Oct. 21, 1958 R. KOMPFNER ET AL 2,857,548

ELECTRON BEAM SYSTEM

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FIG. 1A

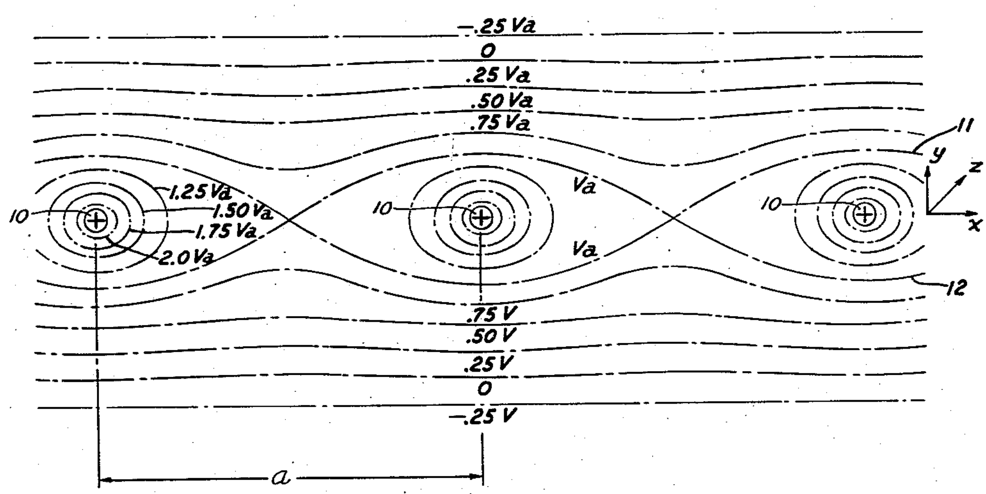
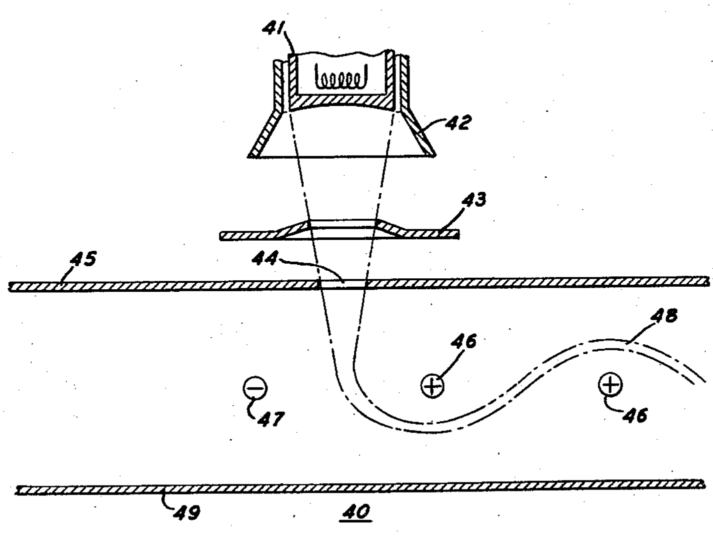


