

Feb. 10, 1942.

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2,272,605

ELECTRIC WAVE SOURCE AND AMPLIFIER

Filed June 23, 1939

4 Sheets-Sheet 1

FIG. 1

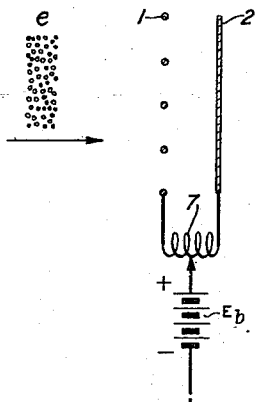


FIG. 2

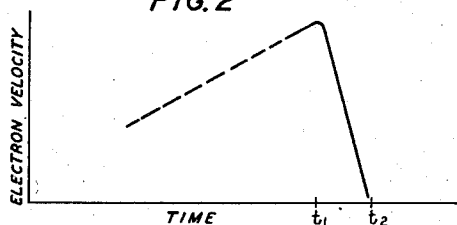
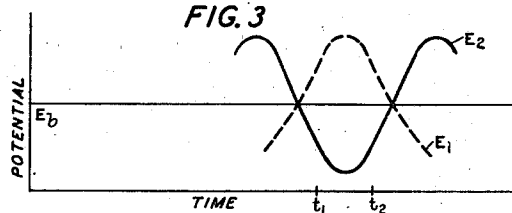


FIG. 3



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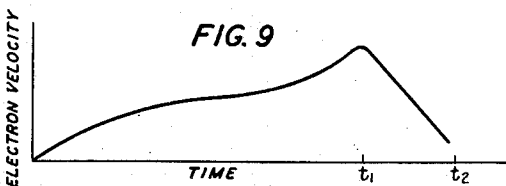
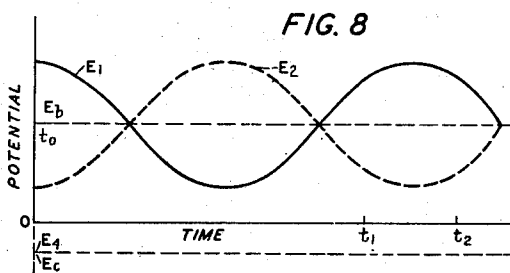
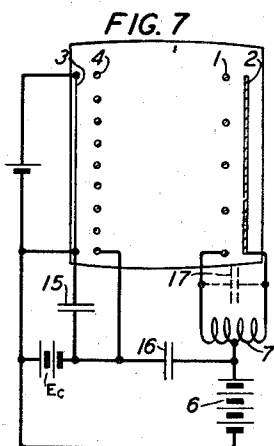
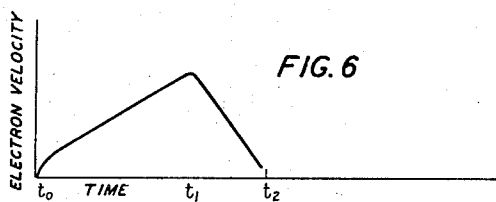
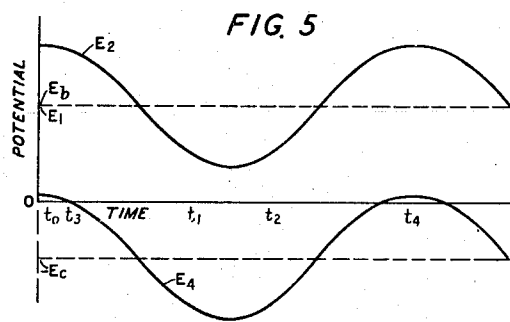
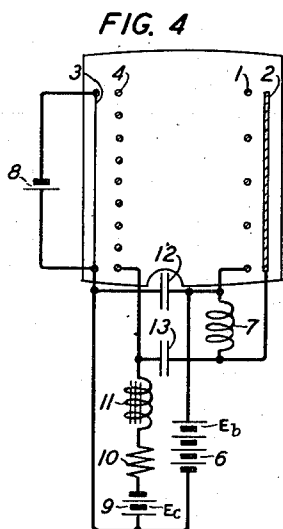
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ELECTRIC WAVE SOURCE AND AMPLIFIER

