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ELECTRON BEAM SYSTEMS
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2,951,964

FIG. 1

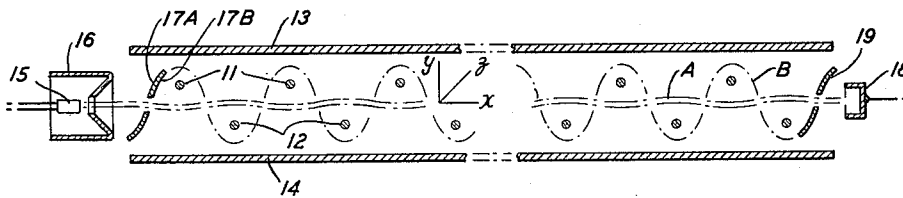


FIG. 2A

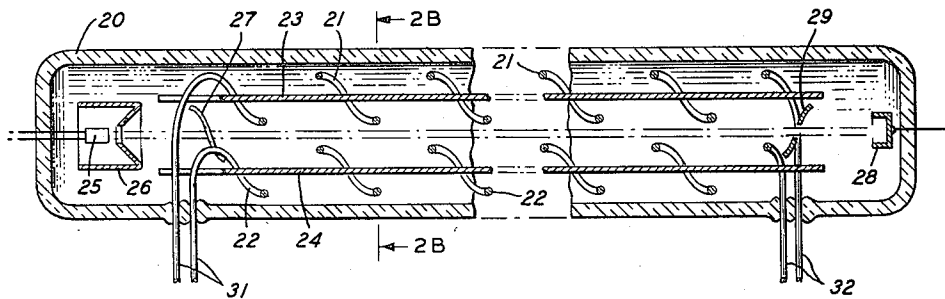


FIG. 2B

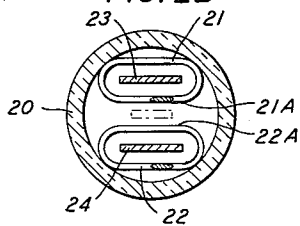


FIG. 3B

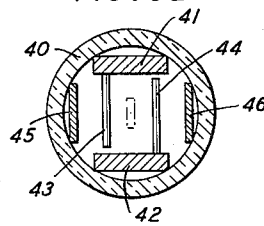
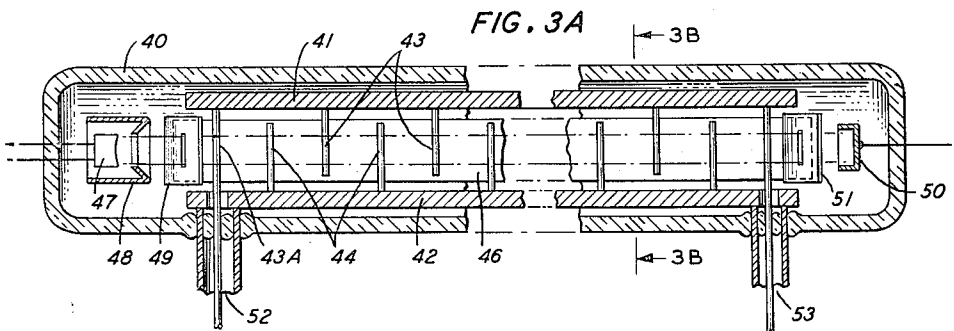


FIG. 3A



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2,951,964

ELECTRON BEAM SYSTEMS

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This invention relates to electrode systems for electrostatically focusing an electron beam, and to apparatus using such electrode systems.

The present invention relates more particularly to an extension of the electrostatic focusing principles which are described in copending application Serial No. 514,423, filed June 10, 1955, by R. Kompfner and W. H. Yocom, now U.S. Patent 2,857,548, issued October 21, 1958. As is described therein, a succession of conductive elements which are arranged in a linear array positioned intermediate between a pair of bounding plates and which are maintained at a positive potential with respect to such plates establishes a pair of singular equipotential surfaces, each of which winds sinusously past successive elements of the array and is so characterized that an electron beam which is introduced thereon with an appropriate velocity will flow stably therealong balanced between centrifugal and electrostatic forces. An important advantage of an electrode system of this kind over previously known electrode systems for focusing an electron beam electrostatically is that the electron flow in this case is along an equipotential surface and so is of constant velocity in the absence of any disturbance of the beam. By way of contrast, previously known electrode systems for electrostatic focusing an electron beam generally have involved periodic acceleration and retardation of the electron beam with consequent periodic changes in its velocity.

