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ULTRA-SHORT-WAVE DEVICE

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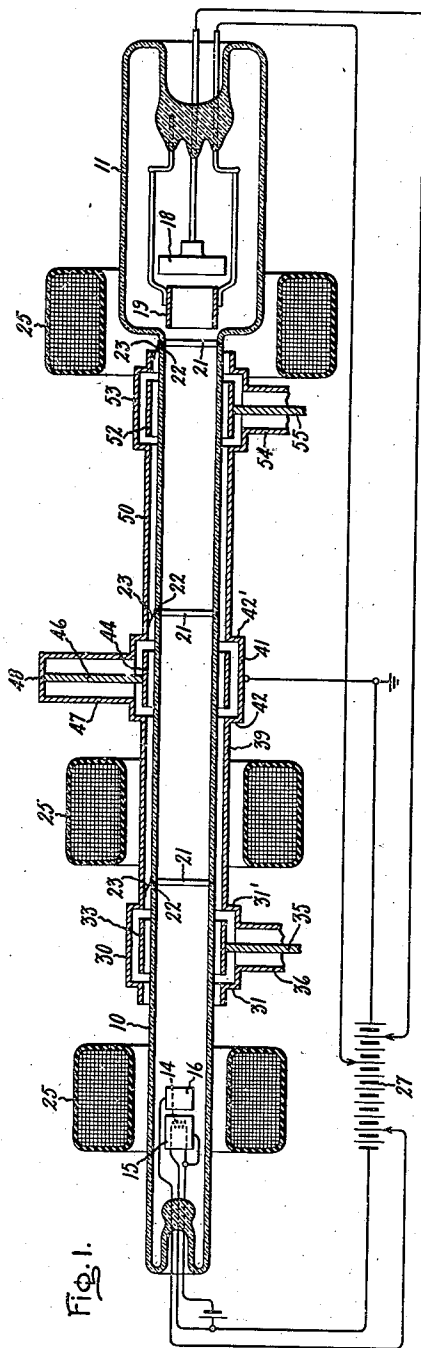


Fig. 1.

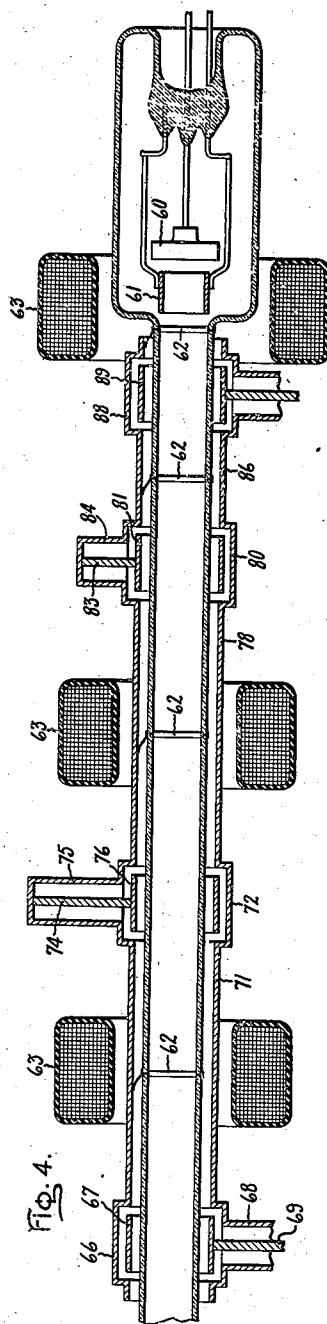


Fig. 4.

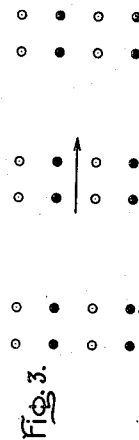


Fig. 3.

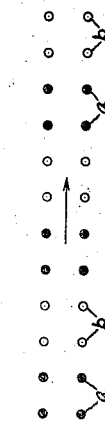


Fig. 2.

