Oct. 15, 1963 J. R. HECHTEL 3,107,313
VELOCITY MODULATED ELECTRON TUBE WITH CATHODE MEANS PROVIDING PLURAL ELECTRON STREAMS
Filed Oct. 30, 1959 5 Sheets-Sheet 1

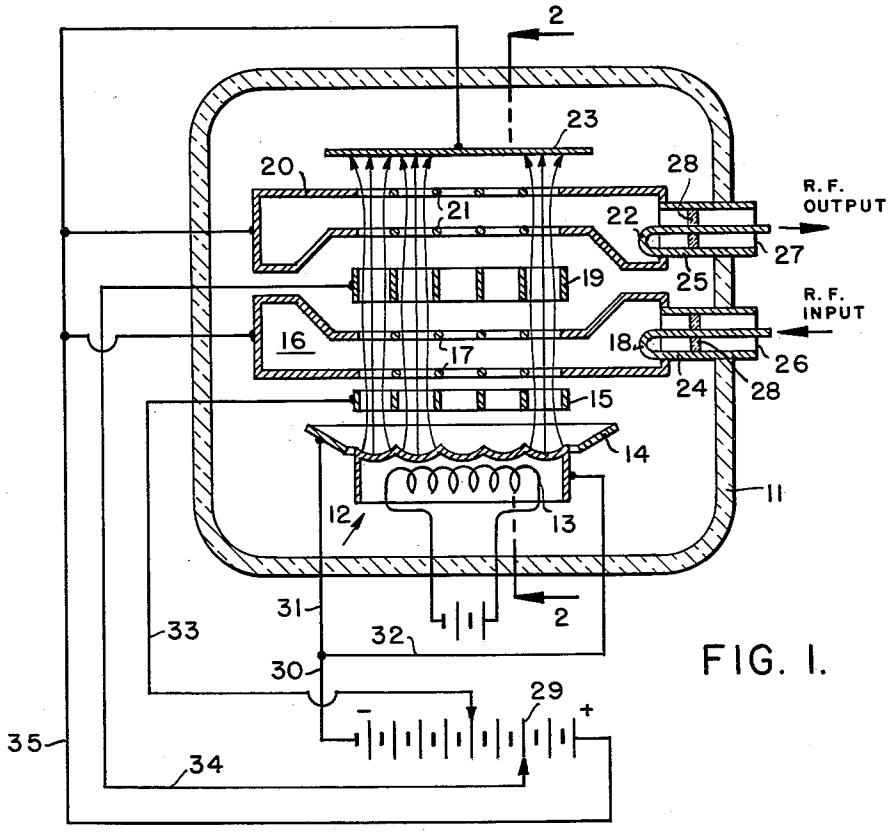


FIG. 1.

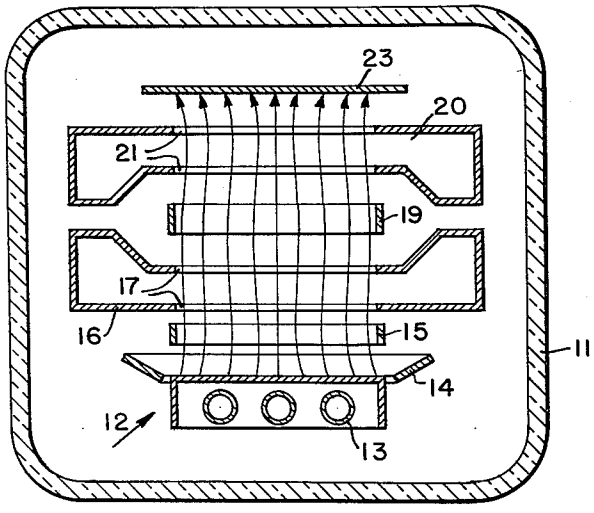


FIG. 2.

INVENTOR.
JOHANN R. HECHTEL

Oct. 15, 1963 J. R. HECHTEL 3,107,313
VELOCITY MODULATED ELECTRON TUBE WITH CATHODE MEANS PROVIDING PLURAL ELECTRON STREAMS
Filed Oct. 30, 1959 5 Sheets-Sheet 2

