

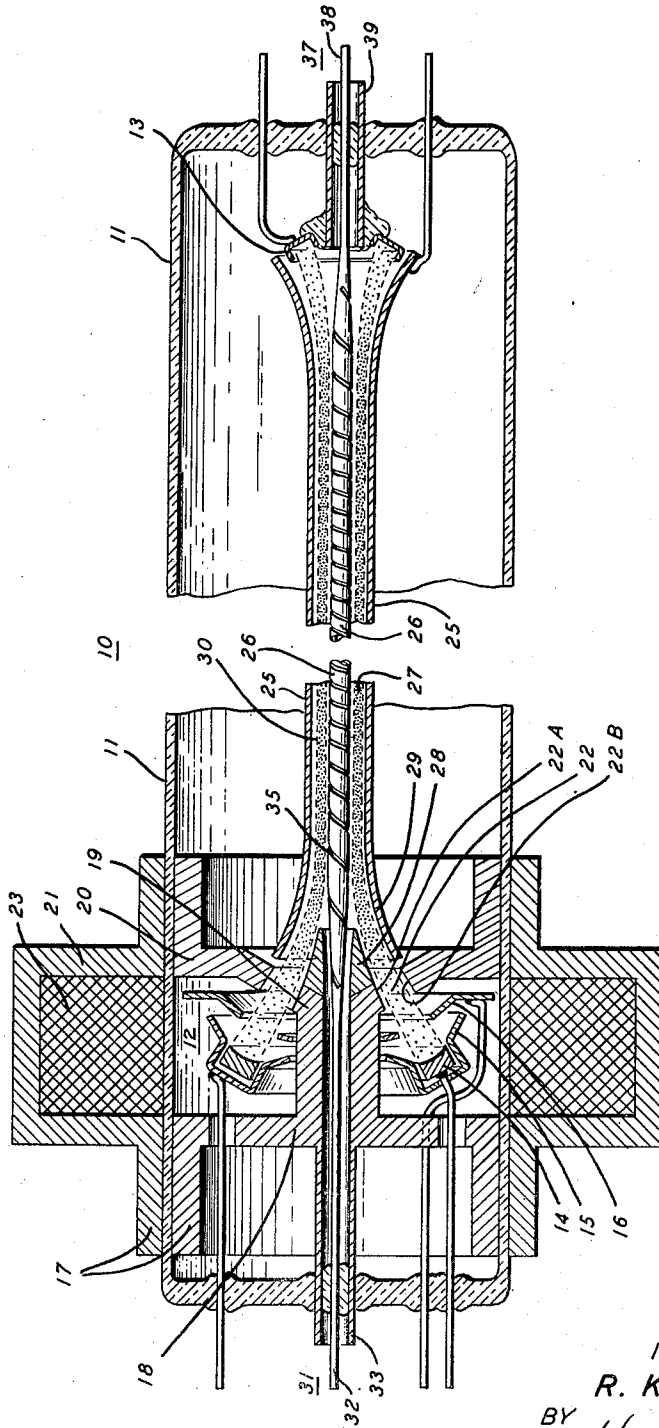
Nov. 5, 1957

R. KOMPfNER
ELECTRON BEAM SYSTEM

2,812,467

Filed Oct. 10, 1952

3 Sheets-Sheet 1



INVENTOR