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UNITED STATES PATENT OFFICE

2,222,901

ULTRA-SHORT-WAVE DEVICE

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Application June 1, 1938, Serial No. 211,124

7 Claims. (Cl. 179—171)

This invention comprises improvements in ultra-short-wave discharge devices of the general type described and claimed in my application Serial No. 153,602 filed July 14, 1937. It relates particularly to amplification devices which are to be used at wave lengths on the order of from 5 meters to 5 centimeters or less.

As pointed out in the aforesaid application, an electron stream may be modulated either as to "electron velocity" or as to "charge density." The first type of modulation involves the production of systematic irregularities in electron velocity from point to point along the beam. The second involves the production of charge density variations, such variations being manifested as systematic irregularities in the electron grouping.

In the conventional design of electronic discharge devices no distinction is made between these two types of modulation. In connection with ultra short wave devices, however, it is advantageous to utilize modulating electrodes which are capable of producing velocity modulation without simultaneously causing appreciable charge density variations. For reasons which need not be elaborated here this expedient avoids the large input losses which are observed with conventional prior art devices when they are operated at extremely high frequencies. Velocity modulation produced as above specified may be subsequently converted into charge density modulation of a higher order of magnitude, thus producing amplification effects.

The foregoing matters are explained in my prior application S. N. 153,602, wherein the details of construction of a single stage amplifier are fully set forth. It is one object of my present invention to provide means whereby the velocity modulation principle may be used to effect multi-stage amplification or other cumulative effects in a single tube having a single electron stream. An important feature of the invention with reference to the attainment of the foregoing and other objects consists in the combination which includes means for producing preliminary velocity modulation of the electron stream, a resonant system adapted to be excited by the modulated stream, and means associated with the resonant system for causing the same to react on the stream in such fashion as to produce additional and augmented velocity modulation thereof.

The features of novelty which I desire to protect herein are 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 drawing in which Fig. 1 illustrates in longitudinal section a complete electronic discharge device suitably embodying my invention; Figs. 2 and 3 comprise theoretical representations useful in explaining the invention, and Fig. 4 shows an alternative application thereof.

Referring particularly to Fig. 1 I have shown an electron beam tube which comprises an evacuated envelope having an elongated shaft portion 10, and an enlarged anode-containing portion 11. This envelope may be suitably constituted of glass, quartz or any equivalent insulating material.

The shaft portion 10 encloses means for producing an electron beam, such as a known type of electron gun. The combination shown comprises an indirectly heated cathode 14 which is indicated in dotted outline and a focusing cylinder 15 for confining the electrons to a concentrated beam. This cylinder may be either connected directly to the cathode or maintained at a few volts negative with respect to it. In order to accelerate the electrons to a desired extent, there is provided an accelerating electrode 16 which is spaced from the cathode and which may be biased to a suitable positive potential, say several hundred volts.

In order that the intermediate portion of the beam path may be maintained at a desired potential level there are provided a number of intermediate electrodes 21 which suitably comprise rings of conducting material applied to the inner wall surface of the envelope. They are provided with lead-in connections 22 and with external contact-making terminals 23. A number of magnetic focusing coils 25 distributed along the envelope serve to prevent dispersion of the electrons and to maintain the beam in focus during its passage through the discharge space. In some cases these coils may be advantageously replaced by electrostatic beam focusing means.

After traversing the envelope, the electron beam is collected by an anode 18 which consists of graphite or other suitable material. A tubular electrode 19 in the nature of a suppressor grid serves to prevent secondary electrons emitted from the anode returning to the discharge space.

In the operation of the device the intermediate electrodes 21 may be maintained at ground potential, the cathode 14 at one thousand to several thousand volts below ground, and the anode 18 at one thousand to several thousand volts above the cathode. The suppressor grid

19 should be biased fifty to several hundred volts negative with respect to the anode 18. These potential relationships may be established, for example, by means of a suitable source of potential, which is conventionally represented as a battery 27 connected as shown.

