

July 15, 1958

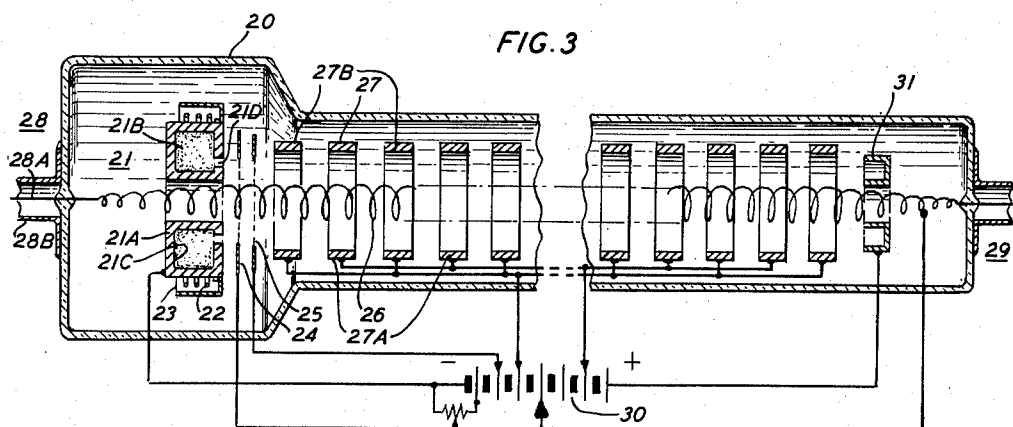
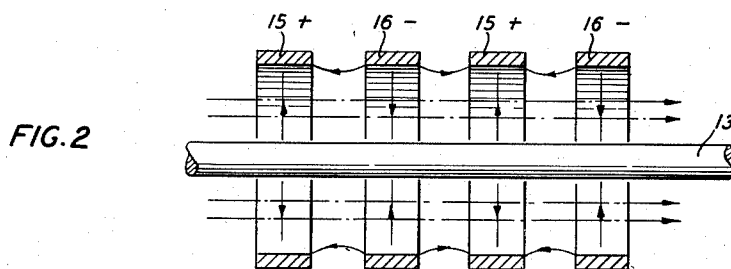
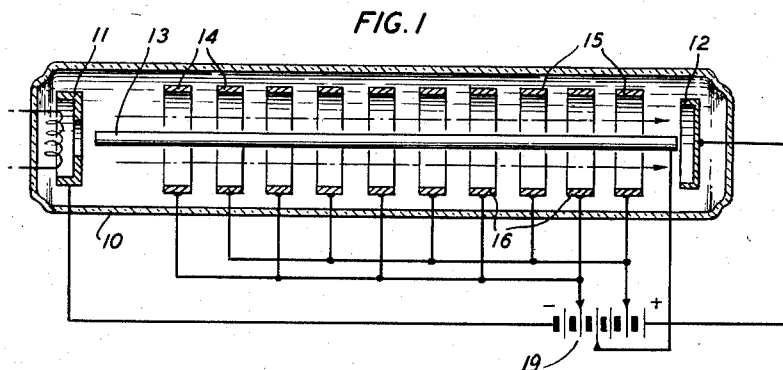
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2,843,793