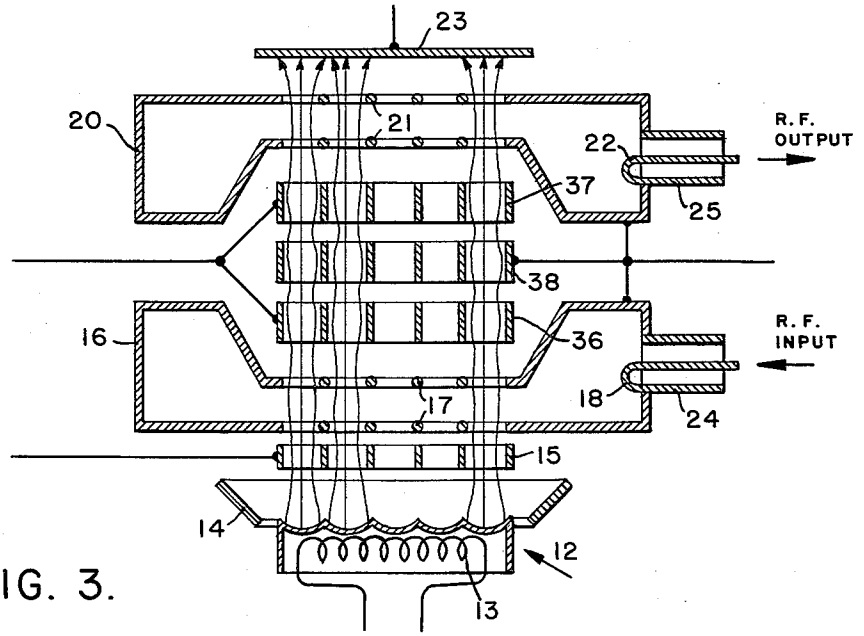


FIG. 3.

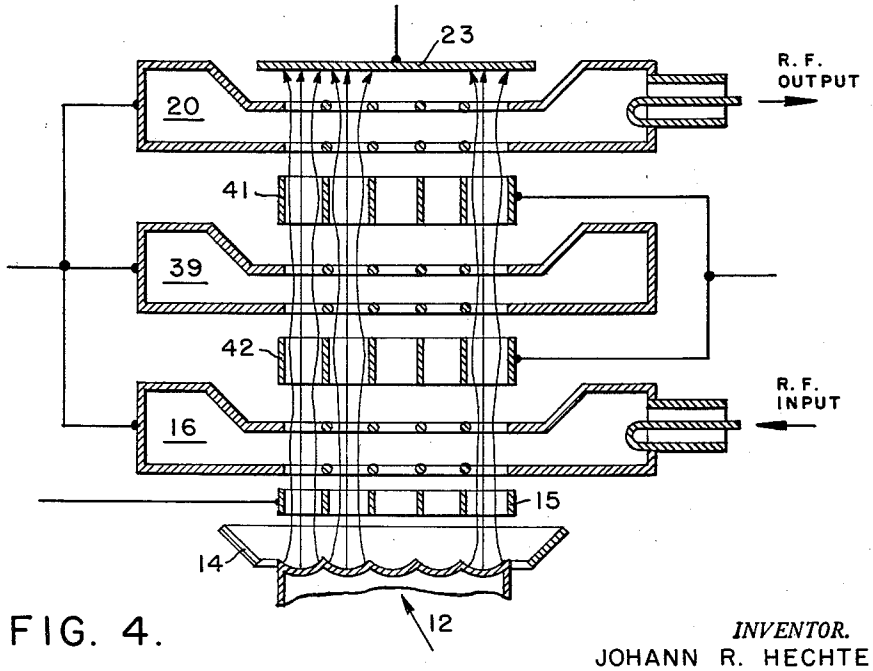
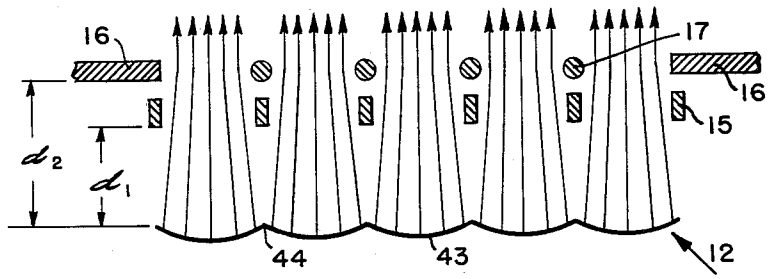


FIG. 4.

INVENTOR.
JOHANN R. HECHTEL
BY

ATTORNEYS.

Oct. 15, 1963 J. R. HECHTEL 3,107,313
VELOCITY MODULATED ELECTRON TUBE WITH CATHODE MEANS PROVIDING PLURAL ELECTRON STREAMS
Filed Oct. 30, 1959 5 Sheets-Sheet 3



$$\frac{1}{2} V_2 \left(\frac{d_1}{d_2}\right)^{4/3} < V_1 < V_2 \left(\frac{d_1}{d_2}\right)^{4/3}$$

FIG. 5.

