

Nov. 5, 1940.

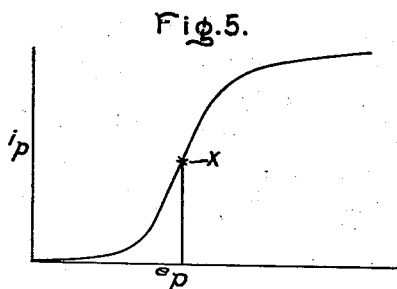
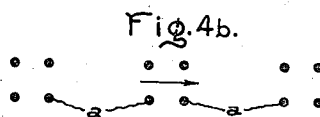
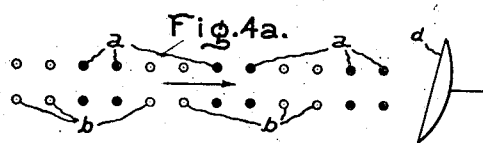
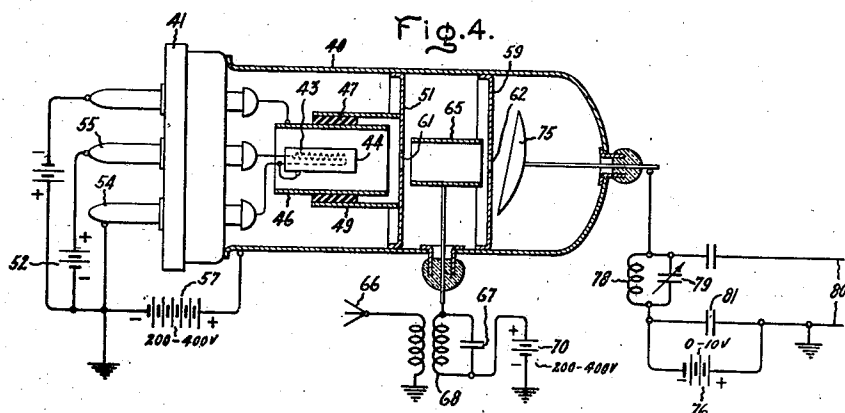
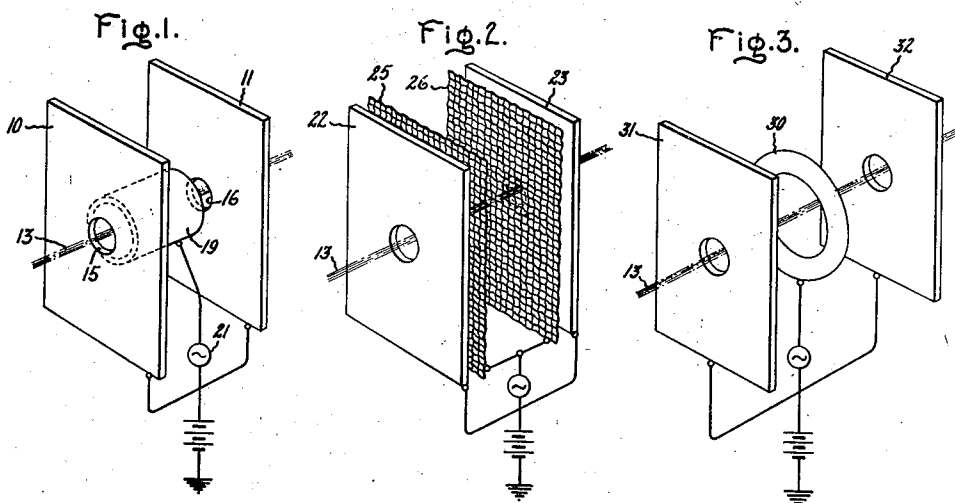
G. F. METCALF

2,220,840

VELOCITY MODULATION DEVICE

Filed April 14, 1938

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

Fig. 6.

