

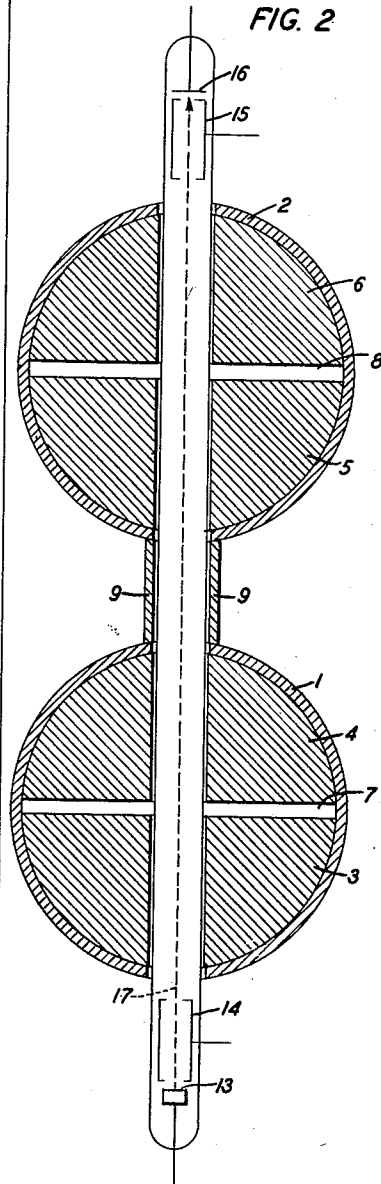
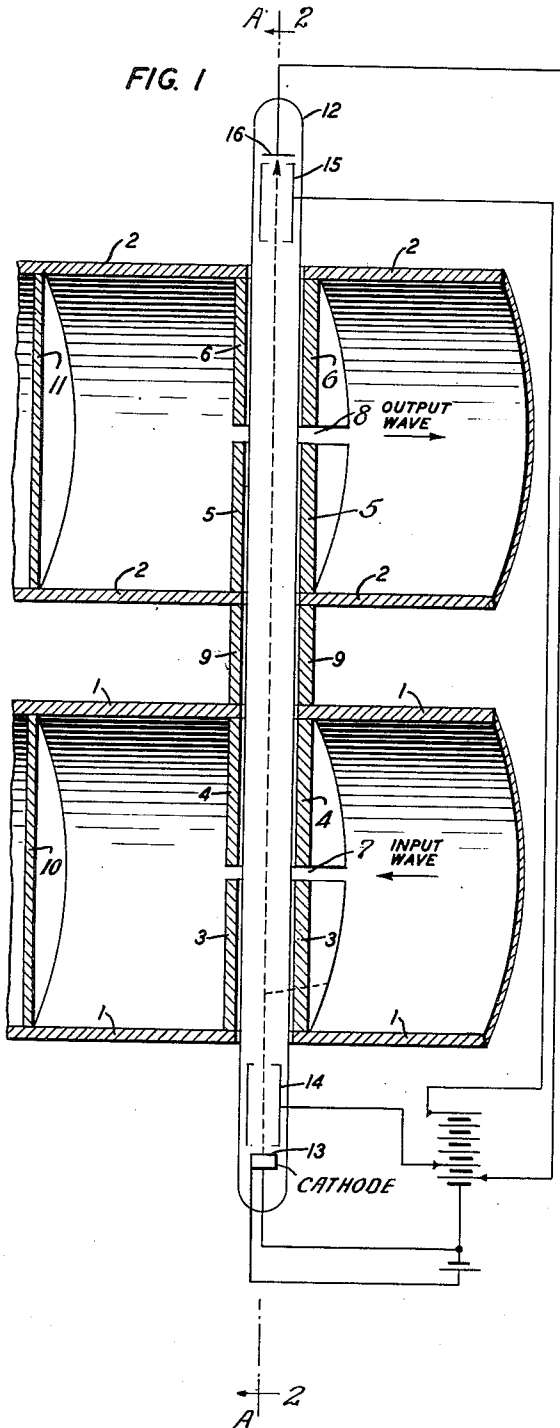
Jan. 23, 1945.