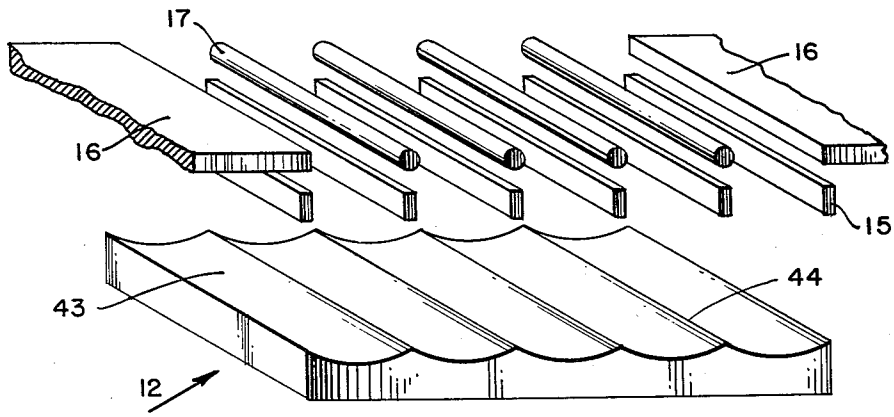


FIG. 6.

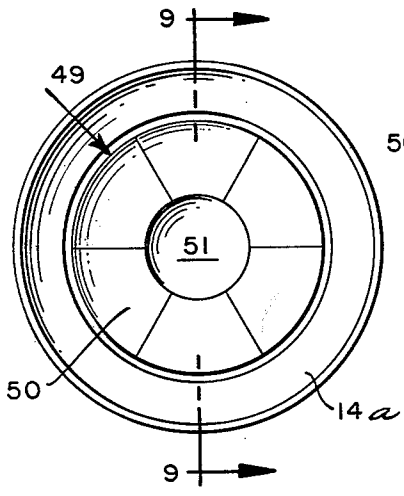


FIG. 8.

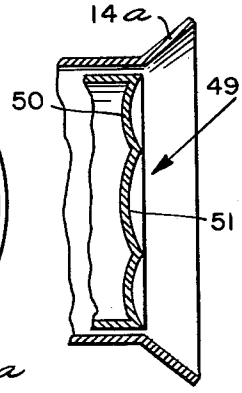


FIG. 9.

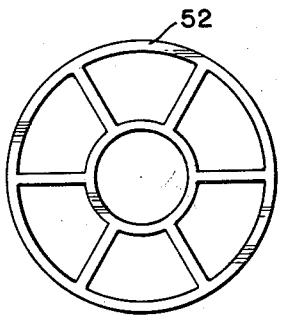
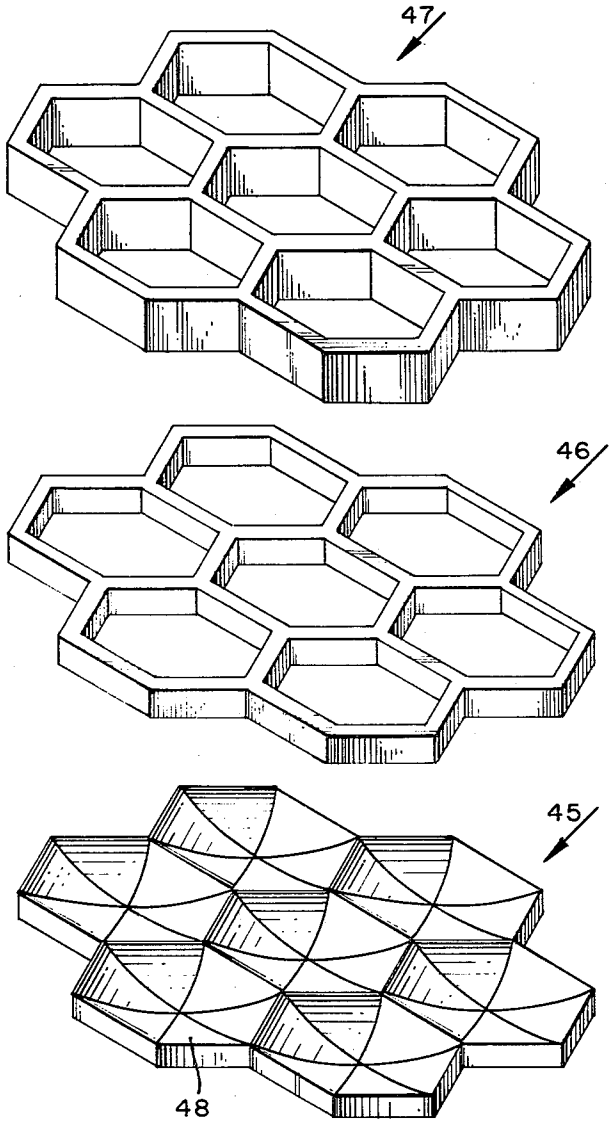


FIG. 10.

INVENTOR.
JOHANN R. HECHTEL
BY

ATTORNEYS.

FIG. 7.



INVENTOR.
JOHANN R. HECHTEL
BY

ATTORNEYS.