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4 Sheets-Sheet 3

FIG. 10

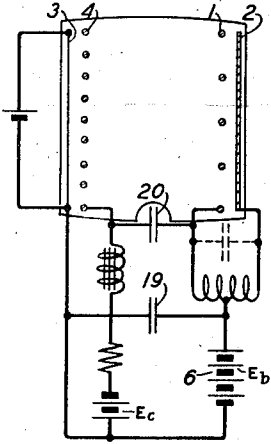


FIG. 11

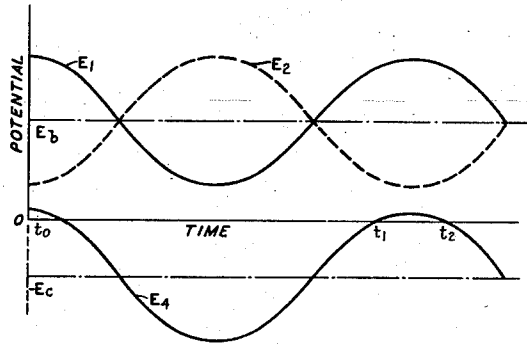


FIG. 12

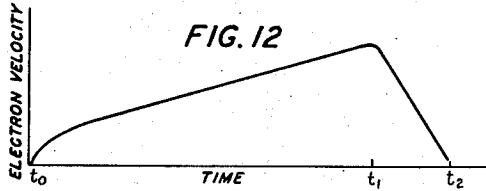


FIG. 13

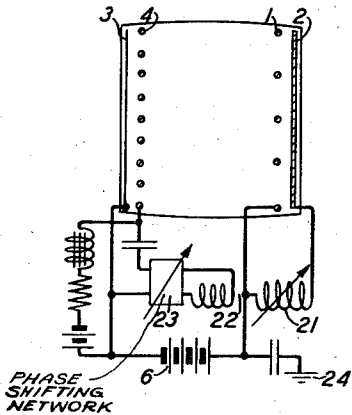


FIG. 14

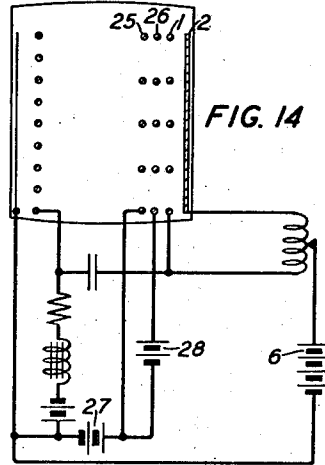


FIG. 15

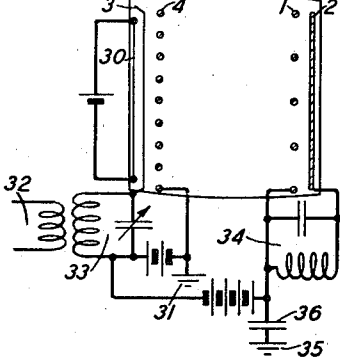
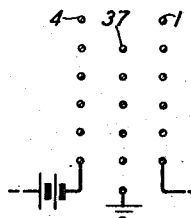


FIG. 16



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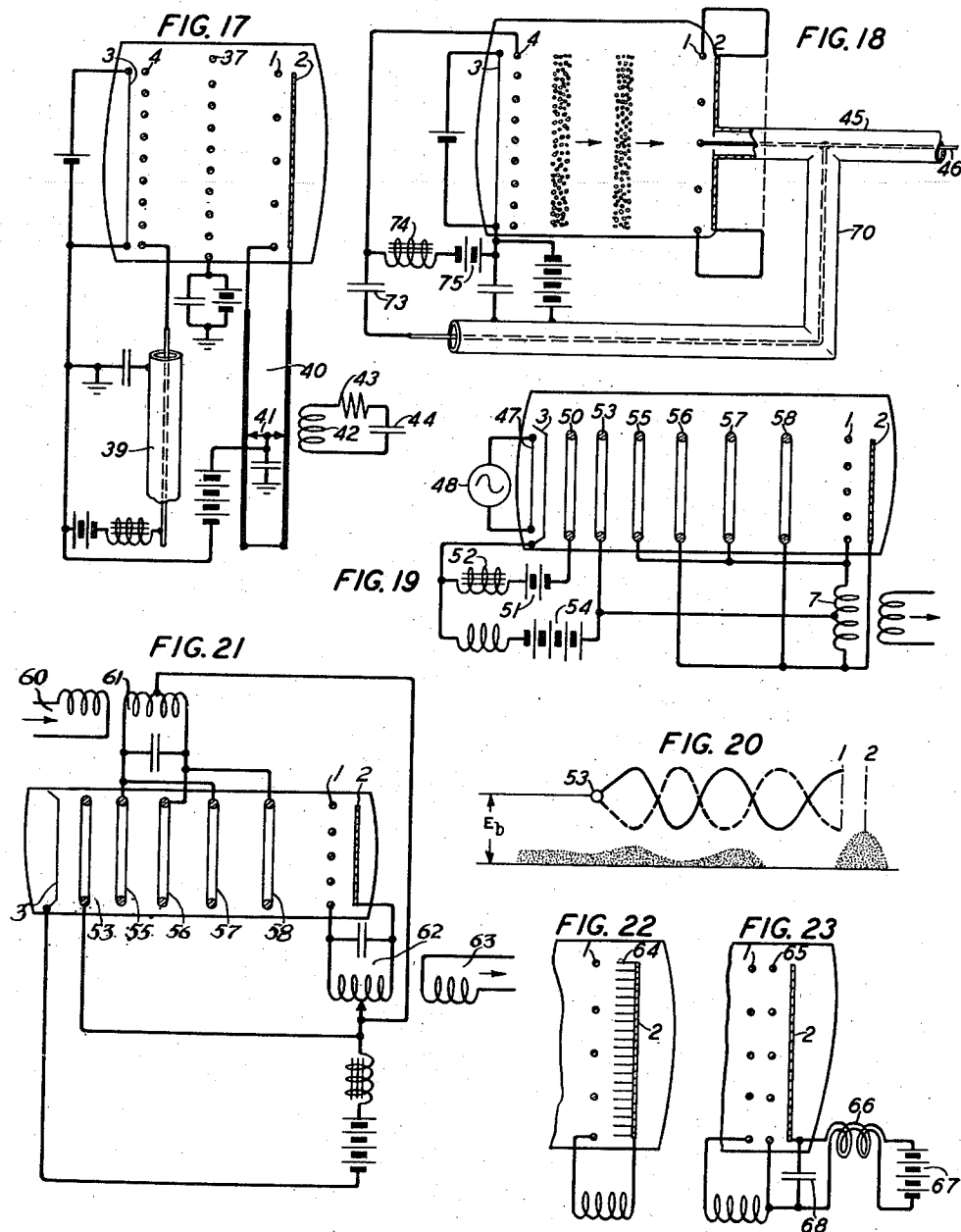
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ELECTRIC WAVE SOURCE AND AMPLIFIER

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4 Sheets-Sheet 4



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UNITED STATES PATENT OFFICE

2,272,605

ELECTRIC WAVE SOURCE AND AMPLIFIER

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Application June 23, 1939, Serial No. 280,702

13 Claims. (Cl. 250—36)

This invention relates to apparatus and techniques involved in the production, control and transmission of electrical oscillations of very high frequencies and more particularly to the field of oscillations having wave-lengths of the order of a few centimeters.

An object of the invention is to enable the production of extremely high frequency oscillations without the necessity of resorting to structures of minute dimensions and infinitesimal spacings.

A further object of the invention is to provide apparatus for production, amplification or control of very high frequency oscillations of substantial amounts of power without the limitations experienced in devices of the prior art because of the short electron travel path essential to their operation.

An additional object of the invention is to provide means for the production of periodic spurts of electrons as distinguished from the more or less continuous electron emission customarily employed.

A feature of the invention is the relatively long path of travel of electrons from their primary source to the positive electrode at which they are absorbed and the phasing of the time of their arrival with respect to the oscillating condition of the system to which they impart energy.

Another feature of the invention is the utilization of periodic pulses or spurts of electrons with intervening electronless voids to excite electromagnetic waves in an oscillation transmission system. One type of apparatus for producing periodic spurts employs an electron emission system controlled to permit emission for a short interval during each cycle but to inhibit it during the major portion of the cycle. An alternative type of device permits continuous emission from the cathode and introduces accelerating and decelerating fields at selected positions along the electron path such as to gradually convert the continuous stream into a series of spaced clouds or bunches of electrons.

