

Feb. 28, 1950

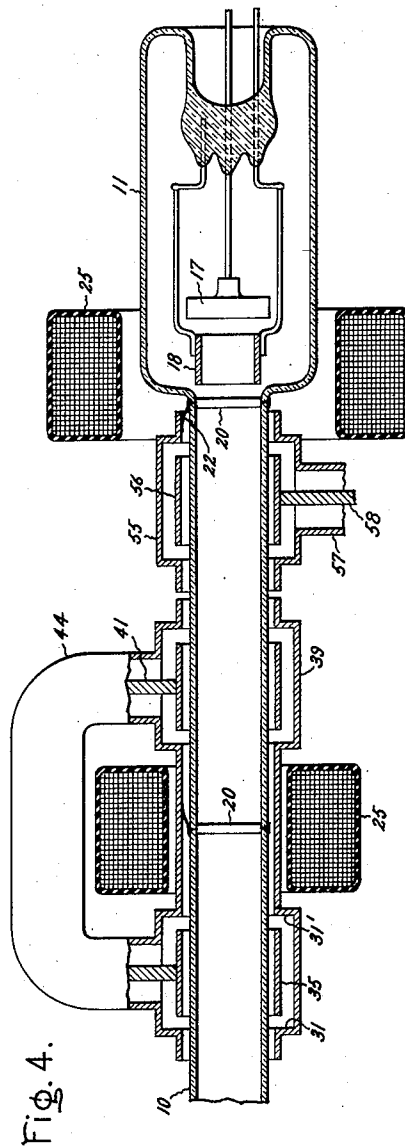
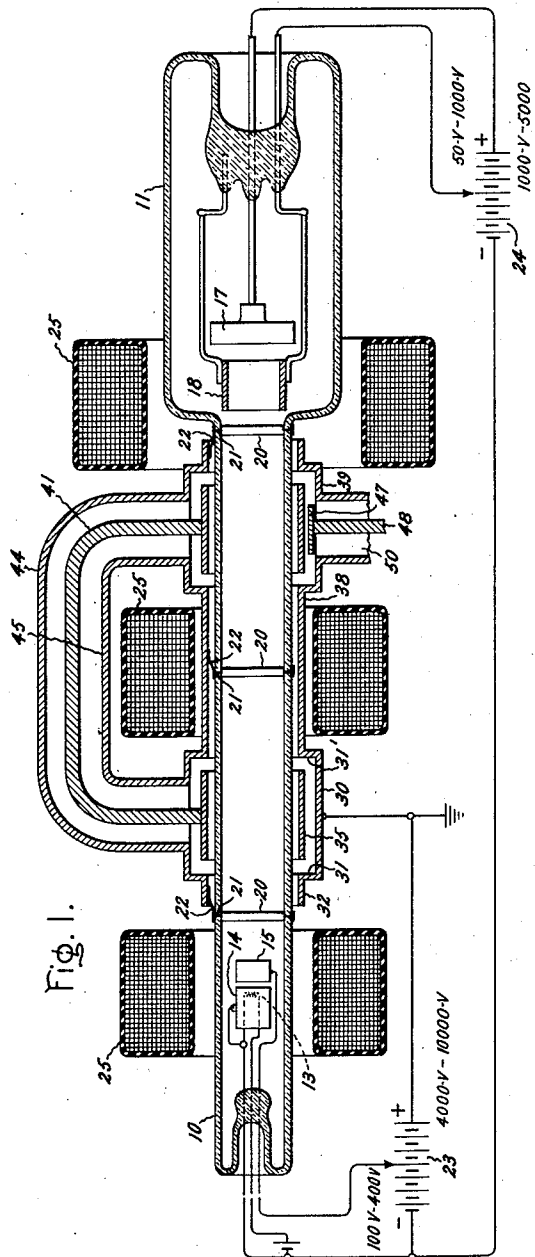
W. C. HAHN