FIG. 4



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ELECTRON BEAM SYSTEM

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FIG. 1B

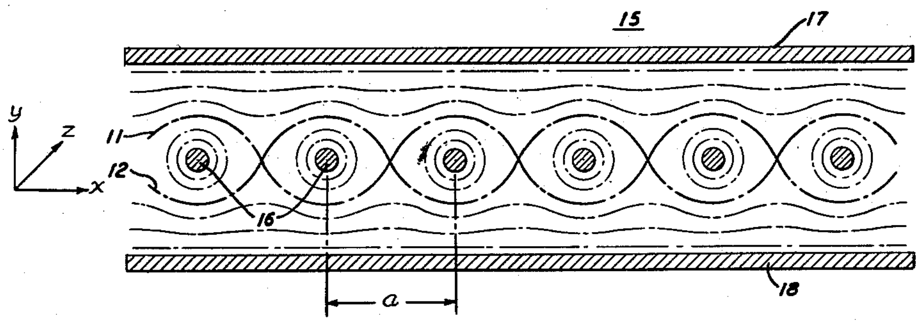

FIG. 2

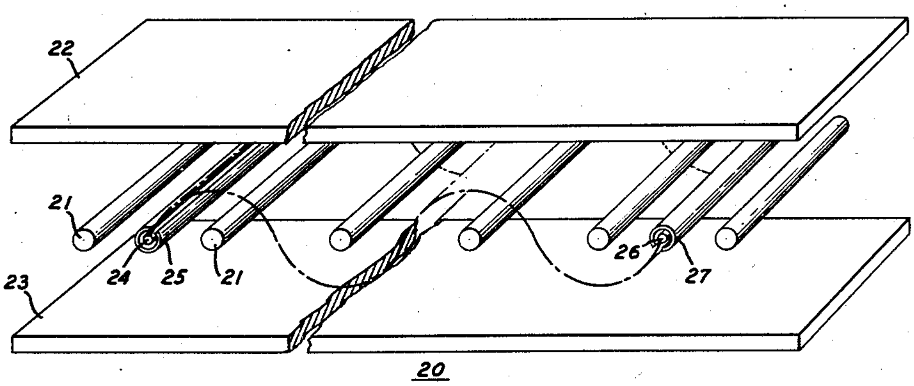

FIG. 3

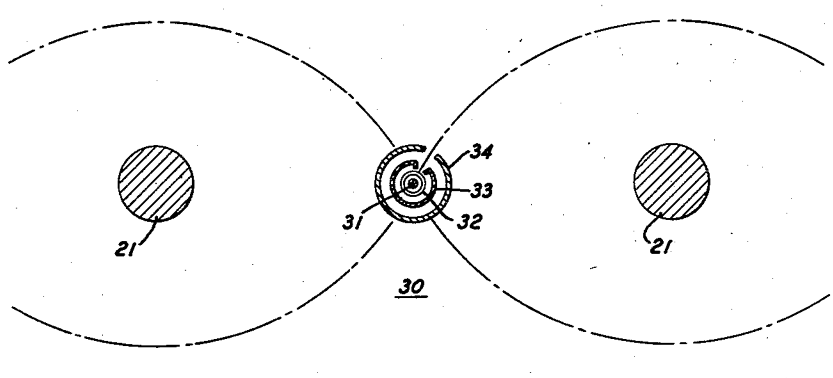

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FIG. 8

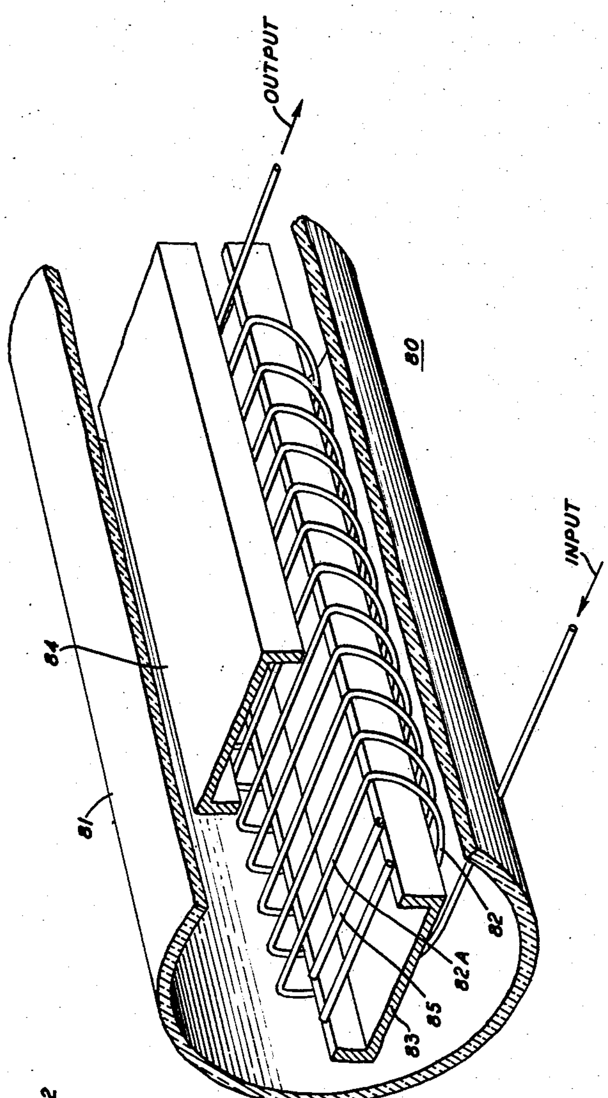
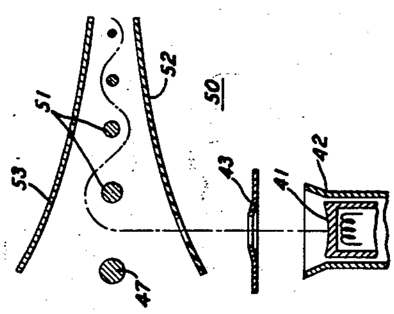