Oct. 15, 1963 J. R. HECHTEL 3,107,313

VELOCITY MODULATED ELECTRON TUBE WITH CATHODE MEANS PROVIDING PLURAL ELECTRON STREAMS

Filed Oct. 30, 1959 5 Sheets-Sheet 5

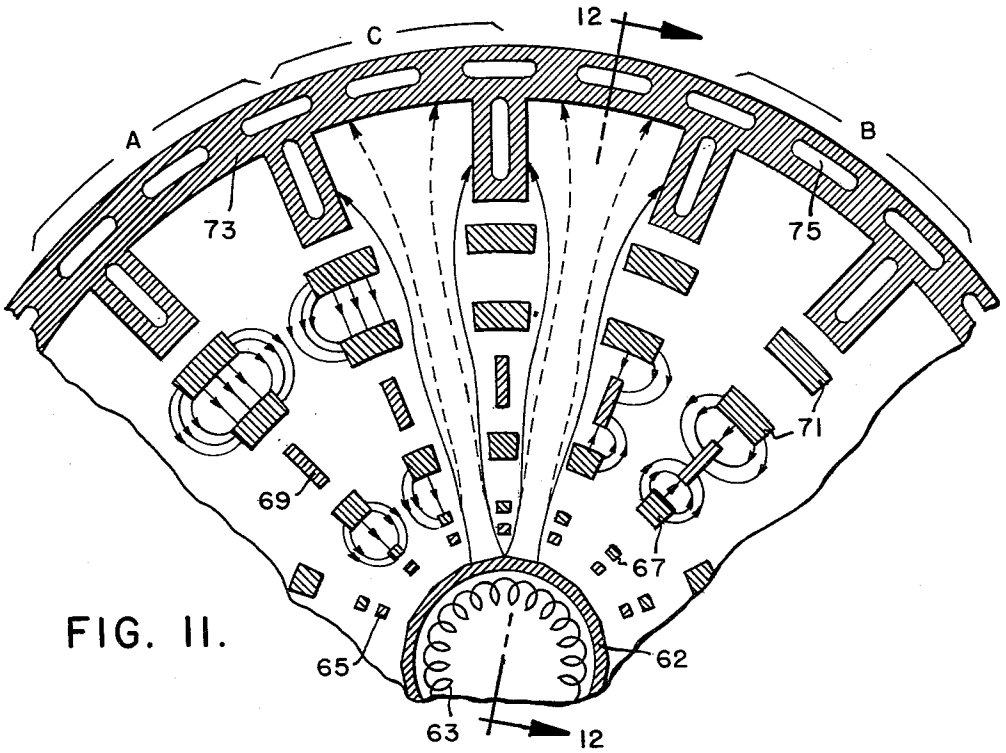


FIG. 11.

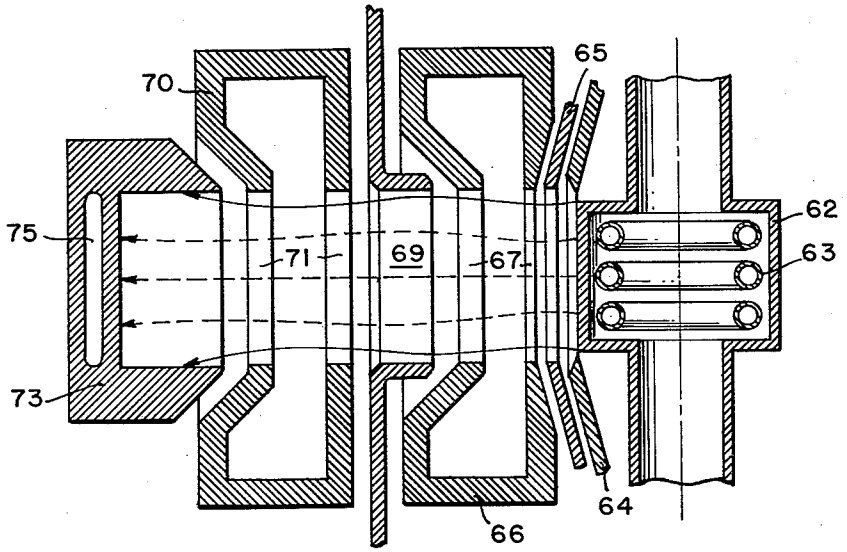


FIG. 12.

INVENTOR.
JOHANN R. HECHTEL

BY

ATTORNEYS.

United States Patent Office

3,107,313

Patented Oct. 15, 1963

3,107,313
VELOCITY MODULATED ELECTRON TUBE WITH CATHODE MEANS PROVIDING PLURAL ELECTRON STREAMS

Johann R. Hechtel, 56B Rodman, China Lake, Calif.

Filed Oct. 30, 1959, Ser. No. 849,997
4 Claims. (Cl. 315—5.16)
(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention herein described may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention is related to electron tubes of the velocity-modulated type. A two-resonator klystron is the simplest example of this type. In it an electron stream is projected across the first resonant cavity (input cavity) in which the electrons are velocity-modulated, that is, periodically accelerated and decelerated. In the field-free space (drift space) following the input cavity the electrons are bunched. A second resonant cavity (output cavity) terminates the drift space. In the output cavity the electrons give up a part of their kinetic energy to the electric R.F.-field. By means of a coupling device, for example, a loop or a window, the R.F.-energy is transferred into an external transmission line.