F. B. LLEWELLYN  
ELECTRON DISCHARGE DEVICE

2,368,031

Filed March 15, 1940

4 Sheets-Sheet 1



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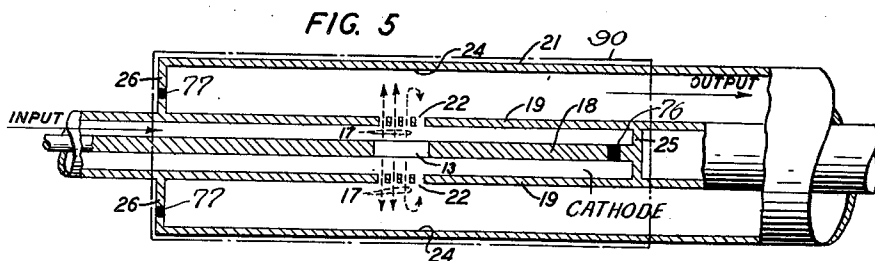
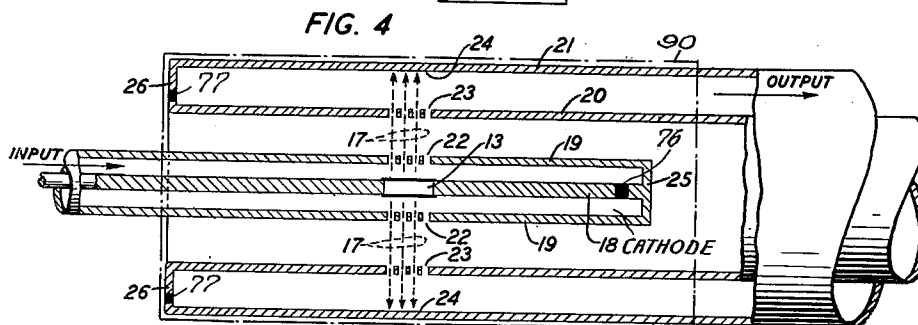
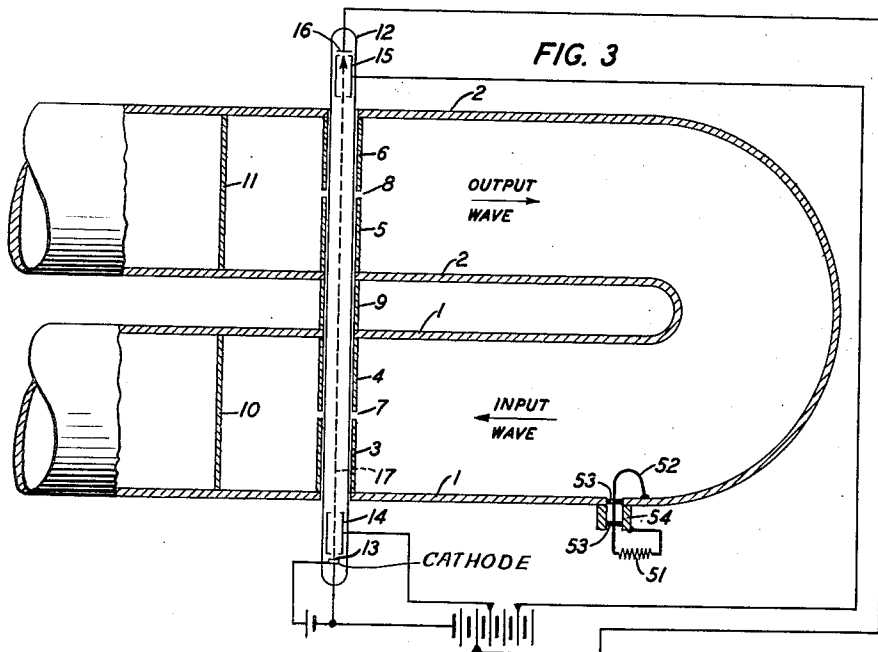
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4 Sheets-Sheet 2



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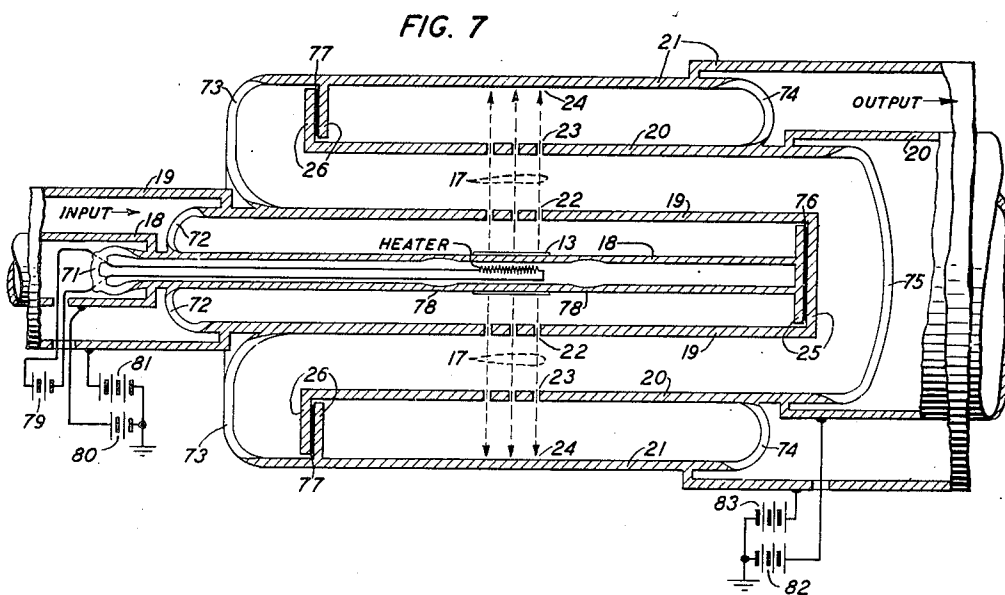
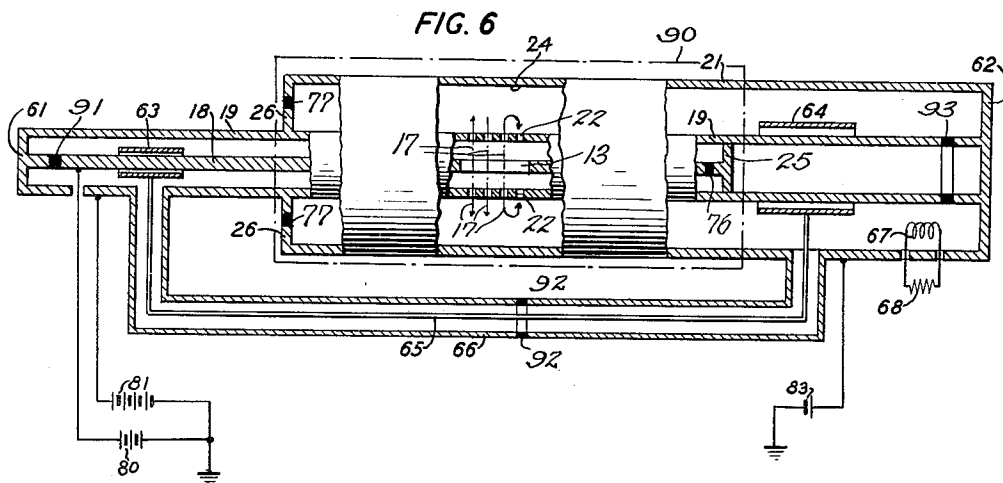
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ELECTRON DISCHARGE DEVICE