FIG. 5



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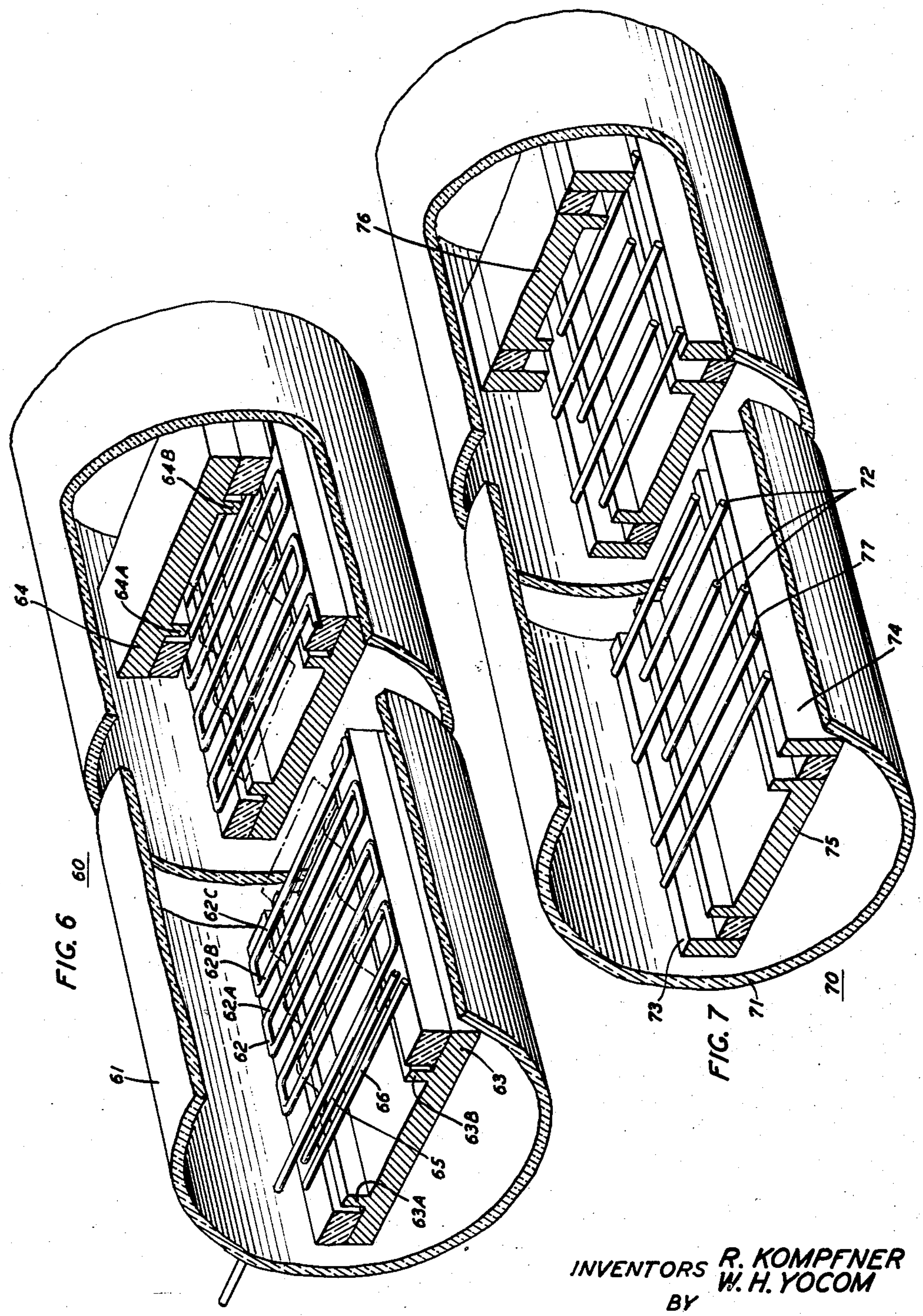

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ELECTRON BEAM SYSTEM

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Application June 10, 1955, Serial No. 514,423

12 Claims. (Cl. 315—3.5)

The present invention relates to an arrangement for focusing electrostatically a beam of charged particles and to apparatus which employs such a beam.

In the focusing of beams of charged particles, it is generally found desirable to provide focusing forces to overcome radial space charge forces and other effects which tend to make the beam diverge. Such focusing forces may be provided by either magnetic or electrostatic fields. The use of a magnetic field is often a disadvantage, especially when beams of high density and long paths are desired, since the equipment necessary to provide the desired magnetic flux is apt to be heavy and bulky. Accordingly, when feasible, it is preferable to employ electrostatic fields for focusing. Hitherto, electrostatic focusing has generally involved the use along the path of flow of an electric field which is time-constant but spatially-alternating in direction. To this end, there has been required an electrode system comprising an array of electrodes in which successive electrodes are maintained alternately at high and low electrostatic potentials. For many applications, focusing in this way is not completely satisfactory. In such an arrangement, the charged particles are passing alternately through regions of accelerating and retarding electrostatic fields, so that the average velocity of the particles is periodically undergoing significant change. This reduces the usefulness of the beam for many applications. Additionally, to establish and maintain the necessary potential differences between successive electrodes of the array imposes requirements that complicate the design of apparatus utilizing such an electrostatically focused beam. Accordingly, there is a need in the electronic art for a simple arrangement for focusing an electron beam over an extended path of flow, which does not require either a magnetic field or spatially-alternating applied electric potentials.

To this end, the principal object of the present invention is to meet this need.

The present invention is based to a considerable extent on the discovery that associated with an electrode system comprising an array of positively biased conductive elements spaced apart longitudinally there exists a pair of "singular" equipotential surfaces which are characterized in that a charged particle moving along either such equipotential surface with a correct velocity (which is a function of the geometry of the electrode system and the applied potentials) will remain substantially on that equipotential surface balanced between electrostatic and centrifugal forces. In particular, it is found that each of these singular equipotential surfaces forms a sinuous path winding in and out between successive elements of the array in a manner suggestive of a skier "slaloming" between successive flag markers. For this reason, it is thought appropriately descriptive to characterize the focusing technique of the invention as "slalom" focusing.

The principles of the invention find particular application, although not limited thereto, in traveling wave tubes. In such tubes, it is desired to project an electron beam closely past a slow wave interaction circuit on which is propagating an electromagnetic wave in a manner that the wave and beam interact to provide amplification of the wave. There are many forms of interaction circuits known to be suitable for good interaction which are characterized by a linear array of transversely extending elements. Such interaction circuits are readily adapted for establishing a singular equipotential surface therealong which will serve as a trajectory for an electron beam.

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There will be described as illustrative embodiments of the principles of the invention several traveling wave tubes, in each of which the slow wave interaction circuit is adapted to serve as the array of elements forming the basic portion of an electrode system used for establishing a singular equipotential surface. In combination with such an electrode system, there is provided an electron gun arrangement which is made to inject an electron beam on the singular equipotential surface for slaloming past the interaction circuit.