R. KOMPFFNER
BY *Hugh S. Wentz*
ATTORNEY

Nov. 5, 1957

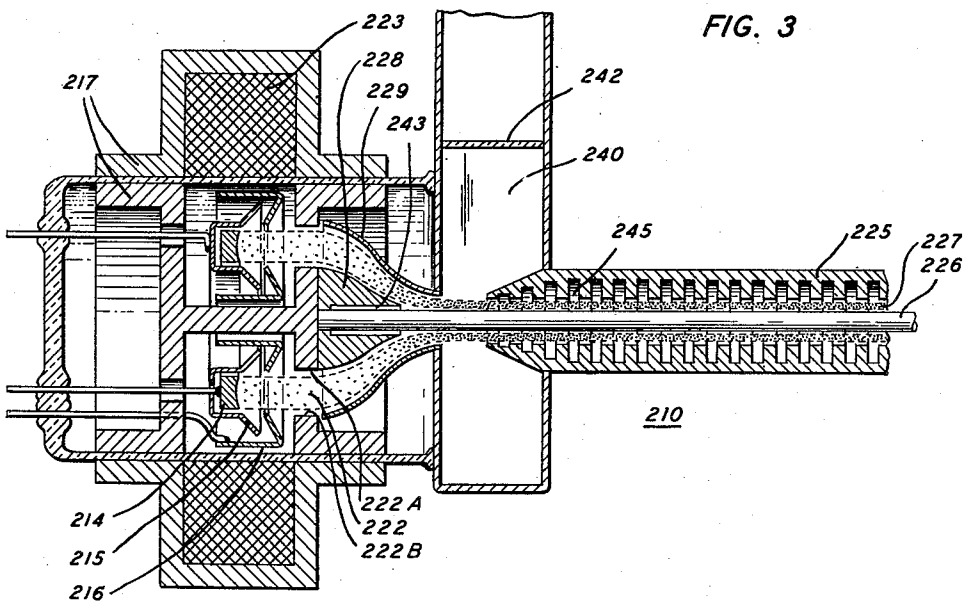
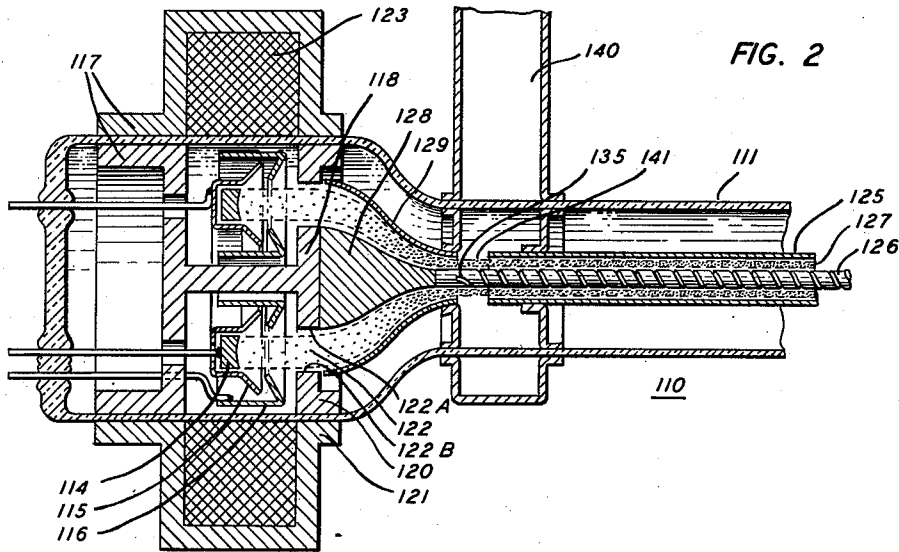
R. KOMPFFNER