In accordance with one embodiment of the invention two closely spaced conducting elements of an electron discharge device are spaced at some distance from a cooperating cathode and are provided with external tuning means connecting them to each other to form a tuned circuit. The element nearer the cathode is apertured to permit electrons to pass therethrough. Both elements are positively polarized with respect to the cathode and the apertured element

is preferably maintained at the high frequency potential of the cathode by a suitable high frequency short-circuit path connecting it to the cathode. Electron emission from the cathode may be controlled by the potential of a grid adjacent to the cathode so as to occur for a short interval during a cycle and to be inhibited during the remaining major portion of the cycle. The electron transit time is made such that a spurt of electrons arrives at the apertured element and passes into the interspace between the conducting elements at such a time as to encounter an opposing electrostatic field. The electrons are accordingly slowed down and deliver energy to the tuned circuit.

Another embodiment of the invention employs a different method of obtaining the electron spurts. According to this method the electron stream is permitted to emanate in an approximately continuous manner from the cathode and is thereafter subjected to successive velocity accelerations and decelerations along its path which have the effect of breaking up the continuous stream into grouped or bunched clouds of electrons which, as they arrive at the conducting elements, are separated by voids.

Other features and objects of the invention will be apparent from a consideration of the detailed specification taken in connection with the drawings in which:

Fig. 1 illustrates diagrammatically the output electrodes of an electric discharge device operating in accordance with the principles of the invention;

Figs. 2 and 3 are graphs showing the performance of the device of Fig. 1;

Fig. 4 is a schematic circuit of an oscillator in accordance with the invention;

Figs. 5 and 6 are graphs showing the performance of the oscillator of Fig. 4;

Fig. 7 is a circuit diagram of an oscillator utilizing a longer transit time than the device of Fig. 4;

Figs. 8 and 9 illustrate the performance of the circuit of Fig. 7;

Fig. 10 is a schematic diagram of a modified form of oscillator;

Figs. 11 and 12 are graphs which aid in explaining its operation;

Fig. 13 shows a circuit of an additional modification of the oscillator circuit in which a phase adjusting device is employed to properly time the initiations of spurts of electrons with respect to the oscillations of the high frequency output circuit;

Fig. 14 illustrates an expedient for reducing electron absorption by the apertured element of a high frequency electron discharge device of the type embodying the invention;

Fig. 15 is a schematic circuit diagram of an amplifier;

Fig. 16 is a schematic diagram of an amplifier with an alternative means for preventing feedback;

Fig. 17 discloses an amplifier circuit having a coaxial input system and a Lecher circuit associated with its output electrodes;

Fig. 18 illustrates a structure having output electrodes which serve to constitute its own resonant circuit;

Fig. 19 illustrates a modified form of oscillator in accordance with the invention in which the spurts of electrons are produced by accelerating and decelerating fields to which an original substantially continuous electron stream is subjected during transit toward the output electrodes;

Fig. 20 is a graph to facilitate explanation of the operation of the device of Fig. 19;

Fig. 21 represents an amplifying device using the electron grouping feature of the oscillator of Fig. 19; and

Figs. 22 and 23 disclose output electrode systems with devices for preventing secondary emission.

At low frequencies the transit time of an electron from the cathode past the grid to the anode of a three-element vacuum tube oscillator constitutes such a small part of the cycle that it is a relatively unimportant factor. As the frequency is raised and the time duration of a cycle grows correspondingly less a limit is reached at about 300 megacycles when attempts to still further increase the oscillation frequency cause the oscillator to stop oscillating. The immediate cause is that the transit time has now become such an appreciable part of the cycle that the ordinary circuits do not permit attainment of the proper phase relations between the voltages on the tube elements and the current between the elements.

It is often convenient to refer transit time or time of flight of an electron from its source to a given point to the period of oscillations under consideration. This may be done in terms of the transit angle, that is, the angle which corresponds to the product of the angular frequency of the oscillations under consideration and the transit time. This is explained in some detail at page 1538 of an article by F. B. Llewellyn entitled "Vacuum tube electronics" appearing in the Proceedings of the Institute of Radio Engineers for November, 1933, vol. XXI, No. 11.

Electrons which have been emitted from the cathode of an electron discharge device tend to proceed toward a positive electrode or anode with an acceleration in velocity which is a function of the potential gradient in the space between their originating cathode and the anode. In accelerating, the electrons receive energy from the electric field which is, of course, supplied by the space current source which sets up the field. If the electrons are projected into a region where the potential gradient is in the opposite direction, that is, toward a point of less positive potential, the opposing field in that region exerts a retarding action upon the electrons or, in other words, the electron gives up energy to the field and loses velocity. From a somewhat different viewpoint the moving electron or negative charge

approaching the locality of a negatively charged point tends to accumulate a still greater negative charge in that region and so to build up the already existing negative potential gradient beyond its original magnitude.

Assuming that as shown in Fig. 1 a group of electrons e is in motion toward the foraminated positively biased electrode 1 and the more remote imperforate anode electrode 2 similarly positively biased electrically. The electrons will be accelerated toward element 1 and will approach it with an increasing velocity as indicated by the upwardly inclined portion of the velocity graph of Fig. 2. At the instant t_1 when the group of electrons reaches the plane of element 1 some are absorbed but most of them pass on through its interstices with a relatively high velocity into the space between elements 1 and 2. Assume further that the tuned circuit comprising the capacitance between elements 1 and 2 and the external inductance 7 connecting them has been set into oscillation in any manner and that at the instant t_1 the foraminated element 1, is electrically positive with respect to anode 2. Under these circumstances the electrons in the interspace progress in a direction counter to that at which the field tends to accelerate them, and are accordingly retarded at the same time giving up energy to the field and augmenting its magnitude. The diagram of Fig. 2 shows how the electron velocity rapidly falls in the course of this process so that as an electron approaches closely to element 2 at instant t_2 it has lost most of its energy. Fig. 3 shows the resulting potentials E_1 and E_2 respectively of elements 1 and 2 as the oscillating potentials of these elements rise and fall about their normal positive bias potential E_b . It accordingly appears that if groups of electrons be shot through the electrode at each cycle at instants when element 1 is positive, oscillations of the natural frequency of the circuit 1, 2, 7 may be obtained. The ultimate source of oscillation energy is, of course, the source E_b by which the electrons are caused to attain a high kinetic or velocity energy which may be converted to oscillatory energy by the reaction of these fast moving electrons on the opposing electrostatic field of the interspace between electrodes 1 and 2.