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

Figs. 1A and 1B are two-dimensional plots of the potential distribution associated with, respectively, a linear array of line charges and a linear array of wire elements biased positively with respect to a pair of bounding plates;

Fig. 2 shows in schematic form an electron beam system in accordance with the invention;

Figs. 3, 4 and 5 show alternative arrangements, for injecting an electron beam into an electron beam system in accordance with the invention; and

Figs. 6, 7 and 8 show different forms of traveling wave tubes embodying electron beam systems in accordance with the invention.

Turning now more specifically to the drawings in Fig. 1A, there is shown in two dimensions the equipotential surfaces forming the potential distribution associated with a plurality of positive line charges **10** extending in a z direction and spaced apart a distance a for forming a longitudinal array extending in the x direction. It can be shown that at any point in the xy plane the potential V is given by

$$V(z, y)=V_a\left[1-\frac{1}{2}ln\frac{1}{2}\left(\cosh\frac{2\pi x}{a}-\cos\frac{2\pi y}{a}\right)\right] \quad (1)$$

where V_a is the potential with respect to an arbitrary reference potential (which for reasons to become apparent later is conveniently chosen as the potential of the source from which originate the electrons in the beam to be focused) of the equipotential surfaces **11** and **12**, which will be designated the "singular" equipotential surfaces and which are characterized by the relation that

$$\cosh\frac{2\pi x}{a}=\cos\frac{2\pi y}{a}+2 \quad (2)$$

It is further characteristic that such singular equipotential surfaces extend longitudinally winding sinuously between successive line charges in the manner suggestive of a "slalom" pattern as shown graphically in Fig. 1A. These two singular equipotential surfaces have a mirror symmetry with the plane of the line charges **10** as the reflection plane. In the drawing there is also indicated the relative potentials of various other equipotential surfaces with respect to the potential V_a characterizing the singular equipotential surfaces.

It is in accordance with the invention to employ an electrode system which provides a similar pattern of singular equipotential surfaces. In Fig. 1B there is shown in two dimensions an illustrative electrode system **15**. Taking the role of the positive line charges are the positively charged conductive elements **16**, typically wires extending in the z direction, arranged in a linear array in which the successive elements are spaced apart the distance a in the x direction. The outer surface of each of these elements advantageously coincides with one of the closed equipotential surfaces of the plot shown in Fig. 1A and the potential applied to each such element should correspond to the potential of the equipotential surface chosen. Additionally, spaced in the y direction on opposite sides of the linear array of elements extend conductive members **17** and **18**. The surface of each of these members facing the linear array advantageously also has a shape which substantially coincides with the equipotential surface of the plot shown in Fig. 1B. In particular, it is advantageous to operate the conductive bounding plates at the potential of the source from which the electrons originate. This corresponds to the zero equipotential surface of Fig. 1A which is substantially planar. Ordinarily, in the electrode systems of primary interest the members **17** and **18** will be sufficiently separated from the linear array that they can be planar plates to conform to the substantially planar equipotential surfaces, shown in Fig. 1A, characteristic of regions appreciably separated in the y direction from the plane of the line charges.

By means not shown, each of the elements **16** of the array is maintained at the same positive potential with respect to that of the boundary members **17** and **18**. The potential of the singular equipotential surfaces may be chosen arbitrarily to have any desired value. Equation 1 then is solved with the parameters of the desired geometry used to fix some of the boundary conditions and in this way there is determined the potentials which need to be applied to the elements **16** and the bounding members **17** and **18** in order to achieve singular equipotential surfaces of the kind desired. There then results the potential distribution in the interspace between plates **17** and **18** of the kind shown by the broken lines, which is identical with that shown in Fig. 1A. There are available as the boundary conditions which serve as possible variables the size of the conductive elements **16** (which incidentally fixes their optimum shape), the spacing of the conductive members **17** and **18** (which also fixes their optimum configuration) and the potentials to be applied to the elements **16** and members **17** and **18**.

In accordance with the invention, it has been found that if an electron is injected for travel on either of the two singular equipotential surfaces **11** and **12** with a velocity v_0 which is given by

$$v_0^2=\frac{2e}{m}V_a \qquad (3)$$

where e and m are, respectively, the charge and mass of an electron, the electrostatic and centrifugal forces acting on the electron moving longitudinally will always be equal and opposite along such singular equipotential surface. Accordingly, an electron injected on one of these singular equipotential surfaces with a velocity v_0 in the direction of the singular equipotential line will follow a trajectory defined by the singular equipotential surface. It will be convenient to describe a velocity which results in stable flow substantially along a singular equipotential surface as a correct velocity. Accordingly, a sheet beam of electrons properly injected can be focused for travel substantially along a singular equipotential surface past an array of conductive elements. It is to be noted that Equation 3 will be automatically satisfied if V_a is made the potential difference through which an election is accelerated from rest before it is injected on the singular equipotential path, since the added velocity imparted to an electron in passing through a potential difference equal to V_a is as given by Equation 3. This means that a correct velocity will be assured if the electron is accelerated to a velocity which corresponds to the velocity imparted by acceleration from rest through a potential difference V_a, the potential corresponding to that the singular equipotential path with respect to the cathode from which the electrons in the beam to be focused originate.