In the electronics art there exist many applications which make use of electron beams in which it is preferable to confine the electron flow to a relatively smooth or planar path, rather than a sinuous one as is characteristic of the electron beam systems described in said Kompfner-Yocom patent, and yet to avoid periodic changes in the beam velocity characteristic of other forms of electron beam systems.

Accordingly, a broad object of the present invention is to focus an electron beam electrostatically along a substantially smooth equipotential surface.

To this end, a feature of the present invention is an electrode system which establishes a singular equipotential surface which is substantially smooth and along which an electron beam which has been properly injected will flow stably. An illustrative electrode system of this kind comprises an array of elements in which alternate elements of the array are displaced transversely with respect to adjacent elements such that adjacent elements are on opposite sides of a reference plane which essentially is to form the singular equipotential surface of electron flow. This array of elements is positioned intermediate between a pair of conductive bounding members and each ele-

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ment of the array is maintained at a positive potential with respect to the bounding members to form of the reference plane one of a pair of singular equipotential surfaces. The other singular equipotential surface will be sinuous as is characteristic of an electrode system of the kind described in the previously identified Kompfner-Yocom patent. By proper injection of an electron beam on the smooth singular equipotential surface, stable flow therealong is achieved.

The present application finds special application in transverse field traveling wave tubes of the kind described in copending application Serial No. 197,412, filed November 24, 1950, by J. R. Pierce, now U.S. Patent 2,801,361, issued July 30, 1957, and my copending application Serial No. 465,580, filed October 29, 1954, now U.S. Patent 2,823,333, issued February 11, 1958. In such transverse field tubes the interaction circuit is designed for excitation in a mode such that along a particular longitudinal smooth surface the electric field of a wave traveling along the interaction circuit is substantially purely transverse. For interaction with the electric field of the traveling wave, an electron beam is projected for flow along this surface. In general, it is true that if the electric field of a wave traveling along a slow wave circuit is purely transverse over a smooth surface, it must also have a longitudinal component at regions removed from this surface. In a transverse field tube, it is characteristic of the mode of operation that the transverse electric fields set up by the slow traveling wave displace transversely the electrons which are flowing longitudinally in the surface of substantially pure transverse field into the regions removed therefrom of longitudinal electric field, and such displaced electrons then interact with the longitudinal electric field component and, as a result, give up energy to the traveling wave, whereby it is amplified.

It is characteristic of a transverse field tube that if in the absence of a signal the electrons are confined to the smooth surface of substantially pure transverse field where the longitudinal field is essentially zero, fluctuations in current density or velocity of the electrons will produce no significant noise power in the circuit. Accordingly, by properly focusing and collimating an electron beam for travel along such a smooth surface in the absence of a signal, it is possible to make the noise figure of the tube very small.

However, it has been difficult hitherto to focus an electron beam for travel along such a smooth surface conveniently. The various expedients which previously have been suggested do not provide complete satisfaction. The use of magnetic fields for providing the focusing forces is not completely satisfactory, both because the extra equipment needed for creating the magnetic flux adds undesirably to the bulk and weight and also because the magnetic field affects the electron beam unfavorably from a noise standpoint. The use for focusing the beam electrostatically of an electrode system of the kind comprising an array of elements in which successive elements are maintained alternately at high and low potentials is not completely satisfactory because, as previously discussed, with such a system even in the absence of a signal the electrons in the beam are passing alternately through regions of accelerating and retarding fields so that the velocity of the electrons is periodically undergoing a substantial change, an effect which is undesirable in a traveling wave tube from the standpoint of interaction efficiency.

Accordingly, a specific object of the invention is to focus the electron beam of a transverse field tube along the desired longitudinal surface of substantially pure transverse field in a manner that both avoids the need for applied magnetic fields and also does not result in large periodic variations of the velocity of the beam.

For application of the principles of the present invention to a transverse field tube, a focusing electrode system of the kind previously described is designed to act also as an interaction circuit of the kind characteristic of transverse field tubes, and the smooth singular equipotential surface of the focusing electrode system is made to coincide with the surface of relatively pure transverse field of the interaction circuit, whereby an electron beam suitably injected on such common surface will flow stably therealong for interaction with the wave traveling along the interaction circuit.