The combination of elements so far described comprises means for producing a unidirectional electron beam of substantially constant average intensity and velocity. As pointed out in my application, Serial No. 153,602, an electron beam of this type may be velocity modulated by applying to the beam longitudinal potential gradients which vary cyclically at a desired frequency. In order that such modulation may be accomplished without the simultaneous production of substantial charge density variations it is desirable that it occur in a modulating space which is adequately shielded from the cathode. In this way the variations of the modulating potential are prevented from reacting directly on the cathode emission. Although numerous suitable velocity modulating structures are shown in the aforementioned application, only one is illustrated in the present case.

This comprises a chamber 30 formed by a conducting structure which is outside the discharge envelope. It is provided with transversely extending wall portions 31 and 31' which extend relatively close to the outer surface of the envelope and which serve to fix the potential level of the boundaries of the modulating space. Within this space there is provided a modulating electrode comprising a conducting tube 33 which surrounds the beam path so as to be coupled thereto. By alternately raising and lowering the potential of this electrode with respect to the boundaries of the modulating space, variable potential gradients are produced which act longitudinally on the electron beam as it traverses the approach spaces between the wall members 31 and 31' and the extremities of the electrode 33. As is explained in my prior application, the modulating effect thus produced will be most pronounced if the length of the tubular electrode 33 is so correlated to the velocity of the beam that the electron transit time therethrough corresponds at least approximately to a half-cycle of the control potential (or to an odd number of such half-cycles). If this condition is fulfilled, an electron which enters the modulating space when the potential of the control electrode 33 is a maximum, is accelerated first by the gradient existing between the wall 31 and the electrode, and again as it leaves the electrode one-half cycle later, when the electrode potential is at a minimum with respect to that of the boundary wall 31'. Similarly an electron which enters the modulating space in such time phase as to be retarded by the effect of the control electrode, is also retarded as it leaves the electrode. As a result of these effects the electron beam leaving the chamber 30 is made up of alternate elements, some of which have a velocity above the average of the beam and others a velocity below such average.

Modulating potential may be supplied to the control electrode 33 from any desired source such, for example as a high frequency oscillation generator (not shown). As a means for connecting this potential to the control electrode structure there is provided a concentric transmission line comprising an inner conductor 35 and an outer conductor 36, these being shown partly broken away.

If only weak control potentials are available, the velocity modulation produced may be relatively slight. However, it may be converted into charge density modulation of a higher order of magnitude by means now to be described. The mechanism by which such conversion may be accomplished will best be understood by a consideration of the following explanation.

In Fig. 2 the beam is shown as it is assumed to issue from the modulating space. It will be seen that at this point it comprises alternate groups of fast and slow electrons, the former being indicated by the black dots *a*, and the latter by the light dots *b*. So far, the beam is still substantially uniform as far as charge density or electron grouping is concerned.

In Fig. 3, the condition of the same beam is indicated at a somewhat later time when the more rapidly moving electrons have caught up with the slower electrons. The electrons have now become grouped so that the beam is charge density modulated in the sense that systematic irregularities in charge density occur from point to point along the beam. The change that has taken place is in its very nature one that requires only the elapse of time and the absence of extraneous influences which might tend adversely to affect conditions within the beam. These requirements may be fulfilled by the provision of an electrostatically shielded drift space in which sorting of the electrons can take place. This may comprise, for example, simply a section of the discharge envelope which is shielded from any but static potentials.

From the discussion given above it might seem that with an appropriate length of drift space even the slightest amount of velocity modulation can be converted into 100% charge density modulation, or, in other words, that the maximum obtainable charge density modulation is independent of the velocity modulation. That this is not the case is due primarily to the action of space charge (that is, of the mutual repulsion of electrons), in opposing the electron grouping which is characteristic of a charge density modulated beam. What actually takes place may best be understood by comparing the electron beam to an elongated tube of a highly elastic solid material such as rubber.

In this connection, let it be assumed that such a tube is being moved longitudinally through space so as to simulate an electron beam having constant average velocity. If a momentary retarding force is applied to one end of the tube and a momentary accelerating force to the other end, a process of compression is initiated. Although the average velocity of the tube as a whole may not be affected, the forces in question start a relative motion of certain elements of the tube from its ends towards its center. After a certain time this motion ceases as a result of compression of the intermediate region of the tube.