2,812,467

ELECTRON BEAM SYSTEM

Filed Oct. 10, 1952

3 Sheets-Sheet 2



INVENTOR
R. KOMPFFNER
BY *Hugh S. Wentz*
ATTORNEY

Nov. 5, 1957

R. KOMPFFNER
ELECTRON BEAM SYSTEM

2,812,467

Filed Oct. 10, 1952

3 Sheets-Sheet 3

FIG. 5

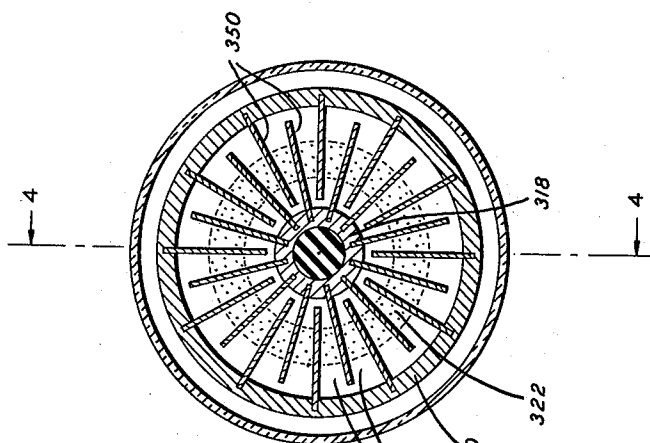
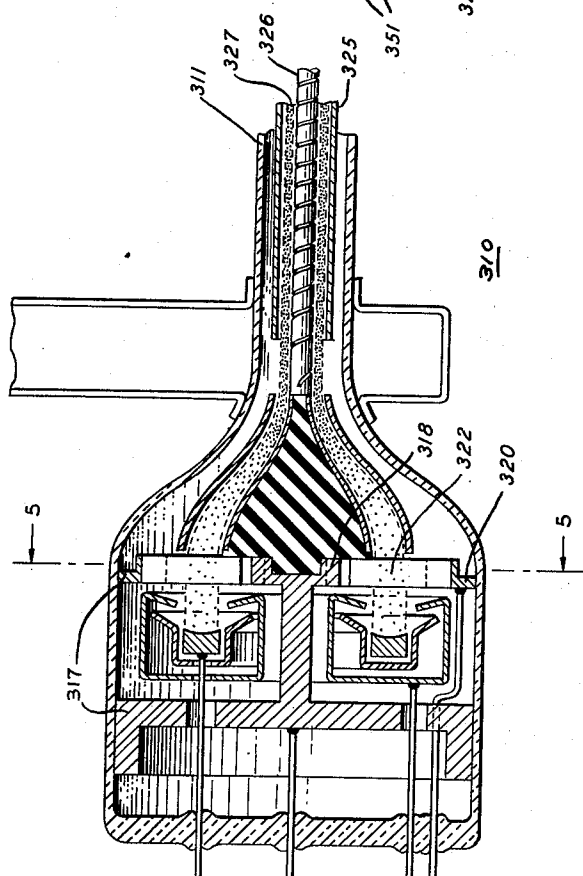


FIG. 4



INVENTOR
R. KOMPFFNER
BY *Hugh S. Wertz*
ATTORNEY

1

2,812,467

ELECTRON BEAM SYSTEM

Rudolf Kompfner, Far Hills, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application October 10, 1952, Serial No. 314,192

16 Claims. (Cl. 315—3.5)

This invention relates to electron beam systems and more particularly to such systems for providing high density annular electron streams for utilization in radio frequency apparatus.

Typical of radio frequency apparatus which can advantageously incorporate electron beam systems in accordance with the invention is the traveling wave tube which employs the interaction between an electron stream and a traveling electromagnetic wave over a plurality of operating wave lengths to secure amplification of the electromagnetic wave. In such a tube, the electron stream is projected longitudinally close past a wave transmission circuit along which propagates the electromagnetic wave, and it is desirable to minimize transverse components in the electron stream which are set up by space charge effects. It has generally been the practice, hitherto, to employ strong longitudinal magnetic fields to reduce such transverse components. However, such magnetic fields require either large permanent magnets which are wasteful of space or else bulky solenoids which are wasteful of both space and power.

One object of the present invention is to minimize the need for magnetic focussing for maintaining the electron flow cylindrical in electron beam systems suitable for radio frequency applications.

Additionally, in such traveling wave tubes, when high power output is desired, it is important to utilize electron streams of high current densities. However, hitherto, it has been difficult to achieve as high densities as is desired, both because of limitations on the emission flow of a given cathode area and because of the large space charge forces set up in high density streams which tend to cause the stream to diverge.

Another object of the present invention is to facilitate the realization and use of high density electron streams.

A related object is to improve the power handling capacities of radio frequency apparatus which employ electron streams.

In an article entitled "Axially Symmetric Electron Beam and Magnetic Field Systems," by L. A. Harris on pages 700 through 708 of the June 1952 issue of the Proceedings of the Institute of Radio Engineers, there is described an electron beam system in which transverse components of an annular electron stream are minimized by first imparting a rotational component to the electrons in the stream and then projecting the electrons through an annular passage formed between two cylindrical electrodes between which exists a radial electric field. The various parameters are adjusted so that equilibrium is maintained between the radially outward space charge forces in the stream, the centrifugal forces on the electrons resulting from the rotational component, and the radially inward forces resulting from the D.-C. electric field set up between the two cylindrical electrodes defining the path of travel of the stream. To this end, an annular cathode is placed inside a magnetically shielded structure, which is apertured for passage therethrough of the cylindrical electron beam emitted from the cathode, and a radial