ELECTROSTATIC FOCUSING OF ELECTRON BEAMS

Filed June 26, 1953

2 Sheets-Sheet 1



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FIG. 4

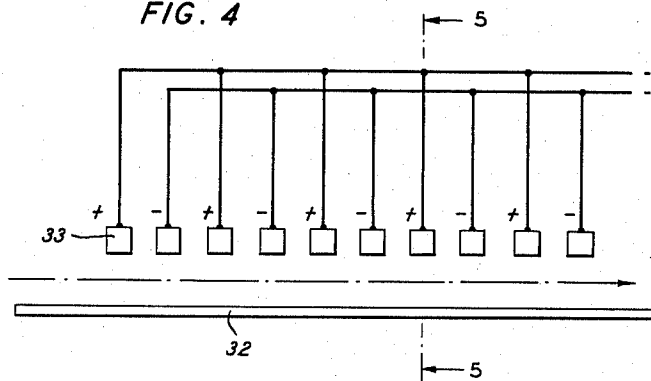


FIG. 5

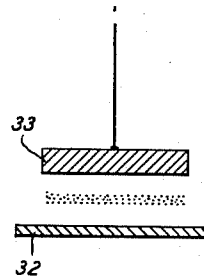


FIG. 6

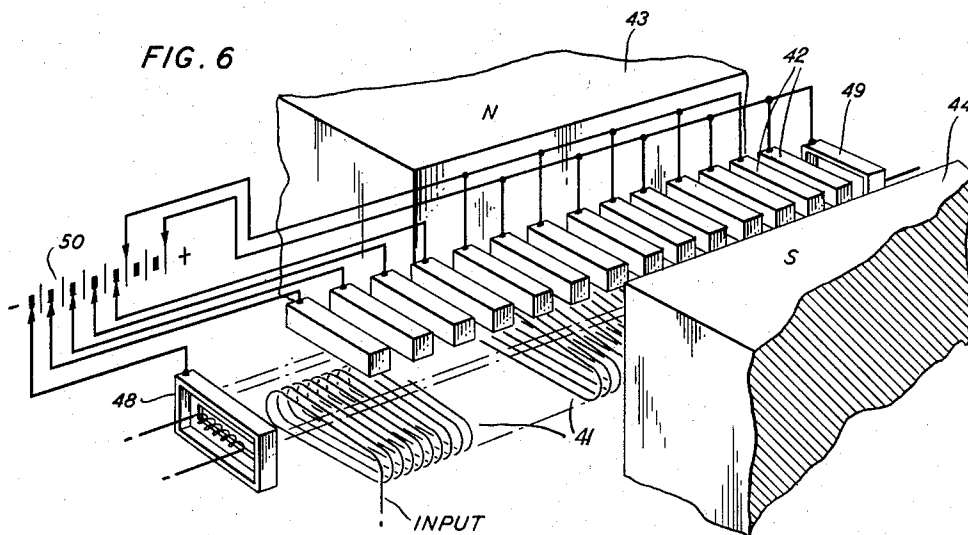
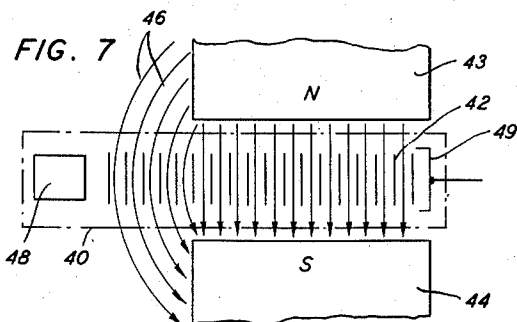


FIG. 7



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ELECTROSTATIC FOCUSING OF ELECTRON BEAMS

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Application June 26, 1953, Serial No. 364,441

6 Claims. (Cl. 315—3.5)

This invention relates to traveling wave tubes which utilize over a distance of a plurality of operating wavelengths the interaction between an electromagnetic wave propagating along a slow wave interaction circuit and an electron beam which flows past the interaction circuit in coupling relation with the propagating electromagnetic wave. The most important classes of such devices are conventional-type traveling wave tubes (usually referred to simply as traveling wave tubes) in which the energy used in the amplification of the traveling wave is derived at the expense of the longitudinal average velocity of the electron stream and a linear magnetron (sometimes referred to as a magnetron amplifier) in which the energy used in the amplification of the traveling wave is derived from a D.-C. transverse electric field cooperating with a transverse magnetic field.

One of the difficult problems associated with devices of this kind is the focusing of the electron stream over its relatively long path so as to maintain its flow close past the interaction circuit without striking it. The electron streams used in such devices are advantageously of high density and the space charge or mutually repulsive forces acting within such electron beams tend to make the beams diverge and accordingly, measures must be taken to keep the flow straight. The problem is especially complex in linear magnetrons where the electrons are projected through crossed electric and magnetic fields.

An important object of the present invention is to facilitate the balancing of such space charge forces whereby the electron beam in a traveling wave tube can be kept from spreading.

