveled over only 120 degrees of its circular path. Applying this to Fig. 1, the electrons of a bunch b_1 formed first at point **32** travel over paths **56**, **57** and complete 120 degrees at the points **131**, **132** just when the next following bunch b_2 is formed at point **32**; bunch b_1 completes its travel for 240 degrees (from point **32**) over paths **56—58**, **57—59** at the point **164**, **165** when the electrons of bunch b_2 complete their travel for 120 degrees over paths **56**, **57** at the points **131**, **132** and a third bunch b_3 is formed at point **32**; and bunch b_1 completes 360 degrees (from point **32**) or one full cycle of rotation at the points **129**, **130** of paths **58**, **59** when bunch b_2 completes its 240 degrees' travel over paths **56—58**, **57—59** at the points **164**, **165** and bunch b_3 completes its 120 degrees travel over paths **56**, **57** at the points **131**, **132**, and a fourth bunch b_4 is formed at point **32**. Each bunch b_1, b_2, b_3, etc. crosses gap **47** twice during each of its cycles, approaching the gap the first time from the side of duant **36** and the second time from the side of duant **37**. The electric field across gap **47** changes its polarity or direction six times during one cycle of rotation of each bunch, i. e. after each 60 degrees travelled by the spinning bunches. Since the successive bunches b_1, b_2, b_3, etc. follow one another in a time interval corresponding to 120 degrees of rotation of each bunch, the direction of the electric field across gap **47** is the same when the successive bunches cross it from point **32** and thereafter at the start of any subsequent cycle, e. g. from points **129**, **130**; since each bunch re-crossing gap **47** after a travel corresponding to 180 degrees from point **32** (or points **129**, **130**), the direction of the electric field across the gap has changed the third time and is opposite to the one which prevailed when the particular bunch crossed it previously. In order to accomplish these changes in the direction of the electric field, the resonance frequency N of the load circuit **48**, **49**, **50** must be thrice the rotation frequency N_r of each bunch b_1, b_2, b_3, etc., i. e. the third harmonic $3N_r$ according to the premise.

In similar manner output frequencies N of any higher odd harmonic, e. g. the fifth, seventh, etc., of the rotation frequency N_r can be produced. In all these cases the decelerations of or energy transformations from all the successive electron bunches are in phase, and additive in the sense previously explained herein.

The radius r, in cm., of the circular path or orbit of an electron entering a magnetic field of H Gauss at a velocity of V volts equals

$$r=\frac{\sqrt{\frac{2V}{e/m}}}{H} \tag{5}$$

and substituting for e/m the known value $1.77.10^7$ I obtain

$$r=3.4.\frac{\sqrt{V}}{H} \tag{6}$$

or with Formula 4

$$r=9.5.10^6.(2k-1)\frac{\sqrt{V}}{N} \tag{7}$$

Assuming that P_0 designates the peak value of the high frequency output voltage P appearing across gap **47** between duants **36**, **37**, and that the latter are included in a resonant high frequency circuit of very low damping (high Q) then the high frequency voltage P will be sinusoidal of frequency N and therefore

$$P=P_0.\sin(2\pi.N.t) \tag{8}$$

Assuming that an electron of a concentrated charge or bunch just entering at point **32** into gap **47** between the duants **36**, **37**, Fig. 1, has a linear velocity v_1 which is decelerated or reduced to v_2 after the charge has crossed the gap against the opposing electric field instantaneously produced across the gap by the high frequency output oscillations in the tuned resonator load circuit, and considering that in this instant the peak output potential difference P_0 prevails across the gap, then

$$v_1^2-v_2^2=2e/m.P_0 \tag{9}$$

or

$$v_1^2-v_2^2=3.5.10^{15}.P_0 \tag{10}$$

The linear tangential velocity v of an electron moving at a rotation frequency N_r along its circular orbit of radius r in the magnetic field is

$$v=2\pi N_r.r \tag{11}$$

Upon substitution of (3) and (11) in (10), and transformation, one obtains

$$r_1^2-r_2^2=3.2.10^7.\frac{P_0(2k-1)}{H.N} \tag{12}$$

wherefrom with given N, H, r_1 and P_0 the consecutive reduced radii r_2, etc., of the orbit of rotation of an electron can be calculated. r_1 can be calculated from (7) under the assumption that the electron has the volt-velocity V after having crossed gap **47** the first time and entered the magnetic field, and (12) permits calculation of r_2 which is the reduced radius of the second half-cycle of rotation through the magnet field after the electron has crossed gap **47** twice; the measure in cm. of radius r_2 is to be inserted as r_1' in (12) wherefrom r_2', i. e. the more reduced radius after the third crossing of gap **47** can be calculated, and so on. The electron volt-velocity V is the difference between the initial volt-velocity of the electrons, i. e. the potential difference between the highest positive accelerating electrode and the cathode, and the amplitude P_0 of the high frequency voltage.