In an illustrative embodiment of the invention, a pair of flat helices are positioned alongside one another and are excited in opposite phase to serve as an interaction circuit of the kind which provides a plane of substantially pure transverse field in the interspace between the two helices. A conductive plate is inserted in each helix to serve as a bounding member of the focusing system. Additionally, the flat portions of the two helices adjacent the plane of substantially pure transverse field serve as the succession of alternately displaced conductive elements of the focusing system. By maintaining the two helices at an appropriate positive potential with respect to that of the pair of conductive plates, the plane of substantially pure transverse field is also made a singular equipotential surface of the focusing system.

The invention also has application to conventional traveling wave tubes in which the interaction circuit establishes a longitudinal electric field along the path of flow of the electron beam. In an illustrative embodiment of the application of the principles of the invention to this type of traveling wave tube, a pair of comb-like arrays of finger elements are positioned on opposite sides of a reference plane in a manner such that their projection on the reference plane forms an interdigital pattern. This structure is excited to establish a longitudinal electric field for travel along the reference plane. To make a singular equipotential surface of this reference plane, a pair of conductive bounding members are positioned to enclose the two comb-like arrays and both such members are maintained at a negative potential with respect to the finger elements of the arrays.

The invention will be better understood from the following more detailed description, taken in connection with the accompanying drawing in which:

Fig. 1 illustrates schematically a prototype of an electron beam system in accordance with the invention;

Figs. 2A and 2B show a longitudinal section and a transverse section, respectively, of a transverse field traveling beam system of the kind shown in Fig. 1; and

Figs. 3A and 3B show a longitudinal section and a transverse section, respectively, of a longitudinal field type of traveling wave tube embodying an electron beam system of the kind shown in Fig. 1.

With reference now more particularly to the drawings, the prototype electron beam system shown in Fig. 1 is adapted to provide longitudinal electron flow along a relatively smooth plane A which acts as an equipotential surface for such flow. For focusing the beam along such plane, a succession of parallel wire-like elements extending in the z direction are spaced apart in the x direction. Adjacent elements of the succession are displaced in the y direction so as to be positioned on opposite sides of the plane A whereby there are formed two sets 11, 12 of linearly aligned elements, each set being on opposite sides but in a plane parallel to the plane A. The two sets of elements are enclosed by a pair of conductive plates 13, 14 which form conductive boundaries parallel to the plane A. The elements of the linear arrays 11, 12 are

maintained at a positive potential with respect to the plates 13, 14. This is designated schematically in the drawing. Suitable choice of the potential difference results in forming of the plane A a singular equipotential surface at a potential V which is intermediate between those on the elements 11, 12 and the conductive plates 13, 14. The electrode system also forms a second singular equipotential surface B which winds sinusously past successive elements 11 and 12 and intersects the singular equipotential surface A periodically at regions midway between successive elements.

The generalized relationships between the different parameters of the electrode system which will result in an equipotential pattern of the kind desired are not amenable to a simple mathematical expression. Typically, parameters such as the voltages to be applied to the various electrodes are best determined by electrolytic tank measurements of the kind known to workers in the art. By way of illustration, there will be set forth hereinafter a set of parameters of an illustrative embodiment.

As is discussed in greater detail in the Kompfner-Yocom patent, it is necessary for stability that the electron beam which is to flow along the singular equipotential plane A be suitably injected thereon. In particular, if the potential of the electron source from which the electron beam originates be considered as ground or the reference level, the electron beam should be accelerated before injection to a velocity corresponding to the potential of the singular equipotential surface along which it is to flow. Moreover, it is also advantageous that the electron gun employed for injection of the electron beam does not appreciably disturb the focusing field patterns at the region of injection.

Injection arrangements suited to both these ends are described in copending application Serial No. 514,421, filed June 10, 1955, by J. S. Cook, R. Kompfner and W. H. Yocom, now U.S. Patent 2,939,034, issued May 31, 1960. An injection arrangement of the kind described in detail therein is shown included in the electron beam system illustrated in Fig. 1. Various other injection arrangements are also described in the aforementioned Kompfner-Yocom patent.

The beam source comprises an electron-emissive strip cathode 15 with which is associated a beam-shaping electrode 16. In these respects, the electron gun is of well known form. Additionally, the electron gun includes an accelerating anode whose surface 17A is such as to cooperate with the beam-forming electrode 16 in forming the electron emission into a beam and whose surface 17B coincides with an extended portion of the singular equipotential surface B. This anode is apertured for passage of the electron flow therepast at the region where its surface 17A, if continued smoothly, would intersect the singular equipotential surface A. The accelerating anode is maintained at the potential V of the singular equipotential surfaces A and B to result in beam injection with the correct velocity on surface A.