Fig. 4 with its explanatory diagrams of Figs. 5 and 6 illustrates an alternative system for producing oscillations in accordance with the principles which have been outlined. Foraminated electrode 1 and anode 2 are positively biased with respect to cathode 3 by a source 6. The inter-electrode capacitance of elements 1 and 2 and the external inductance 7 determine the natural oscillation frequency of the circuit 1, 2, 7. Cathode 3 may be energized in any well-known manner and as illustrated is directly heated by current from a source 8 of heating current. Closely adjacent the cathode is a control grid 4 which is maintained biased by a source 9 to an average negative potential E_c with respect to the cathode of such magnitude as to normally inhibit flow of electrons from the cathode. In the bias circuit for grid 4 are a resistance 10 and an inductance 11 to prevent transmission of oscillation frequency currents over the bias path. Cathode 3 is connected to electrode 1 by a capacity element 12 of such magnitude as to serve as a path of negligible impedance at the oscillation frequency so that at that frequency cathode 3 will partake of the same potential variations as electrode 1. Similarly the grid 4 and the anode

2 are connected by a capacity element 13 so that no high frequency variations of potential will exist between them. Under these circumstances with the potential of cathode 3 taken as zero the potential E_1 of element 1 which is connected to the cathode by the high frequency short-circuiting path of capacity 12 will remain constant at the positive magnitude E_b . Oscillations in circuit 1, 2, 7 will cause the potential E_2 of anode 2 to alternatively rise above and fall below that of E_1 as indicated in Fig. 5. Similarly the potential E_4 of grid 4 which is constrained by the short-circuit path through capacity element 13 to follow the potential E_2 will rise and fall with an instantaneous magnitude which is always below that of E_2 by an amount equal to the sum of the space current and grid bias potentials E_b and E_c .

The magnitudes of the biasing sources are so related that during each cycle there are intervals of electron flow as, for example, from t_0 to t_3 when the potential of grid 4 is positive and again in the interval centering at instant t_4 . If the group of electrons emitted at time t_0 is accelerated by the electric field as indicated in Fig. 6 it will reach element 1 and pass through it at an instant t_1 , the interval between t_0 and t_1 , that is, the transit time required for electrons from cathode to reach electrode 1, depending upon a number of factors including the magnitude of the accelerating potential E_b and the distance between cathode 3 and electrode 1. Assume that the various magnitudes entering into the transit time have been so chosen and that the structure of the discharge device has been so pre-designed that the electrode 2 which at the instant of emission of the group of electrons under consideration was at a potential positive with respect to electrode 1 as indicated at t_0 in Fig. 5 has undergone a substantially 180 degree change so as now to be negative with respect to E_1 as indicated at t_1 in Fig. 5. The group of electrons passing electrode 1 will encounter in the interspace between electrodes 1 and 2 a field opposing their progress and they will be retarded and will give up energy to that field as in the case of Fig. 1. Fig. 6 shows how the velocity of the electrons rapidly falls from t_1 to t_2 so that at the latter instant little energy remains to be dissipated as the decelerated slow moving electrons impact upon the anode 2. It will, therefore, be appreciated that once in each cycle a group of electrons is released from the cathode and that at approximately three-eighths cycle to one-half cycle later that group of electrons delivers up its energy to the circuit associated with the electrodes 1 and 2.

Fig. 7 illustrates a somewhat different system in which the spacing of electrodes 1 and 2 with respect to electrodes 3 and 4 is altered and in which the electrodes are related in a different manner in so far as high frequency potentials are concerned. Capacitances 15 and 16 connect cathode 3 and the positive terminal of source 6 to grid 4 thus holding these three points at fixed high frequency potentials. The potentials E_1 and E_2 , respectively, of the electrodes 1 and 2 rise and fall with respect to the positive terminal of source 6 as indicated in Fig. 8. At the instant t_0 , E_1 is at a maximum positive potential which exceeds μE_c where μ is the mutual conductance of the discharge device. Consequently a group of electrons is released in the interval from t_0 to t_3 and it proceeds toward electrode 1 with accelerating velocity as indi-

cated in Fig. 9. It is desired that the electron group enter the interspace 1, 2, that is, pass electrode 1 at an instant t_1 when there is an opposing or counter electromotive force between electrodes 1 and 2 so that electrode 1 will be at the higher potential. This condition may be attained by making the transit time elapsing between t_0 and t_1 about seven-eighths cycle, that is, approximately equal to a cycle. It will be noted from the velocity graph in Fig. 9 that the electrons are accelerated throughout their transit from the cathode to electrode 1 but that the acceleration decreases during the period in which the potential E_1 is rapidly falling. Accordingly the velocity graph of Fig. 9 undergoes a rapid rise in its early portion with an intermediate zone of little acceleration and a final portion during which the acceleration is again high as the potential E_1 rapidly rises. As the group of electrons passes electrode 1 and begins to deliver energy to the circuit 1, 2, 7, another group of electrons will be released at the cathode. Thus, the oscillating action continues with groups of electrons spaced apart one cycle in transit time successively impulsing the circuit 1, 2, 7 with its inherent capacity 17.

Fig. 10 illustrates another modification in which the cathode 3 is connected by a low impedance path through capacitance 19 to the positive terminal of space current source 6 while the control grid 4 is connected by a low impedance path through capacity 20 to electrode 1. As shown in Fig. 11 the potentials E_1 and E_2 will alternately rise and fall about the potential of the positive terminal of source 6 and the potential of the grid 4 will partake of the same variations as that of electrode 1 but will be lower by an amount equal to the sum of the space current potential E_b and the grid bias potential E_c . With this arrangement the group of electrons leaving the cathode at t_0 is assisted by the slightly positive potential of the control grid 4 while at other times the much lower potential of the grid is exerted toward inhibiting emission of the electrons. Accordingly a somewhat better electron grouping or discrimination between periods of electron emission and no emission may be secured. As in the circuit of Fig. 7 the spacing of the electrodes and the design of the various elements of the structure together with the potentials of the space charge and biasing sources should be such that the transit time between the cathode and the electrode 1 will be about seven-eighths cycle. The approximate velocity relations of the electrons are indicated in Fig. 12.