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4 Sheets-Sheet 3



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ELECTRON DISCHARGE DEVICE

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4 Sheets-Sheet 4

FIG. 8

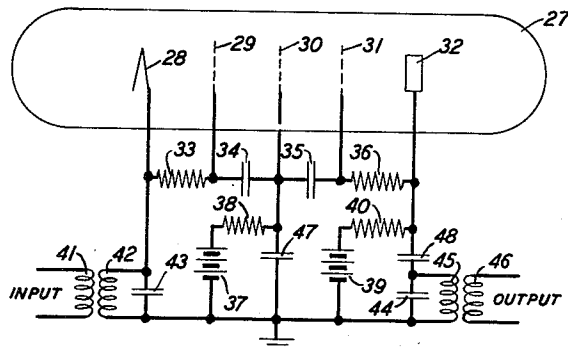


FIG. 9

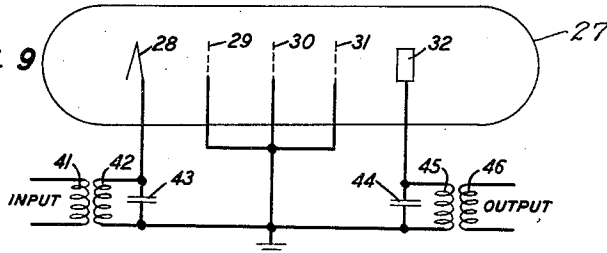


FIG. 10

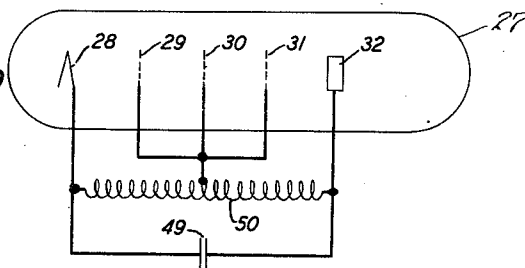
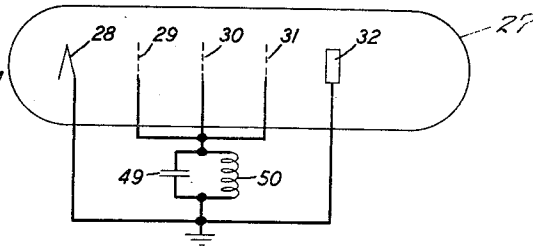


FIG. 11



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## UNITED STATES PATENT OFFICE

2,368,031

## ELECTRON DISCHARGE DEVICE

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Application March 15, 1940, Serial No. 324,058

10 Claims. (Cl. 315—6)

This invention relates to ultra-high-frequency circuits and more particularly to those in which high frequency energy is developed through interaction between moving electrons and a high frequency electromagnetic field.

A principal object of the invention is to utilize conventional wave guide, transmission line and tube structures for the purposes of high frequency amplification and oscillation.

Another object is to produce directly within the transmission medium, wave guide or coaxial line, the high frequency energy resulting from amplification or oscillation.

Previous conventional oscillator and amplifier circuits are generally unsuitable for use at ultra-high frequencies because high losses are encountered and also on account of effects due to the high frequency period becoming comparable to the time required for electrons to traverse the spaces between vacuum tube elements. Such difficulties are avoided according to this invention by arranging for the transfer of energy from an electron stream directly to the electric field within a transmission medium and also by utilizing spaces between the elements of a vacuum tube to velocity modulate and group electrons and then extract energy from them at high frequency.

In operation utilizing the velocity modulation principle the electron control element of an electron discharge device energized by the high frequency input circuit acts to vary the velocity of the electrons of a steady or substantially constant density stream without affecting substantially the density of the stream in the region of the control element. Casual variations in electron density occurring in the region of the control element are of minor importance, the substantial variations utilized for producing high frequency energy in the output circuit occurring after the electron stream has passed the influence of the control element and as a result of the velocity variations previously impressed by it.

This velocity modulation operation minimizes losses occasioning input loading due to high frequency currents being induced in the input circuit by variations in the density of the electron stream, or in other words in the electron conduction current, as the stream traverses the region of the control element.

As stated by W. C. Hahn and G. F. Metcalf in an article entitled "Velocity modulated tubes," page 106, Proceedings of the Institute of Radio Engineers, February, 1939:

"One method of reducing these losses is to reduce the transit angles, and is the method so far

used. Another method would be to arrange the grid structure so that the grid voltage does not directly produce conduction-current variations at signal frequency but varies the velocity of the electron stream. The variations in longitudinal velocity thus produced are then converted into variations in conduction current."

This latter method, which the above article characterizes by the term "velocity modulation" and for which method of operation the system is designed to have the high frequency output dependent upon the conversion of electron velocity variations into density variations of the electron stream in the output region of the electron tube thereby avoiding otherwise required substantial variations in the rate of flow or density of the electron stream by direct action of the control element, is the method utilized by the devices to be described.

The various features of the invention will be understood from the following detailed description of the illustrative embodiments shown in the accompanying drawings.