Referring to Fig. 13, the path of an electron the initial velocity v_1 of which at point **32** has been reduced by crossing gap **47** to v_2 (indicated by the length of the arrow), is shown. It travels a half-cycle or semi-circle around the virtual or momentary center c_2 situated on a plane through gap **47**, Fig. 1, or **163**, Fig. 13, retaining its tangential (linear) velocity v_2; the radius of its orbit is r_2. Upon re-crossing gap **47** or plane **163**, its linear velocity v_2 is reduced to v_2' and its subsequent half-cycle or semi-circle is completed at this tangential velocity around the momentary center c_3 also situated on plane **163**; the radius of its orbit is reduced to r_2'. Upon re-crossing the second time gap **47**, its linear or tangential velocity is reduced to v_2'' at which it completes its third half-cycle or semi-circle spinning around the momentary center c_4, again situated on plane **163**, at the radius r_2''. At the end of this third half-cycle this electron may be sufficiently decelerated so as to be caught by a collector electrode (such as **66**, Fig. 1), with only small residual energy and consequent little heating effect. The

velocities v_2, v_2', v_2'' and the radii r_2, r_2', r_2'' can easily be calculated from (7), (10) and (12). Each electron travels over successive half-circles at constant angular velocity while its tangential velocity is reduced at each crossing of gap **47** by a value to be calculated from (10). The areas f_2, f_2', f_2'', etc. covered by the radii r_2, r_2', r_2'', etc., respectively, during the first, second, third, etc. half-cycles equal

$$r_2^2 \cdot \frac{\pi}{2}$$

etc. and it follows with (12) that the differences between any two successive areas (f_2-f_2'), $(f_2'-f_2'')$, and so on, are constant and equal

$$f_2-f_2'=f_2'-f_2''=5.10^7 \cdot \frac{P_0(2k-1)}{H.N} \qquad (13)$$

It will be appreciated that the semi-circular areas f_2, f_2', etc. are covered by the radii within equal periods; hence this relation is similar to one of the Keppler laws of planetary motion.

If very high accelerating voltages are used, of the order of 10,000 volts or more, and the electron velocities approach the velocity of light, the increase of the mass of the moving electrons according to the relativity theory becomes of importance; if m_0 is the rest mass of the electron, the mass m of the electron moving at the velocity v becomes

$$m=\frac{m_0}{\sqrt{1-(v/c)^2}} \qquad (14)$$

This increased mass of the faster electrons results in a difference in their angular velocities and somewhat disturbs the relationship which, in the absence of this relativistic influence, would cause all electrons of a bunch to cross and recross gap **47** simultaneously. The influence will be the less, the larger P_0 is, i. e. the larger the decelerating force of the electric field is across gap **47**, and will become apparent in general only at the first few recrossings of the gap when the electron velocity is still very large. The phase difference between electrons of maximum velocity (measured in volts) and other electrons of half that velocity within a bunch will amount to only about 2% for a maximum electron velocity of 10,000 volts, and to ½% for a maximum electron velocity of 2,500 volts. Since these phase differences can appear only when the electrons of a bunch cross gap **47** a second or subsequent time and the velocities of all the electrons are considerably reduced by the previous action of the opposing or decelerating field across the gap, it will be appreciated that the effect of these slight phase differences will in general be even less and negligible for velocities up to about 10,000 volts. Should, however, this phase difference be significant, i. e. in the rather rare cases where voltages of higher order are used, these phase differences can be compensated by the use of a magnetic field the strength of which slightly increases towards the outer larger radii. Thereby a faster electron of increased effective mass which results in an increase of the radius of its orbit, will be forced back by the increased field strength into an orbit of smaller radius, and that electron which otherwise would have lagged behind arrives at the gap earlier. Thus the effect of increased orbit radius due to increased mass at very high velocities is counteracted by the slightly stronger magnetic field and compensation of the phase leg can be accomplished.