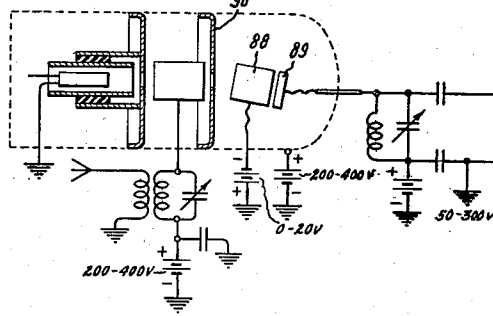
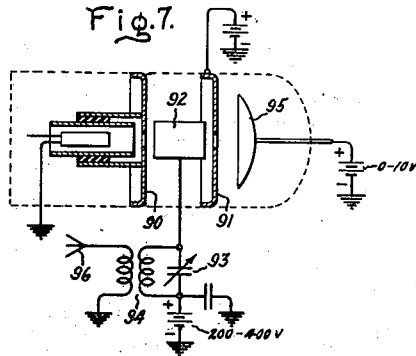


Fig. 7.



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UNITED STATES PATENT OFFICE

2,220,840

VELOCITY MODULATION DEVICE

George F. Metcalf, Scotia, N. Y., assignor to General Electric Company, a corporation of New York

Application April 14, 1938, Serial No. 201,953

10 Claims. (Cl. 250—36)

The subject matter of this application was initially described and claimed in application Serial No. 153,602, filed July 14, 1937, as a joint application of this applicant and William C. Hahn.

The present invention relates to improvements in ultra short wave systems, and more especially in oscillators and other energy converters for use at wave lengths of the order of one meter to five centimeters or less.

Inasmuch as an adequate explanation of the invention necessarily involves the repeated use of various terms of a more or less technical character, I have in the following paragraphs set forth the meaning which I desire to attach to certain such terms.

By "conduction current" I intend to designate a stream of moving charges, such, for example, as an electron beam current passing through an evacuated or gas-filled conduction space.

By "charge density modulation" I mean the controlled production of irregularities in the distribution of charges within a conduction current stream. Thus, a charge density modulated electron beam is a beam in which at any given time the electron density varies from point to point along the beam in accordance with some controlled pattern of variation.

By "velocity modulation" I mean the controlled production of irregularities in charge velocities within a conduction current stream. Thus, a velocity modulated electron beam is a beam in which at any given time the electrons at various points along the axis of the beam are moving with different velocities according to some controlled pattern of variation.

Quantitatively, any type of modulation may be measured as the ratio of the magnitude of the maximum departure of the modulated quantity from its average value to the magnitude of such average value. Thus, a charge density modulated electron beam in which the electron density along the beam axis varies from zero to twice the average density may be said to possess one hundred per cent charge density modulation.

In conventional electronic vacuum devices the control member or grid is ordinarily so constructed and arranged as to affect directly the electron emission from the cathode, thus producing a type of "charge density modulation", as hereinbefore defined. It may be shown that the current variations so produced by the grid have the effect of inducing a similarly varying

current in the grid circuit. Under ordinary conditions and at low frequencies this induced current, which is caused by instantaneous differences in the electron charges approaching and receding from the grid, is relatively small and is approximately 90 degrees out of phase with the grid voltage, so that it produces no appreciable power loss. However, as the operating wave length is decreased so that the electron transit time becomes appreciable with respect to the reciprocal frequency ($1/f$) of the control grid potential variations, the induced current not only increases but becomes more nearly in phase with the grid voltage. These two effects combine to produce the result that the apparent shunt resistance of the grid circuit varies inversely as the second power of the frequency of the operating voltage. It is for this reason that at very high frequencies (i. e. very short wave lengths) the conventional type of grid attains such a low shunt impedance and involves such a large power loss as to be practically unusable.

In the application Serial No. 153,602 previously referred to, novel discharge devices and methods of operation are described such that the shunt impedance of the control circuit may be maintained at a very high value even when control potentials of very short wave lengths are involved. In one view of the invention disclosed in the said application, this is accomplished by providing control electrode structures which are so constructed and operated as to produce primarily "velocity modulation" of the discharge current without the occurrence of appreciable "charge density" variations in the vicinity of the control electrode. The velocity modulation thus produced is subsequently converted into charge density modulation under conditions which have no adverse reaction on the control electrode circuit.