In the drawings:

Fig. 1 and Fig. 2 show an amplifier arrangement employing velocity modulation and a drift space for grouping the electrons applied to a wave guide circuit;

Fig. 3 shows a modification of Fig. 1 arranged to function as an oscillator;

Fig. 4 shows an amplifier arrangement employing velocity modulation and a drift space for grouping the electrons applied to a coaxial transmission line;

Fig. 5 shows a modification of Fig. 4 in which the drift space for grouping the electrons has been eliminated;

Fig. 6 shows a modification of Fig. 5, which is applicable to Fig. 4 also, whereby the input and output are coupled together to produce self-oscillation;

Fig. 7 indicates a practical form of construction of the arrangement shown in Fig. 4, which is also applicable to the arrangement shown in Fig. 5. Structural features not shown in Fig. 4 and Fig. 5 are indicated;

Fig. 8 shows an amplifier arrangement using a pentode tube in which velocity modulation and a drift space for grouping the electrons are employed;

Fig. 9 shows the high frequency circuit of Fig. 8; and

Figs. 10 and 11 show modifications of Fig. 9 to permit oscillation rather than amplification.

Fig. 1 and Fig. 2 are views, in section, of the ter-

minating portions of two circular wave guides between which an amplifier is inserted. The two guides 1 and 2 might be parts of one continuous guide were it not desired to effect amplification and it may be considered that the line is cut and terminated at 10 and 11 to form the input and output circuits of the amplifier. Also, the guides may be other than circular in section, if desired. The source of amplified energy is the electron gun shown passing through the two portions of wave guide. This gun is shown as made up of the envelope 12, cathode 13, accelerating electrodes 14 and 15 and collector 16 and an electron stream is directed from the cathode 13 to collector 16 as indicated by line 17. The gun may be of any form suitable for directing an electron stream through the portions of wave guide as indicated and instead of using a gun separately constructed and inserted through openings in the guide as shown for an example in the drawings, one made integral with the guide structure may be employed.

The input of the amplifier comprises wave guide portion 1 and the input wave arrives as indicated. The output of the amplifier comprises wave guide portion 2, the output wave leaving as indicated by the arrow. The input wave, through the field set up by it in guide 1, reacts upon the electron stream at gap 7 between members 3 and 4 and the electron stream reacts upon the output wave in guide 2 to deliver energy to it at gap 8 between members 5 and 6. The metallic members 3, 4, 5 and 6 may be 180-degree sectors of discs fitting inside of the guide portions and with material removed along the straight edge to allow the open gaps at 7 and 8. The disc sectors 3, 4, 5 and 6 are of sufficient thickness to permit a hole through the center parallel to the surfaces for insertion of the electron gun as indicated. These members 3, 4, 5 and 6, shield the electron stream from the fields within the guides except at the places of gaps 7 and 8 and the disc sectors, closely fitting the guide, are preferable to a slotted tube for the purpose since undesirable resonance effects of the tube in conjunction with the walls of the guide are avoided. 9 may be a metallic tube between the guide portions to complete the shielding of the electron stream between 7 and 8. The end closures 10 and 11 of the guide portions are placed approximately  $\frac{1}{4}$ ,  $\frac{3}{4}$  or  $\frac{5}{4}$ , etc., wave-length (based on the wave velocity in the guide) from the position of the electron stream so that the reflected waves reinforce the fields at the gaps 7 and 8 to give maximum fields for reaction with the electron stream.

In operation, the electric field of the input wave arriving in guide 1 acts to velocity modulate the steady electron stream at gap 7. That is, electrons entering the field in the gap 7 in one phase of the field are accelerated while electrons entering in the other phase are retarded so that from this point on there is a cyclic variation in the velocities of the electrons. In passing through the field free drift space from 7 to 8, the accelerated electrons tend to overtake previously retarded electrons while the retarded electrons tend to lag and be overtaken by later accelerated electrons. Consequently, in passing from 7 to 8 the electrons become grouped so that at 8 the stream is no longer of uniform density but is density modulated in accordance with the alternating input wave. At gap 8 each group of electrons is retarded by the electric field at that point and the energy lost by the electrons is given to

the output wave. After passing 8 and 15, the electrons are collected at relatively low velocity by collector 16. Since the grouping of the electrons is done by the input wave, the output wave which is generated by the grouped electrons is in accordance with the input and represents an amplification of it which is transmitted as desired in wave guide 2. This arrangement is therefore an efficient amplifier for use in wave guide circuits, the high frequency energy being generated directly within the guide in which it is to be transmitted.

Fig. 3 shows how the arrangement of Fig. 1 and Fig. 2 may be modified by connecting guide portions 1 and 2 together converting the amplifier circuit into an oscillator circuit. The electron gun and terminal portions of the guides are the same as in Fig. 1. The terminal portions, however, instead of being connected, 1 to an incoming guide and 2 to an outgoing guide, are connected together by a length of wave guide so that the generated output wave is transmitted to the input guide portion 1 for velocity modulating the electron stream at gap 7. The time required for the wave to travel in the guide from 8 to 7 and the electron transit time through the drift space from 7 to 8 must be such that the electric fields associated with the input and output waves at 7 and 8, respectively, are in the proper phase relation to cooperate in sustaining oscillations. The operation of the circuit is otherwise the same as that of Fig. 1. Any of the known methods of coupling to a wave guide may be employed to derive high frequency energy from this oscillator system. One possible method is illustrated in Fig. 3 where the lead 52 forms a coupling loop within the guide and is then carried by insulating spacers 53 through the shield 54 to the load 51, 54 and the outer shell of the wave guide completing the circuit between the ends of 51 and 52.