In the conventional-type traveling wave tube (as distinguished from the linear magnetron), it is usual to employ a longitudinal magnetic field to balance out the space charge forces for confining the electron beam. This expedient requires additional magnetic flux producing equipment which it would be advantageous to eliminate. To this end, the principles of the present invention permit electrostatic focusing of an electron beam in a manner which requires no magnetic flux equipment.

In the linear magnetron, because of the primary requirement for a transverse magnetic field, it is inconvenient to employ a longitudinal magnetic field in focusing the electron beam. Accordingly, to minimize the space charge effects it is usual to employ electron beams of relatively low density and to inject the electrons into the crossed fields in a way which provides an initial velocity distribution in the electrons. However, such injection techniques are often unsatisfactory, requiring special electron guns and critical positioning of such guns. It would be advantageous to employ an electron beam in which all electrons are injected into the region of crossed fields with the same initial velocity.

Accordingly, another object of the invention is to facilitate the injection of the electron beam into the region of crossed electric and magnetic fields characteristic of a magnetron amplifier.

To this end, the principles of the present invention

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permit the electrostatic focusing of the electron beam in the crossed field regions in a way whereby there is obviated the need for an initial velocity distribution in the electrons injected. This, in turn, permits the injection of an electron beam of substantially uniform velocity from a field free region (i. e. region free of the crossed electric magnetic fields) into the region of crossed electric and magnetic fields.

It is in accordance with the broad principles of the invention to utilize an electrostatic focusing arrangement which includes a first electrode for establishing an equipotential surface along the desired path of flow and a succession of electrodes disposed along the path of flow opposite said first electrode for defining a surface of spatially varying potential one set of, alternate members of the succession of electrodes being at a potential greater than members proximate thereto, and the first electrode being at a potential advantageously intermediate those of an adjacent pair of electrodes of the succession and at a potential less than the mean potential of an adjacent pair of electrodes of the succession. Additionally, the first electrode advantageously serves as the wave interaction circuit for propagating an electromagnetic wave for interaction with the electron flow. Moreover, in a magnetron amplifier the problem of injecting an electron stream from a field free region into the region of focusing is simplified by increasing gradually the mean potential on pairs of adjacent electrodes of the succession.

In a conventional-type traveling wave tube illustrative embodiment of the invention, a hollow cylindrical electron beam is projected coaxial with and surrounding a helix-type interaction circuit. A succession of annular electrode members are disposed coaxial with and surrounding the electron beam and the interaction circuit. By suitable connections to a voltage supply, one set of alternate annular electrodes are maintained at a potential higher than the electrodes adjacent thereto, and the helix is maintained at a potential less than the mean potential of pairs of adjacent annular electrodes.

In a linear magnetron traveling wave tube illustrative embodiment of the invention, a plane electron beam is projected past a flattened helix which serves as a slow wave interaction circuit. Disposed along the path of flow opposite the flattened helix is a succession of lateral fins or plates. One set of alternate fins are maintained at a potential positive with respect to the fins contiguous thereto, and the flattened helix is maintained at a potential less than the mean potential on a pair of adjacent fins. Additionally, a magnetic field is set up perpendicular both to the path of electron flow and to the electric field set up between the flattened helix and the succession of fins. In particular, to facilitate the injection of the electron stream from a field free region into the region of crossed electric and magnetic fields, the electric field component of the crossed fields is increased gradually in the fringe region of the magnetic field component of the crossed fields by increasing gradually the mean potentials of pairs of successive fins.

The invention will be better understood from the following more detailed description taken in conjunction with the accompanying drawings in which:

Fig. 1 shows an electrostatic focusing system in accordance with one aspect of the invention which employs a succession of annular elements together with a center conductor for focusing a hollow cylindrical electron beam;

Fig. 2 shows on an enlarged scale a portion of the system shown in Fig. 1 for illustrating the electrostatic fields acting on the electron beam;

Fig. 3 shows a conventional-type traveling wave tube illustrative embodiment employing electrostatic focusing in accordance with the invention;

Figs. 4 and 5 are side and front views, respectively,

of a portion of an electrostatic focusing system which employs a succession of fins opposite a conductive plate for focusing a flat electron beam;

Fig. 6 shows in perspective cut away view, a schematic linear magnetron type traveling wave tube illustrative embodiment of the invention; and

Fig. 7 is a cut away top view of a schematic linear magnetron of the kind shown in Fig. 6 which better illustrates the positioning of the electron gun in a field free region in accordance with one feature of such an embodiment.