An examination of Equation 1 and the number of variables whose value may be readily controlled shows that there are available more parameters than necessary. Accordingly, it is feasible to choose independently many of the parameters based on other considerations related to the particular application being made of the focusing arrangement. In particular, it is feasible to eliminate the conductive plates, which corresponds to an infinite separation of the plates from the array, or to have the separations of the individual plates from the linear array be different. The latter arrangement necessitates a different potential on the two plates. Alternatively, it is feasible to fix at a particular desired value the potential, the spacing, and size of the elements forming the array and thereafter to adjust the value of the potential of the plates and the plate spacing so that the singular equipotential path will have a desired potential. It is also feasible to vary two or more of the parameters with travel in the direction of flow as shown in the arrangement of Fig. 5 to be discussed below without appreciable cumulative effect on the singular equipotential path if such variations are made to compensate one another in their individual effects. Moreover, it is feasible to employ in place of either of the conductive plates an array of conductive elements for forming a bounding equipotential surface approximating one of those shown in Fig. 1A. Finally, even the potentials and sizes of the elements of the array may be varied if each elements is made to coincide in position and potential with a closed surface of Fig. 1A.

Additionally, it can be shown that the velocity with which the electrons are injected on the singular equipotential path may vary several percent without appreciable ill effects on the focusing. In particular, it is found that the flow along the desired path is stable so that a minor perturbance of the flow merely results in a trajectory which oscillates about the singular equipotential path.

In Fig. 2 there is shown in perspective an electron beam system **20** in accordance with the invention. An array of parallel wires **21**, each of which extends in a direction transverse to the desired direction of flow which are spaced apart a uniform distance in the longitudinal direction extends along the interspace between conductive plates **22** and **23**. Each of the wires is maintained at a positive potential with respect to the pair of plates. Intermediate between an adjacent pair of wires is positioned an electron source which comprises a filamentary cathode **24** extending parallel to the individual elements of the array surrounded by an anode **25**. The anode **25** is positioned in the region of the intersection of the singular equipotential surfaces associated with the array of wires and maintained at a potential V_a which corresponds to that characterizing the singular equipotential surfaces. As a consequence, the effect of the presence of the electron gun is minimized with regard to any disturbance of the potential distribution in the interspace, particularly the singular equipotential surface. Additionally, the difference in potential between the cathode **24** and anode **25** is made equal to the potential V_a. The anode **25** is a cylindrical element which is slit for exit of the electrons therepast at a region which corresponds to a singular equipotential. Accordingly, the electrons passing from the cathode beyond the anode are formed into a sheet beam and are injected on the desired singular equipotential surface shown by the broken line at a correct velocity so that the beam has a trajectory which substantially corresponds to the singular equipotential surface. In a specific design of an arrangement of this kind, 32 wires each of 60 mils diameter, with a center to center spacing of 180 mils formed the linear array of elements positioned midway between two conductive plates 300 mils apart. Typical operating parameters included a wire potential of $+390$ volts, an accelerating anode potential of $+230$ volts, a plate potential of -150 volts, and a current of several milliamperes.

It is also feasible, although not here shown, to provide a second beam for flow along the other singular equipotential surface by a second slit in the anode **25** at the region corresponding to its interception of this other singular equipotential surface.

Electrons are collected ordinarily by a target electrode positioned at a point along their path of flow beyond which the beam has completed its necessary role in the application intended. For example, in traveling wave tube applications, it will generally be desirable to extend the electrode structure establishing the singular equipotential surface beyond the end of the radio frequency signal circuit. This may be done by employing elements in the linear array which are not part of the radio frequency circuit. In the arrangement shown, the target electrode includes a collecting element **26** maintained at the potential of the elements **21** which is partially surrounded by a collector housing **27** maintained at the potential of the singular equipotential surface. By maintaining the housing at this potential, disturbancy of the potential distribution is minimized. The housing is slit at a point corresponding to the interception of the singular equipotential surface which serves as the path of electron flow for entrance therethrough of the electrons to the collecting element. The collecting element is maintained at the higher potential to minimize giving rise to the emission of secondary electrons. Alternatively, the electrons may be collected advantageously in the manner described in the copending application Serial No. 514,421, filed June 10, 1955, by J. S. Cook, R. Kompfner and W. H. Yocom.

In Fig. 3 there is shown in greater detail a form of electron gun **30** suitable for use as the electron source in the practice of the invention when the interelectrode distances which are tolerable are relatively large. A filamentary heater wire **31** extends coaxially through a cylindrical cathode housing **32**, a portion of whose outer surface is made electron-emissive to serve as the cathode. The cathode coating advantageously is positioned in the region of the interaction of the two singular equipotential surfaces provided by the array of elements **21**. To minimize magnetic effects, the cathode housing **32** is made the return path for heating currents flowing through the heater wire **31**. A beam forming electrode **33** partially surrounds the cathode housing, being slit in the region opposite the electron-emissive coating for passage of the electrons therepast. Lips are provided at the slit for beam shaping. Partially surrounding the beam forming element **33** is the accelerating anode **34**, also appropriately apertured for passage of the electrons therepast for injection on a singular equipotential surface. As before, the electrons are accelerated by a potential V_a before injection for travel along the singular equipotential path so as to have a correct velocity.

The schemes already described for injecting the electrons for flow along a singular equipotential have both involved injection internally from a region included with the interspace enclosed by the bounding plates. For some applications, it may be preferable to inject electrons from a region external to such an interspace. In particular, in applications where the linear array is to serve as a radio frequency wave propagating structure, it may in some cases be desirable to isolate the path for the radio frequency wave as much as possible from the electron gun.