The present invention is especially concerned with the provision of effective means for accomplishing the conversion of velocity modulation into charge density modulation and for utilizing the energy of the resultant charge density modulated beam.

An important object hereof consists in the application of the principles of my invention to amplifiers, oscillators, and the like which are suitable for operation at very short wave lengths.

The features of novelty which I desire to protect herein will be pointed out with particularity in the appended claims. The invention itself, together with further objects and advantages

thereof, may best be understood by reference to the following description taken in connection with the drawings in which Figs. 1 to 3 are schematic representations illustrating certain basic elements of velocity modulation devices; Fig. 4 is a discharge device embodying one application of my present invention; Figs. 4a, 4b, and 4c are representations useful in explaining the operation of the device of Fig. 4; Fig. 5 is a graphical representation illustrating certain of the characteristics of the device of Fig. 4; Fig. 6 illustrates a modification of the device of Fig. 4, and Fig. 7 shows the invention as applied to an oscillator.

In the drawings above referred to I have indicated certain voltage ranges as being suitable for the operation of the various electrodes. It should be understood, however, that the values given are exemplary only and that they may be varied within wide limits even to the extent of changing their order of magnitude.

As is explained in the aforesaid application Serial No. 153,602, the operation at ultra-high frequencies of a given modulating system is improved by the provision of a modulating space which is substantially shielded from the stream source or cathode. By virtue of such shielding, current or potential variations which occur in the modulating space have no tendency to effect changes in the cathode emission or to produce charge density variations in the space.

A modulating space as specified in the foregoing may comprise, for example, a space which is arranged to be traversed by an electron beam, and the entrance and exit boundaries of which are maintained at fixed potentials with respect to one another. Thus, in the particular arrangement shown in Fig. 1, a modulating space is provided between two apertured conducting barriers or diaphragms 10 and 11 which diaphragms are electrically connected to one another and maintained at a definite potential with respect to ground. The chamber thus defined is, in use, traversed by an electron beam 13 which may enter through an opening 15 in the diaphragm 10 and leave through a corresponding opening 16 in the diaphragm 11.

In order to produce modulation of an electron beam traversing a modulating space such as that bounded by the diaphragms 10 and 11, the potential level of an intermediate region of the space may be cyclically raised and lowered with respect to the boundary potentials at such a rate that the velocity of any given electron in the beam is similarly affected as the electron approaches and recedes from such intermediate region. In connection with the particular structure of Fig. 1, this may be accomplished, for example, by the use of a control electrode in the form of a tube 19 which is positioned between the diaphragms 10 and 11 and spaced slightly from each of them. If the potential of this electrode is caused to vary above and below that of the diaphragms with the proper periodicity, as by connection to a source of cyclically varying control voltage 21, effective velocity modulation of the transmitted beam may be obtained. The "proper periodicity" as specified in the last sentence is determined by the following considerations.

Consider an electron which has just passed through the diaphragm 10 at a moment when the potential of the electrode 19 is at a positive maximum with respect to that of the diaphragm. Such an electron is obviously accelerated in the

approach space between the diaphragm and the open end of the electrode tube. In the case illustrated, the interior of the tube 19 constitutes an essentially field-free space, so that the velocity of the selected electron neither increases nor diminishes during its passage through the tube. If, however, the potential of the tube reverses so that the tube is at a potential minimum with respect to the diaphragm 11 at the instant the electron leaves the tube, then the electron is again accelerated in the approach space between the tube and diaphragm. Similarly, an electron which enters the modulating chamber at an instant when the control electrode is negative will be twice retarded as it successively traverses the two "approach spaces." These are effects which will occur most perfectly if the transit time of the electron through the tube 19 corresponds to a half cycle of the control potential applied to the tube, or to some odd number of such half cycles.