An arrangement for providing amplification in a coaxial transmission line circuit by utilizing velocity modulation of an electron stream and direct coupling of the electron stream with the electric fields in the transmission line in a manner similar to that described in connection with Fig. 1 is shown in Fig. 4. Here the terminal portions of the incoming and outgoing lines are of different diameters, are made to overlap and are shown concentric one within the other. The incoming line, carrying the input energy, comprises inner conductor 18 and outer conductor 19 and is terminated by a short circuit for high frequencies at 25. An insulating spacer indicated at 76 provides insulation for direct current potentials but has sufficient capacitance to provide a virtual short circuit at high frequencies. The inner conductor is supported within the outer conductor and insulated therefrom elsewhere by insulating spacers, not shown. The outgoing line, carrying the amplified output energy, comprises inner conductor 20 and outer conductor 21 and is terminated by a short circuit for high frequencies at 26. An insulating spacer indicated at 77 provides insulation for direct current potentials but has sufficient capacitance to provide a virtual short circuit at high frequencies. The inner conductor is supported within the outer conductor and insulated therefrom elsewhere by insulating spacers, not shown. Insulating supports obviously required for maintaining the relative positions of the terminal portions of the two lines are also omitted to simplify the drawing. The boundary of the evacuated enclosure is indicated by line 80. A portion of the inner con-

dactor 18 of the input line is made an electron emitting cathode as indicated at 13 from which electrons are emitted radially in all directions perpendicular to the common axis of the lines. The construction of such a cathode is shown in more detail in Fig. 7. At 22 in the outer conductor of the input line opposite to and surrounding cathode 13 is placed a grid to control and permit passage of the electron stream. A grid is similarly placed in the inner conductor of the output line at 23. The electrons after passing through the grids 22 and 23 are collected at 24 on the inner surface of 21 or on a separate collecting electrode placed at 24 for the purpose. Grid 22 may be polarized either positively or negatively with respect to cathode 13. Grid 23 and conductor 21, or the collecting electrode at 24, are polarized positively with respect to the cathode 13 but 21 or 24 may be polarized to a less degree than grid 23. Insulation required to isolate these polarizing potentials, potential sources, means for heating the cathode and an enclosure to permit the electron discharge to take place in an evacuated space are not shown in detail in Fig. 4 to avoid unnecessary complication. All these elements, essential for operation, may be provided in any of the ways well known in the art of constructing such devices, care being taken to provide the necessary high frequency paths and to avoid excessive high frequency losses. Examples of such details of a typical structure are shown in Fig. 7 and will be referred to later. The closed ends of the lines, at 25 and 26, should be distant along the lines approximately  $\frac{1}{4}$ ,  $\frac{3}{4}$  or  $\frac{5}{4}$ , etc., wave-length (based on the wave velocities in the lines) from the position of the electron stream 17 so that the reflected waves reinforce the fields to give maximum strength of field at the points of reaction with the electron stream. The lines may be terminated with open rather than closed ends, in which case the distances referred to above should be approximately  $\frac{1}{2}$ ,  $\frac{3}{2}$ ,  $\frac{5}{2}$ , etc., wave-length.

The operation of the amplifier is very similar to that of Fig. 1. A flow of electrons from cathode 13 is induced by the positively charged grid 23. Paths of these electrons are as indicated by lines 17. The electric field within the input line modulates the electron stream in the interconductor space between 13 and 22. In the drift space between 22 and 23 the electrons become grouped so that the stream is density modulated, as previously described in connection with Fig. 1, and so enabled to deliver energy at the input frequency to the electric field of the interconductor space between 23 and 24 in the output line. This action is the same as that previously described in connection with Fig. 1, and here again an amplification of the input is generated within the output line through which it is to be transmitted.

Fig. 5 shows a variation of Fig. 4 wherein the electron drift space between 22 and 23 is eliminated and line conductor 20 is eliminated by making conductor 19 common to both input and output lines. The designations of Fig. 5 are the same as those of Fig. 4 and as in Fig. 4 the insulation for polarizing potentials, potential sources, cathode heating means and the enclosure to permit the electron discharge to take place in an evacuated space are merely indicated in Fig. 5 to avoid unnecessary complication of it. In this arrangement the electrode at 24 is negative with respect to cathode 13 rather than positive as in Fig. 4, so that it tends to repel electrons. As 75

in Fig. 4 a stream of electrons 17 leaves the cathode 13 under the influence of the positive grid 22 and in the interconductor space between 13 and 22 the stream is modulated by the alternating field in the input line 18, 19 as previously explained. The electrons pass through 22 into the alternating field in the output line 19, 21 between 22 and 24 with different velocities, some having been accelerated by the input field and some having been decelerated. The various polarizing potentials are adjusted so that slow moving electrons are reversed and turned back toward 22 by the repelling action of the negatively charged electrode 24. Thus only fast moving electrons reach 24 so that the electron stream as it approaches 24 is density modulated through elimination of the slow moving electrons which separated the groups of fast moving electrons as the stream left the space between 13 and 22 and spurts of energy are delivered by the electron stream to the field in the output line 19, 21 in accordance with the input to line 18, 19 just as in Fig. 4, where the density modulation of the electron stream was allowed to take place in the drift space 22 to 23. The action in Fig. 5 becomes similar to that of a Barkhausen oscillator system but in Fig. 5 the electric fields from the input and output spaces are separated from each other by conductor 19 of which grid 22 is a part. In both Fig. 4 and Fig. 5 the two line sections are shown in coaxial relationship. A possible variation from that arrangement is to place the sections side by side and direct the electron stream from the inner conductor of one to the inner conductor of the other.