2

magnetic field is set up across the aperture in the structure for imparting a rotational twist to the electrons in the beam as they exit therefrom. Thereafter, this electron beam is directed along an annular passage formed between two cylindrical electrodes across which there is maintained a radial electric field for creating a radially inward force. The parameters are suitably related so that the various forces are balanced and electron flow through the passage between the two electrodes remains cylindrical. However, it appears that an electron beam system of this type when designed for providing electron streams suitable for microwave tubes will ordinarily require large radial magnetic fields, a factor which considerably diminishes its usefulness for such applications.

The present invention relates to improvements in the electron beam system of the above-described type which better adapt it for incorporation in radio frequency apparatus, as for example, traveling wave tubes. In particular, since the strength of the radial magnetic field necessary to give rotational momentum to the electrons is inversely related to the cross sectional area of the beam, it is advantageous to make the cross sectional area of the beam large at the point where it traverses the region of radial magnetic field so that a small radial magnetic field will suffice. Additionally, in order to achieve electron beams of high current densities it is generally advantageous to utilize initially the emission from a cathode surface large in comparison to the desired beam cross section since there are practical limits on the emission available for a given surface area and, thereafter, to concentrate the electrons into a beam of the desired cross section. To these ends, in an electron beam system in accordance with the invention, there is utilized an annular cathode of relatively large surface and its emission is made to converge to annular cylindrical flow of relatively smaller cross sectional area, the rotational momentum, however, being imparted to the electrons at a point where the beam is still of large cross section. As a result, there can be achieved a beam of high current density without an overtaxing of the emission properties of the cathode, and at the same time there is minimized the strength of the radial magnetic field necessary for imparting the desired rotation, thereby effecting still greater economies in magnetic flux. Moreover, by reducing the radial magnetic field necessary, the resulting simplification of design of the magnetically shielded structure makes possible the incorporation of other features of the invention. In particular, since in order to achieve a radial magnetic field over the entire annular beam, it will generally be necessary to employ an axial yoke which passes through the cathode, the design requirements on this yoke will be considerably lightened, making practical the use of a hollow yoke. This, in turn, permits radio frequency connection to the axis of the electron beam which is often desirable in microwave tube applications, as will be described more fully hereinafter.

Additionally, it is desirable to minimize transverse components in the electron beam which tend to be set up in the region between the point at which the electrons traverse the region of radial magnetic field and the point at which the electrons enter the region of radial electric field. To this end, in accordance with the invention, the region of radial magnetic field is simultaneously the start of the region of the radial electric field. Accordingly, another feature of the invention is a cathode magnetically shielding structure which comprises two electrically isolated sections between which there is maintained a potential difference. In this way, there can also be set up a radial electric field between the two opposite surfaces in the aperture of the shielding structure across which there exists the radial magnetic field used to introduce the radial components to the electrons in the beam.

Moreover, it is possible in accordance with another feature of the invention to eliminate completely the need for magnetic fields. To this end, electrostatic fields are employed to introduce the desired rotational components to the electrons in the beam.

Additionally, for particular application to traveling wave tubes, it is in accordance with still another feature of the invention to utilize one of the two electrodes which define the annular passage for the flow of the electron beam as a wave transmission circuit along which propagates the electromagnetic wave for interaction with the electron flow. In an illustrative embodiment to be described hereinafter, the inner electrode is a helical conductor along which propagates the electromagnetic wave. In this embodiment, it is convenient to utilize a radio frequency connection to the axis of the electron beam of the kind mentioned above. In another illustrative embodiment to be described, the outer electrode is a corrugated conductor along which propagates the electromagnetic wave.