In the following, two numerical examples are calculated for the device according to the invention on the basis of the above formulae, one to yield an output frequency N of 1000 megacycles at a voltage V' of 2,500 volts (effective after the electrons crossed gap **47** the first time) and the other for an output frequency N of 10,000 megacycles at a voltage V' of 10,000 volts (effective after the electrons crossed gap **47** the first time); in other words, the effective voltage V' in each example equals the difference between the voltage V between an electrode of highest potential and the cathode, and the high frequency voltage P_0. The examples show how the same output frequency can be produced in each case as a fundamental or an odd harmonic of the rotation frequency of an electron bunch or charge within the "spinning" space of the device, and state proper values for the magnetic fields and first (or maximum) orbit radii.

Example 1

Assuming an output frequency N=1000 megacycles corresponding to a wave length of 30 cm., and a voltage of V'=2500 volts, as hereinbefore defined, then for the fundamental oscillation (k=1) and odd harmonics thereof (k=2, 3, 4, etc.) the following data are obtained:

k	Order of harmonic	H in Gauss	Radius in cm. of first orbit
1	fundamental	360	0.47
2	3	120	1.42
3	5	72	2.36
4	7	51	3.34
5	9	40	4.25

and the inner diameter of the two duants **36**, **37** together should be 10 cm. or smaller, depending upon the selected harmonic.

Example 2

Assuming an output frequency N=10,000 megacycles corresponding to wave length of 3 cm., and a voltage of V'=10,000 volts as hereinbefore defined, then the following data are obtained:

k	Order of harmonic	H in Gauss	Radius in cm. of first orbit
1	fundamental	3,600	0.095
2	3	1,200	0.284
3	5	720	0.472
4	7	510	0.666
5	9	400	0.849

and the inner diameter of the two duants **36**, **37** together should be about 3 cm. or smaller, depending upon the selected harmonic.

It has been assumed in the foregoing considerations and exemplifications of the invention that the velocity modulation voltages impressed upon electrodes or grids **23**, **24** are essentially of sinusoidal form. Thereby the initial substantially equal velocities of the electrons emerging from the emitter or cathode are varied and, as a consequence, the charge density of the electron beam or stream past the velocity modulation electrodes varies over its drift path with the distance from the electrodes. As a result, at a certain distance from the velocity modulation electrodes, bunches or charge concentrations of great density are formed in the beam or stream recurrently at the same place; in the time intervals between successive bunches or charge concentrations, a relatively very small charge density prevails. A curve representing the variations of

charge densities against time at that place of bunching will therefore comprise equi-distant sharp peaks of very short duration spaced by intervals of far larger duration in which the charge or current density is very small. These peaks of highly concentrated charge density, cross gap 47 between the duants 36, 37 and excite or induce in the latter recurrent impulses of equally short duration. As is well known in the art, the voltage variations induced by sharp impulses of this type resolved mathematically into harmonics according to a Fourier series, comprise a fundamental and a great number of higher harmonics of considerable amplitudes. If the high frequency output or load circuit is comprised, for instance, of cavity resonators of the type illustrated in Figs. 8, 9, and 16, it is of a very low damping or high Q. It can be tuned to any sharp resonance frequency N' which can equal an integer multiple k' of the velocity modulation frequency or fundamental output frequency $N=(2k-1)N_r$ considered and explained hereinbefore. Therefore the output frequency will be

$$N'=k'.N=k'(2k-1).N_r \qquad (15)$$

wherein k and k' are any integer number 1, 2, 3, etc.; k and k' may be of course the same or different integer numbers.

From the above it follows that upon excitation of the electrodes or grids 23, 24 by an input modulation frequency N, the output frequency N' can be made equal to or a selected multiple of N, and in the latter case frequency multiplication is obtained. The modulation frequency N can be derived from any desired source and, in particular, by feed-back from the output frequency N'; if the latter be a multiple of N, a selective circuit of a resonator, such as a cavity resonator should be coupled with the grids 23, 24 and tuned to the modulation frequency N. Assuming a device corresponding to Example 2, it is possible to produce therewith, by proper tuning of the load or output circuit to higher harmonics, ultra-high frequencies N' of 20,000 30,000, 40,000, etc. megacycles with a corresponding wave length respectively of 15, 10, 7.5 millimeters, etc. while the modulation frequency still equals N=10,000.