The arrangements of Fig. 4 and Fig. 5 have been described as amplifiers. They may, of course, be modified to function as oscillators by the usual expedient of connecting the input and output lines together through such lengths of line that the phase relations of the electric fields at the points of reaction with the electron stream are proper for sustaining oscillations. Fig. 6 illustrates such a modification of Fig. 5 which can be applied equally well to Fig. 4. Here the two lines which were shown extending indefinitely at "input" and "output" on Fig. 5 are terminated in short circuits for high frequencies at 61 and 62 respectively. Coupling sleeves 63 and 64 are placed around the inner conductors 18 and 19 of these lines. The sleeves may be insulated from the inner conductors to provide isolation for the polarizing potentials at the same time that a practical connection for the high frequency is effected through the capacitance between each sleeve and its associated inner conductor. The sleeves are spaced from the terminations 61 and 62, respectively, according to the voltage desired. The two sleeves are connected together by the transmission line 65, 66. In this manner the excitation voltage derived from the "output" line 19, 21 is applied to the "input" line 18, 19. As an example of connection to a load circuit, the load resistor 68 is shown coupled to the "output" line by means of the coupling coil 67. Spacers which insulate for direct current potentials but have sufficient capacitance to provide high frequency paths of low impedance are indicated at 91, 92 and 93. Polarizing potentials for elements 13, 22 and 24 are derived from the sources 80, 81 and 83, respectively.

Fig. 7 is a modification of Fig. 4. Its purpose is to indicate how in practice the elements of either Fig. 4 or Fig. 5 may be insulated to separate the polarizing voltages and still provide

the necessary high frequency paths; also to show how the cathode may be heated, the polarizing voltages applied, and an enclosure provided for the evacuated space. For the sake of simplicity such details were omitted from Fig. 4 and Fig. 5. In Fig. 7 the unshaded portions 71, 72, 73, 74 and 75 are of glass, or other suitable insulating material, and are sealed to the conducting portions of the device as indicated to enclose the space in which the electron discharge takes place. Within the enclosure, insulating spacers 76 at the input line termination 25 and 77 at the output line termination 26 are provided between flanges of the conductors to complete the insulation of polarizing potentials. The capacitance across these spacers is made large enough to have negligible impedance at high frequencies thereby constituting a high frequency short circuit at these terminations. If the device should be designed to operate with these terminations open circuited rather than closed, the flanges and the spacers 76 and 77 would, of course, be omitted. The cathode 13 is shown as an emissive coating on the inner conductor 18. This coating is heated by means of an adjacent heater within 18 and energized by source 79. The wall of conductor 18 is made thin at 78 each side of 13 to minimize conduction of heat away from the cathode. Polarizing potentials for elements 13, 22, 23 and 24 are derived from the sources 80, 81, 82 and 83, respectively. Where necessary to carry leads from the potential sources through the walls of the transmission lines, the openings should be made at voltage nodal points to minimize high frequency losses and will be closed by suitable insulating beads in the manner well known in the art.

In Fig. 8 is shown a circuit arrangement for using an electron tube of the pentode type to amplify high frequency oscillations by employing modulation and a drift space as has been described. The five tube elements are shown in the evacuated space enclosed by envelope 27. The grid 29 is operated at a potential negative with respect to, or near, that of the cathode 28 in the usual manner. For this purpose it may be desirable to add a biasing potential source in conjunction with resistor 33 or to add a biasing potential source and choke either with or in place of resistor 33. The "screen" 30 is operated positive with respect to 28. The "suppressor" 31 is operated at about the same potential as 28, the proper potential being obtained through the potential drop in resistor 36 or, if preferable, by adding a suitable biasing potential source. The plate 32 is operated positive with respect to 28. By-pass condensers 34 and 35 keep 29, 30 and 31 at the same alternating potential. 38 and 40 may be either resistors or inductive chokes in series with potential sources 37 and 39. 47 and 48 are blocking condensers. The tuned input circuit 42, 43 and output circuit 44, 45 are shown inductively coupled to incoming and outgoing lines by coils 41 and 46, respectively. The tuned high frequency circuits in practice may preferably be lecher wires or cavity configurations having low losses at very high frequencies.

The high frequency circuit alone of Fig. 8, excluding by-pass condensers, resistors and potential sources, is shown in Fig. 9. The drawing is schematic in form and, as indicated above, the tuned circuits and coupling means may be of any type suitable for use at the frequency employed. In operation, the electron stream

from 28 is modulated and the electrons are grouped to some extent by the control grid 29 through action of the alternating electric field between 29 and 28, produced by the high frequency voltage across the input circuit 42, 43. As the electrons drift through the space between grids 29 and 31 they are grouped to a greater extent and then in passing from grid 31 to plate 32 they react on the field therebetween delivering energy to it and the output circuit 44, 45 in accordance with the input at 41. The drift time of the electrons between grids 29 and 31 should be as long as possible compatible with high current density and effective grouping of electrons. For non-regenerative amplification, the input and output circuits should be well shielded from each other. However, if oscillations are desired, the input and output circuits may be coupled together in the well-known manner for that purpose.

Alternative oscillator circuit arrangements are shown in Fig. 10 and Fig. 11. These figures are similar to Fig. 9 in that the high frequency circuit alone is shown omitting the by-pass condensers, resistors and potential sources. Here the input and output voltages are developed across the one, common, high frequency circuit 49, 50. Operation is similar to that described in connection with Fig. 9. The total transit time of electrons from the cathode 28 to plate 32 should be approximately the period of either  $\frac{1}{4}$ ,  $1\frac{1}{4}$ ,  $2\frac{1}{4}$ ,  $3\frac{1}{4}$  . . . etc., cycles of the operating frequency for the arrangement shown in Fig. 10, while for the arrangement shown in Fig. 11 that transit time should be approximately the period of either  $\frac{3}{4}$ ,  $1\frac{3}{4}$ ,  $2\frac{3}{4}$ ,  $3\frac{3}{4}$  . . . etc., cycles of the operating frequency. Power may be taken from the system by coupling as desired to the circuit 49, 50.