The systems which have been described embody a considerable improvement over prior electron discharge devices in that the spacings between the cathode and the elements 1 and 2 may be relatively very large. For instance, with an anode potential of 100 volts and with an operating frequency of 300 megacycles an electron leaving the cathode of Fig. 7 or Fig. 10 at t_0 will travel over one centimeter in one cycle so that elements 1 and 2 should be located at a distance from the cathode 3 of the order of one centimeter. This is a much greater distance than that which is required in electron discharge devices of the ordinary types to operate at the frequency and voltage specified. With an anode potential of 400 volts, other conditions being the same, the electrons will travel over two centimeters in one cycle, which is a prodigiously large dimension compared to that obtaining in

standard electron discharge practice for this frequency. These dimensions will be reduced in proportion to the wave-length so that at a frequency of 1200 megacycles, that is, a wave-length of 25 centimeters, in an electron discharge device operating with an anode potential of 400 volts, the spacing between the cathode and the electrodes 1, 2 may be of the order of one-half centimeter.

In the apparatus and circuits thus far described the transit time or time of flight of an electron from the cathode to electrode 1 for the greatest efficiency is a function of the anode potential and of the operating frequency. If the major number of electrons arrives before the instant t_1 or after the instant t_2 the efficiency will be greatly reduced. If they arrive too much before or too much later than these instants, oscillations will not occur.

Fig. 13 represents a generalized circuit schematic whereby a particular structure may be utilized for variable potentials and variable frequencies. In that structure the elements 1 and 2 are associated with a suitable external circuit such as the inductance 21 illustrated. Feedback from the external circuit to the circuit of the cathode 3 and grid 4 may be effected by feedback path including the transformer 22 and the variable phase shifting network or transmission line 23 so as to produce proper phase timing of electrons emitted at the cathode. Viewed from a somewhat different angle the transit time of electrons passing from the cathode 3 to the plane of electrode 1 may be made different from that which has been described in connection with the previous systems and the difference may be compensated for by the phase shift which occurs in the device 23. Of course, the elements 1 and 2 should be placed as close together as convenient for the reason that in this system as in all the preceding systems which have been discussed, the energy delivered up from the electrons to the oscillatory circuit is delivered in the interspace 1, 2 and the shorter the time in which this exchange of energy may occur the shorter the half cycle of the operating frequency may be. In all these systems it is also quite desirable to place the control electrode 4 close to the cathode since a considerable part of the cycle is utilized for the electrons to attain sufficient velocity to pass the control electrode 4. In order to prevent feedback in the circuit of Fig. 13 except through the feedback circuit 22, 23, element 1 may be connected to earth through a large blocking condenser as indicated at 24. As an alternative the electrode 4 may be directly connected to earth at its lower terminal.

Since in each of the systems described the electrons which perform the useful work pass through interstices of electrode 1, it is desirable to give that electrode such configuration that it may be passed through by as many electrons as possible with as few as possible intercepted by it. The electrode 1 may, therefore, be formed as a plane grid or the electrodes may all be arranged in the conventional concentric manner in which electrode 1 will have an annular or cylindrical conformation. To prevent interception of electrons by the electrode 1 a system of focussing or guiding of the electrons may be utilized in each of the systems which has been illustrated. Such a device, as shown in Fig. 14, may comprise one or more additional grids 25 and 26, the former of which is biased by a source 27 to a slightly lower potential than that of the source 6, and

the latter of which is biased by a focussing source of low potential 28 to a potential between the potentials of elements 25 and 1. With this feature the conductors of the grid 25 which are aligned with those of element 1 will intercept and dissipate the energy of electrons which would otherwise be directly incident upon the conductors of electrode 1. Such electrons as are not intercepted by the grid 25 will be slightly deflected by the field adjacent to grids 25 and 26 but between 25 and 26, and between 26 and electrode 1 from paths incident upon the conductors of electrode 1 so as to pass between those conductors. It will be understood that in other respects the systems of the preceding figures will be unaffected by the introduction of the electron intercepting and focussing feature of Fig. 14.

Fig. 15 is a schematic of an amplifying system in which the unipotential cathode 3 is heated by a heater element 30. As illustrated, the control grid 4 is connected to earth at 31 but in lieu of this the cathode 3 may be directly grounded if desired. The electromotive force of the wave to be amplified is impressed by a circuit 32 which is inductively coupled to the tuned circuit 33 connected between cathode 3 and control grid 4. The groups of electrons from the cathode move across to the electrodes 1 and 2 and deliver energy to the circuit 34 as will be readily understood. The effect of the impressed input electromotive forces is to change the magnitude of the emitted groups of electrons. Consequently the energy transferred to the circuit 34 will accordingly vary and its amplitude will be greatly increased by virtue of the kinetic electron velocity energy which has been introduced into the oscillating system during the process. In order to prevent feedback the control electrode 4 is grounded at 31 as described and the foraminate output electrode 1 may also be connected to ground at 35 through a capacitance 36 which is of negligible impedance at the frequency of oscillations to be amplified.

As an alternative device for preventing feedback in a system of the type disclosed in Fig. 15 the electrodes 4 and 1 may be left ungrounded as shown in Fig. 16 in which a grounded shielding electrode 37 is interposed between electrodes 4 and 1. The shield 37 should have its conducting elements preferably so placed as to lie between the individual beams issuing from the interstices of control electrode 4 so that it will intercept as few electrons as possible. This may be effected by placing the conductors of the element 37 in alignment with those of the control grid 4 in the direction of travel of electrons. Its potential should be maintained between those of elements 4 and 1.

Fig. 17 illustrates a modification of the amplifier, Fig. 15, in which the tuned circuit 33 is replaced by the coaxial input line 39 and the tuned output circuit 34 is replaced by the Lecher circuit 40 with its slidable tuning device 41. A load circuit 42 of any type indicated in a generalized fashion by resistance 43 and capacity 44 may be associated with the Lecher output circuit. The apparatus of this device is provided with a grounded shield 37 maintained at a suitable potential to prevent undesired feedback from the output to the input circuit.