2,498,886

ULTRA SHORT WAVE DEVICE

Filed June 1, 1938

3 Sheets-Sheet 1



Inventor:
William C. Hahn,
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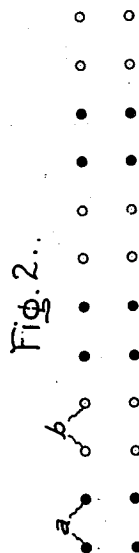
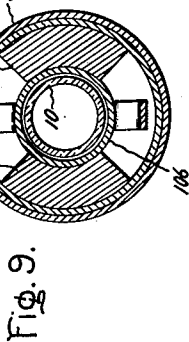
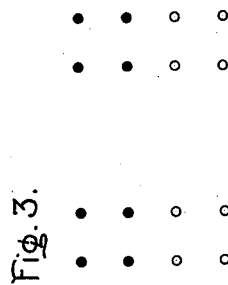
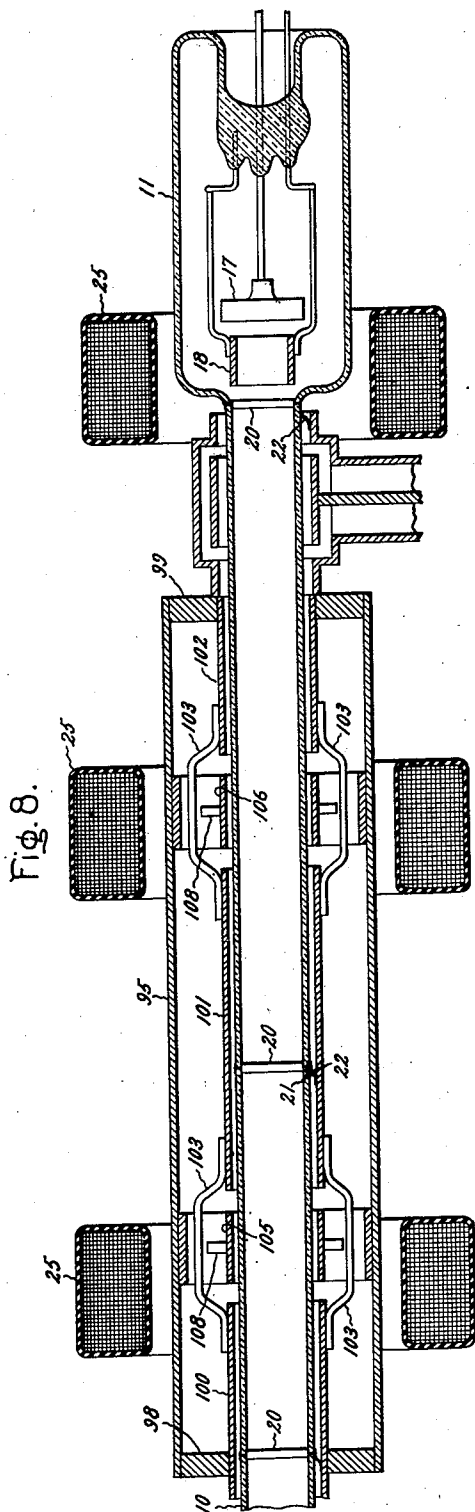
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2,498,886

ULTRA SHORT WAVE DEVICE

Filed June 1, 1938

3 Sheets-Sheet 2



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Feb. 28, 1950

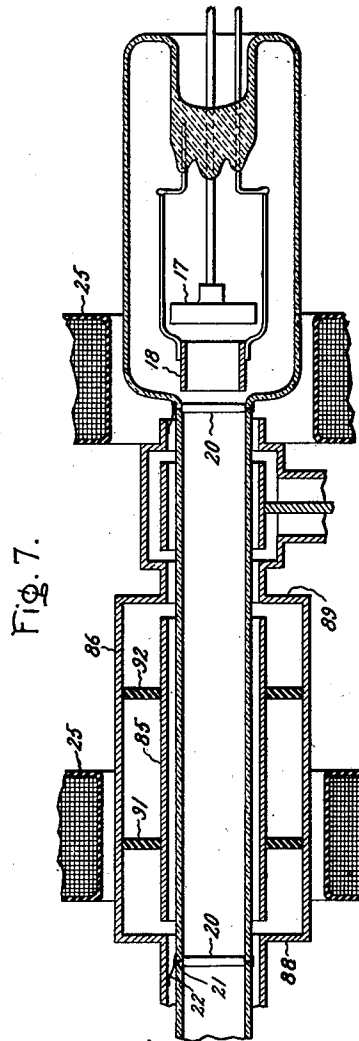
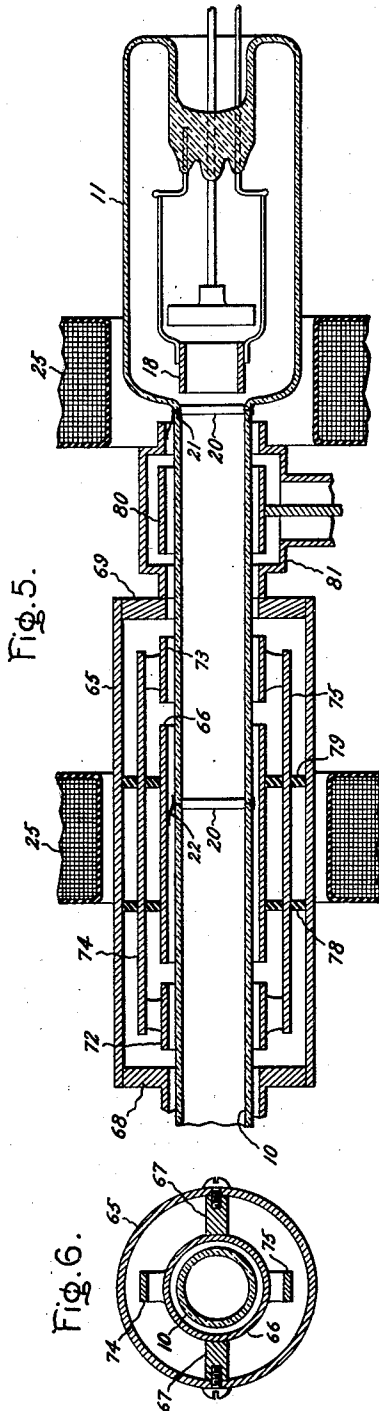
W. C. HAHN

2,498,886

ULTRA SHORT WAVE DEVICE

Filed June 1, 1938

3 Sheets-Sheet 3



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UNITED STATES PATENT OFFICE

2,498,886

ULTRA SHORT WAVE DEVICE

William C. Hahn, Scotia, N. Y., assignor to General Electric Company, a corporation of New York

Application June 1, 1938, Serial No. 211,123

32 Claims. (Cl. 315-39)

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My invention relates to discharge devices and is especially applicable in connection with ultra short wave oscillators, such as oscillators adapted to operate at from five meters to five centimeters or less. The invention represents a further application of the principles set forth in my prior application Serial No. 153,602, filed July 14, 1937, now U. S. Patent 2,220,839, granted November 5, 1940.