I have so far considered the frequency of the control potential as the independently variable quantity. It will be obvious, however, that for any fixed frequency of control potential the electron transit time itself may be varied to fulfill the condition emphasized in the foregoing paragraph. This may be done as a practical matter either by changing the length of the tube 19 or by varying the average velocity of the electron beam.

Assuming that the dimensions of the various structural elements are properly correlated to the average velocity of the beam to produce effective mutual reaction therewith for a desired operating frequency, as above proposed, it will be seen that there is available an extremely efficient mechanism for producing velocity modulation of the beam. With a given peak value of the control potential, certain electrons in the beam will be accelerated by an amount corresponding to a potential variation approaching twice that value, while others will be retarded by an equal amount. The ratio actually existing between the maximum electron acceleration or retardation (expressed in volts) and the peak value of the control potential may be called the "velocity ratio" of the control electrode. It will vary somewhat with the electrode geometry, but for the construction illustrated will be only slightly less than two.

It may also be noted that the production of velocity modulation by the method and means so far described is accomplished without appreciable power loss in the control circuit. This is due to the fact that the current variations produced in the vicinity of the control electrode structure are actually extremely small so that the resulting current induced in the control electrode is substantially negligible. As has been previously suggested herein, the utility of the arrangement lies partly in the fact that slight velocity variations, produced without substantial power loss, may be subsequently converted into higher magnitudes of charge density variation.

The precise form of control electrode structure shown in Fig. 1 is not essential, and in Fig. 2 there is shown another structure which may be alternatively used. In this figure the diaphragms 22 and 23 correspond generally to those already described in Fig. 1. The control electrode structure, however, comprises a pair of wire grids 25 and 26 which are spaced to enclose a region of substantially the same axial extent as the region enclosed by the tube 19 of Fig. 1. 75

Since these members are electrically connected together, this enclosed region constitutes a substantially field-free space; consequently, if the potential of the grids is cyclically raised and lowered with the proper periodicity as previously specified, velocity modulation of a passing electron beam will occur.

A still further possible modification of the control electrode structure is shown in Fig. 3, in which the control electrode differs from those previously described in comprising a conducting member of negligible axial extent. This member is illustrated as a ring 30, but may alternatively comprise an apertured diaphragm or other equivalent structure.

With this arrangement the optimum conditions to be fulfilled are somewhat different from those previously postulated. Specifically, it is desired that the electron transit time between either of the boundary diaphragms 31 and 32 and the plane of the control electrode correspond to a half cycle of the control potential. This being true, an electron which enters the modulating space at the instant the control electrode has assumed a positive potential is accelerated throughout the duration of its passage from the plane of the diaphragm 31 to the plane of the control electrode. Also, since a voltage reversal occurs as the electron passes the control electrode, it is again accelerated during the entire period of its passage from the plane of the control electrode to the plane of the diaphragm 32. In the same way an electron which enters the modulating space one-half cycle later will be retarded both as it approaches and as it recedes from the ring 30. A similar result is obtained if the transit time between each of the boundary diaphragms and the control electrode is an odd multiple of one-half cycle rather than a single half cycle as described in the foregoing.

The matters set forth in the foregoing paragraphs relate primarily to the production of velocity modulation of an electron beam. However, as I have previously stated, the effective utilization of the principle requires the presence of some means for subsequently converting the velocity modulation into charge density modulation which can be employed in the production of desired effects in an external circuit. The particular conversion means which comprises my present invention may best be understood by reference to a particular discharge device such as that shown in Fig. 4.

Referring particularly to Fig. 4, I have shown a discharge device which comprises a sealed metal envelope including an elongated tubular portion 40 and a base portion 41 sealed thereto. Within the envelope there is provided means for developing an electron beam of substantially constant average intensity and velocity. Such means may include any known type of "electron gun," and that illustrated constitutes only one example of many possible constructions. In the arrangement shown, the electron source comprises a thermionic cathode including a filamentary heater 43 and an enclosing cylinder 44. Surrounding the cathode as a whole there is provided a focusing electrode in the form of a conducting tubular member 46. This latter element is supported directly by an insulating bushing 47 and indirectly by means of a second tubular member 49 which is rigidly secured to a transverse barrier 51.