The illustrative embodiments of the invention which have been shown will suggest variations to those skilled in the art, and it is intended that the invention be not limited to the forms disclosed but only by the scope of the claims.

What is claimed is:

1. A high frequency system comprising two portions of coaxial transmission line placed one within the other in coaxial relationship, a cathode connected to the inner conductor of the inner transmission line portion, a foraminate control electrode surrounding the cathode in radial directions connected to and forming a part of the outer conductor of the inner transmission line portion, an anode surrounding the control electrode in radial directions connected to the outer conductor of the outer transmission line portion and including between it and the control electrode at least some of the interconductor space of the outer transmission line portion, means for directing an electron stream from the cathode in radial directions to the anode such that electrons traverse two high frequency electric fields each within the interconductor space of and produced from energy associated with one of the line portions, means whereby the first traversed field acts to cause variation in the velocity of the electrons without substantially changing the rate of flow thereof, and means responsive to the said electron velocity variation for producing density variation in the electron stream in the region of the second traversed field whereby the second traversed field acts to abstract energy from the electron stream.

2. A high frequency system comprising two portions of coaxial transmission line placed one

within the other in coaxial relationship, a cathode connected to the inner conductor of the inner transmission line portion, a foraminate control electrode surrounding the cathode in radial directions connected to and forming a part of the outer conductor of the inner transmission line portion, an anode surrounding the control electrode in radial directions connected to the outer conductor of the outer transmission line portion and including between it and the control electrode at least some of the interconductor space of the outer transmission line portion, means for directing an electron stream from the cathode in radial directions to the anode such that electrons traverse two high frequency electric fields each within the interconductor space of and produced from energy associated with one of the line portions, the interconductor spaces of the two line portions being shielded from each other by substantially complete closure of each to high frequency fields such that the only openings leading directly from one to the other of the interconductor spaces are those provided for the passage of the said electron stream therebetween, means whereby the first traversed field acts to cause variation in the velocity of the electrons without substantially changing the rate of flow thereof, and means responsive to the said electron velocity variation for producing density variation in the electron stream in the region of the second traversed field whereby the second traversed field acts to abstract energy from the electron stream.

3. A high frequency repeater comprising two portions of coaxial transmission line placed one within the other in coaxial relationship, a cathode connected to the inner conductor of the inner transmission line portion, a foraminate control electrode surrounding the cathode in radial directions connected to and forming a part of the outer conductor of the inner transmission line portion, an anode surrounding the control electrode in radial directions connected to the outer conductor of the outer transmission line portion and including between it and the control electrode at least some of the interconductor space of the outer transmission line portion, means for directing an electron stream from the cathode in radial directions to the anode such that electrons traverse two high frequency electric fields each within the interconductor space of and produced from energy associated with one of the line portions, means whereby the first traversed field acts to cause variation in the velocity of the electrons without substantially changing the rate of flow thereof, means responsive to the said electron velocity variation for producing density variation in the electron stream in the region of the second traversed field whereby the second traversed field acts to abstract energy from the electron stream, input means for energizing at the desired high frequency the inner transmission line portion, and output means for utilization of the high frequency energy produced in the outer transmission line portion.

4. An oscillating system comprising two portions of coaxial transmission line placed one within the other in coaxial relationship, a cathode connected to the inner conductor of the inner transmission line portion, a foraminate control electrode surrounding the cathode in radial directions connected to and forming a part of the outer conductor of the inner transmission line portion, an anode surrounding the control electrode in radial directions connected to the outer

conductor of the outer transmission line portion and including between it and the control electrode at least some of the interconductor space of the outer transmission line portion, means for directing an electron stream from the cathode in radial directions to the anode such that electrons traverse two high frequency electric fields each within the interconductor space of and produced from energy associated with one of the line portions, means whereby the first traversed field acts to cause variation in the velocity of the electrons without substantially changing the rate of flow thereof, means responsive to the said electron velocity variation for producing density variation in the electron stream in the region of the second traversed field whereby the second traversed field acts to abstract energy from the electron stream, and means for interconnecting the two line portions in feedback relation so that electrical oscillations are set up in the system.

5. A wave transmission system comprising two portions of coaxial transmission line placed one within the other in coaxial relationship, the outer conductor of the inner transmission line portion serving also as the inner conductor of the outer transmission line portion, a cathode connected to the inner conductor of the inner transmission line portion, a foraminate control electrode charged positively with respect to the cathode surrounding the cathode in radial directions connected to and forming a part of the outer conductor of the inner transmission line portion, an anode charged negatively with respect to the cathode surrounding the control electrode in radial directions connected to the outer conductor of the outer transmission line portion and including between it and the control electrode at least some of the interconductor space of the outer transmission line portion, means including the said control electrode for directing an electron stream from the cathode in radial directions toward the anode such that electrons traverse first the interconductor space of the inner transmission line portion and immediately thereafter the interconductor space of the outer transmission line portion, means for energizing the inner transmission line portion whereby a high frequency electric field is produced in the interconductor space to cause variation in the velocity of the electrons traversing that space without substantially changing the rate of flow thereof, and means comprising the negatively charged anode responsive to the said velocity variation of the electrons whereby electrons which have had their velocity reduced during traversal of the interconductor space of the inner line are retarded and not permitted to reach the anode while electrons which have had their velocity increased are permitted to reach the anode, so that high frequency energy corresponding to that energizing the inner transmission line portion is generated in the outer transmission line portion.