After the maximum compression is reached, the elasticity of the medium produces a restorative motion of the displaced elements toward the ends of the tube. Here again compression and cessation of such motion occur and the whole process is repeated. If the medium in question is perfectly elastic, an indefinite number of repetitions are possible, periods of maximum compression being alternated with periods of maximum mobility.

This is considered to be the sort of thing which

happens in an electron beam which has been subjected to velocity modulation. With the passage of time (that is, with the passage of the velocity modulated beam through space), the action of the faster electrons in overtaking the slower ones produces compressions or localized increases in electron density. As soon as maximum charge density is attained, i. e., as soon as the mutually repulsive forces of the electrons become sufficient to prevent their further compression, electron dispersion will be initiated. This, in turn, will over-shoot, so to speak, thus producing further compressions, and so on. The variations of compression may be referred to as the charge density modulation of the beam, while the variations of velocity comprise its velocity modulation.

Taking into consideration the space charge factor, it may be shown that the distance (drift space) required to be traversed by the beam for conversion of the initial velocity modulation into the maximum possible charge density modulation is independent of the magnitude of the velocity modulation for small amounts of the latter. It is, however, a function of the beam velocity, the average charge density of the beam, the modulating frequency, the diameter of the beam, the diameter of metal and glass parts surrounding the beam, and of the magnitude of any external electrostatic or magnetic forces acting on the beam. An approximate formula which has proven useful in determining the proper length of the drift space is as follows:

$$L_M = 9.02 \times 10^{-8} a \frac{V_0^{3/4}}{I_0^{1/2}} \lambda$$

Where

L_M represents the maximum length of the drift space in centimeters (measured from center to center of the grids at each end of the space).

V_0 represents the average velocity of the beam in volts.

I_0 represents the beam current in milliamperes.

λ represents the wave length of the applied signal in centimeters (in vacuum).

a is a constant whose value is determined by the dimensions of the envelope and electrode parts. For most practical cases it will fall between 1.0 and 2.0 and may be assigned an average value of 1.3.

Once the physical length of the drift space has been fixed by utilization of this formula, a final optimum adjustment may be obtained by varying the beam velocity from the value used in the computation. The best adjustment may be determined objectively by continuously varying the potential applied between the cathode and the intermediate electrodes 21 until maximum output is obtained from the discharge device as a whole. (The significance of this last statement will be better understood when the remaining elements of the device have been described.)

Referring again to the particular structure of Fig. 1, it is to be considered that the drift space of the illustrated device is co-extensive with the tubular conducting section 39 which extends from the boundary wall 31'. It is further assumed that the right-hand extremity of this tubular portion marks the point of maximum charge density modulation of the beam for the intended condition of operation of the discharge device.

It has already been pointed out that a given amount of velocity modulation may produce a

much larger amount of charge density modulation. Nevertheless, since the initial control voltage or signal may be very small, a single stage of amplification may still yield an insufficient output. In accordance with my present invention, further means are provided by which multi-stage amplification may be accomplished in an extremely simple and effective manner. In the embodiment shown in Fig. 1 this means includes a second, or "modulation-intensifying" chamber 41 having transverse wall portions 42 and 42' which define the entrance and exit boundaries of the chamber. Within this chamber and surrounding the beam path there is provided a tubular electrode 44 generally similar to the electrode 33 which has been previously described.

In accordance with principles set forth in my prior application, Serial No. 153,602, the charge density modulated beam in traversing the approach spaces which exist between the extremities of the electrode 44 and the boundary walls 42 and 42' induces a cyclically varying current in the electrode 44. The magnitude of this induced current is greatest if the length of the electrode 44 corresponds approximately to the spacing between adjacent charge density maxima and minima in the beam so that the approach of a charge density maximum corresponds with the recession of a charge density minimum and vice versa.