In the aforementioned application, it is pointed out that 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 stream. The second involves the production of variations in charge density, 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. With reference to ultra short wave devices, however, improved results are obtained by using constructions in which velocity modulation and charge density modulation are produced separately. In the prior application referred to, I have disclosed control electrode structures which function to velocity modulate an electron beam without simultaneously producing appreciable charge density variations in the vicinity of the control structure. The velocity modulation is subsequently and independently converted into charge density modulation of a higher order of magnitude so as to produce amplification effects. For reasons which need not be elaborated here, this expedient avoids the objectionable lowering of the input impedance which is observed in connection with prior art devices when they are operated at ultra high frequencies.

In application Serial No. 201,953, filed April 14, 1938, by G. F. Metcalf, now U. S. Patent 2,220,840, granted November 5, 1940, there is disclosed and claimed broadly one means by which the velocity modulation principle may be applied to short wave oscillators. It is an object of my present invention to provide alternative and improved arrangements for fulfilling the same function.

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 drawings in which Fig. 1 is a view in longi-

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tudinal section of a discharge device suitably embodying the invention; Figs. 2 and 3 are imaginative representations useful in explaining the invention. Fig. 4 comprises a modification of the construction of Fig. 1; Fig. 5 is a longitudinal sectional view of an alternative embodiment of the invention; Fig. 6 is a sectional view taken on line 6-6 of Fig. 5; Fig. 7 shows a partial section of a further embodiment of the invention and Figs. 8 and 9 are two sectional views of a still further embodiment.

In Fig. 1, the elements at the left of the figure constitute an electron gun for producing an electron beam. In the remaining figures, these elements have been omitted to conserve space, but their presence as a part of the illustrated combination is to be understood.

Referring particularly to Fig. 1, there is shown a tubular glass envelope which consists of an elongated shaft portion 10 and an enlarged anode-containing portion 11. At one extremity of the shaft portion, there is provided means for producing an electron beam, such means comprising any known type of "electron gun." The particular combination illustrated includes a cathode 13, shown in dotted outline, a focusing cylinder 14 surrounding the cathode and electrically connected thereto and an accelerating electrode 15 positioned adjacent to the focusing cylinder and maintained at a high potential with respect to the cathode.

At the opposite end of the envelope, there is provided an anode 17 which is adapted to receive electrons projected toward it from the cathode 13 and which may consist of graphite or an equivalent refractory material. Adjacent to the discharge-receiving face of the anode, there is provided a cylinder 18 which is adapted to serve as a suppressor grid for intercepting secondary electrons emitted from the anode during operation. This cylinder is ordinarily maintained at a negative potential with respect to the anode.

In the intermediate portion of the envelope, there are provided a series of electrode elements 20 which serve to fix the potential of the interior surface of the envelope wall. These may suitably comprise bands of conducting material, for example, resistance paint applied circumferentially to the interior wall surface. They are provided with lead-in connections 21 and spring contacts 22 which make it possible to apply a definite potential to the electrodes 20. With circuit connections such as those shown, the electrodes 20 are at ground potential, while the cathode is maintained several thousand volts negative by means

of a battery 23. The accelerating electrode 15 is biased to a potential intermediate that of cathode and ground, and the anode 17 is held several thousand volts above the cathode by the use of a battery 24. These potentials are, of course, exemplary and may be varied within wide limits.

In order to maintain the electron beam in focus during its passage through the envelope, there are provided a series of magnetic coils 25 mounted co-axially with the envelope. These may be excited with direct current and function in a known manner to prevent dispersion of the beam. In some cases, they may advantageously be replaced by electrostatic beam-focusing means.

The electrode combination which has been so far described comprises means for producing a unidirectional electron beam of constant average intensity and velocity. My present invention provides means by which such a beam may be caused to produce ultra-high-frequency oscillations.

In order to effect such oscillations, there is provided a modulating space of the general character described in my aforesaid application Serial No. 153,602. This may comprise, for example, a tubular chamber 30 having wall portions 31 and 31' which are transverse to the axis of the beam and which approach relatively closely to the envelope wall. These wall portions serve to fix the boundary potentials of the modulating space. They also assist in shielding the modulating space from the beam source (i. e. the cathode 13) so that potential variations which occur within the space have no effect on the cathode emission. This shielding function is improved by the use of a tubular extension 32 projecting in the direction of the cathode.

In my aforementioned prior application, I have shown that if the potential of an intermediate region of a modulating space such as that described is alternately raised and lowered with respect to the boundary potentials, velocity modulation of the beam may be produced. While numerous structures for accomplishing this result are described in the said application, only one is illustrated here. This comprises a tubular control electrode 35 having its extremities relatively close to the wall portions 31 and 31'. Assuming that the potential of this electrode is being alternately raised and lowered by application of a control potential thereto, maximum velocity modulation of the beam will occur when the length of the electrode is so correlated to the velocity of the beam that the electron transit time there-through corresponds approximately to one-half cycle (or an odd number of half-cycles) of the control potential. Under these conditions, an electron which enters the modulating space at a time when the control electrode 35 is at a positive maximum will be accelerated as it traverses the approach space between the wall portion 31 and the entrance of the tubular electrode 35. Furthermore, since it will leave the electrode one-half cycle later (that is, when the electrode potential is at a minimum), a second acceleration will occur in the approach space between the right hand extremity of the electrode 35 and the wall portion 31'. On the other hand, an electron which enters the modulating space in such time phase as to be retarded as it approaches the electrode 35 will also be retarded as it leaves the electrode. As a result of these successive accelerating and retarding effects, the beam issuing from the modulating space will be velocity modulated in the sense that recurrent variations in electron

velocity will exist from point to point along the beam.