In lieu of the parallel plane configurations of elements 1 and 2 or of the alternative concentric cylindrical configurations of these elements the two may be designed to constitute together a resonant enclosed tank as indicated in cross-section

tion in Fig. 18. The external circuit connected to the tank may comprise a high impedance coaxial output line having an outer conductor 45 connected to the anode 2 and a central inner conductor 46 passing through an opening in the anode 2 to a point in the electrode 1. In order to control the phasing of the emission of clouds of electrons a feedback path is provided comprising a coaxial conductor 70 of suitable length leading back and connecting to elements 3 and 4 through stopping condenser 73. A bias choke coil 74 and biasing source 75 are connected directly between the cathode and grid to apply a proper polarizing potential thereto whereby in the absence of oscillating electromotive forces electron emission from the cathode is substantially inhibited. It is to be understood that the circuits of Figs. 1, 4, 7, 10, 13, 14, 15, 16 and 17 as well as of the systems remaining to be described may be deemed to embody such a closed container type of resonant tank circuit as is shown in Fig. 18. Obviously in lieu of the coaxial line output connection a loop coupling element such as that of the secondary of the transformer associated with output line 42 of Fig. 17 may be introduced within the tank circuit to couple in the output circuit.

An electron discharge apparatus of quite different form for producing electron groupings in the proper time phase is illustrated in Fig. 19. The electrons are emitted by a cathode 3 which may be of a hot wire or of a plane sheet form as desired, and which is heated by the heater 47 connected to a source 48 of heating current. The output electrodes 1 and 2 may similarly designate output electrodes like those of the systems which have already been described. A grid or ring-shaped electrode 50 closely adjacent the cathode and biased negatively with respect thereto by a source 51 in series with the high frequency choke coil 52 serves with a similarly shaped accelerating electrode 53 which is polarized positively by the source 54, to focus electrons from the cathode 3 and project them at high velocity through one or more intermediate electrodes such as 55, 56, 57 and 58 to the output electrodes 1 and 2. Intermediate electrodes 55, 56, 57 and 58 are spaced along the path of electron movement at intervals which correspond to half cycle transit times, the last intermediate electrode being spaced at a half cycle transit time distance from a plane in the interspace 1, 2 just in front of the anode 2 or proper odd or even multiple of such half cycle transit time distance depending upon polarity connection to the output circuit. In the operation of this system a steady stream of electrons leaving the cathode 3 passing through the focussing element 50 and the accelerator 53 will during one half cycle as indicated in Fig. 20, find that electrodes 55 and 57 have potentials which are elevated above that of electrode 53 and electrodes 56 and 58 will have decreased potentials below that of electrode 53. The potential gradient between electrode 55 and its neighboring electrodes will accelerate electrons approaching it and retard those which have passed it. Similarly the elevated potential on electrode 57 will accelerate electrons between 56 and 57 and retard those which have passed 57 on their way to electrode 58. During the next half cycle of oscillations in the circuit 1, 2, 7, the reversal of potentials on electrodes 55 to 58, inclusive, will be such as to accentuate the bunching or grouping of the electrons so that

ultimately the major part of the electrons will be gathered in groups each falling within a half cycle transit time distance and separated by substantially electronless voids of equal duration as is indicated by the group of electrons in the neighborhood of electrodes 1 and 2 in Fig. 20. It will, of course, be understood that the spacings between the electrodes 1 and 2 and that between these two electrodes and the elements 55, 56, 57 and 58 must be in accord with the principles which have been disclosed in order that the groups of electrons may arrive at electrode 1 at such time as to yield their energy to the opposing field between electrodes 1 and 2.

Fig. 21 discloses the manner in which the structure of Fig. 19 may be employed as an amplifier. To simplify the drawings the cathode 3 and the accelerator electrode 53 are shown, the various biasing and accelerating external circuits, the focussing grid and the cathode heating source being omitted. As illustrated in Fig. 21 an incoming line or antenna 60 may be inductively coupled with the tuned input circuit 61 which is connected between electrodes 55 to 58, inclusive, in the manner shown. An accelerating electrode 53 is connected as in Fig. 19 to power supply source of the output electrodes 1 and 2. The tuned output circuit 62 is inductively coupled to an outgoing line 63. The variable alternating potential impressed on the electrodes 55 to 58 will cause bunching of the electrons in proportion to the amplitude of the incoming high frequency wave and there will, therefore, be delivered to the output electrode system 1, 2, and to the resonant circuit 62 and the load circuit 63 coupled therewith, amplified high frequency energy in proportion to the bunching which occurred within the discharge device.

Fig. 22 illustrates an expedient to inhibit emission of secondary electrons by the anode 2. The anode may be constructed of carbon or of carbonized metals. As an additional precaution against secondary electron emission, element 2 may be provided with conductor strips 64 parallel to the direction of motion of the incident electrons. Accordingly most of the secondary electrons emitted will be intercepted by the strips 64 and will be absorbed.

An alternative expedient as illustrated in Fig. 23 is to provide the anode 2 with a supplemental grid-like structure 65 placed in front of it in such a manner as to catch secondary electrons emitted from the anode 2. The grid 65 and the anode 2 may be connected directly together or they may be connected as shown in Fig. 23 through a bifilar choke coil 66 and a biasing source 67 which renders the grid 65 slightly negative with respect to the anode 2. In this circuit a large capacity connecting anode 2 and grid 65 maintains them at relatively fixed high frequency potentials with respect to each other.

It will, of course, be understood that the expedients of Figs. 22 and 23 may be employed in any of the systems shown.

It is to be understood that when the tubes are constructed with plane shaped elements, and electron flow desired to be one dimensional as indicated in the figures, a longitudinal magnetic field may be employed together with focussing or electron directing methods described, or in lieu of them to guide the electrons along the desired path. It is also to be understood that the elements may be cylindrical in shape, with the cathode at the center, or any other suitable

shape, in which case electron flow will occur in two or more dimensions.

With respect to certain aspects of the invention this application is a continuation in part of the subject-matter of an application of R. A. Heising Serial No. 93,546, filed July 31, 1936, which was issued May 7, 1940 as United States Patent 2,200,063.