Fig. 14 shows a hollow wave guide formed by a conductive tube or pipe 133 which may be flared at 134 to form a horn radiator for directed electromagnetic waves. While the circuit connections and various sources of voltages and current for operating device 135 according to the invention are not shown (and are in essence the same as described hereinbefore more in detail), duants 36, 37 are connected by proper conductors 136, 137 and preferably adjustable taps 138, 139 with suitable points of wave guide 133 and so are the velocity modulating electrodes (grids) 23, 24 by means of conductors 140, 141 and adjustable taps 142, 143 to effect a feed-back. Any other suitable connection than shown may be used between points of the wave guide and of the electronic device, which assures proper phase relations and amplitudes for maintaining and radiating self-sustained oscillations of desired frequency determined either by proper dimensions of the wave guide and/or by tuned resonators or resonating circuits (not shown) associated with it.

Fig. 15 shows rather schematically the coupling with a radiating or receiving system of a device 144 according to the invention of a type

as exemplified in Fig. 12, and with other elements as illustrated in Fig. 1. Beam 15 is focused through window 125 e. g. by means of a magnetic focusing device 29 arranged at proper inclination. The duants 36, 37 are adjustably connected with the conductors 145, 146 pertaining to a tuned Lecher wire system and the velocity modulation electrodes 23, 24 are adjustably connected with the same conductors at other points of proper voltage-amplitude and phase relative to those prevailing at the points where the duants 36, 37 are connected. The high steady acceleration potential is preferably applied to the duants 36, 37 through conductors 145, 146 and tuning bridge 147. Conductors 145, 146 may end at their opposite ends in a radiating dipole or half-wave antenna as indicated in dotted lines by its branches 148, 149. This dipole may be arranged in or near the focus of a parabolic metallic reflector as indicated in dotted lines 150 which is large compared with the size of the dipole antenna and capable of producing an almost parallel beam of electromagnetic ultra-short waves. It is understood by anybody skilled in the art that similar means comprising high frequency guides and resonators can be used for directional reception of electromagnetic radiations; the device according to the invention in a suitable and per se known circuit and connection with the wave guides and resonators (or resonating circuits) then acts as an amplifier and/or indicator (detector or demodulator) for the received radiation and intelligence modulated upon it and impressed upon the electrodes 23, 24.

Fig. 16 shows an arrangement of a device 151 according to the invention with cavity resonators of the doughnut type 152, 153, respectively connected between the duants 36, 37 in a manner similar to that shown with reference to Fig. 8, and with the velocity modulation electrodes 23, 24. As to the latter arrangement it will be appreciated that ring-shaped conductive supports 154, 155 of the modulating electrodes 23, 24 pass and are sealed in the envelope and connected at their circular circumferences with the hollow rotation body 152. The resonators 152, 153 are tuned to the same high or ultra-high frequency and a feed-back established between them through coaxial line 156, 157. The ends 158, 159 of the inner conductor 157 project into the space of the rotation bodies 152, 153, respectively, and form therein loops for electromagnetic coupling. By properly dimensioning the conductors, the proper phase and voltage-amplitude relations can be established for an effective feed-back. The generated high or ultra-high frequency energy is derived from resonator 152, for instance by means of another coaxial line 160, 162 the end of which is coupled by loop 161 with the space of the cavity resonator. If the device is used as a frequency multiplier, or for generating an output frequency forming a harmonic of the velocity modulation frequency, the resonance frequency of resonator 158 should be the desired multiple of the resonance frequency of resonator 159.

It will be appreciated from the foregoing that the phase and voltage amplitude relations are closely dependent on the geometric dimensions of the electronic device according to the invention and various voltages applied, and particularly on the distance of point 32 or gap 47 from the electrodes or equivalent elements which effect electron velocity modulation of the beam or stream so as to provide a proper drift path for the latter.