The quantity characterizing the interaction between an electric R.F.-field and an electron stream is called the beam coupling coefficient β. If the electric field is homogeneous and has a length l, β is given by the expression

$$\beta=\frac{\sin\theta/2}{\theta/2}=\frac{\sin(\omega l/2v)}{\omega l/2v}$$

where v is the velocity of the electrons and $\omega=2\pi f$ the circular frequency of the R.F.-field. θ is the transit angle of the electrons. For $\theta=2\pi$ the beam coupling coefficient becomes zero. The transit angle θ therefore must be smaller than 2π. Typical values of θ in klystrons are between $\pi/4$ and $\pi/2$.

Resonant cavities are mostly of the reentrant type. The reentrant parts of the cavity forming a gap confine the length of the electric field to a certain amount, which must be compatible with the above mentioned condition for the transit angle. As the cross section of the electron beam normally is circular the reentrant parts of the cavity have a cylindrical or conic shape and an inner diameter which is slightly larger than the outer diameter of the electron beam. At the edge of the electron beam the electric field can be regarded as nearly homogeneous and the beam coupling coefficient can be calculated approximately from the width of the gap.

Approaching the axis of the beam, the length of the lines of electric force increases and therefore the beam coupling coefficient decreases. The decay of the beam coupling coefficient towards the axis of the beam is more serious, if the diameter of the gap-forming electrodes is great. As the beam coupling coefficient is not allowed to sink below a certain value the inner diameter of the gap and therefore the diameter of the beam is limited. On the other hand the beam diameter is closely related to the tendency of an electron beam to spread out in a field-free space. This tendency originates from the mutual repulsion of the electrons or in other words forms the space charge of the beam. The outward directed force on an electron at the edge of the beam is directly proportional to the current in the beam and inversely proportional to the radius of the beam. If a continuous increase of the beam diameter is to be prevented, an external electric or magnetic focusing field must be applied which is able to produce an inward directed force of the same amount as the outward directed space charge force. Since the strength of the available focusing fields is limited for practical reasons, the maximum current in an electron beam is likewise limited.

Another reason why the usable current in a single electron beam is limited, is that a potential difference exists between the edge and the center of the beam. For a perveance of $I/V^{3/2}=10^{-6}$ amp./volt$^{3/2}$ the potential difference is 1.5% of the acceleration voltage. For a perveance 10 times larger, which would be desirable in microwave tubes, the potential difference would be intolerably high.

Part of the above mentioned difficulties can be overcome by using grids to confine the length of the electric field within the gap. However, the use of conventional grids has the disadvantage of limiting the maximum current. Several mechanisms contribute to this limiting process. (1) The grids are heated as the result of intercepting a part of the electron current. Consequently, thermionic emission of electrons or deterioration of the grids by evaporation contribute to the limiting process. (2) The production of secondary electrons in the grids reduces the quality factor of the resonant cavities which in turn reduces the efficiency of the tube and contributes to the limiting process.

The maximum perveance of solid electron beams used today in klystrons or traveling wave tubes is of the order of 2 to 3×10^{-6} amp./volt$^{3/2}$. There are several reasons why still higher values of the perveance are desirable. For a given power a high perveance could be used to compensate for a low voltage. At high power levels this would be a distinct advantage as very high voltages are inconvenient. On the other hand, for a given voltage the attainable power grows with increasing perveance. Besides this a lower D.C.-voltage also means a lower R.F.-voltage and this reduces the circuit losses of a given cavity.

Another advantage of an increased perveance would be an enlarged electronic bandwidth. That is, an increased perveance would provide the capability of tuning an amplifier or an oscillator over a certain frequency range by merely changing voltages. The present invention shows a way to achieve higher values of the perveance of an electron stream and at the same time to improve the coupling between the electron stream and the R.F.-fields of a velocity-modulated electron tube.

It is known that in a conventional tetrode or pentode the first grid, which is normally negative relative to the cathode, deflects the electrons coming from the cathode in such a manner that the electron stream is divided into streamlets. However, the electrons in the streamlets move in different directions and therefore the streamlets soon intermingle. With an arrangement of this kind it is possible to reduce the current intercepted by the second grid, but it is not possible to control the entrance conditions for the electrons into the space beyond the second grid. For this reason it would not be possible to prevent the electrons from colliding with successive grids.