The velocity modulation thus produced may be relatively slight if only weak control potentials are available. Its useful application lies in the fact that a relatively slight amount of velocity modulation may be converted into charge density modulation of a higher order of magnitude by means now to be described. The principle involved in the conversion may best be understood by reference to the explanatory representations shown in Figs. 2 and 3 (see second sheet of drawings).

In the first of these figures there is shown an electron beam as it is assumed to issue from the modulating space. It will be seen that this beam comprises an alternate arrangement of fast and slow electrons, the former being represented by black dots *a* and the latter by light dots *b*. In Fig. 3, the same beam is shown at a somewhat later period. At this time the fast electrons have, by virtue of their greater velocity, overtaken the slower electrons and become grouped with them. Accordingly, the electron beam as a whole has become "charge density modulated" in the sense that recurrent variations in charge density occur from point to point along its axis.

The change which has taken place is from its nature one that requires only the lapse of time and the absence of extraneous influences which might tend adversely to affect conditions within the beam. These requirements may be fulfilled in a practical manner by permitting the velocity modulated beam to pass through a relatively long "drift space" which is free from any but static potentials. In the arrangement which is shown in Fig. 1 the drift space may be considered to comprise roughly that portion of the envelope which is co-terminous with the intermediate tubular conductor 33. This tube serves to shield the drift space from external fields.

From the discussion given above it might seem that with an appropriate length of drift space even the slightest amount of velocity modulation could 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 be 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 will cease 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 occurs and the whole

process will be 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. It will be understood that during all these periods the tube as a whole is continuing its motion through space.

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 is initiated. This, in turn, over-shoots, 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:

$$L_M = 9.02 \times 10^{-5} a \frac{V_0^{5/4}}{I_0^{1/2} \lambda}$$

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.)

So far, no mention has been made of the means by which the control electrode 35 is caused to vary in potential. In accordance with my invention such means may comprise a feedback

coupling between the portion of the beam issuing from the drift space and the control electrode. In the arrangement shown the means for effecting the coupling includes a chamber 39 generally similar to the chamber 30 previously described, and a tubular electrode 41 within the chamber. In my application Serial No. 153,602 previously referred to, it has been shown that such a combination may be utilized to abstract energy from a charge density modulated electron beam. This result is obtained most satisfactorily when the length of the tubular electrode 41 corresponds approximately to the spacing between adjacent charge density maxima and minima in the beam. Under these conditions, the approach of a charge density maximum will coincide with the recession of a charge density minimum and a resultant current pulse will be induced in the electrode. Another current pulse, of opposite sign, is induced a half-cycle later when the approach of a charge density minimum coincides with the recession of a charge density maximum.

In order that these current variations may produce corresponding variations in the potential of the control electrode 35 a suitable connection must be provided between that electrode and the electrode 41. For oscillator operation this connection preferably comprises a circuit which is resonant at the desired frequency of oscillation. If this condition be fulfilled the system may be maintained in self-sustained oscillation by mutual reaction with the beam.

For ultra high-frequency operation, it is difficult to form a satisfactory circuit from conventional circuit elements. It is, therefore, preferable to utilize as a feed-back connection conductive elements which inherently function as a resonant transmission line. In the arrangement shown in Fig. 1 these elements comprise an outer tubular conductor 44 and an inner concentric conductor 41, the two in combination forming a co-axial transmission line which is open-circuited at both ends. Because of the resonance in this line the structure may be referred to as a space-resonant device. For resonant operation, the theoretical optimum length of such a line is a half-wave length or a number of half-wave lengths. However, because of the capacitive end loading caused by the electrodes, the line itself, insofar as it consists of the combination of the conductors 44 and 41 should be somewhat less than the theoretical length.

If it be assumed that the system described is started in oscillation, say by virtue of random electron velocity variations in the beam, sustained operation will ensue. In this operation, velocity modulation is produced by potential variations of the electrode 35; the velocity modulation is converted into charge density modulation in the drift space within the tube 38, and the reaction of the charge density modulated beam on the electrode 41 and the transmission line maintains the system in a state of continuous oscillation.

In order that energy may be taken from the oscillating system thus established and fed to an external utilization circuit, some additional means of coupling to the beam must be provided. In Fig. 1, this is accomplished by coupling capacitively to the electrode 41 by means of a conducting plate 47 positioned in proximity thereto. This plate may constitute one terminus of a conductor 48 which forms the inner member of a concentric transmission line the inner and outer conductors of which comprise a space-resonant

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device. The outer conductor of the transmission line comprises a conducting tube 50 extending outwardly from the chamber 39. This line may also be of the resonant type and may be connected at its outer extremity to a suitable circuit or to another discharge device, such as an amplifier.