Various other objects and features will appear to a worker skilled in the tube art from the following more detailed description. Moreover, it will also become evident that the various features to be described can be employed either singly or in combination. The invention will be described in conjunction with the following drawings in which:

Fig. 1 shows schematically in longitudinal section a traveling wave tube which incorporates an electron beam system in accordance with the invention and which is characterized by coaxial input and output coupling connections to the inner of the two electrodes which define the annular passage of electron flow;

Fig. 2 shows schematically in longitudinal section the electron gun end of a traveling wave tube which incorporates an electron beam system in accordance with the invention and which employs a hollow wave guide input coupling connection to the inner of the two electrodes which define the annular passage of electron flow;

Fig. 3 shows schematically in longitudinal section the electron gun end of a traveling wave tube which includes an electron beam system in accordance with the invention and which makes use of wave guide input coupling connections to the outer of the two electrodes which form the annular passage for electron flow;

Fig. 4 shows schematically in longitudinal section taken along line 4—4 of Fig. 5, the electron source end of a traveling wave tube which utilizes an electron beam system in accordance with the invention employing electric fields to impart rotation to the electrons in the beam; and

Fig. 5 is a transverse section taken along line 5—5 of Fig. 4.

With reference now to the drawings, Fig. 1 shows by way of example, a traveling wave tube 10 which employs an electron beam system in accordance with one aspect of the invention. In the interest of simplicity most of the various supports, spacers and like structural details have been omitted. At one end of an evacuated tubular glass envelope 11, there is positioned the electron gun 12 symmetrically disposed around the longitudinal axis of the tube and, at the opposite end in target relationship therewith, there is positioned a suitable collector electrode 13, similarly disposed symmetrically with the longitudinal axis of the envelope.

The electron gun 12, which is shown schematically, can be substantially of the kind known as the Pierce type, the principles of which are set forth in Chapter X of a book by J. R. Pierce entitled "Theory and Design of Electron Beams," published by D. Van Nostrand Co., Inc., New York (1949). Such an electron gun comprises essentially a cathode 14, a heater (not shown) and an electrode system for shaping and accelerating the electron beam. In this particular embodiment, the electron emissive surface of the cathode 14 is an annular spherical zone. The electrode system basically comprises an annular beam shaping electrode 15 partially enclosing the cathode 14 and an

annular accelerating anode 16. This electrode system is designed to form the electrons emitted from the cathode 14 into a convergent conical annular beam. Suitable lead-in conductors are provided to the various elements of the electron gun through the glass envelope from suitable voltage supply sources. The various design considerations applicable in deriving the desired flow configuration are set forth in the above-mentioned Pierce book. This electron gun is to be supported in a magnetic field free region, and, accordingly, it is enclosed by a magnetically shielding structure 17. This structure, which is of a suitable magnetic material such as iron, comprises a central inner portion 18 including a hollow axial yoke 19, an intermediate portion 20, and an outer portion 21 external to the envelope. The three portions of the structure are aligned in the manner shown to form a substantially continuous magnetic shield around the cathode except for the annular aperture 22 which is aligned with the cathode 14 in the direction of electron flow. In operation, the electron beam exits through this aperture. A solenoid 23 external to the envelope is used to create magnetic flux through the shielding structure 17 for establishing a magnetic field across the two opposing surfaces 22A and 22B of the annular aperture 22. Alternatively, a portion of the shielding structure can comprise permanent magnets for forming a magnetic field across the two opposing surfaces of the annular aperture 22. There is maintained a D.-C. potential difference between the inner and intermediate portions of the shielding structure by suitable lead-in conductors connected to a voltage supply source. To this end, the inner and intermediate portions 18 and 20, respectively, of the structure 17 are maintained electrically insulated from one another. There results a radial electric field between opposite surfaces of the annular aperture 22 since the outer surface 22B is associated with the intermediate portion 20 while the inner surface 22A is associated with the inner portion 18. In this way there is simultaneously applied to each electron as it traverses the annular aperture 22 a radial or transverse magnetic field which imparts a rotational velocity component thereto and a radial or transverse electric field which creates a radially inward force which acts to maintain equilibrium between the various transverse forces acting on each electron. As has been indicated above, in order to minimize the strength of the magnetic field needed to impart the necessary rotation, it is advantageous to induce this rotational component to the electron beam at a point when the beam is still of considerable cross section. It is also advantageous to adjust the geometry of the surfaces of the annular aperture 22 and the strength of the electric and magnetic fields thereacross to cooperate in effecting the convergence of the there substantially conical stream into a substantially cylindrical annular beam at a region beyond this aperture. To this end, there are also provided electrodes 25 and 26, each symmetrically disposed about the tube axis and extending therealong toward the collector end of the tube for forming between them an annular passage for the cylindrical electron beam. To provide the desired radially inward force on the electrons, the inner electrode 26 is maintained at a positive potential with respect to the outer electrode 25 by means of lead-in conductors from a suitable voltage supply source. In the tube of Fig. 1, the outer electrode 25 is a hollow open-ended cylinder and the inner electrode 26 is a helical ribbon conductor. To secure the electric field configurations desirable for converging the conical electron beam exiting from the aperture 22 into a cylindrical beam for projection along the passage 27, there is positioned therebetween an electrostatic lens comprising an inner electrode 28 and an outer electrode 29, the region between which forms a continuation of the path of electron flow between the aperture 22 and the passage 27. To minimize disturbance of the magnetic field across the aperture 22, electrodes 28 and 29 are of non-magnetic material. Lead-in