In Fig. 4, there is shown in a longitudinal sectional view an alternative arrangement **40** for injecting electrons with a correct velocity on a singular equipotential line. In this case, an electron gun comprising a cathode **41**, and a beam forming electrode **42** and accelerating anode **43** are positioned external to the interspace and provide an electron beam which is projected into the interspace through an opening **44** in one of the plates **45** bounding the region of the linear array of wires **46**. Positioned as a continuation of the linear array of wires **46** is a deflecting element **47** which is maintained at a potential negative with respect to the potential of the remaining wires **46** of the array and is used to deflect the beam injected into the interspace. The geometry of the arrangement and the various potentials applied to the gun and deflecting element are adjusted so that electrons are injected with a correct velocity on a singular equipotential surface **48** with the trajectory shown. It is feasible to inject an electron beam in an analogous manner through an aperture in plate **49** on to the other singular equipotential surface.

For many applications, it will be important to work with beams whose transverse dimension in the direction of plate separation is small but which have rather high densities. To this end, it is desirable to employ an electron gun of relatively large dimensions but to converge the electrons emitted therefrom into a sheet beam of the desired narrow transverse dimension. In Fig. 5 there is shown as a longitudinal sectional view an electron gun arrangement **50** suitable for such purposes. It is characterized by the inclusion of a tapered section in which the dimensions of the focusing structure are gradually tapered down from large initial sizes to smaller sizes more suited for the intended application. As shown, the spacing in the x direction between successive wires **51** forming longitudinal array is gradually decreased, together with the radii of successive wires. Concurrently, the spacing in the u direction of the conductive bounding plates **52** and **53** from the array is gradually decreased. By making the rate of change with distance of the various dimensions small compared with the distance, an electron beam properly injected will still substantially follow longitudinally a singular equipotential surface wtihout an appreciable loss of electrons. The electron beam may be injected by any of the arrangements previously described. By way of illustration, the external injection arrangement described in conjunction with Fig. 4 is being shown in Fig. 5 in which electrons emitted from a cathode **41** positioned external to the interspace between the bounding plates are formed into a beam which is projected into the interspace through an aperture in one of the plates **52** and deflected with a correct velocity by a deflecting electrode **47** into the singular equipotential path.

Still another arrangement suitable for injecting an electron beam with a correct velocity on a singular equipotential surface is described in copending application Serial No. 514,421, filed June 10, 1955, by J. S. Cook, R. Kompfner and W. H. Yocom.

It will be convenient in the traveling wave tubes to be discussed hereinafter which utilize an electron beam system of the kind described as in accordance with the invention to show only schematically the electron gun used to inject the electron beam along a singular equipotential surface. It is to be understood that any suitable gun, of which those described herein are illustrative, may be used.

In Fig. 6 there is shown a perspective view of a traveling wave tube **60** which incorporates the focusing principles of the invention for providing electron flow suitable for interaction with a signal wave. Within an evacuated envelope **61**, which typically may be of glass there is positioned a wave guiding circuit comprising a zig-zag transmission line **62**. Such a line comprises a conductor which is folded back and forth a plurality of times substantially in a single plane, successive folds being spaced apart in a longitudinal direction. The line is shown schematically supported at its folded ends.

It is known that a folded line of this kind is suited for use as an interaction circuit for propagating an electromagnetic wave which has a longitudinal component of electric field having a phase velocity a fraction of the speed of light so that this velocity can be readily matched to the velocity of an electron beam in the manner typical of traveling wave type interaction.

It is evident that such a line provides in the longitudinal direction along the intermediate portion of the folds a succession of parallel conductive elements such as **62**A, **62**B and **62**C spaced apart in a linear longitudinal array. Moreover, by positioning conductive plates **63** and **64** on opposite sides of the transmission line, there results an electrode structure which resembles that shown in Fig. 1B. By suitable lead-in connections from a D. C. voltage source the line may be maintained at a suitable positive potential with respect to the conductive members, so that a potential distribution characterized by a pair of singular equipotential surfaces of the kind displayed in Fig. 1A may be realized along the line.

An electron beam in sheet form is injected along one of such surfaces for travel past the transmission line by an electron gun **65** shown schematically positioned at one end of the line. By the techniques previously described, the electron beam is injected on one of the singular equipotential surfaces with a correct velocity. It is convenient for achieving an arrangement like that shown in Fig. 2 to position an auxiliary electrode **66** beyond each end of the line to serve as extensions of the linear array of elements extending beyond the electron gun to minimize abrupt discontinuities in the potential distribution beyond the ends of the line.

For traveling wave operation, the longitudinal electron beam velocity must be matched to the phase velocity of a longitudinal electric field component of the traveling wave. The phase velocity of the wave can be adjusted by the geometry of the line in a maner known to workers in the art. The desired beam velocity can be realized by appropriately fixing the potential of the singular equipotential surface. Such potential may be realized by proper choice of boundary conditions. The boundary conditions most easily adjusted are the D. C. potential of the line and the spacing of the conductive plates. It is generally convenient to operate the plates at the same potential as the cathode of the electron gun. To aid in confining the edges of the sheet beam, it is advantageous to include longitudinal projections **63**A, **63**B and **64**A, **64**B which extend from each plate **63** and **64** towards the linear array of elements at points slightly wider than the edges of the beam. Moreover, it is also feasible to employ two sheet beams injecting one on each of the two singular equipotential surfaces in the manner previously described when high powers are important.