With reference now more particularly to the drawings, in Fig. 1 an evacuated glass envelope 10 houses at opposite ends a source 11 of a hollow cylindrical electron beam and a target electrode 12. For purposes of simplicity, the beam source 11 has been shown schematically as the annular cathode of an electron gun. It will, of course, be necessary generally to associate beam forming electrodes and accelerating anodes with such a cathode to provide the desired beam. Positioned along the axis of the envelope is a central cylindrical conductor 13 which provides an equipotential surface and disposed coaxially therealong is a succession of annular discs or rings 14 which are biased to define an envelope or a surface of periodically varying potential. The electron flow is confined to the interspace between the central conductor 13 and the surrounding discs 14. It is in accordance with the invention to have one set of alternate discs of the succession at a positive potential with respect to the discs contiguous thereto and to have the central conductor 13 at a potential negative to the mean potential between pairs of adjacent discs. This may be described as forming the succession of discs 14 into two interleaved sets of discs 15 and 16, the discs of set 15 each being at a positive potential with respect to each of the discs of set 16 and the average potential of sets 15 and 16 exceeding the potential of conductor 13. To this end, the discs of each set are connected together electrically and further connected by suitable lead-in conductors to taps on a voltage supply 19 and the central conductor 13 is connected by a suitable lead-in connector to an intermediate tap on the voltage supply 19. The cathode 11 which serves as the source of the hollow beam is maintained by a suitable lead-in connection from voltage supply 19 at a potential negative with respect to those on the central conductor 13 and succession of discs 14.

Qualitatively, the focusing action can be described as follows. First, suppose the case of a solid beam being projected through the succession of rings 14 in the absence of the central conductor 13. With reference to the enlarged fragmentary sketch shown in Fig. 2 where the electric field lines are shown, it can be appreciated that as a result of the fringing fields between adjacent discs, there is an outward force acting on the electrons in the regions adjacent the more positively charged discs 15 and an inward force at the regions adjacent the more negatively charged discs 16. These forces are of equal magnitude. However, in going from a region opposite a positively charged disc to a region opposite a negatively charged disc the electrons encounter a retarding electric field whereas in going from a region opposite a negatively charged disc to a region opposite a positively charged disc the electrons are in an accelerating field. As a result, the electrons move more slowly in the neighborhood of the negatively charged discs and, accordingly, are exposed to the inward force longer. The result is a net inward force.

In the case of a hollow electron beam with a central conductor the electric fields on the outer edge electrons are nearly the same as in the case of a solid beam so that a net inward force is present in this case also. Moreover, since in accordance with the invention the central conductor is adjusted to a potential less than the mean potential of a pair of adjacent discs, there will be a net outward force on electrons along the inner edge of the

hollow electron beam and near the central conductor. The net inward force on the outer edge electrons and the net outward force on the inner edge electrons can be adjusted to keep the electron beam cylindrical as it progresses down the tube. To achieve a balance, the net inward force can be increased by increasing the potential difference between adjacent discs and the net outward force can be increased by decreasing the potential of the central conductor relative to the mean potential of pairs of adjacent discs.