An alternative means of taking power from the charge density modulated portion of the beam is shown in Fig. 4 in which parts corresponding to those previously described are similarly numbered. In this case, the energy-abstracting means comprises the combination of a shielded chamber 55 and a tubular electrode 56 which is traversed by the electron beam after its passage through the drift space. These elements function in a manner similar to that of the elements 39 and 41 described in connection with Fig. 1. However, in this case the induced current is fed into an external utilization circuit which is entirely independent of the feed-back system. A concentric transmission line having conductors 57 and 58 affords a convenient connection between the electrode 56 and the utilization circuit. This system has an advantage over that shown in Fig. 1 in that it imposes less loading on the oscillating feed-back circuit. Since it is entirely separate from that circuit, it has no damping effect whatever on it.

With a feed-back coupling arrangement such as that described in connection with Figs. 1 and 4, the losses in the feed-back circuit are still somewhat greater than one might desire. This is due in part to the fact that mechanical requirements make it difficult to keep the length of the transmission line as short as theoretical considerations would suggest (i. e., one-half wave length). That is to say, the fact that the transmission line must pass outwardly around the focusing coil 25 imposes a definite restriction on the least length which can be employed. Furthermore, it is necessary because of space limitations to make the diameter of the outer conductor 44 considerably less than the value which is optimum from the standpoint of power loss.

In Fig. 5, an alternative arrangement is shown whereby this difficulty may be overcome. (Here again parts which have been already described bear similar numbers). In this case, the outer conductor of the transmission line comprises a conductive shell 65 which encloses the beam path for a substantial portion of its length. Within this shell, there is provided another tubular conductor 66 which is concentric with it and which is directly electrically connected to the shell by intermediate members 67 shown in Fig. 6.

The tubular conductor 66 encloses a drift space, as hereinbefore defined, while its extremities determine certain boundaries of a modulating space and of an energy-abstracting space. The other boundaries of these spaces are formed by transverse annular wall members 68 and 69 which extend inwardly from the conductive shell 65. In the gaps which exist between these members and the extremities of the tubular conductor 66, there are positioned electrodes 72 and 73 which correspond in function to the electrodes 35 and 41 shown in Fig. 1. These electrodes are connected by means of longitudinally extending conductors 74 and 75 which pass through and engage insulating spacers 78 and 79.

By proper choice of dimensions, the conductors 74 and 75 can be made to function as the

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inner elements of a resonant transmission line of which the shell 65 and the tubular member 66 form the cooperating parts. Assuming that the shell is solidly grounded, it can be considered that standing waves are formed along the conductors 74 and 75, these waves having maximum values at the conductor extremities (if the conductors are one-half wave length long). With this arrangement, velocity variations produced by electrode 72 in the space between the annular wall member 68 and the left hand extremity of the tubular member 66 will be converted into charge density modulations within the space confined by the member 66. These charge density variations in turn will so react on the electrode 73 as to maintain the standing waves on the conductors 74 and 75 and to sustain the system in oscillation. Energy may be taken from the oscillator by means of a tubular electrode 80 and an enclosing conducting structure 81.

In Fig. 7, I have shown a further modification which represents a simplification of the structure of Fig. 5. In this embodiment the conductive elements of the feed-back space-resonant system comprise simply an inner tubular member 85 and an outer shell 86 concentric therewith. The outer shell is provided with transverse conductive end walls 88 and 89 which cooperate with the extremities of the member 85 to permit the establishment of potential gradients acting on the electron beam. Insulating spacers 91 and 92 serve to maintain the various parts in the desired relationship.

With this arrangement the outer shell 86 and the tubular member 85 form a resonant transmission line which is adapted to oscillate at a characteristic frequency determined by the length of these parts. Such oscillations may be established and maintained by the reaction of the beam as it traverses the approach spaces formed between the ends of the member 85 and the opposed surfaces of the walls 88 and 89. In the left hand one of these spaces velocity modulation of the beam will take place, and in the right hand space energy abstraction will occur as the beam issues from the drift space provided by the member 85. The velocity of the beam should be so correlated to the length of this member as to assure effective conversion of the velocity modulation into charge density modulation in accordance with the principles already explained. As a result of this arrangement a standing wave having voltage maxima at its ends will be maintained along the member 85, thus providing periodically varying potential gradients across the approach spaces. Energy may be taken from the beam for transmission to an external circuit by means of an electrode 94 coupled thereto.

The combination just described has the advantages of structural simplicity and of low capacitive loading at the ends of the transmission line. From the latter viewpoint it is especially adapted for use at extremely short wave lengths. However, it is markedly less effective in its reaction on the beam than the other arrangements referred to above. This is a result of the fact that only one approach space is provided at each end of the line. For reasons which need not be fully set forth here, this halving of the number of approach spaces results in a reduction to one-fourth of the "mutual conductance" of the system.

For tubes intended to be used at extremely high frequencies it is desirable to preserve the feature of low end loading in order to permit the use of a full half-wave length transmission line. (High

end loading requires a compensatory foreshortening of the line and results in inconveniently small parts.) This may be done with diminishing the number of approach spaces by the use of a construction such as is shown in Figs 8 and 9. In this embodiment the transmission line comprises the combination of an outer conductive shell 95 and an inner tubular structure which is within the shell and extends longitudinally thereof. These parts in combination form a line which is closed at its ends by means of transverse wall members 98 and 99 extending between the extremities of the shell and the tubular structure.