In order that the induced current may be caused to produce the effects desired in the present connection, the control electrode 44 and the wall of chamber 41 should be connected through a high impedance circuit. This has the function of causing the induced current variations to produce relatively great potential variations between the electrode 44 and the boundary walls 42 and 42'. In theory, any type of high impedance connection may be used for this purpose, such as a high resistance, inductance, or capacitive reactance. As a practical matter, however, the unavoidable presence of a certain amount of inherent shunt capacitance between the elements in question makes it expedient to utilize a parallel tuned circuit which is at least approximately resonant at the desired frequency of operation of the device.

Since for short wave lengths it is difficult to construct a parallel resonant circuit of conventional circuit elements, I prefer to employ for this purpose a pair of juxtaposed conductors acting as a resonant transmission line. These may comprise, for example, an inner conductor 46 connected with the electrode 44 and an outer tubular conductor 47 projecting from the wall of the chamber 41. These two conductors may be directly connected to one another at one end as indicated at 48 so that the point of connection is a quarter wave length from the open circuited end of the transmission line. (The capacitive end loading caused by the presence of the electrode 44 and the adjacent wall portions of the chamber 41 may require that the transmission line be somewhat less than a quarter wave length if perfect resonance is to be attained.)

With an arrangement such as that indicated, the current induced in the electrode 44 will tend to produce sustained oscillations of the transmission line and will cause a voltage maximum or anti-node to exist at the open circuited end of the line, i. e., between the electrode 44 and the adjacent walls 42 and 42'. This voltage will be of cyclically varying character and will have a frequency determined by the rate of approach and recession of charge density maxima in the

beam; that is to say, by the frequency of the initial velocity modulating potential.

By analogy with the operation of the control electrode 33 it will be seen that the potential gradients produced in this way will necessarily act to cause additional velocity modulation of the electron beam. Furthermore, since the voltage swing of the electrode 44 may be very much greater than that of the input electrode 33, the magnitude of the new velocity modulation may be correspondingly larger than that of the initial modulation. Where this is in fact the case, it is not especially significant to inquire whether the new velocity modulation is in phase with the old, since the influence of the former may completely overshadow that of the latter. In other words, the future action of the beam may be controlled almost entirely by the modulation produced by the electrode 44 and only to an insignificant degree by the modulation produced by the electrode 33.

On the other hand, in some cases the charge density modulation developed in the drift tube 39 is so extremely small that only a small voltage is developed on the electrode 44. Where this is so it may be desirable to assure that whatever velocity modulation is produced by this electrode is in phase with and additive to that produced by the electrode 33. This can be accomplished as a practical matter by varying the tuning of the circuit connected to the electrode 44 as by adjusting the dimensions of the conductors 46 and 47. A slight detuning of the circuit from true resonance will be effective to accomplish a relatively great change in the phase of the voltage existing across the approach spaces within the chamber 41.

If the device is operated in the manner specified in the foregoing so that secondary velocity modulation of increased intensity is produced by the control electrode 44, the conversion process previously described in connection with the electrode 33 may be repeated. That is to say, the velocity modulation produced in the chamber 41 may be converted into a still higher degree of charge density modulation by providing a further drift space to be traversed by the portion of the beam issuing from the chamber. In the arrangement shown this drift space is provided within the portion of the envelope enclosed by the conducting tube 50, such tube being of the same length as the tube 39.

By virtue of the multi-stage amplification effects described in the foregoing, the portion of the beam issuing from the drift tube 50 will be very highly charge density modulated, the percentage of charge density modulation being perhaps several hundred times the initial velocity modulation effected by the control electrode 33. In order that this result may be effectively utilized, a third electrode 52, appropriately designated an output electrode, is coupled to the portion of the beam issuing from the drift space. This electrode is enclosed within a chamber 53 similar to the modulating chambers previously described, and is adapted to have conduction currents induced in it in accordance with the principles previously set forth herein. These currents may be supplied in turn to an appropriate utilization circuit such as a radiating antenna or another discharge device. The utilization circuit, which is not shown, may be connected to the electrode 52 by means of another coaxial transmission line including inner and outer conductors 54 and 55. (Shown broken away.)