In the use of the device the filamentary heat-

er 43 is energized by means of a suitable energy source, such as a battery 52 connecting with the heater through bayonet contacts 54 and 55 and lead-in connections associated therewith. The focusing electrode 46 is maintained at cathode potential or at a potential which is slightly negative with respect to the cathode, and when so charged is effective to concentrate the electrons emitted from the cathode surface into a beam of generally cylindrical outline. Such a beam may be given the desired velocity by impressing an appropriate potential between the cathode and the transverse diaphragm 51. The magnitude of the potential to be applied varies within wide limits depending on the conditions of operation. For a particular case it may be on the order of from 200 to 400 volts and may be provided by means of a battery 57 connected between one of the cathode terminals and the metal structure of the discharge envelope.

Somewhat spaced from the conducting member or diaphragm 51 there is provided a second diaphragm 59 which in the case illustrated is maintained at an identical potential with the first diaphragm by being electrically connected thereto. These diaphragms are respectively provided with central apertures 61 and 62 and in combination define a chamber which is shielded from the beam source or cathode. In the contemplated use of the device this shielded chamber constitutes a modulating space in which the velocity of the constituent electrons of an electron beam traversing the space may be affected or modulated in a desired manner. Such velocity modulation may be accomplished in any of the ways described in connection with Figs. 1 to 3, and in the particular arrangement illustrated I have shown a tubular control electrode 65 of the particular type illustrated in Fig. 1.

In the use of the device as an amplifier the potential of the electrode 65 may be alternately raised and lowered by impressing thereon a cyclically varying control potential. This may be derived, for example, from a radio frequency input circuit shown as including an antenna 66 and a tuned circuit comprising a condenser 67 and an inductance 68. A battery 70 is also employed to impress on the control electrode structure a direct current potential of the same order of magnitude as that impressed on the diaphragms 51 and 59.

Assuming the device to be in normal operation, the electron beam issuing from the opening 62 is velocity modulated; that is, it is characterized by successive variations in electron velocity from point to point along the beam. The degree of modulation may be extremely slight if only weak control potentials are available, but it may be changed into charge density modulation of a considerably higher order of magnitude by conversion means now to be described.

Such means may comprise, for example, an electrode 75 positioned in alignment with the opening 62 and adapted to reflect at least the lower velocity component of the beam. This electrode, which is substantially shielded from the modulating space by the diaphragm 59, may be biased, as by a battery 76, to such a low voltage that only approximately one half of the electron beam is collected, the other half being reflected back along the beam axis. If the beam is velocity modulated as described above, the faster electrons hit the collector while the

slower ones are repulsed by it. Since the faster and slower electrons are respectively bunched in alternately spaced groups along the axis of the beam, it will be seen that both the collected current and the reflected current will be charge density modulated.

The method of separating fast and slow electrons described in the foregoing will, perhaps, be better understood by referring to the diagrammatic representations of Figs. 4a, 4b, and 4c. In Fig. 4a, for example, I have shown a stream of electrons which is assumed to be velocity modulated so as to comprise alternate groups of fast and slow electrons. The fast electrons are represented by the groups a, and the slow electrons by the groups b. The line d represents the plane of the collecting anode hereinbefore described. In Figs. 4b and 4c, I have shown the components of the electron beam which have been respectively collected and reflected by the anode d. It will be seen that each of these components is characterized by successive variations in charge density and is therefore charge density modulated within the definition of that term previously given herein.