What is claimed is:

1. An electron discharge device comprising a cathode, a pair of conducting elements widely separated therefrom but closely spaced with respect to each other, the element nearest the cathode being apertured, a resonant electrical system connected to the conducting elements, means for polarizing the elements positively with respect to the cathode, means controlled by the resonant system for causing electrons emanating from the cathode to arrive at the apertured positive element in periodic spurts at times when the electrostatic field in the interspace between the conducting elements occasioned by oscillations in the resonant system is directed to oppose electrons proceeding from the cathode, the spurts being separated by intervals of substantially no electron flow, the frequency of the resonant system and the velocity of the electrons upon arrival at the apertured element being so related that during the entire transit of the electrons between the pair of conducting elements, the electrostatic field of the interspace between the conducting elements abstracts energy from the electrons.

2. An electron discharge device comprising a cathode, a pair of elements at some distance from said cathode and closely spaced with respect to each other, means for causing electrons to be radiated from the cathode in periodic spurts with intervening spaces during which relatively few electrons are radiated, a high frequency external path of negligible impedance connecting the cathode to the nearer element which is apertured to fix the timing of emission of electron spurts, an oscillation path connected between the two elements, a source of unidirectional polarizing potential connected to the cathode and to the two elements through the oscillation path to render both elements positive with respect to the cathode, the spacing between the cathode and the elements being such and the timing of the electron spurts from the cathode being so related to the oscillations in the high frequency external path that a spurt of electrons from the cathode reaches the elements in a transit time such that the electrons after passing the first element traverse the interspace between the two elements in opposition to the electrostatic field gradient therein and accordingly deliver up energy to the system comprising the two elements and the oscillation path.

3. An electron discharge device comprising a cathode, a pair of elements in the path of electrons from said cathode and closely spaced with respect to each other, means for causing electrons to be emitted from the cathode in periodic spurts with intervening spaces during which relatively few electrons are emitted, an external path connecting the cathode to the nearer element which is apertured, the path having negligible impedance at a desired operating frequency to enable the potential of the apertured element to regulate the electron spurt emission instants at the cathode, an oscillation path connected between the two elements, a source of unidirectional polarizing potential connected to the cathode and to the two elements through the oscillation path to ren-

der both positive with respect to the cathode, the spacing between the cathode and the elements being such and the emission instants of the electrons being so controlled that a spurt of electrons from the cathode reaches the elements in a transit time such that the electrons after passing the first element traverse the interspace between the two elements in opposition to the electrostatic field therein and accordingly deliver up energy to the oscillating system comprising the two elements and the oscillation path.

4. A wave transmission system including an electron discharge device comprising a source of electrons, means for causing the source to emit electrons in groups separated by spaces at the periodicity of a wave which the system is designed to transmit, two electrodes positively polarized with respect to the source of electrons and located at respectively different distances therefrom, the electrode nearer the source being foraminant, and means for impressing between the two electrodes an alternating electromotive force to set up an electric field, the electromotive force being so phased that at the instants of incidence of each group of electrons upon the foraminant electrode that electrode is positive with respect to the more remote electrode whereby in passing from the locality of the foraminant electrode toward the other electrode the electrons yield energy to the field and the velocity of the electrons upon incidence at the foraminant electrode being so related to the frequency of the oscillations produced that their time of transit between the foraminant electrode and the other positive electrode is less than a half cycle of the oscillations.

5. An electron discharge apparatus comprising in combination a thermionic cathode, a control electrode adjacent thereto, two positive electrodes toward which the electrons from the cathode are projected in groups, means for polarizing the positive electrodes to positive potentials with respect to the cathode and for polarizing the control electrode to such a normal negative potential with respect to the cathode as normally to prevent transmission of electrons from the cathode toward the positive electrodes, the positive electrodes being located at different distances from the cathode and the nearer positive electrode being apertured to permit electrons to pass there-through into the space between the positive electrodes, means for electrically connecting the positive electrodes to constitute therewith an oscillation circuit, and a path of negligible impedance at the oscillation circuit frequency connecting the apertured electrode to the cathode to cause the potential of the cathode to rise and fall with respect to the potential of the control grid in consonance with oscillations of the oscillation circuit to permit groups of electrons to be transmitted cyclically from the cathode toward the positive electrodes at instants when the potential control grid is most positive with respect to the cathode, the magnitude of the polarizing potential on the positive electrodes and the space between the cathode and the positive electrodes being such that the transit time for electrons passing from the cathode to the nearer positive electrode enables the electrons to pass through said nearer electrode and to react with the electromagnetic field between the positive electrodes only during intervals in which the field opposes transit of the electrons and accordingly abstracts energy therefrom.

6. A wave transmission system including an electron discharge device having a thermionic cathode, a control electrode adjacent thereto to assist in breaking up the continuous stream of electrons emitted from the cathode into separated groups, a pair of positive electrodes toward which the groups of electrons are projected, one of the positive electrodes being apertured and located nearer to the cathode than the other to permit electrons to pass therethrough into the space between the two electrodes, means electrically connecting the positive electrodes to constitute therewith an oscillation circuit, a path of negligible impedance at the oscillation circuit frequency connecting a point of the oscillation circuit to the cathode to impress upon the cathode with respect to the control electrode potentials which rise and fall in consonance with oscillations of the oscillation circuit and means for impressing positive potentials upon the positive electrodes with respect to the cathode, the magnitude of said potentials being so related to the distance between the cathode and the positive electrodes that a group of electrons passing from the cathode reaches and passes through the nearer positive electrode at such a time interval after its emission from the cathode that the electromagnetic field between the two positive electrodes opposes electrons in their transit and abstracts energy therefrom.

7. A wave transmission system including an electron discharge device having a thermionic cathode, a control electrode adjacent thereto to assist in breaking up the continuous stream of electrons emitted from the cathode into separated groups, a pair of positive electrodes toward which the groups of electrons are projected, one of the positive electrodes being apertured and located nearer to the cathode than the other to permit electrons to pass therethrough into the space between the two electrodes, means electrically connecting the positive electrodes to constitute therewith an oscillation circuit, means to impress upon the positive electrodes potentials of such magnitude with respect to that of the cathode and with respect to the spacing between the cathode and the positive electrodes that a group of electrons emitted from the cathode will pass through the apertured positive electrode into the space between the two positive electrodes during an interval in which the apertured electrode is at a positive potential with respect to the other positive electrode so that the electrons may yield energy to the opposing electromagnetic field between the positive electrodes and a path of negligible impedance at the oscillation circuit frequency connecting an intermediate point in the oscillation circuit to the control electrode to make the potential of the control electrode sufficiently more positive for a small portion of the cycle to enable a group of electrons to be projected from the cathode.