In the device of Fig. 1 only two stages of amplification are employed. It should be understood, however, that as many additional stages as desired may be added, up to the point where the velocity modulation produced in the last stage corresponds to one hundred per cent modulation of the beam. Using three stages, that is, two modulation intensifying chambers, it has proven possible to produce a swing of as much as 1500 volts in the last modulating electrode with a potential of only four or five volts (at eighty centimeters) applied to the input electrode. Even greater amplifications are considered practicable.

In Fig. 4 I have shown a further application of which my invention has been found capable. The device there illustrated is a frequency multiplier invented by V. K. Fraenckel and claimed by him in application Serial No. 310,059, filed December 19, 1939. I claim as my invention only the particular velocity-modulation-intensifying means shown and not the combination thereof in a frequency multiplying device.

In this arrangement there is provided an elongated discharge envelope of the same general character as that described in connection with Fig. 1. This includes a collecting anode 60, a suppressor grid 61, and a series of intermediate electrodes 62. It is also understood to be provided at its left hand extremity with an electron gun of the character shown in Fig. 1. (This has been broken away in the drawing in order to conserve space.) A series of magnetic focusing coils 63 are distributed along the length of the discharge path in order to maintain the electron beam in focus.

As in the arrangement previously described, there is provided a first modulating space comprising a chamber 66 and a modulating electrode 67. An input potential is applied between an outer tubular member 68 and an inner conductor 69 which form the elements of a coaxial transmission line. Velocity modulation which is produced in the modulating chamber 66 is converted into charge density modulation of a higher order of magnitude in the drift space which exists within that portion of the envelope enclosed by the conducting tube 71.

The charge density modulated portion of the beam which issues from this drift space enters a modulation-intensifying space defined by the chamber 72 and is there caused to excite an oscillating circuit comprising coaxial conductors 74 and 75. The mutual reaction of the oscillating circuit and the beam, as effected through the intermediation of the tubular electrode 76, serves to augment the velocity modulation of the beam in accordance with the principles explained in the foregoing.

The length of the conductors 74 and 75 is preferably made to correspond to a quarter wave length of the fundamental frequency applied to the input electrode 67. Consequently, the additional velocity modulation which is imparted to the beam in the second modulating chamber 72 is of the fundamental frequency. This new velocity modulation is again converted into charge density modulation in a second drift space which is enclosed by a tubular conductor 78.

It may be shown that where relatively weak sinusoidal velocity modulation is involved, space charge effects tend to cause the charge density modulation resulting therefrom to be also of sinusoidal character. However, if a higher degree of velocity modulation is employed, the charge density modulation produced thereby may be of

distinctly non-sinusoidal character as a result of the greater "electron compression" made possible by the higher electron velocity differences in the beam. Consequently, even if the original control potential applied to the electrode 67 is of sinusoidal form, the charge density modulated beam issuing from the drift space within the tube 78 will contain harmonic components. By using a further modulation-intensifying circuit similar in principle to those previously described but tuned to a different frequency, a given one of these contained harmonics may be selectively amplified.

In the present case, means for accomplishing this result is provided in the form of a third modulating space contained within the chamber 80. As before, the modulating means includes a tubular electrode 81 and a connected circuit comprising inner and outer concentric conductors 83 and 84. The latter, however, are of such dimension as to be adapted to produce oscillations corresponding to a selected harmonic, say the second, of the fundamental frequency applied to the control electrode 67. To this end the conductors may have a length corresponding approximately to a quarter wave length of the harmonic frequency in question. The action of the elements contained within the modulating chamber 80, therefore, is to impress on the beam velocity modulation at the harmonic frequency. This velocity modulation may be converted into charge density modulation of the same frequency by permitting it to pass through a drift space of appropriate length, provided for example, by the portion of the envelope which is enclosed by the conducting tube 86. Assuming that the second harmonic is that desired, the appropriate length of this drift space will be somewhat less than half that of the drift spaces utilized in connection with the electrodes 67 and 76. In order to abstract energy at the harmonic frequency from the modulated beam, one may utilize an energy-abstracting combination including a chamber 88 and a tubular electrode 89, these being connected to a circuit which is tuned to the harmonic frequency so as to be readily excited thereby.