conductors from a suitable voltage supply source furnish the necessary operating potentials. These operating potentials and the geometry of the electrostatic lens are suitably chosen to effect the convergence of the conical beam of relatively large cross section exiting through aperture 22 into a cylindrical beam of relatively smaller cross section for travel through passage 27. The envelope of the electron stream is shown by the broken lines 30. It is possible to associate elements of this electrostatic lens either with portions of the shielding structure or with the two electrodes forming the passage 27. In the embodiment here shown, the outer electrode 29 of the electrostatic lens is a flared extension of the outer electrode 25 while the inner electrode 28 of the lens is a non-magnetic tapered projection brazed to and extending axially from the yoke 19 of the magnetic shield 17 into the region enclosed by the outer electrode 29.

The potential difference provided between the outer and inner electrodes 25 and 26 is adjusted to create a radially inward force which balances the radially outward space charge forces and the centrifugal force resulting from the electron rotation. In the previously identified Harris paper, there are set forth the various design relationships to be satisfied for effecting the desired balance. The potentials on these electrodes also serve to control the longitudinal electron stream velocity.

At the collector end of the electron path, the outer electrode 25 is outwardly flared to provide a field configuration which causes divergence of the electron flow away from the tube axis. This change in flow direction diverts most of the electron beam into the collector electrode 13 which preferably is maintained at a positive potential with respect to the electrodes 25 and 26. This collector electrode is preferably a hollow annular enclosure open at one end for admittance of the electron beam and oriented to surround the divergent electron flow in a manner to minimize secondary electron emission which is generally undesirable.

This tube shown in Fig. 1 is particularly adapted for coaxial input and output connections to the wave transmission circuit. Input waves are applied to the coaxial input terminal 31 at the electron gun end of the tube which comprises an inner conductor 32 which is an extension of the inner electrode 26 and an outer conductor 33 which is an extension of the axial yoke 19 of the shielding structure 17. The inner conductor 32 passes through the hollow yoke 19 of the shielding structure 17 for connection to the inner electrode 26. The diameter of this inner conductor gradually increases as it progresses inwardly into the tube until it matches the diameter of the inner electrode 26 to which it is connected. The inner electrode 26 preferably is a tubular cylindrical conductor tapering gradually at each end and which has a helical grooving 35 so as to be effectively a helical ribbon conductor of the kind which is suitable as a wave transmission circuit. For broad band matching purposes, the pitch of this grooving 35 decreases with distance away from its two ends being substantially constant along the major central portion. As is well known, the pitch of this grooving determines the axial velocity of waves propagating therealong, the term "pitch" meaning the distance measured axially between corresponding points on adjacent turns or grooves.

From the coaxial output terminal 37 at the collector end of the tube, output waves are abstracted for utilization. The coaxial output terminal 37 resembles the input terminal 31. The inner conductor 38 is essentially an axial extension of the inner electrode 26, being a tapered conductor which is connected to the end of the tubular conductor which serves as the inner electrode 26. The outer conductor 39 is a tubular cylinder which extends into the tube for surrounding the inner conductor 38 slightly beyond the region to which the latter is connected to the inner electrode 26. It is of course necessary that both the input and output terminals be vacuum tight.