In an arrangement according to the present invention the electron stream starting from a cathode of relatively large area is divided in such a manner that the electron flow in the resultant streamlets is nearly parallel and the space between two adjacent streamlets is small compared to the diameter or thickness of a single streamlet. This is achieved by dividing the cathode surface into small concave elements and by arranging in front of the cathode two acceleration grids of similar geometry, the rods or wires of which are opposite to the ridges between the concave parts of the cathode. If the distances of the two grids from the cathode are respectively d_1 and d_2 the

relation $d_2-d_1 \ll d_1$ should be fulfilled. This is because the relationship

$$\frac{1}{2}V_2\left(\frac{d_1}{d_2}\right)^{4/3} < V_1 < V_2\left(\frac{d_1}{d_2}\right)^{4/3}$$

for grid voltages V_1 and V_2 must be complied with.

The single elements of the cathode may be parts of a circular cylinder or they may have some other shape. If the cathode seen as a whole is of cylindrical shape, the single elements can also be plane. The R.F.-fields, to which the electron stream is coupled, are confined by grids of the same structure as the acceleration grids, the rods or wires of all grids being aligned in the spaces between the electron streamlets. Thereby the first R.F.-field confining grid may be identical with the second acceleration grid.

Normally the distance between successive R.F.-fields or cavity resonators is so great that the electron streamlets would intermingle. In order to prevent this effect between two successive R.F.-fields or cavities an odd number of lens electrodes is arranged which are similar to the other grids but may have a greater extension in the direction of the electron flow. These electrodes only produce D.C.-fields. If one is used, its potential is above or below the potential of the neighbouring R.F.-grids. It is desirable to use an electrode potential below the neighbouring R.F.-grids since lower potentials are more readily obtained and employed. This potential difference is necesary in order to establish electrostatic fields between the electrode and the R.F.-grids which fields provide a net inward force on the electrons of the respective streamlets. A separation is thereby maintained between the streamlets and intermingling is prevented. If several lens electrodes are used, their potentials are alternatingly low and high.

An object of the present invention is to increase the perveance of the electron stream and at the same time improve the coupling between the electron stream and the R.F.-field of velocity modulated electron tubes.

Another object of the present invention is to increase the efficiency of velocity modulated electron tubes.

A further object is to increase the perveance of an electron stream and thereby increase the available power output of velocity modulated electron tubes.

A still further object is to prevent the grids of a velocity modulated tube from intercepting part of the electrons thereby materially reducing thermionic emission and increasing the qualtiy factor of the resonant cavities.

A still further object is to emit from the cathode of a velocity modulated tube a plurality of electron streamlets having spaces free of electrons therebetween and electrostatically maintaining the separation of the streamlets thereby increasing the perveance and the efficiency of the tube.

A still further object is to increase the electronic bandwidth of a velocity modulated tube.

A still further object is to improve the coupling between the electrons and the R.F.-fields of a velocity modulated tube.

Other objects and many of the attendant advantages of this invention will become readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings where:

FIG. 1 shows a sectional view of a two-resonator tube according to the invention;

FIG. 2 is a sectional view of the same tube taken through the plane 2—2 of FIG. 1;

FIG. 3 is a sectional view of a modified form of a two-resonator tube;

FIG. 4 is a sectional view of a three-resonator tube;

FIG. 5 shows more completely the cathode region of tubes according to FIGS. 1 through 4;

FIG. 6 is a perspective view of the system shown in FIG. 5;

FIG. 7 shows an exploded view of a modified form of the cathode region;

FIG. 8 shows a plan view of a modified form of the cathode;

FIG. 9 shows a section of the cathode taken on line 9—9 of FIG. 8;

FIG. 10 shows a plan view of the acceleration electrode which operates in conjunction with the cathode of FIGS. 8 and 9;

FIG. 11 is a sectional view of a further alternative device with radial electron flow; and

FIG. 12 is a sectional view of the same device taken through the plane 12—12 of FIG. 11.

In the drawings, like numerals refer to like parts in each of the views.

Referring to FIGS. 1 and 2, within a vacuum envelope 11 are arranged a cathode 12, which is heated by a heater 13, a beam focusing electrode 14 which is normally connected to the cathode, an acceleration grid 15, an input resonator cavity 16 with a pair of grids 17 and a coupling loop 18, an electrostatic lens 19, an output cavity resonator 20 with a pair of grids 21 and a coupling loop 22, and a collector 23. Short pieces of transmission lines 24 and 25 lead from cavities 16 and 20 to connection pieces 26 and 27 outside the vacuum envelope 11. Insulators 28 are provided between transmission lines 24 and 25 and coupling loops 18 and 22. A source of direct current potential 29 is provided wherein the cathode focusing electrode and cathode are at the same potential and are connected to the potential source by means of lead lines 31 and 32, respectively. The acecleration grid 15 is connected by means of lead line 33 to the potential source at a potential higher than the potential of the focusing electrode and cathode. As shown, electrostatic lens 19 is connected by means of lead line 34 to the potential source at a potential higher than the potential of the acceleration grid; however, this potential relation is not necessary. The input and output resonator cavities and the collector are at the same potential and are connected to the potential source by means of lead line 35.