The tubular structure referred to comprises a series of conducting tubes numbered 100, 101 and 102 respectively, the tubes being relatively spaced so as to provide gaps between them. These gaps are conductively bridged by means of metallic elements 103 connecting with the various tubes. In each of the gaps there is provided a tubular electrode (indicated at 105 and 106) which corresponds in nature and function to the electrodes 35 and 44 described in connection with Fig. 1. In this case however, the electrodes are directly electrically connected to the shell 95 by means of metallic members 108 extending between them (see Fig. 9). Consequently, assuming that the shell 95 is solidly grounded, it may be considered that the electrodes 105 and 106 are maintained at a fixed invariable potential. On the other hand potential variations (resulting from the creation of a standing wave) may be caused to occur from point to point along the elements 100 to 103. As a result of the oscillatory variations of the standing wave, the extremities of the tubes 100, 101 and 102 nearest to the electrodes 105 and 106 will be caused to rise and fall in potential with respect to these electrodes. Consequently, velocity variations of the beam will be produced adjacent to former electrode while feed-back will occur at the latter as a result of charge density variations in the portion of the beam which traverses it.

The combination just described may alternatively be operated as a full wave or a half-wave transmission line. In either case satisfactory operation will result if the beam velocity be properly correlated to the length of the tubular elements 101, 105 and 106. As to the element 101 the correlation should be with a view to obtaining substantial charge density modulation in the drift space provided within that element. As to the electrode 106 on the other hand, the best operating condition is that in which the length of the electrode corresponds, at least approximately, to the spacing between adjacent charge density maxima and minima in the beam.

It will be noted that with the construction of Fig. 8 the area of the electrodes 105 and 106 which is exposed to parts at a different potential from the electrodes is relatively small. (This is a result of the fact that most of the parts which surround the electrodes are directly electrically connected to them.) Consequently the capacitive loading imposed on the feed-back system by the presence of these electrodes is appreciably less than in the constructions of Figs. 1 to 6. It is, therefore, possible to make the transmission line function as a half-wave line without such compensatory shortening of its parts as would make their dimensions impracticably small. This is a feature which is of special value at the higher frequencies and which, therefore, gives this modification particular utility at wave-lengths below, say, 30 centimeters.

While I have described my invention in connection with particular structures, it will be understood that many modifications may be made by those skilled in the art without departure from the invention. I, therefore, aim in the appended claims to cover all such equivalent variations as fall within the true spirit and scope of the foregoing disclosure.

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

1. In high frequency apparatus, the combination which comprises means for producing a beam of electrons, a plurality of aligned tubular conductive members mutually spaced to permit the establishment of potential gradients acting on the beam at a plurality of points along its axis, the said members being dimensionally correlated to the velocity of the beam so as to assure effective mutual reaction with the beam for a desired condition of operation of the apparatus, and a conductive shell coaxially surrounding the said members, the said shell serving by virtue of its electrical coaction with the members to provide effective feed-back between members last traversed by the beam and those initially traversed by it, thereby to maintain the apparatus in self-sustained oscillation at a frequency corresponding to the said desired condition of operation.

2. An oscillator comprising means for developing an electron beam, means including a control electrode structure effective to produce velocity modulation of the beam without producing appreciable charge density variations in the vicinity of the electrode structure, means providing a drift space to be traversed by the beam after production of such velocity modulation, the drift space being sufficiently long to effect transformation of the velocity modulation into charge density modulation, and means functioning as a transmission line resonant at the desired frequency of oscillation of the oscillator for providing feed-back coupling between the control electrode structure and the portion of the beam issuing from the drift space.

3. An oscillator comprising an elongated tubular envelope, means for projecting an electron beam longitudinally through the envelope, a first set of conductive elements coupled to the beam for producing velocity modulation thereof, means providing a drift space to be traversed by the beam after production of such velocity modulation, the drift space being sufficiently long to effect transformation of the velocity modulation into charge density modulation of a higher order of magnitude, means providing a feed-back coupling between the portion of the beam issuing from the drift space and the said conductive elements thereby to maintain the oscillator in self-sustained oscillation, and another set of conductive elements coupled to the last-mentioned portion of the beam independently of the feed-back means for abstracting energy from the beam.

4. The combination which includes means for producing an electron beam, means for velocity modulating the beam, means providing a drift space of substantial length to be traversed by the beam after velocity modulation thereof, conductive elements coupled to the portion of the beam issuing from the drift space, a conductive shell surrounding the beam and extending longitudinally thereof at least throughout the region which comprises the drift space, and means within the shell forming therewith a resonant transmission line connecting between the said conduc-

tive elements and the velocity modulating means, thereby to maintain the system in self-sustained oscillation.

5 The combination which includes means for producing an electron beam, conductive elements for producing potential gradients acting longitudinally on the beam at two spaced regions thereof, the said regions being sufficiently spaced so that electron velocity variations produced by gradients acting at the region nearer the beam source may be converted into appreciable charge density variations in the distance intervening between the regions, and an elongated conductive shell surrounding the beam path and the conductive elements and forming in conjunction with the said elements a resonant transmission line adapted to function as a feed-back connection between the two regions, thereby to maintain the combination in self-sustained oscillation.

6 The combination, which includes means for producing an electron beam, a pair of concentric tubular metal shells surrounding the beam path for a substantial portion of its length, the inner shell being appreciably shorter than the outer shell and being directly electrically connected thereto, means projecting inwardly from the ends of the outer shell so as to provide conductive surfaces in spaced opposed relationship to the extremities of the inner shell, a pair of tubular electrode elements respectively positioned in the spaces between the said surfaces and the said extremities and cooperating therewith to permit the establishment of potential gradients acting on the beam, and means connecting the said electrodes and forming in conjunction with the tubular shells a resonant circuit adapted to be maintained in oscillation by mutual reaction with the beam.