For collecting the beam at the end of its path of flow, an analogous arrangement is advantageously employed to minimize disturbance of the focusing field pattern. The collector 18 is shielded from the focusing field by an electrode 19 whose surface 19A coincides with singular equipotential surface B and which is apertured for passage therethrough of the electron beam at the region where such surface, if continued smoothly, would intersect the singular equipotential surface A.

In an illustrative embodiment of the electron beam system shown, wire elements 11, 12 of 12 mils diameter have a center-to-center separation in the x direction of 62.5 mils and a center-to-center separation in the y direction of 47 mils. The plates 13 and 14 each have a separation from the centers of the elements of corresponding linear arrays 11 and 12 of 33.5 mils. The plates 13, 14 are maintained at 130 volts above the reference level which is the potential of the cathode 15 of the electron

gun. The accelerating anode 17A, 17B and the collector shielding electrode 19 are each maintained at 1000 volts which corresponds to the potential of the singular equipotential surfaces A and B. The wire elements 11, 12 are maintained at 1130 volts, 1000 volts above the potential of the plates 13, 14. The collector 18 is also maintained at 1130 volts. An electrode system of this kind is designed to focus an electron beam having a density of 100 milliamperes/centimeters².

Figs. 2A and 2B show a transverse field traveling wave tube which includes an electrode beam system of the kind shown in Fig. 1. The various tube elements are enclosed within a vacuum envelope 20, typically of glass. In the interest of simplicity, details such as support rods, spacer elements and lead-in connections have been omitted in the drawing. An identical pair of helices 21 and 22, which are wound in flattened form as seen in Fig. 2B, are positioned alongside one another with their flat surfaces parallel and spaced apart to define therebetween an interaction space through which is to be projected an electron beam. The two helices are wound in the same sense and are positioned so that their flat portions 21A, 22A adjacent the interaction space form a succession of elements which resembles and is the electrical equivalent of the succession formed by the two linear arrays 11, 12 of the electrode system shown in Fig. 1. In respective helices 21 and 22, there are inserted conductive plates 23 and 24 to serve as the electrical equivalents of plates 13 and 14 of the electrode system shown in Fig. 1. Accordingly, by suitably relating the parameters of the electrode system formed by helices 21 and 22 and the conductive inserts 23 and 24, there is established a pair of singular equipotential surfaces, corresponding to surfaces A and B of the electrode system shown in Fig. 1. Of these, one will be relatively smooth and extend longitudinally in the interspace between the two helices.

Beyond one end of the pair of helices, an electron gun of the kind discussed with reference to Fig. 1 and including an electron-emissive cathode 25, beam forming electrode 26 and suitably apertured accelerating anode 27 is arranged to inject a flat electron beam for stable flow along the singular equipotential surface set up in the interspace. At the opposite end of the pair of helices, a collector 28 and suitably apertured shielding electrode 29 are used to collect the spent beam in a manner analogous to that described for the arrangement shown in Fig. 1.

In operation, by a coupling connection to the input end of the pair of helices, an input wave from a signal source is applied to the interaction circuit formed by the pair of helices for travel therealong for interaction with the electron beam flowing in the interaction space. In order that the singular equipotential surface of electron flow will correspond to a surface along which the electric field of the traveling wave is almost purely transverse, the two helices are excited such that the radio frequency potentials of adjacent flattened portions of the two helices remain substantially 180 degrees apart in phase. This end is readily achieved, for example, by connecting the input ends of the two helices to different conductors of a parallel-wire transmission line 31 as shown. The distance around a complete turn of each helix is adjusted relative to the separation between turns, or pitch, such that the phase velocity of the electric field traveling along the intersection surface in the interspace is substantially equal to the velocity of electron flow therealong, in the manner characteristic of traveling wave tube operation.

As a consequence, there is interaction between the electric field of the signal wave and the electron flow, whereby the signal wave is amplified. At the collector end of the interaction circuit, the amplified wave is abstracted for transfer to a load by a parallel-wire coupling connection 32 of a kind similar to that used at the input end.

Provision may be made for minimizing any tendency to self-oscillation by the insertion of loss along the inter-

action circuit in the manner known to workers in the art.