The invention is not limited to any of the exemplifications and mathematical examples stated hereinbefore and shown in the drawings, but is to be derived in its broadest aspect from the appended claims. It is capable of many variations and modifications within the skill of the art. Consequently, it has been pointed out hereinbefore and shown that the invention can be used for generating self-sustained high or ultra-high frequency oscillations and radiations, particularly for wireless or wired wireless transmission, which can be modulated in any desired audible or other, particularly intermediate high frequency, representing e. g. intelligence of any kind including telegraph, telephone, picture signals and television to be transmitted. Those frequencies or signals (modulations) can be applied for instance by means of input modulator **17**, Fig. 1, or in any other way well known per se. The method and device according to the invention can also be used for amplification of high frequency oscillatory energy locally produced or received, and then the energy to be amplified is preferably applied to the velocity modulation electrodes; the method and device herein described can particularly be used as an amplifier and indicator (detector) or demodulator of modulated high frequency energy, and the rectified or demodulated signal currents can be derived e. g. from the collector circuit; they can also be used as frequency multiplier as hereinbefore described, and as frequency converter in heterodyne fashion.

While the collector electrode or electrodes are shown in the exemplifications of the drawings (except Fig. 7) connected with and at the same potential as the duants, it is of course possible to arranged the collector electrodes, for instance in the form of an extremely fine wire grid, within gap **47** and to support the grid by a separate holder on the same potential as the duants or on another one; in the latter event, the collector electrode and its support are to be insulated from the duants. While the duants shown are of metal, it is obvious that their main purpose is to produce equi-potential spinning spaces; therefore, if separate collector electrodes are used or if the dissipation of energy therein is small, the duants may be formed by thin conductive layers of metal, such as silver, e. g. evaporated, sputtered or chemically deposited upon the inside of the glass wall of portion **33**, Fig. 1, of the envelope and spaced from one another to form a gap **47**.

While in the foregoing reference has been made to the production of charge concentrations of electrons by means of electron velocity modulation, it should be understood that such charge concentrations or current density variations can be produced in various other manners without deviating from the gist of the invention. Thus for instance a constant velocity beam can be periodically directed into and deflected from window **44**, Fig. 1, by passing it through an alternating (electric or magnetic) deflecting field, and thereby charges injected recurrently into the "spinning space"; or a velocity modulated beam can be deflected similarly by passing it through a deflecting field of constant strength. To similar effect, the density of a constant velocity electron beam can be modulated by direct intensity modulation for instance by a grid electrode in the path of the beam. The last mentioned mode of intensity modulation will be particularly effective if beams or streams of ions are used instead of electrons for the purposes and the effects of the invention.

The method and device according to the invention is of utility for all the purposes mentioned hereinbefore though not by way of limitation, and particularly adapted for various methods of detecting, locating and range determining by means of short electromagnetic waves, as used e. g. for or on ships, airplanes, icebergs in "radar" instruments and for navigation purposes.

What I claim is:

1. An electric discharge device for producing electric oscillations, comprising substantially an envelope including two communicating spaces, an electron gun in the first of said spaces for directing an electron beam into the second of said spaces, means for modulating within said first space the velocities of the electrons of said beam to form recurrent electron concentrations within said second space at predetermined distance from said modulating means, two hollow electrodes arranged in said second space, an aperture in one of said electrodes facing said first space so that said electron beam can enter therethrough the cavity of said electrode, said electrodes arranged so that their cavities communicate and their adjacent edges are narrowly spaced to form a gap in a plane essentially perpendicular to the path of said beam, means for inducing a magnetic field of predetermined strength passing said second space and the cavities of and gap between said electrodes, said field substantially perpendicular or slightly inclined to the path of said beam and charge concentrations formed therein to cause the electrons comprised by the latter to spin in circular orbits within the space of said communicating cavities, a resonating circuit connected with said electrodes to produce across said gap an electric field component of alternating polarity, said circuit tuned to the output frequency and controlling said field component to decelerate the electrons of each concentration crossing said gap, and collecting electrodes for said decelerated electrons arranged close to or inside said gap.

2. An electric discharge device for producing electric oscillations, comprising substantially an envelope including two communicating spaces, an electron gun in the first of said spaces for directing an electron beam into the second of said spaces, means for modulating within said first space the velocities of the electrons of said beam to form recurrent electron concentrations within said second space at predetermined distance from said modulating means, means for focusing said beam at a place within said second space, two hollow electrodes arranged in said second space, an aperture in one of said electrodes facing said first space so that said electron beam can enter therethrough the cavity of said electrode, said electrodes arranged so that their cavities communicate and their opposed edges are narrowly spaced to form a gap in a plane essentially perpendicular to the path of said beam, the place at which said beam is focused close to said plane, means for inducing a magnetic field of predetermined strength passing said second space and the cavities of and gap between said electrodes and crossing the path of said beam and charge concentrations formed therein to cause the electrons comprised by the latter to spin in circular orbits within the space of said communicating cavities, a resonating circuit connected with said electrodes to produce across said gap an electric field component of alternating polarity, said circuit tuned to the output frequency and controlling said field component to decelerate the electrons of each concentration crossing said gap,

and collecting electrodes for said decelerated electrons arranged close to or inside said gap.