An important advantage of electrostatic focusing arrangements for incorporation into devices which utilize the interaction between an electron stream and a slow electromagnetic wave is that part of the focusing structure can be made to serve as the slow wave circuit. In a copending application Serial No. 345,503, filed March 30, 1953, of J. R. Pierce, in which the electrostatic focusing structure comprises a bifilar helix which forms an envelope or surface of periodically varying potential and which is surrounded by a cylindrical electrode which serves as an equipotential surface or envelope, the bifilar helix also serves as a wave interaction circuit for propagating a slow traveling electromagnetic wave. It is found, however, that sometimes the dimensions of the bifilar helix best suited for adapting the helix as a wave interaction circuit are incompatible with the dimensions best suited for utilizing the bifilar helix to provide a surface along which the potential varies periodically with distance. To this end, copending application Serial No. 364,242, filed June 26, 1953, by P. K. Tien relates to a traveling wave tube which utilizes for electrostatic focusing a bifilar helix which forms a surface of periodically varying potential and a single wire helix which forms an equipotential surface disposed opposite the first-mentioned surface. In such an arrangement, the single wire helix is made to serve as the wave transmission circuit. However, for some applications the surface along which the potential varies periodically can be secured most advantageously by a succession of rings or discs in accordance with one aspect of the present invention. In the above-mentioned Tien application, there are developed relationships for the focusing potentials which result in optimum focusing for the bifilar helix focusing structure and the analysis indicates how these results can be applied to a focusing system which employs a succession of rings surrounding the path of flow.

In the conventional-type wave tube shown schematically in Fig. 3, an evacuated elongated glass envelope 20 houses the various tube elements. At opposite ends of the envelope, an electron gun 21 and a collector electrode 31 in target relation with the electron gun define a path of travel for an electron beam along the tube axis. The electron gun 21 is advantageously of the hollow-cathode type of which a more detailed description is found in Patent 2,810,089, issued October 15, 1957, of D. MacNair. Such an electron gun is well adapted for providing a high density hollow cylindrical electron beam. The electron gun comprises a cathode assembly which includes a hollow metallic body 21A including an internal toroidal cavity 21B whose bounding surface is coated with a layer 21C of electron emissive material. The toroidal cavity 21B communicates with the exterior by an annular orifice 21D in the face of body 21A. A heater 22 is formed by a series of turns or resistance wire about body 21A within heater shield 23. The intensity of the electron beam which is emitted via the orifice 21D is controlled by the intensity control electrode 24. The velocity of the electron flow is controlled by the accelerating anode 25. Both intensity control electrode 24 and accelerating anode 25 are advantageously annular mesh grids suitably supported in alignment with orifice 21D spaced along transverse to the path of desired flow.

For confining the electron flow in its travel from the electron gun to the collector, a central cylindrical elec-

trode 26 is disposed along the tube axis and a succession of annular disc-shaped electrodes or rings 27 is disposed along the path of flow coaxial with and surrounding the electron beam. As discussed above with reference to Fig. 1, the electron beam is confined to the interspace between the central conductor 26 and the outer rings 27 by adjusting the potentials on the various elements to provide a net radially outward force on the inner edge electrons of the hollow beam and a net radially inward force on the outer edge electrons of the beam. To this end, by suitable lead-in connections from voltage supply 30, a set of alternate rings 27A is maintained at a positive potential with respect to the set of alternate rings 27B interleaved therewith, and the central conductor 26 is maintained at a potential negative to the mean of the potentials on sets 27A and 27B. Generally the potentials on both the central conductor 26 and all the rings 27 will be positive with respect to that of the hollow body 21A of the electron gun 21.

Moreover, to realize the maximum benefits of this focusing structure, the central conductor 26 is advantageously a helix, either of the wire or tape type, which serves as the wave interaction for propagating a radio frequency wave for interaction with the electron stream in accordance with known traveling wave amplification principles. Input waves can be applied to the helix wave circuit and output waves abstracted therefrom by any of the transducer arrangements known to the art. By way of illustration, in the tube shown the helix 26 is extended through a central aperture in the body 21A and led out through the tube envelope where it is coupled to a coaxial line connection 28 in the manner known to the art. To this end, the helix 26 is connected to the inner conductor 28A of coaxial connection preferably by way of a transition region in which the pitch of the helix is gradually increased while its diameter is decreased to form a smooth transition to a straight conductor. The outer conductor 28B of the coaxial connection is flared out at its end to form a flange-like member which is mounted flush with the end wall of the envelope. Similarly the collector end of the helix is extended through the collector electrode 31 which is made annular for this purpose and coupled to the coaxial connection 29 in the manner characteristic of the electron source end of the helix.