A traveling wave tube of the kind described may be employed in the forward wave mode as an amplifier or in the backward wave mode as an amplifier or oscillator. For use as a forward wave amplifier, the input signal is applied from a signal source to the transmission line forming the circuit at the upstream or electron source end and the output wave is abstracted at the downstream or collector end for use by the load. Connection to the circuit can be made simply by connecting the end of the circuit to the inner conductor of a coaxial line. Additionally, for use as a forward wave amplifier, it is advantageous to insert loss along the circuit to minimize the effect of reflections in causing instability.

For use as a backward wave oscillator, the beam velocity is matched to the phase velocity of a negative space harmonic of a wave traveling along upstream the circuit in the manner characteristic of backward wave operation. Additionally, the beam current is made sufficiently high that oscillations are set up. The output oscillatory wave is abstracted for use by the external load by a connection to the upstream or gun end of the wave. Additionally, the downstream end of the circuit is terminated to be substantially reflectionless, as by the insertion of a section in which resistive lossy material is introduced gradually. The frequency of the oscillations may be varied readily simply by varying the velocity of the electron beam. This corresponds to varying the potential of the singular equipotential surface. The potential of this surface can be varied without upsetting the focusing conditions if all of the potentials of the electrode system are varied proportionately. In particular, by supplying each of the potentials necessary for stable flow to the electrode system by tapping at various appropriate points a potentiometer which is connected across a suitable voltage source, variations made in the voltage of the source will result in proportionate variations in the potentials at the various taps in a way that will maintain undisturbed the various relations necessary for stable flow between the potentials of the electrode system.

For use as a backward wave amplifier, the beam velocity is again matched to the phase velocity of a negative space harmonic traveling upstream along the circuit. The input signal is applied to the circuit at its downstream end and the amplified output abstracted at the upstream end. Caution must be taken to insure that the beam current is insufficient to set up backward wave oscillations and the loss along the line is minimized.

Alternatively, the backward wave oscillator may be of the kind described in copending application Serial No. 392,946, filed November 18, 1953, by H. Heffner and R. Kompfner in which a backward wave circuit sets up oscillatory space charge waves on the beam which are abstracted by a forward wave circuit positioned downstream of the backward wave circuit.

In Fig. 7 there is shown in perspective a traveling wave tube **70** which employs an interdigital transmission line as the wave interaction circuit. Such a tube can be operated as a forward wave amplifier, backward wave amplifier and backward wave oscillator in accordance with principles known to workers in the art described above. Within an evacuated envelope **71**, suitably positioned is an interdigital transmission line of the kind known to workers in the art and described in detail in U. S. Patent 2,823,332, issued February 11, 1958, to R. C. Fletcher. This line comprises a linear array of conductive finger elements **72**, successive finger elements extending from opposite conductive end support members **73**, **74** for forming an interdigital array which serves to provide a zigzagging path for the traveling wave in a manner resembling the wave path provided by the zigzag line of the tube shown in Fig. 6. Positioned on opposite faces of the interdigital line are the top and bottom conductive plates **75**, **76**. By insulating the interdigital line from the plates **75**, **76** and establishing a potential difference therebetween, there is effectively achieved a structure which functionally resembles that of Fig. 1B and, accordingly, establishes a pair of singular equipotential surfaces which serve as stable trajectories for electrons injected properly thereon. In the manner described above, sheet beams of electrons may be injected from an electron source **77** on each of these singular equipotential surfaces with a correct velocity for substantially following these singular equipotential surfaces. The potential of the singular equipotential surface is chosen so that the longitudinal velocity of electron flow will be matched with the phase velocity of the longitudinal electric field signal component with which interaction is desired. Coupling connections may be provided to the ends of the interaction circuit in the manner known to workers in the art.

In Fig. 8 there is shown in perspective a traveling wave tube **80** of the kind which employs a helix as the interaction circuit and in which the principles of the invention are incorporated. Within an evacuated envelope **81** there is supported a helix **82** which is to serve as the interaction circuit. To adapt better the helix for use as a focusing electrode in accordance with the invention, at least one portion **82**A of the helix is flattened to provide a substantially coplanar linear array of spaced conductive elements which can serve as a linear array of elements of the kind shown in Fig. 1B. Positioned on opposite sides of this array of elements are a pair of conductive plates 83, 84 which serve as the bounding plates shown in the arrangement of Fig. 1B. The helix is insulated from the plates and maintained at a suitable positive potential therewith whereby there are set up a pair of singular equipotential surfaces which extend past this flattened portion of the helix. A sheet beam of electrons is injected on this surface with a correct velocity from a suitable electron source 85. As in the tubes described earlier, the potential of the singular equipotential surfaces is chosen so that an electron velocity correct for focusing is also suited for interaction between the beam and a signal wave propagating along the helix. The signal wave may be applied to and abstracted from opposite ends of the circuit by coupling techniques known to workers in the art.

It will also be apparent to workers in the art that the principles employed in the tube shown in Fig. 8 may be extended to the projection of an annular electron beam past a conventional helix, i. e., one whose winding is smooth and whose cross section is substantially circular. In such a case, inner and outer cylindrical electrodes coaxial with the helix would serve as the conductive bounding members and the successive turns of the helix form a longitudinal array of parallel conductive elements. There will then be set up a pair of helicoidal singular equipotential surfaces, each of which winds sinuously past successive turns of the helix. Each of these surfaces will be closed and a cross section thereof taken normal to the helix axis will be substantially circular.