3. An electric discharge device for producing electric oscillations, comprising substantially an envelope including two communicating spaces, an electron gun in the first of said spaces for directing an electron beam into the second of said spaces, means for modulating within said first space the velocities of the electrons of said beam to form recurrent electron concentrations within said second space at predetermined distance from said modulating means, two hollow electrodes arranged in said second space, an aperture in one of said electrodes facing said first space so that said electron beam can enter therethrough the cavity of said electrode, said electrodes arranged so that their cavities communicate and their adjacent edges are narrowly spaced to form a gap in a plane essentially perpendicular to the path of said beam, an auxiliary electrode outside but close to said aperture and path of said beam, means for inducing a magnetic field of predetermined strength passing said second space and the cavities of and gap between said electrodes and crossing the path of said beam and charge concentrations formed therein to cause the electrons comprised by the latter to spin in circular orbits within the space of said communicating cavities, a resonating circuit connected with said electrodes to produce across said gap an electric field component of alternating polarity, said circuit tuned to the output frequency and controlling said field component to decelerate the electrons of each concentration crossing said gap, and collecting electrodes for said decelerated electrons arranged close to or inside said gap.

4. An electric discharge device for producing electric oscillations, comprising substantially an envelope including two communicating spaces, an electron gun in the first of said spaces for directing an electron beam into the second of said spaces, means for modulating within said first space the velocities of the electrons of said beam to form recurrent electron concentrations within said second space at predetermined distance from said modulating means, two hollow electrodes arranged in said second space, an aperture in one of said electrodes facing said first space so that said electron beam can enter therethrough the cavity of said electrode, said electrodes arranged so that their cavities communicate and their adjacent edges are narrowly spaced to form a gap in a plane essentially perpendicular to the path of said beam, adjustable electromagnetic means ending outside but close to the portion of said envelope enclosing said second space for producing a magnetic field of predetermined strength

passing said second space and the cavities of and gap between said electrodes and crossing the path of said beam and charge concentrations formed therein to cause the electrons comprised by the latter to spin in circular orbits within the space of said communicating cavities, a resonating circuit connected with said electrodes to produce across said gap an electric field component of alternating polarity, said circuit tuned to the output frequency and controlling said field component to decelerate the electrons of each concentration crossing said gap, and collecting electrodes for said decelerated electrons arranged close to or inside said gap.

5. An electric discharge device as described in claim 1, in which said resonating circuit is formed by a cavity resonator attached to the outer edges of a pair of spaced annular discs, each disc being connected with an edge of said hollow electrodes.

6. In an electric discharge device as described in claim 1, said means for modulating the electron velocities including a tunable circuit as exemplified by a cavity resonator and a Lecher wire system.

7. An electric discharge device as described in claim 1, in which said resonating circuit comprises a wave guide, and said means for modulating the electron velocities are coupled with said wave guide.

8. An electric discharge device as described in claim 1, in which said resonating circuit is coupled with said means for modulating the electron velocities to produce a feed-back of selected frequencies.

ADOLPH H. ROSENTHAL.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,096,817	Malter	Oct. 26, 1937
2,124,973	Fearing	July 26, 1938
2,153,190	Hollmann	Apr. 4, 1939
2,220,839	Hahn	Nov. 5, 1940
2,225,689	Demuth	Dec. 24, 1940
2,232,050	Clavier	Feb. 18, 1941
2,233,779	Fritz	Mar. 4, 1941
2,245,670	Hollmann	June 17, 1941
2,263,248	Roberts	Nov. 18, 1941
2,278,210	Morton	Mar. 31, 1941
2,281,935	Hansen	May 5, 1942
2,284,829	Ludi	June 2, 1942
2,321,723	Llewellyn	Mar. 2, 1943
2,350,907	Kroger	June 6, 1944