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

1. In combination, means for producing an electron beam, a set of juxtaposed conductive members capable of producing potential gradients acting longitudinally on the beam at a particular region thereof, means for impressing an alternating voltage of high frequency between said members thereby to modulate the beam, means providing a drift space to be traversed by the beam after its passage through the said particular region, circuit means coupled to the portion of the beam issuing from the drift space and adapted to be excited by current variations therein, means including a second set of juxtaposed conductive members for impressing on the said portion of the beam longitudinal potential gradients produced as a result of the excitation of the said circuit means, means providing a second drift space to be traversed by the beam after passage thereof through the second set of conductive members, and energy-abstracting means coupled to the portion of the beam issuing from the second drift space.

2. In combination, means for producing an electron beam, means coupled to the beam for producing longitudinal velocity modulation thereof, means providing a drift space to be traversed by the velocity modulated beam, said drift space

being of sufficient length to permit effective conversion of the said velocity modulation into charge density modulation, circuit means coupled to the portion of the beam issuing from the drift space so as to be excited thereby, and means for subjecting the said portion of the beam to a potential developed as a result of the excitation of the said circuit means, thereby to change the velocity modulation of the beam.

3. In combination, means for producing an electron beam, means for producing initial longitudinal velocity modulation of the beam, means providing a drift space of substantial length to be traversed by the beam after such modulation thereof, an oscillatory circuit coupled to the portion of the beam issuing from the drift space so as to be excited to oscillation thereby, means energized by a potential developed in said oscillatory circuit for superimposing additional velocity modulation on the said portion of the beam, the circuit being adjusted to produce a desired phase relationship between the said superimposed velocity modulation and the said initial velocity modulation of the beam.

4. In combination, means for producing an electron beam, means providing a first modulating space to be traversed by the beam, means within said space for producing initial longitudinal velocity modulation of the beam, means providing a modulation-intensifying space to be traversed by the beam after initial velocity modulation thereof, circuit means coupled to the beam within the modulation-intensifying space and adapted to be maintained in oscillation by the action of the beam, means within said space and energized by an oscillating potential developed by said circuit means so as to produce additional longitudinal velocity modulation of the beam, and means for effectively abstracting energy from the doubly modulated beam.

5. In combination, means for producing an electron beam, means for producing initial longitudinal velocity modulation of the beam, means providing a drift space to be traversed by the velocity modulated portion of the beam, thereby to convert the velocity modulation into charge density modulation, means providing a modulation-intensifying space to be traversed by the portion of the beam issuing from the drift space, circuit means coupled to the beam within the modulation-intensifying space and adapted to be excited to oscillation by the action of the beam, means within said space and energized by the said circuit means for producing additional velocity modulation of the beam, and means for effectively abstracting energy from the doubly modulated portion of the beam.

6. A multi-stage amplifier for high frequencies, including means for producing an electron beam, means for producing initial longitudinal velocity modulation of the beam, means providing a drift space to be traversed by the beam after velocity modulation thereof for converting the velocity modulation into charge density modulation, means coupled to the portion of the beam issuing from the drift space for producing additional longitudinal velocity modulation thereof, said last-named means comprising a space traversed by the beam and having relatively fixed boundary potentials, an electrode within said space and freely variable in potential with respect to the boundaries thereof, said electrode being coupled to the beam so as to be affected by the passage of charge density maxima and minima in the beam, and means providing a high impedance

connection between the electrode and the bounding walls of the space, and means for effectively abstracting energy from the beam after its passage through the said space.

- 5 7. In combination, means for producing an electron beam, a series of axially alined tubular conductive elements which are successively traversed by the beam, said elements being mutually spaced to provide gaps between them,
10 means for producing cyclically varying potential gradients which act longitudinally on the beam

at a first one of said gaps to cause velocity modulation thereof, a resonant system adapted to be excited by the variations existing in the beam as it traverses a second one of said gaps which is appreciably displaced from the first gap in the direction of the electron movement, said resonant system being effective by virtue of its reaction on the beam to produce additional velocity modulation thereof, and means for abstracting energy from the doubly modulated beam.

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