Additionally, the same focusing principles can be extended to the case of an electron beam of rectangular cross section of the kind which is useful in a linear magnetron. In the schematic arrangement shown in Figs. 4 and 5, a flat electron beam is shown projected through the interspace between a conducting electrode member 32 which forms an equipotential surface and a succession of plates or lateral fins 33 which are alternately at positive and negative potentials with respect to the potential on electrode 32 for defining a surface along which the potential varies periodically with distance. By suitable choice of potentials, there can be provided with reference to the plane of the paper a net downward force on the electrons in the upper edge of the beam and a net upward force on the electrons in the lower edge of the beam. Although the beam is not confined in a direction perpendicular to the plane of the paper as shown in Fig. 4, the spreading in this direction for most applications ordinarily will not be unduly severe.

This technique for focusing a flat electron beam makes possible an improved form of linear magnetron-type traveling wave tube. As has been discussed above, it has been generally desirable in prior art magnetron amplifiers in order to compensate for space charge effects to inject the electron beam initially into the region of crossed electric and magnetic fields in a way that provides a velocity distribution across the beam. To this end, the emitting surface generally has been positioned in a region of crossed magnetic and electric fields and disposed so that the emission is initially in a direction transverse to that desired for flow through the interaction space, and

the flow is gradually deflected to the desired longitudinal direction for travel through the region of crossed electric and magnetic fields. Various precautions must be taken to avoid undue electron oscillations normal to the magnetic field which make injection in this way rather complex.

In accordance with one aspect of the present invention, there is avoided the need for a velocity distribution across the beam in its travel between the regions of crossed electric and magnetic fields by confining the flow in the interspace between an equipotential surface and a surface along which the potential varies periodically to create a force for balancing the space charge forces. As is well known, for a given electron velocity there is a given ratio of transverse electric and transverse magnetic fields for which an electron passing longitudinally there-through feels no net force in a transverse direction except for space charge forces. In the characteristic arrangements, the potential difference between the equipotential surface and the opposite surface is first adjusted to that value which results in no net force in a transverse direction other than space charge forces on the electrons for the magnetic field strength being used. Then there is superimposed on this opposite surface a potential variation sufficient to provide a force on the electrons which balances out the space charge forces. As a result, there is not net force acting on the electrons in a direction transverse to the electron beam. Since now there is obviated the need for a velocity distribution across the beam in the region of crossed electric and magnetic fields, it is possible to inject the electron beam into such a region with a constant velocity distribution. To this end, it is possible to inject the electrons from a substantially field-free region. However, in passing from a field free region into the region of crossed fields there is necessarily encountered a transition region corresponding to the region of fringing magnetic field. To maintain the ratio of the crossed electric and magnetic fields constant in this transition region, it is important to increase the electric field gradually in a way to match the gradually increasing magnetic field. This can be done by tapering gradually the separation of the members which set up the transverse electric field. Alternatively, the electric field can be increased gradually in the transition region by steadily increasing the potential of successive lateral fins.

Figs. 6 and 7 show a linear magnetron embodying the principles just set forth. Within an evacuated glass envelope 40, designated by the broken line in Fig. 7 and omitted in Fig. 6, a flattened helix 41 serves as the wave interaction circuit for propagating a slow electromagnetic wave and additionally provides an equipotential surface extending parallel to the tube axis. Coupling connections for applying or abstracting wave energy to or from the helix have been omitted since they may be of any known form. Opposite the flattened helix 41, a succession of lateral fins 42 establishes a surface along which the potential is constant with time but varies spatially. The electron flow is confined to a longitudinal path of travel parallel to the tube axis in the interspace between the helix 41 and the succession of lateral fins 42 in the manner characteristic of the arrangement shown in Fig. 4. Magnetic flux producing means, for example poles of permanent magnets 43 and 44 positioned external to the glass envelope, provide a magnetic field perpendicular both to the direction of desired longitudinal flow and to the transverse electric field existing between the helix 41 and the succession of lateral fins 42. The magnetic flux producing means are disposed advantageously opposite a region of the path of electron flow downstream from the point where the succession of lateral fins and helix begin, and the helix and the succession of lateral fins begin at the point where the fringing magnetic fields set up by the flux producing means 43, 44 become significant. The relative positioning can be seen more clearly in the top view shown in Fig. 7 where the magnetic field lines are shown as the lines 46. In order to balance out the forces on the