From a consideration of the idealized situation represents in the foregoing it might seem that even the slightest degree of velocity modulation of the electron beam would produce 100 per cent charge density modulation of both the collected and reflected components of current. That this is not so is due in part to the random electron velocity variations inevitably present in the beam even before modulation takes place. Because of such variations the ideal grouping of fast and slow electrons shown in Fig. 4a cannot actually occur, some slow electrons being necessarily mixed with the first groups and vice versa. This being so, some random fast electrons are collected from even the slow electron groups and some random slow electrons are reflected from the fast groups. As a result, a given amount of velocity modulation produces through the mechanism described an amount of charge density modulation which may be considerably lower than 100 per cent and which is variable with the degree of velocity modulation involved.

The actual relation between velocity modulation and charge density modulation is determined by the slope of the $e_p - I_p$ (i. e. potential against current) static curve of the collector as illustrated in Fig. 5. This slope, which for any given tube is fixed at least in part by the random electron velocity variations occurring in the discharge stream, may be very steep for practical tube constructions. Consequently, if such a bias is applied that the collector operates, say, at the point X, substantial amplification may be accomplished.

In the use of the above-described device as an amplifier improved results are obtained if means are provided to prevent the reflected portion of the beam from returning into the modulating space and thus creating regenerative oscillations by its reaction on the control electrode. The occurrence of such an effect may be prevented by tilting the collecting anode slightly as illustrated so that reflection of the beam occurs in a direction calculated to cause it to impinge on a solid portion of the diaphragm 59. This feature (i. e. the tilting of the anode to avoid regenerative effects) is the separate invention of Harry L. Thorson and is particularly described and claimed by him in his

application, Serial No. 264,877, filed March 30, 1939.

The conduction current variations induced in the anode 75 by means of the charge density variations in the collected and reflected components of the electron beam may be converted into alternating potential by means of a circuit which is tuned to the desired operating frequency of the apparatus and which is shown as comprising an inductance 78 and a capacitance 79. This in turn may be connected to an output circuit whose terminals are indicated at 80. A condenser 81 shunting the battery 76 permits the unimpeded passage of radio frequency currents to these terminals.

It is believed that the foregoing discussion makes clear one manner in which velocity modulation may be converted into charge density modulation by reversing only the lower velocity components of the beam. It has been shown that such conversion can also be obtained by the process of reversing the entire beam. In connection with the device of Fig. 4, for example, such complete reversal may be accomplished by biasing the electrode 75 to such a low voltage (zero or several volts negative) as to repel all electrons in the approaching beam.

It has been noted that when the collecting anode serves simultaneously as a beam reversing means and as an output electrode for connection to an output circuit, its apparent shunt impedance is undesirably low. This difficulty may be overcome in one way by the arrangement indicated in Fig. 6, in which the reversing and output functions are accomplished by separate elements. This may be done, for example, by positioning before the output anode an electron-permeable reversing electrode 88 which is biased at such a voltage as to reverse at least the lower velocity electrons and to transmit higher velocity electrons. The transmitted component of beam current is charge density modulated in accordance with the principles previously explained and when collected by the anode 89 produces alternating potential variations across the terminals of the output circuit. The reversed component of current is so deflected by suitably tilting the electrode 88 as to intersect a solid portion of the boundary diaphragm 90, thus being prevented from returning into the modulating space where it might tend to produce regenerative oscillations.

For simplicity in explanation, I have so far described my invention in connection with discharge devices adapted to be used as amplifiers. I consider, however, that it has an even more important use in oscillators operating on the velocity modulation principle.

Broadly stated, oscillator operation is obtained by the use of a control electrode effective to velocity modulate the electron beam, a reversing field for converting the velocity modulation into charge density modulation, and means providing coupling between the charge density modulated portion of the beam and the said control electrode. One way in which this may be accomplished is illustrated in Fig. 7.