8. A wave transmission system including an electron discharge device having a thermionic cathode, a control electrode adjacent thereto to assist in breaking up the continuous stream of electrons emitted from the cathode into separated groups, a pair of positive electrodes toward which the groups of electrons are projected, one of the positive electrodes being apertured and located nearer to the cathode than the other to permit electrons to pass therethrough into the space between the two electrodes, means electrically connecting the positive electrodes to constitute therewith an oscillation circuit, means to

impress upon the positive electrodes potentials of such magnitude with respect to that of the cathode and with respect to the spacing between the cathode and the positive electrodes that a group of electrons emitted from the cathode will pass through the apertured positive electrode into the space between the two positive electrodes during an interval in which the apertured electrode is at a positive potential with respect to the other positive electrode so that the electrons may yield energy to the opposing electromagnetic field between the positive electrodes, and a path of negligible impedance at the oscillation circuit frequency connecting the cathode to the control electrode to make the potential of the control electrode sufficiently more positive for a small portion of the cycle of the natural frequency of the oscillation circuit to enable a group of electrons to be projected from the cathode.

9. An electron discharge device including a foraminate electrode and a substantially imperforate electrode parallel to the foraminate electrode and substantially as close as possible thereto, a source of electrons for projecting groups of electrons at intervals corresponding to the cycle time of oscillations to be transmitted, the direction of propagation of the electrons being such as to cause them to pass through the foraminate electrode toward the other electrode and their time of emission being so controlled that incidence of a group of electrons in the general plane of the foraminate electrode occurs when that electrode is at an oscillation potential which is positive with respect to that of the other electrode, a polarizing source for impressing upon the imperforate electrode a potential which is positive with respect to that of the source of electrons and of such magnitude with respect to the length of the space path between the source of electrons and the foraminate electrode that a projected group of electrons from the source requires a substantial portion of a cycle to reach the foraminate electrode, a circuit resonant at the frequency of the oscillations to be transmitted connected between the foraminate electrode and the adjacent electrode, means controlled by the resonant circuit for causing the source of electrons to project groups of electrons at correct intervals and to inhibit transmission of electrons during the remaining portion of the cycle whereby passage of electrons through the foraminate electrode and toward the imperforate electrode is always attended with an opposing electric field between said two electrodes to which the electrons yield energy.

10. An electron discharge apparatus, an electron emitting source, a screen electrode, means making the potential of said screen electrode positive with respect to said source, means comprising a high frequency input circuit for causing electrons leaving said electron source to arrive at said screen electrode in groups, an output electrode beyond said screen electrode but placed very closely with respect thereto, means making the potential of said output electrode positive with respect to said electron source, an output oscillation circuit including said screen electrode and said output electrode and resonant at the frequency of desired input oscillations, the separation of the screen electrode and output electrode from the electron emitting source being such that with the positive polarizing potential applied to the output electrode the transit angle for electrons between the cathode and screen

electrode is sufficiently great to cause the electron groups to arrive at the screen electrode at instants of the high frequency cycle at which oscillations in the output circuit render the screen electrode positive with respect to the output electrode whereby after passing through the screen electrode and while moving across to the output electrode the electrons of each group react against the counter field between the screen and output electrode to deliver power to the load circuit, the transit time for electrons passing from the screen electrode to the output electrode being less than a half cycle of the output oscillation frequency.

11. In electron discharge apparatus, a source of electrons, a screen electrode spaced therefrom, an output electrode beyond said screen electrode and closely spaced therefrom, means making said screen electrode positive relative to said source of electrons, an oscillatory load circuit included between said screen electrode and output electrode resonant at the frequency of desired oscillations and a high frequency input circuit including an electrode adjacent the path of travel of electrons from said source of electrons toward said screen electrodes for causing said electrons to arrive at said screen electrode in groups, the separation of the screen electrode from the cathode being such that the transit angle for electrons from the cathode to the screen electrode is of the value required to cause the groups of electrons to reach the screen electrode when that electrode is at a positive portion of its oscillatory load circuit potential cycle with respect to the output electrode whereby the electrons proceeding in the interspace between the screen electrode and the output electrode encounter an opposing electrostatic field and deliver energy thereto and the transit angle for electrons to pass from the screen electrode to the output electrode being less than a half cycle of the oscillatory load circuit oscillations.

12. In electron apparatus in the order named, a source of electrons, electrode means adapted to be controlled by high frequency potentials for causing electrodes to pass in groups, a space traversed by said groups of electrons, a screen electrode and an output electrode closely spaced

therefrom, means for impressing a positive potential on said screen electrode and said output electrode with respect to said cathode, a tuned load circuit connected between said output electrode and said screen electrode, and means for maintaining the positive potentials on the screen electrode and output electrode of such magnitude that the time of electron transit from the source to the output electrode is correct to cause the electrons to pass through the screen electrode during the time when the tuned load circuit oscillation makes the screen electrode positive with respect to the output electrode whereby the electrons deliver energy to the field between the screen electrode and the output electrode.

13. In an electron discharge device, a source of electrons, a screen electrode spaced therefrom, an output electrode beyond said screen electrode but closely spaced with respect thereto, a high frequency input circuit, electrode means adjacent said source of electrons and coupled with said input circuit for producing high frequency variations in the electron stream from said source to said output electrode, electrode means intermediate said first electrode means and said screen for increasing the velocity of the electrons between said output electrode whereby they arrive at said screen with high velocity and a load circuit terminated on said screen and output electrode tuned to said high frequency, a source of polarizing electromotive force for impressing upon the screen electrode and the output electrode a positive potential with respect to the source of electrons, the magnitude of said potential being so related to the distance of the electron travel that the maximum intensity portions of the electron current arrive at the screen electrode at instants in the high frequency load circuit cycle at which the screen is positive with respect to the output electrode and at velocities such that their transit time from the screen electrode to the output electrode is less than a half cycle of the high frequency load circuit oscillations whereby after passing through the screen they deliver power to the load circuit when they move across to the output electrode.

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