Under the influence of positive voltage applied to grids 15 and 17, electrons leaving the cathode 12 are accelerated towards grid 15. The cathode comprises a plurality of parallel concave elements which emit slightly convergent streamlets of electrons, the concavities each facing toward collector 23 so that the streamlets extend along parallel emission axes, forming a beam in which the closely adjacent streamlets can be individually subjected to separate electrostatic fields as provided by means of axially aligned sections of the acceleration and cavity resonator grids. From FIGS. 1 and 2 it can be seen that the width is small as compared to the height of the transverse section of each streamlet.

In order to split the stream of electrons emitted from the cathode into ribbon like streamlets, it is necessary that the voltages of the acceleration grid and the input cavity grid be properly selected with relation to the distances of the acceleration grid and input cavity from the cathode, respectively, as was previously explained. Upon proper selection of these distance and voltage factors each streamlet entering the openings of grid 17 will be slightly convergent and have a thickness slightly less than the width of the openings. In consequence of the space charge of the electron stream and the lens effect of the radio frequency field between the grids 17 each streamlet tends to increase in thickness after having passed through the grids 17. This diverging tendency is counteracted by the grid like lens 19 which is operated at a potential below that of the grids 17 and 21. Having met the conditions of the space charge and the voltages correctly, the streamlets leave the lens 19 slightly convergent and enter the output resonator cavity 20 without coming into contact with the wires of grid 21. After the electron streamlets have delivered part of their kinetic energy to the radio frequency field of the output resonator cavity 20 the elec-

trons finally reach the collector 23, where the remainder of their kinetic energy is transferred into heat. In this manner the perveance of the total electron stream is increased and at the same time the coupling between the electron stream and the R.F.-field is increased thereby increasing the efficiency and available power output.

FIG. 3 shows an arrangement similar to that of FIG. 1, the difference being that the distance between the grids 17 and 21 is greater and that a greater number of electrostatic lenses 36, 37 and 38 are employed. Due to this increased distance there is a higher amplification of the radio frequency signal applied to the input cavity 16 by means of transmission line 24. To avoid intolerable spreading of these streamlets, three grid like electrodes or electrostatic lenses 36, 37 and 38 are mounted between the two cavities 16 and 20. To achieve the desired lens action, it is necessary to establish an electrostatic field between the various lenses and the radio frequency grids. These fields provide a net inward force on the electrons of the respective streamlets and thereby maintain a separation between the streamlets and prevent contact of the streamlets with the grids. To establish these electrostatic fields the middle electrode 38 is maintained at the same potential as grids 17 and 21, while the other two electrodes 36 and 37 have a lower potential. The vacuum tube envelope, potential source and lead lines connected thereto have been omitted in FIG. 3 for clarity.

The modification shown in FIG. 4 illustrates the new focusing principle in connection with a three-cavity klystron amplifier, which has a very high amplification. The middle resonator 39 of such a device is freely oscillating. Lens electrode 41 is positioned in the drift space between adjacent cavities 39 and 20 and lens electrode 42 is positioned between cavities 16 and 39. The potential of lens electrodes 41 and 42 is lower than the potential of cavities 16, 20 and 39. The vacuum tube envelope, potential source and lead lines have been omitted for clarity.

FIGS. 5 and 6 more clearly show the cathode region of the tubes according to FIGS. 1 to 4. Cathode 12 has a relatively large surface area which is divided into a plurality of focusing elements 43 of equal size wherein each element is contiguous with another. Each of the elements is transversely concave and axially parallel to the other elements thereby forming a ridge 44 between adjacent elements. The rod or wire members of acceleration grid 15 and of input cavity grids 17 are arranged in axial alignment. Axial alignment is also maintained in the electrostatic lens and the output cavity. Due to the concave shape of the cathode elements the electrons are emitted therefrom at a slightly convergent angle thereby forming streamlets with spaces free of electrons therebetween. The distance from the cathode to the acceleration grid is denoted as d_1 and the distance from the cathode to the grid of the input cavity is denoted as d_2. In order to provide the necessary focusing action the relationship

$$\frac{1}{2}V_2\left(\frac{d_1}{d_2}\right)^{4/3}<V_1<V_2\left(\frac{d_1}{d_2}\right)^{4/3}$$

must be maintained. In this relationship V_1 is the potential of the acceleration grid and V_2 is the potential of the input cavity.

The embodiment of FIG. 7 shows a perspective view of a modified form of the cathode region wherein cathode 45 emits electron streamlets which pass between the grid wires of acceleration grid 46 and the grid wires of cavity resonator 47. Cathode 45 comprises a plurality of hexagonal concave elements 48 which focus the electrons emitted therefrom into convergent streamlets having spaces free of the electrons therebetween.

FIGS. 8 and 9 show a modified form of a cathode. The outer and inner periphery of elements 50 are circular. Element 51 is also circular and is contiguous with the inner periphery of elements 50 thereby forming a solid circular cathode. Each of the elements are concave and emit electron streamlets that are slightly convergent.