With the arrangement shown in Fig. 7 there is provided a velocity modulating space defined by boundary diaphragms 90 and 91 and containing a velocity modulating electrode 92. This electrode is connected externally to an oscillating circuit comprising, for example, a condenser 93 and an inductance 94 and is adapted to be cyclically varied in potential level in accordance

with the oscillations of such circuit. The electron beam, after being velocity modulated by passage through the modulating space is directed toward an anode 95 which is adapted to reverse a portion or all of the beam, thereby converting velocity modulation into charge density modulation. The charge density modulated component, or part of it, is returned into the modulating space and caused to pass through the electrode 92, thereby inducing current variations in the circuit connected to the electrode. The returning electrons, which by this time have become appreciably defocused, are largely collected by the barrier 90 or by the other metallic surfaces adjacent to the cathode end of the tube. Those that are not collected are again reversed by the action of the cathode field. However, since these are few in number, they have little further effect upon the operation of the tube.

Assuming that the length of the beam path from the electrode 92 to the collector 95 is properly correlated to the velocity of the beam, the current variations induced in the electrode will produce self-sustained oscillations. That is to say, the charge density variations of the returning beam, if the variations are correctly phased, produce voltage swings of the electrode 92 effective to maintain the system in continuous oscillation. The desired operation may be obtained for any particular case by properly adjusting the tube dimensions, the beam velocity, or the strength of the retarding field. The energy of the oscillating circuit may be utilized either by being supplied to an antenna 96 or to some other utilization device coupled to the circuit.

While I have in the foregoing referred to particular structural embodiments, various modifications may be made by those skilled in the art without departing from my invention. I therefore aim to cover in the appended claims all such variations of form and use as come within the true scope of the foregoing disclosure.

The further application of the principles described herein to high frequency detectors is described and claimed in my copending application, Serial No. 326,933, filed March 30, 1940.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. An oscillator comprising means including a cathode for developing an electron beam, a modulating space shielded from the cathode and formed by spaced conducting parts normally maintained at a fixed potential with respect to one another, said conducting parts being provided with openings to permit passage of the beam through the modulating space, a control electrode within the modulating space for imparting velocity modulation to the beam, circuit means connecting with the control electrode and adapted to oscillate at a predetermined frequency, and means for producing a reversing field acting on the beam to convert its velocity modulation into charge density modulation and to return a portion of the energy of the charge density modulated part of the beam to the modulating space.

2. An oscillator comprising means for developing a concentrated beam of electrons, a pair of spaced conducting parts provided with openings to permit passage of the beam therethrough and being normally maintained at a fixed potential with respect to one another, means including a control electrode coupled to the beam in the space between said conducting parts for imparting velocity modulation to the beam, means con-

necting with the control electrode and adapted to oscillate at a predetermined frequency, means for reversing the direction of motion of at least the lower velocity component of the beam, and for returning a part of the reversed component into energy-exchanging relation with the control electrode.

3. An oscillator comprising means for developing a concentrated beam of electrons, a pair of spaced diaphragms arranged transversely to the beam, both of said diaphragms being provided with openings to permit passage of the beam therethrough and being normally maintained at a fixed potential with respect to one another, means including a modulating electrode within the space defined by said diaphragms for imparting velocity modulation to the beam, means connecting with the modulating electrode and adapted to oscillate at a predetermined frequency and means including an electrode in the path of the beam for reversing at least the lower velocity components of the beam after its passage through the modulating electrode and for returning the reversed components into energy-exchanging relation with said modulating electrode.

4. In high frequency apparatus from which it is desired to derive an output voltage of a particular frequency, the combination which includes means for producing a concentrated beam of moving charges, a modulating electrode having an opening therein through which the entire beam may pass without interception, means including said electrode for producing variable potential gradients acting longitudinally on the beam, thereby to cause high frequency velocity variations in the components of the beam which successively traverse the electrode, and means for reversing at least the lower velocity components of the beam after its traversal of the electrode, the apparatus including as a part thereof circuit means tuned to the said particular frequency and coupled to a portion of the beam affected by the said reversing means so as to be excited at the said frequency by the variations which exist in such portion of the beam when the reversing means has acted thereon.