electrons in this transition region, the potential of each of the lateral fins in this region of fringing magnetic fields is gradually increased whereby the ratio of the intensities of the crossed magnetic and electric fields is substantially constant throughout the transition region. To this end, successive lateral fins are maintained at suitable potentials by connection to lead-in conductors from appropriate taps on the voltage supply 50. With such an arrangement, it is feasible to inject the electron beam from a substantially field free region. As shown in Fig. 7, at one end of the tube beyond the point where the crossed fields become significant, there is positioned a conventional electron gun 48 which includes an electron emissive cathode and an electrode system for forming and accelerating a flat electron beam for travel through the interspace between the helix and succession of lateral fins. At the opposite end of the tube there is a positioned target electrode 49 which serve to collect the spent electrons at the end of their paths.

It is to be understood that the various arrangements which have been described are merely illustrative of the principles of the invention. Various modifications can be devised by a worker skilled in the art without departing from the spirit and scope of the invention. For example, the focusing principles described can be incorporated in other types of traveling wave tubes, such as backward wave oscillators and amplifiers both of the conventional type traveling wave tubes and the linear magnetron type traveling wave tubes. Moreover, various forms of wave interaction circuits can be utilized in tubes utilizing the electrostatic focusing principles set forth.

What is claimed is:

1. A traveling wave tube comprising an elongated envelope, an electron gun at one end of said envelope for projecting an electron beam having a pair of boundaries along said envelope, electron collector means at the other end of said envelope, means situated in said envelope along the path of said beam for maintaining one boundary of said beam constant, said means including a succession of distinct electrodes adjacent said one boundary and means for maintaining alternate of said distinct electrodes at different potentials, and means situated in said envelope along the path of said beam for maintaining the other boundary of said beam constant without disturbing said one boundary, said last mentioned means including a single electrode extending adjacent said other boundary and means for maintaining said single electrode at a potential less than the mean potential of said alternate distinct electrodes.

2. A traveling wave tube comprising an elongated envelope, an electron gun at one end of said envelope for projecting a hollow electron beam along said envelope, electron collector means at the other end of said envelope,

means situated in said envelope for maintaining the outer boundary of said hollow beam at a substantially constant diameter, said means including a succession of distinct annular electrodes encompassing said beam and arranged in alternate groups and means for maintaining said groups of distinct annular electrodes at different potentials, and means situated within said beam for maintaining the inner boundary of said beam at a substantially constant diameter without disturbing said outer boundary, said last mentioned means including a single electrode within said beam and coaxial therewith and means for maintaining said single electrode at a potential less than the mean potential of said groups of electrodes.

3. A traveling wave tube in accordance with claim 2 wherein said single electrode is a helical conductor and defines the interaction circuit of the traveling wave tube and said distinct annular electrodes are coaxial with said electron beam.

4. An electron discharge device comprising an elongated envelope, an electron gun at one end of said envelope for projecting a substantially flat electron beam having an upper and a lower boundary along said envelope, electron collector means at the other end of said envelope, means situated in said envelope along the path of said beam and adjacent the upper boundary thereof for maintaining the upper boundary of said beam substantially constant, said means including a succession of distinct electrodes arranged in alternate groups and means for maintaining said groups of distinct electrodes at different potentials, and means situated in said envelope along the path of said beam and adjacent the lower boundary thereof for maintaining said lower boundary substantially constant without disturbing said upper boundary, said last mentioned means including a single electrode adjacent said lower boundary and means for maintaining said single electrode at a potential less than the mean potential of said groups of electrodes.

5. An electron discharge device in accordance with claim 4 wherein said single electrode is a wire helix.

6. An electron discharge device in accordance with claim 4 further comprising means for maintaining a magnetic field transverse to the electric field between said groups of electrodes and said single electrode.

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