6. A wave transmission system comprising two portions of coaxial transmission line placed one within the other in coaxial relationship such that there is a radial separation between the outer conductor of the inner transmission line portion and the inner conductor of the outer transmission line portion, a cathode connected to the inner conductor of the inner transmission line portion, a foraminate control electrode surrounding the cathode in radial directions connected to and forming a part of the outer conductor of the inner transmission line portion, a foraminate control electrode surrounding the cathode in radial directions connected to and forming a part of the outer conductor of the inner transmission line portion, a foraminate electrode surrounding the control electrode in

radial directions connected to and forming part of the inner conductor of the outer transmission line portion and including between it and the control electrode an annular space which is between the two transmission line portions and external to the interconductor space of both, an anode surrounding the control electrode and the foraminate electrode which is part of the inner conductor of the outer transmission line portion in radial directions connected to the outer conductor of the outer transmission line portion and including between it and the control electrode at least some of the interconductor space of the outer transmission line portion, means for directing an electron stream from the cathode in radial directions to the anode such that electrons traverse in the order stated, the interconductor space of the inner transmission line portion, the space external to the interconductor space of both transmission lines and disposed between the outer conductor of the inner line portion and the inner conductor of the outer line portion, then the interconductor space of the outer transmission line portion, and means for energizing the inner transmission line portion whereby a high frequency electric field is produced in the interconductor space to cause variation in the velocity of the electrons traversing that space without substantially changing the rate of flow thereof, the said electron directing means and the length of the electron path through the said space external to the transmission line portions being such that the electron velocity variations imposed on the electron stream in the interconductor space in the inner transmission line portion result in density variations in the electron stream as it traverses the interconductor space of the outer transmission line portion whereby high frequency energy is generated in the outer transmission line portion.

7. A high frequency system comprising two portions of coaxial transmission line placed one within the other in coaxial relationship, a cathode connected to the inner conductor of the inner transmission line portion, an anode surrounding the cathode in radial directions connected to the outer conductor of the outer transmission line portion and including between it and the cathode at least some of the interconductor space of the outer transmission line portion, a foraminate electron accelerating electrode surrounding the cathode in radial directions and positioned between the anode and the interconductor space of the inner transmission line portion, means including electric potential means for charging the accelerating electrode positively with respect to the cathode, for producing a stream of electrons from the cathode in radial directions through the interconductor space of the inner transmission line portion and toward the anode in the interconductor space of the outer transmission line portion, means for impressing a high frequency control voltage between the cathode and the outer conductor of the inner transmission line portion in the region traversed by the electron stream such that variations in electron velocity are impressed upon the electron stream without substantially changing the rate of flow thereof, and means external to the said region whereby as a result of the impressed electron velocity variations density variations occur in the electron stream as it traverses the interconductor space of the outer line portion thereby energizing electrically the outer line portion in

accordance with the high frequency control voltage.

8. A high frequency system comprising two portions of coaxial transmission line placed one within the other in coaxial relationship, a cathode connected to the inner conductor of the inner line portion, an anode surrounding the cathode in radial directions connected to the outer conductor of the outer line portion and including between it and the cathode at least some of the interconductor space of the outer line portion, the portions of line conductor interposed between the cathode and anode being mesh-like with openings to permit the flow of electrons from the cathode to the anode, an electron accelerating electrode, positively charged with respect to the cathode, comprising at least some of said mesh-like portions of line conductor surrounding the cathode in radial directions and positioned between the anode and the interconductor space of the inner line portion, means including said accelerating electrode for producing a radial stream of electrons from the cathode through the interconductor space of the inner transmission line portion and toward the anode in the interconductor space of the outer transmission line portion, means for impressing a high frequency input control voltage between the inner and outer conductors of the inner line portion such that variations in electron velocity are impressed upon the electron stream without substantially changing the rate of flow thereof, means whereby as a result of the impressed electron velocity variations density variations occur in the electron stream as it traverses the interconductor space of the outer line portion producing electrical energy therein, and means for conducting high frequency output energy from the outer transmission line portion.

9. A high frequency system comprising two electrically resonant portions of coaxial transmission line placed one within the other in coaxial relationship, a cathode connected to the inner conductor of the inner transmission line portion, a foraminate control electrode surrounding the cathode in radial directions connected to and forming a part of the outer conductor of the inner transmission line portion, an anode surrounding the control electrode in radial directions connected to the outer conductor of the outer transmission line portion and including between it and the control electrode at least some of the interconductor space of the outer transmission line portion, means for directing an electron stream from the cathode in radial directions to the anode such that electrons traverse two high frequency electric fields each having a standing wave pattern and each within the interconductor space of and produced from energy associated with one of the line portions, means whereby the first traversed field acts to cause variation in the velocity of the electrons without substantially changing the rate of flow thereof, and means responsive to said electron velocity variation for producing density variation in the electron stream in the region of the second traversed field whereby the second traversed field acts to abstract energy from the electron stream.

10. A high frequency system comprising two portions of coaxial transmission line placed one within the other in coaxial relationship, a cathode connected to the inner conductor of the inner transmission line portion, a foraminate control electrode surrounding the cathode in radial directions connected to and forming a part of the

outer conductor of the inner transmission line portion, an anode surrounding the control electrode in radial directions connected to the outer conductor of the outer transmission line portion and including between it and the control electrode at least some of the interconductor space of the outer transmission line portion, means for directing an electron stream from the cathode in radial directions to the anode such that electrons traverse two high frequency electric fields each within the interconductor space of and produced from energy associated with one of the line portions, means whereby the first traversed field acts to cause variation in the velocity of the elec-

trons without substantially changing the rate of flow thereof, and means responsive to the said electron velocity variation comprising a drift space between the outer conductor of the inner 5 transmission line portion and the inner conductor of the outer transmission line portion which is traversed by the electron stream in passing from one of the said high frequency fields to the other for producing density variation in the electron stream in the region of the second traversed field whereby the second traversed field acts to ab- 10 stract energy from the electron stream.

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