7 The combination which includes means for producing an electron beam, a tubular member surrounding the beam path for an appreciable portion of its length, a conductive shell concentric with and surrounding the said tubular member, means conductively connected with the said shell and cooperating with the extremities of the tubular member to permit the production of potential gradients acting longitudinally on the beam adjacent such extremities, the tubular member and the shell comprising in combination a resonant circuit which is maintained in oscillation by the reaction of the beam, and means coupled to the portion of the beam issuing from the tubular member for receiving energy therefrom.

8 An oscillator including an anode and cathode for producing an electron beam, an elongated conductive shell enclosing the path of the beam, a conductive tubular structure within the shell and forming therewith a resonant transmission line, said tubular structure also enclosing the path of the electron beam and being provided with a pair of spaced gaps, conductive means bridging said gaps, and electrode members in said gaps connected to the conductive shell so as to be maintained at a fixed potential with respect thereto, the electrode members and the tubular structure cooperating through the intermediation of the electron beam to maintain the transmission line in self-sustained oscillation, and means coupled with the beam after its passage through the conductive shell for receiving energy from the beam.

9 An electron discharge device having a tank circuit including a pair of concentric tubular

conducting members which, in combination, form a standing wave system, a further conducting member spaced axially from the inner tubular member to provide a gap therebetween, said further member being permeable to electrons and being electrically connected to the outer tubular member, means for projecting a stream of electrons axially of said tubular members and across said gap, and means for modulating said stream prior to its passage across the gap, thereby to produce excitation of the tank circuit.

10 An electron discharge device having a tank circuit including a pair of concentric tubular members which, in combination, form a standing wave system, another tubular member coaxial with the inner of the two concentric tubular members and axially spaced therefrom to provide a gap between the members, said other member being electrically connected to the outer concentric member, means for projecting a stream of electrons axially of said tubular members across said gap, means for modulating said stream of electrons prior to its passage across said gap and means for collecting the electrons after passage through said tubular members.

11 An electron discharge device having a tank circuit including a pair of concentric tubular conducting members which, in combination, form a standing wave system, a further conducting member spaced axially from the inner tubular member to provide a gap therebetween, said further member being permeable to electrons and being electrically connected to the outer tubular member, means for projecting a stream of electrons axially of said tubular members and across said gap, and means adjacent the end of the inner tubular member more remote from the gap for modulating the electron stream at a frequency corresponding to the resonant frequency of the tank circuit, thereby to produce excitation of such circuit by passage of the modulated electron stream across the gap.

12 An electron discharge device including a tank circuit having a pair of coaxial tubular members spaced axially to form a gap and a concentric outer tubular member forming a standing wave system with one of said coaxial tubular members, a cathode and grid positioned adjacent one end of one of said pair of coaxial tubular members for projecting an electron stream axially of said coaxial tubular members and across said gap to excite the said standing wave system, and a collecting electrode for receiving the electron stream after its traversal of the said tubular members.

13 Electric discharge apparatus including an elongated hollow electrode which is enabled to resonate as a standing wave system by virtue of its relationship to the other parts of the apparatus structure, a pair of electron permeable conducting members which form parts of the apparatus structure and which are respectively spaced from the extremities of the said electrode to provide gaps adjacent such extremities, and means for projecting an electron stream through the said conductive members and axially of the electrode, thereby to produce excitation of the said standing wave system by the action of the stream at the said gaps.

14 Electric discharge apparatus including an elongated hollow electrode, conductive means constituting a part of the said apparatus structure and positioned in proximity to the said electrode, the electrode forming in conjunction with the said conductive means a resonant stand-

ing wave system, electron permeable conducting members respectively spaced from the extremities of the said electrode to provide gaps adjacent such extremities, and means for projecting an electron stream through the said conductive members and axially of the electrode at such velocity as to produce excitation of the said standing wave system by the action of the stream at the said gaps.

15. The combination which includes means for producing an electron beam, a tubular conductive member surrounding the beam path for an appreciable portion of its length, a conductive shell surrounding the said tubular member, and further electron permeable conductive members which are respectively spaced from the extremities of the said tubular member to provide gaps adjacent said extremities, the said member and the said conductive shell comprising in combination a standing wave system which is adapted to be maintained in oscillation by the reaction of the electron beam on the members at the said gaps.

16. The combination which includes means for producing an electron beam, a tubular conductive member surrounding the beam path for an appreciable portion of its length, a conductive structure surrounding the said tubular member, means conductively connected with the said structure and cooperating with the extremities of the tubular member to produce potential gradients acting longitudinally on the beam adjacent said extremities, the tubular member and the said conductive structure comprising in combination a standing wave system which is adapted to be maintained in oscillation by the reaction of the electron beam thereon.

17. Apparatus of the character described having, in combination, means for creating a confined standing electromagnetic field having an electric field portion extending in a predetermined region, means for confining the electric field portion to the region, and means for passing an electron stream through the electric field portion to cause the electrons to assume periodically varying velocities and thereafter past the field to cause the electrons to become concentrated in groups.

18. Apparatus of the character described having, in combination, means for creating an electron stream of substantially uniform velocity, a space-resonant device, means for creating a standing electromagnetic field within the space-resonant device, the exterior surface of said device being free of alternating potentials of the frequency of operation of the apparatus, and means for directing the electron stream through the field of the space-resonant device to cause the electrons to assume periodically varying velocities due to the action of the internal field therein.