FIG. 10 illustrates the shape of the acceleration grid wires or rods which receive the electron streamlets emitted from cathode 49.

Referring to FIGS. 11 and 12, the cathode 62 is an approximately cylindrical member the outer surface of which is composed of a plurality of small plane or slightly concave surfaces. The flow path of the electron streams emitted from each of the surfaces of the cathode extend radially outward. The upper and lower ends of the cathode are provided with a beam forming electrode 64. The cathode 62 is heated by heater 63 and is surrounded by an acceleration grid 65, input cavity resonator grids 67, an array of focusing lens electrodes 69, output cavity resonator grids 71 and a collector 73 which is provided with cavities 75 for circulation of cooling water.

In FIG. 11, section A shows the electric lines of the R.F.-fields and section B shows the electric lines of the D.C.-field. Lens electrode 69 has in this case a lower potential than that of grids 67 and 71. The function of the different electrodes is the same as in the arrangement of FIG. 1. In section C of FIG. 11 the electron flow path at the edge of each streamlet is shown for two different cases. The R.F.-field between the grids of the cavities has certain focusing or defocusing properties, depending on the phase of the field with respect to an electron. For electrons passing the middle plane of the R.F.-field at a moment when the field is zero and changing from deceleration to acceleration, the R.F.-field acts like a diverging lens. This case is shown by the solid lines of section C. For electrons which pass the middle plane of the R.F.-field at a moment when the field changes from acceleration to deceleration, the R.F.-field acts like a converging lens. This means, the beam diameter is reduced by the action of the R.F.-field which is shown by the dashed lines of section C.

Obviously many modifications and variations of the present invention are possible in the light of the above teaching. For example, the teachings of the invention could be applied to high power traveling wave tubes or backward wave oscillators of the O-type. One possibility of realizing this would be to give the succeeding electrodes of the delay line alternating high and low D.C. potentials. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A velocity modulated electron tube comprising a cathode the surface of which is divided into a plurality of small elements emitting streamlets of electrons separated by spaces free of electrons; first and second acceleration grids; a first radio frequency cavity resonator; electrostatic focusing means; and a second radio frequency cavity resonator all arranged in series, respectively, and in operable relation with the electron streamlets individually; wherein distances d_1 and d_2 from the cathode to said first and second acceleration grids, respectively, comply with the relation $d_2-d_1<<d_1$ so that the voltages V_1 and V_2 of said first and second acceleration grids, respectively, obey the relation

$$1/2\left(\frac{d_1}{d_2}\right)^{4/3}<\frac{V_1}{V_2}<\left(\frac{d_1}{d_2}\right)^{4/3}$$

whereby said acceleration grids, said cavity resonators and said electrostatic focusing means maintain the separation of said electron streamlets.

2. In a velocity-modulated electron tube, the combination comprising: a collector electrode; a single-cathode electrode having contiguous electron-emissive concavities for providing separate electron streamlets extending along substantially parallel and coextensive axes toward said collector electrode; at least two cavity resonators positioned in serial order between said cathode and collector electrodes; an acceleration electrode positioned between said cathode electrode and said cavity resonators; and electrostatic focusing means, positioned between said

cavity resonators, for preventing spreading action of said electron streamlets; said cavity resonators, acceleration electrode and electrostatic focusing means having grids which are each formed to define fully open passages, of like number and in registry with said streamlets, for effecting electrostatic field action upon said streamlets individually.

3. In a velocity-modulated electron tube, the combination comprising: a collector electrode; a single-cathode electrode having contiguous electron-emissive concavities for providing separate electron streamlets extending along substantially parallel and coextensive axes toward said collector electrodes; at least two cavity resonators positioned in serial order between said cathode and collector electrodes; and an acceleration electrode positioned between said cathode electrode and said cavity resonators; said cavity resonators and said acceleration electrode having grids which are each formed to define fully open passages, of like number and in registry with said streamlets, for effecting electrostatic field action upon said streamlets individually.

4. In a velocity-modulated electron tube, the combination comprising: a collector electrode; a single-cathode electrode having contiguous electron-emissive concavities for providing separate electron streamlets extending along substantially parallel and coextensive axes toward said collector electrode; and a plurality of grids positioned in serial order between said cathode and collector electrodes, each said grid being formed to define fully open passages, of like number and in registry with said streamlets, for effecting electrostatic field action upon said streamlets individually.

References Cited in the file of this patent

UNITED STATES PATENTS

2,399,223	Haeff	Apr. 30, 1946
2,402,983	Brown	July 2, 1946
2,407,667	Kircher	Sept. 17, 1946
2,482,766	Hansen et al.	Sept. 27, 1949
2,547,061	Touraton et al.	Apr. 3, 1951
2,584,323	Berterottiere	Feb. 5, 1952
2,610,306	Touraton et al.	Sept. 9, 1952