It is, of course, feasible to incorporate an electron beam system of the kind shown in Fig. 1 in various other forms of traveling wave tubes, both of the transverse field type and the longitudinal field type. By way of another example, in Figs. 3A and 3B, there is shown such an electron beam system incorporated in a longitudinal field tube.

The various tube elements are housed in a vacuum envelope 40. The interaction circuit is of the interdigital type in which an interdigital array of conductive elements form a slow wave circuit. To this end, the circuit comprises a pair of support plates 41, 42 spaced apart parallel to one another. From each of these support plates extends a separate set of coplanar conductive finger elements 43, 44 to form a comb-like structure. The two sets are interleaved in an interdigital pattern, but each is positioned in one of two separate planes on opposite sides of the plane which is to act as the interaction surface along which the electron beam is made to flow. Such an arrangement serves as a slow wave circuit and a wave suitably applied to one end will travel therealong and establish longitudinal electric fields in the interspace between the two sets of elements.

It can be appreciated that the two sets of elements 43, 44 correspond to the sets 11, 12 of the arrangement shown in Fig. 1. Bounding conductive plates 45, 46 are positioned parallel to and on opposite sides of the planes formed by elements 43, 44 to correspond to plates 13, 14 of the arrangement shown in Fig. 1. By suitably relating the parameters of the electrode system formed by elements 43, 44 and plates 45, 46 a singular equipotential surface may be established in the interspace between elements 43, 44 to serve as the path of flow for a beam which is to interact with the electric field established thereby a wave traveling along the slow wave interdigital circuit formed.

The lengths of the elements 43, 44 are chosen so that the phase velocity of the traveling wave is suited for interaction between the traveling wave and the electron flow.

In the manner previously described, an electron gun including a strip cathode 47, a beam forming electrode 48 and a suitably apertured accelerating anode 49 serves as the source of the electron flow and the collector 50 and the suitably apertured shielding electrode 51 serve to collect the spent beam.

An input wave is applied to the input end of the interaction circuit by a coaxial connector 52 comprising an inner member which forms an extension of the end finger element 43A of the array and an outer member which surrounds such extension and is connected to side plate 42. A similar coaxial connector 53 is used to abstract amplified wave energy from the output end of the circuit.

It should now be obvious that the principles of the invention are not limited to traveling wave tubes. Electron beam systems of the kind shown in Fig. 1 may be incorporated in switching tubes, counting tubes, and any apparatus in which it is desired to focus electrostatically an electron beam for flow along a relatively smooth surface.

Accordingly, it is to be understood that the specific embodiments described are merely illustrative of the general principles involved. Various modifications may be made by one skilled in the art even in the basic electrode arrangement without departing from the spirit and scope of the invention. In particular, it is unnecessary to have uniformity in either the size and shape of the elements of the succession, the spacing between successive elements, or the spacing between the elements and the bounding members so long as proper compensation is made for any deviation from such uniformity, as by the application of different potentials to successive ele-

ments or to the two bounding members. Moreover, it is feasible also to eliminate the bounding members completely by proper compensation. The general principles of compensation for non-uniformities are set forth in the aforementioned Kompfner-Yocom patent.

What is claimed is:

1. In high frequency apparatus which employs the interaction between an electron beam and a traveling wave to amplify the wave, an electron source providing an electron beam; means for focusing the electron beam for flow along a relatively smooth path comprising a succession of conductive elements spaced apart in the desired direction of flow, alternate elements of the succession forming different arrays of elements and the different arrays of elements lying in different planes which are on opposite sides of and substantially parallel to the desired path of flow and adjacent thereto, a pair of conductive members on opposite sides of the desired path of flow extending substantially the entire length thereof and enclosing therebetween the succession of elements, and means for maintaining the succession of elements at a positive potential with respect to said pair of conductive members; means intermediate the electron source and the focusing means for injecting the electron beam from the source on the desired path of flow with the correct velocity; and means including said succession of elements for propagating a traveling wave to have an electric field along the desired path of flow with a phase velocity substantially equal to that of the electron flow.