19. Apparatus of the character described having, in combination, means comprising a space-resonant device for creating an electron stream having the electrons thereof concentrated in groups, and means for passing said groups when formed into said space-resonant device for absorbing the energy of the groups in said space-resonant device.

20. Apparatus of the character described having, in combination, means for creating an electron stream, means comprising a space-resonant device for causing the electrons of the stream to become concentrated in groups external to the field of said device, and means comprising said space-resonant device for absorbing energy from the groups.

21. Apparatus of the character described having, in combination, means for creating an electron stream, means comprising a space-resonant device for periodically varying the velocity of the electrons of the stream, means for causing the electrons of the stream thereafter to become concentrated in groups, and means for passing said group into the field of said space-resonant device whereby said field absorbs energy from the groups.

22. Apparatus of the character described having, in combination, means for creating an electron stream, means comprising a space-resonant device for causing the electrons of the stream to become concentrated in groups, and means comprising said space-resonant device for absorbing energy from the groups.

23. Apparatus of the character described having, in combination, a space-resonant device, means for producing a grouped electron stream for traversing the space-resonant device, and means comprising the grouped stream for creating an alternating electromagnetic field in the space-resonant device to absorb energy from the stream, said first means including means to subject electrons to said field to produce said grouped electrons stream.

24. In combination, an apertured hollow member having a conducting portion, a second apertured smaller hollow member also having a conducting portion suspended within said first member and spaced therefrom to provide a hollow cavity resonator between the outer surface of said inner member and the inner surface of said outer member, means for providing an oscillating electromagnetic field within said hollow cavity resonator at a resonant frequency thereof comprising, means for producing a beam of electrons, means for projecting said beam through an aperture of said first member, through the space between the inner wall of said first member and said second member, through said second member and outwardly thereof through a second space between said second member and said first member, to thereby set up standing electromagnetic waves between said inner and outer hollow members at the natural frequency of said hollow cavity resonator for cyclically varying the number of electrons emerging from within said inner hollow member into the second space between said inner and outer members, to enhance and maintain the standing waves at the natural frequency of said hollow cavity resonator.

25. In a generator of electromagnetic waves comprising an electromagnetically resonant hollow conducting member arranged to have an electric field therein, means for producing a stream of electrons, means for projecting said stream of electrons through a portion of the electric field of said resonator wherein energy change is suffered by the electrons of said stream to initiate velocity grouping of electrons, means for shielding said electrons from the field of said resonator for a time interval sufficient to allow velocity grouping to be completed, and means for projecting said velocity grouped electrons through another portion of the electric field of said resonator wherein the electrons suffer changes of energy to deliver electromagnetic energy to said resonator.

26. An electron discharge device circuit having a tank, said tank being comprised of an outer conductor and a single hollow inner coaxially arranged conductor separated axially at both ends from said outer conductor by gaps, the

length of said inner conductor between said gaps being a multiple including unity of one-half the length of the operating wave corresponding to the resonant period of said tank, a source of electrons for projecting a stream of electrons through the entire length of said hollow inner conductor and across said gaps in succession, and means for attracting and collecting the electrons crossing the last gap to be traversed by said electrons.

27. In an electronic apparatus having means for producing an electron beam, a resonant electrode system including a conductive structure surrounding the beam for a substantial portion of its path length, and including a single conductive tubular element a multiple, including unity, of a half wave long concentrically positioned within said structure so as to be axially traversed by the beam and spaced at its extremities from said conductive structure to provide a pair of gaps to be traversed by said electron beam, the length of said tubular element being correlated to the average velocity of the beam and to the desired frequency of operation of the apparatus.

28. An electronic device including an electronic gun, means for beaming the electrons from said gun, a hollow resonant electrode for shielding electrons projected from external fields, said resonant electrode having an effective length equal to an integral number of half wave lengths of the oscillatory currents established thereon, means for directing said beam of electrons through said hollow electrode along its longitudinal axis, and means for adjusting the velocity of the electrons passing through said hollow electrode so that the distribution of oscillatory potentials along the length of said electrode alters the energy of said electrons.

29. An electronic device including a source of electrons, means for beaming said electrons, a hollow resonant electrode for shielding electrons within said hollow from external fields, said electrode having such length that it resonates at the operating frequency, means for directing said

beam through said hollow electrode along its longitudinal axis, and means for adjusting the period of dwell of electrons within said hollow electrode so that the oscillatory potentials on the ends of said hollow electrode alter the energy of electrons entering and leaving said hollow electrode.

30. An electronic oscillator including a hollow resonant electrode for shielding electrons within said hollow from external fields, said electrode having such a length that it resonates at the operating frequency, means for establishing a beam of electrons, means for directing said beam through said electrode along its longitudinal axis, and means for adjusting the velocity of said electrons within said electrode so that oscillatory currents are created and sustained in said electrode as a function of its resonant characteristics.

31. In a device of the character of claim 28, an apertured diaphragm electrode adjacent the hollow end of said resonant electrode, and means for adjusting the electron transit time between said last two electrodes.

32. In a device of the character of claim 28, a pair of apertured diaphragm electrodes located at the opposite ends of said resonant electrode, and means for adjusting the electron transit times between said diaphragm electrodes and said hollow electrode ends.

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

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Certificate of Correction

Patent No. 2,498,886

February 28, 1950

WILLIAM C. HAHN

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows:

Column 9, line 3, for the word "with" read *without*;
and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 25th day of July, A. D. 1950.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.