The focusing principles of the invention are by no means limited to applications in traveling wave tubes. Typical of other electronic devices which may be devised consistent wtih the principles of the invention are switching tubes and storage tubes of the kind described in copending application Serial No. 514,424, filed June 10, 1955, by R. Kompfner.

Accordingly, it is to be understood that the specific embodiments described in detail are merely illustrative of the general principles of the invention. Various other arrangements may be devised by one skilled in the art without departing from the spirit and scope of the invention. For example, although in the arrangements depicted the elements have always been arranged in a linear array, it is feasible to arrange them in a curved array so long as appropriate changes are made in the boundary conditions associated therewith.

What is claimed is:

1. In an electron discharge device, in combination, a source of charged particles, a plurality of conductive elements spaced apart in a longitudinal array, the elements being maintained at a potential difference with respect to said source for forming a singular equipotential path which extends in a longitudinal direction wnding sinuously past the elements, and means for njecting particles from said source into said singular equipotential path at a velocity for following substantially along said singular equipotential path.

2. In an electron discharge device, in combination, a plurality of parallel conductive elements spaced apart in a longitudinal array, each element being maintained at a positive potential with respect to a reference level for forming a singular equipotential path which extends in a longitudinal direction winding past the elements, means at the reference potential level providing an electron beam, and means maintained at the potential of the singular equipotential surface for accelerating the electrons and injecting the electrons into the singular equipotential path with a velocity for following said path.

3. In an electron discharge device, in combination, a spaced pair of conductive means bounding the interspace therebetween, a plurality of conductive elements spaced apart in an array which extends longitudinally in said interspace, means for biasing the elements with respect to said bounding means and establishing a pair of singular equipotential surfaces each of which extends longitudinally along said interspace winding sinuously past the elements, and means for injecting electrons on to at least one of said equipotential surfaces at a velocity for following substantially longitudinally along said one surface.

4. In an electron discharge device, in combination, a spaced pair of conductive plates, a plurality of conductive elements spaced apart and extending transversely for forming a longitudinal array in the interspace between the pair of plates, means for biasing the elements positive with respect to said plates for establishing a pair of singular equipotential surfaces, each of which extends longitudinally winding sinuously past the elements in the interspace, and means for injecting electrons into at least one of said singular equipotential surfaces at a velocity for following substantially longitudinally along said surface.

5. In an electron discharge device, in combination, a spaced pair of conductive plates, a plurality of spaced conductive elements forming a linear array which extends longitudinally in the interspace between the pair of plates equidistant from the two plates, means for biasing the elements of the array positive with respect to said plates and establishing a pair of singular equipotential surfaces which extend longitudinally in the interspace winding sinuously past the elements, means forming an electron beam, and means maintained at the potential of the singular equipotential surface for accelerating the electrons in said beam and injecting the electron beam onto one of said singular equipotential surfaces at a velocity for following substantially along said singular equipotential surface.

6. In an electron discharge device, in combination, a plurality of parallel conductive elements spaced apart in a longitudinal array, each of the elements being maintained at a positive potential for establishing a pair of singular equipotential paths, each of which extends longitudinally winding past the elements, and means positioned substantially at an intersection of the pair of singular equipotential surfaces for injecting electrons into one of said singular equipotential paths for travel substantially therealong at the correct velocity.

7. In an electron discharge device, in combination, a plurality of parallel conductive elements spaced apart in a longitudinal array, one of a pair of conductive bounding means on opposite sides of the longitudinal array, means for maintaining the elements of the array at a positive potential with respect to said conductive bounding means for forming a pair of singular equipotential paths which extend longitudinally in the interspace between the conductive bounding means, and means positioned external to said interspace for forming an electron beam which is injected into said interspace at a velocity for substantially along one of said singular equipotential surfaces.

8. In an electron discharge device, in combination, a transmission line for propagating an electromagnetic wave, portions of the transmission line forming an array of conductive elements, an electron source, means for biasing said portions positive to said electron source for forming a pair of single equipotential surfaces extending past said portions, and means for injecting electrons from said source into one of said single equipotential surfaces with a velocity to follow substantially along said single equipotential surface.

9. In an electron discharge device, in combination, an electron source providing a sheet beam of electrons, a transmission line which comprises a conductor which is folded back and forth to form a zig-zagging wave path, portions of the transmission line forming a linear array of parallel conductive elements along the beam path, means for biasing said portions positive to said electron source for forming a pair of singular equipotential surfaces winding between successive portions of the linear

array, and means injecting said sheet beam onto one of said singular equipotential surfaces with a velocity for following substantially along said surface.

10. An electron discharge device comprising means for defining an electric field characterized by a plurality of equipotential surfaces, said means including a longitudinally extending array of spaced electrodes, conducting means on each side of said array and spaced therefrom, and means for applying potentials to said spaced conducting means and to said array such that at least one of said equipotential surfaces winds between successive electrodes of said array; and means including a source of electrons and accelerating means for injecting electrons substantially onto said one equipotential surface at

a velocity to cause said electrons to travel substantially along said one equipotential surface.

11. An electron discharge device as claimed in claim 10 wherein said conducting means are maintained at a potential negative with respect to the electrodes in said array.

12. An electron discharge device as claimed in claim 10 wherein said array constitutes a slow wave circuit.

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