2. In high frequency apparatus, an electrode arrangement for providing a relatively smooth singular equipotential surface comprising a succession of conductive elements, alternate elements of the succession forming different sets of elements, and the different sets lying in different planes which are on opposite sides of and substantially parallel to the desired singular equipotential surface and adjacent thereto, a pair of conductive members on opposite sides of said surface and extending substantially the entire length thereof and enclosing therebetween the succession of elements, means for maintaining the succession of elements at a positive potential with respect to said pair of members for establishing the desired singular equipotential surface, means including an electron source and electron accelerating means for injecting an electron beam on said established singular equipotential surface with the correct velocity for stable flow therealong, and means for propagating an electromagnetic wave having an electric field in the region of said singular equipotential surface for interaction with the electron flow.

3. In an electron beam system, means for focusing the beam comprising a succession of conductive elements, alternate elements of the succession forming separate sets of elements and the separate sets lying in separate planes extending on opposite sides of and parallel to a reference plane adjacent thereto, conductive members on opposite sides of the reference plane for enclosing the two sets of elements, means for maintaining the conductive elements at the same potential positive with respect to the bounding conductive members for making the reference plane substantially a singular equipotential surface, and means for injecting an electron beam for stable flow along said singular equipotential surface.

4. In an electron beam system, an electrode system for establishing a singular equipotential surface which is relatively smooth comprising a succession of conductive elements equally spaced in the direction desired for electron flow, alternate elements of the succession forming two linear arrays of elements and different linear arrays lying in different planes extending adjacent to, on opposite sides of and parallel to a reference plane which substantially defines the relatively smooth singular equipotential surface, conductive members extending on opposite sides of and parallel to the reference plane for

enclosing the two linear arrays of elements, and means for maintaining the conductive elements at the same potential positive with respect to the conductive members, and means for injecting an electron beam with the correct velocity for stable flow along said relatively smooth singular equipotential surface.

5. In an electron beam system, an electrode arrangement for establishing a pair of singular equipotential surfaces of which one is relatively smooth and the other sinuous, comprising a succession of conductive elements, alternate elements of the succession being on opposite sides of and adjacent to a reference plane which corresponds to the desired smooth equipotential surface, a pair of conductive elements on opposite sides of said reference plane enclosing the succession of elements, and means for maintaining the conductive elements at a positive potential with respect to the conductive members; and means for injecting an electron beam on said relatively smooth equipotential surface at a region where it intersects the sinuous singular equipotential surface comprising an electron source for providing the electron beam and an accelerating anode having a surface which substantially coincides with the singular equipotential surface and which is apertured for passage of the electron beam therethrough at a region of intersection with the relatively smooth sinuous equipotential surface.

6. In high frequency apparatus which employ the interaction between an electron beam and a traveling wave, means providing an electron beam, means for focusing electrostatically the electron beam for flow along a singular equipotential surface which is relatively smooth comprising a succession of conductive elements, alternate elements of the succession forming two sets of elements, different sets lying in different planes extending adjacent to and on opposite sides of and parallel to a reference plane which substantially defines the relatively smooth singular equipotential surface, conductive members spaced on sides of the reference plane for enclosing the two different sets of elements, and means for maintaining the conductive elements at the same potential positive with respect to said conductive members, and means including the succession of conductive elements for establishing an electric field for travel along said reference plane for interaction with the electron flow.

7. In high frequency apparatus, a pair of longitudinally extending conductive helices spaced apart alongside one another, the axes of said helices being spaced apart along the length of said helices the turns of each helix including a flat portion adjacent the interspace between the two helices, adjacent flat portions of the two helices being displaced longitudinally with respect to one another, means for exciting the two helices in opposite phase to establish in the interspace therebetween a longitudinal plane along which the electric field of the excitation is substantially purely transverse, and means for making said plane substantially a singular equipotential surface, said means comprising said pair of helices, a conductive member within each of said helices and extending axially therealong, and means for maintaining said helices at a positive potential with respect to said conductive members; and means for providing an electron beam for stable flow along said singular equipotential surface.

8. In high frequency apparatus, a wave propagating structure comprising a pair of spaced conductive supports, a linear array of conductive elements extending from each support towards the other support, each of the two linear arrays lying in a different plane, the planes of said arrays being on opposite sides of and parallel to a reference plane therebetween and displaced longitudinally such that their projection on said plane forms an interdigital pattern, means for forming a singular equipotential surface which substantially coincides with the reference plane, said means comprising said linear arrays of elements, a pair of spaced conductive members enclosing said arrays and said reference plane, and means for

maintaining said elements at a positive potential with respect to said conductive members; and means for injecting an electron beam with the correct velocity for stable flow along said surface.

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