5. In high frequency apparatus from which it is desired to derive an output voltage of a particular frequency, means for producing a concentrated beam of electrons, a hollow conductive member axially traversed by the beam, means including the said member for producing variable potential gradients acting longitudinally on the beam, thereby to cause high frequency velocity variations in the components of the beam which successively traverse the member, and means for producing a retarding field effective to reverse at least the lower velocity components of the beam after its traversal of the said member, the said apparatus having as a part thereof circuit means tuned to the said particular frequency and coupled to a portion of the beam subjected to the said retarding field so as to be excited at the said frequency by the variations which exist in such portion when the retarding field has acted thereon.

6. In high frequency apparatus from which it is desired to derive an output voltage of a particular frequency, the combination which includes means for producing a beam of electrons, means including spaced conductive parts defining a shielded space traversed by the electron beam, a modulating electrode structure within said space for causing high frequency velocity variations in

the components of the beam which successively traverse the space, the said structure being effective to produce potential gradients acting longitudinally on the beam at two appreciably displaced regions within the modulating space, and means for reversing at least the lower velocity components of the beam after its traversal of the said modulating space, the said apparatus having as a part thereof circuit means tuned to the said particular frequency and coupled to a portion of the beam affected by the said reversing means so as to be excited at the said frequency by the variations which exist in the beam when the reversing means has acted thereon.

7. In high frequency apparatus from which it is desired to derive an output voltage of a particular frequency, means including an electron emissive cathode for producing a stream of electrons, a modulating electrode coupled to the stream but sufficiently shielded from the cathode to be incapable of affecting the electron emission therefrom, means including the said electrode for velocity modulating the stream, and means independent of the electrode for converting the velocity modulation of the stream into charge density modulation, said last-named means including electrode structure for producing a retarding field effective to reverse only the lower velocity components of the stream and for collecting the unreversed components of the stream, the said apparatus having as a part thereof circuit means tuned to the said particular frequency and coupled to a portion of the stream affected by the retarding field so as to be excited at the said frequency by the charge density variations which exist in the stream when the said field has acted thereon.

8. In high frequency apparatus from which it is desired to derive an output voltage of a particular frequency, means including an electron emissive cathode for producing a beam of electrons, a modulating electrode coupled to the beam but sufficiently shielded from the cathode to be incapable of affecting the electron emission therefrom, means including the electrode for velocity modulating the beam, and means independent of the control electrode for converting the velocity modulation of the beam into charge density modulation, said last-named means comprising an electron-permeable electrode structure arranged in the path of the velocity modulated portion of

the beam, means including said electrode structure for reversing only the lower velocity components of the beam, and an anode for collecting the higher velocity components of the beam upon their passage through the said electrode structure, the said apparatus having as a part thereof circuit means tuned to the said particular frequency and coupled to a portion of the beam affected by the said reversing means so as to be excited at the said frequency by the charge density variations produced in the beam by the action of the reversing means thereon.

9. An oscillator comprising means for producing a beam of moving charges, an elongated hollow electrode surrounding a portion of the beam path for varying the velocity of the charges which successively traverse the electrode, the extension of the electrode in the direction of the beam axis being correlated to the average velocity of the beam to assure effective mutual reaction therewith for a desired condition of operation of the apparatus, circuit means connecting with the said electrode and tuned to a frequency corresponding to the said desired condition of operation, and means for reversing at least the lower velocity components of the beam after its traversal of the said hollow electrode and for returning the reversed components in such proximity to the electrode as to produce self-sustained excitation of the circuit means.

10. An oscillator for use at a particular frequency, comprising means for producing a stream of moving charges, means including spaced conductive parts defining a shielded space to be traversed by the stream, a modulating electrode structure within said space for causing high frequency velocity variations in the components of the stream which successively traverse the space, said electrode structure being effective to produce potential gradients acting on the stream at two appreciably displaced regions within the modulating space, circuit means connecting with the said electrode structure and tuned to the said particular frequency, and means for reversing at least the lower velocity components of the stream after its traversal of the said modulating space and for returning the reversed components to the modulating space so as to produce self-sustained excitation of the said circuit means.

GEORGE F. METCALF.