The operation can be that of a conventional traveling

wave tube. Input waves are applied by way of the input terminal 31 to the upstream end of the inner electrode 26 which serves as the wave transmission circuit for propagating a traveling wave through the tube. The electron stream which is emitted from the cathode 14 is formed into conical flow, given a rotational component, converged into a high density cylindrical beam, projected past the inner electrode 26 for interacting with the electromagnetic wave propagating therealong, and finally gathered in the collector electrode 13.

For conventional traveling wave tube operation, the pitch of the grooving 35 in the inner electrode 26 is chosen to provide an axial wave velocity substantially equal to the longitudinal electron beam velocity. However, this tube can conveniently be utilized for spatial harmonic type operation of the kind described in copending application Serial No. 99,757, filed June 17, 1949, now U. S. Patent 2,683,238, issued July 6, 1954, to S. Millman. In such operation, the relative velocities of the electron stream and the traveling wave are adjusted so that a particular group of electrons will see the same phase of the electric field at successive traversals of the gaps of high electric field corresponding to the groovings in the tubular inner electrode 26. Alternatively, this tube as well as the other embodiments to be described, can conveniently be operated as backward wave tubes in which the useful interaction occurs between the electron beam and an oppositely directed traveling wave. Operation of this kind is described in copending application Serial No. 288,437, filed May 17, 1952, by R. Kompfner, and copending application Serial No. 288,438, filed May 17, 1952, by R. Kompfner and N. T. Williams.

Fig. 2 shows the electron gun end of a traveling wave tube 110 which utilizes an electron beam system slightly modified from that utilized in the tube 10 shown in Fig. 1. Additionally, tube 110 is designed particularly for use with hollow wave guide input and output connections to the inner of the two electrodes defining the major portion of the path of electron flow. However, in the interest of simplicity, elements in this tube corresponding to elements of tube 10 have generally been designated by reference characters which differ by one hundred from those of the corresponding elements of tube 10. In tube 110, the electrons emitted from the cathode 114 are formed into an annular cylindrical beam of relatively large cross sectional area. Then after the electrons in this beam have been given their rotational impetus, this beam is converged into an annular electron beam of relatively smaller cross sectional area. To this end, cathode 114 which serves as the source of the electron stream is an annulus of relatively large inner and outer diameters. The electrons emitted are formed by means of the beam shaping electrode 115 and the accelerating anode 116 into an annular cylindrical beam of relatively large inner and outer diameters. This large beam then passes through the aperture 122 in the shielding structure 117 which encloses the electron gun, and at this time there is imparted to it a rotational component by the radial magnetic field created by solenoid 123 which exists across the aperture 122. Moreover, as in the tube described in Fig. 1, there is also provided a D. C. electric field across the opposite surfaces 122A and 122B of the aperture 122 which provides a radially inward force to balance the radially outward space charge and centrifugal forces. There are also provided outer and inner electrodes 125 and 126 which extend along the major amplifying portion of the tube length and which between them define an annular passage 127 for the electron flow. The inner electrode 126 is a helical ribbon conductor which serves as the wave transmission circuit. Between the annular passage 127 and the aperture 122, there is positioned an electrostatic lens comprising electrodes 128 and 129 for reforming the cylindrical beam exiting from aperture 122 into a cylindrical beam of relatively smaller inner and outer diameters but higher current density for travel

through passage 127. Lead-in conductors (not all of which are shown) from voltage supply sources provide suitable operating potentials on the various elements. The electrode 128 can be a non-magnetic projection from the inner portion of the shielding structure and also be integral with the inner electrode 126. The surfaces of electrodes 128 and 129 and the potentials applied thereto are adjusted to provide the desired convergence of the electron flow.

In tube 110 input waves are supplied to the inner electrode 126 by way of a hollow wave guide input connection of the kind well known for coupling to the helical wave transmission circuit of a helix type traveling wave tube. The input connection comprises a section of standard rectangular hollow wave guide 140 which has a pair of opposite side walls apertured for the passage therethrough of the tube envelope 111. This wave guide section is closed off at one end while the other end can be a continuation of a wave guide transmission system. The inner electrode 126 is in field coupling relation with the wave guide 140 along a coupling region 141. The grooving 135 of the inner electrode 126 preferably begins at the electron gun end of the coupling region 141 and decreases in pitch therealong. The length and positioning of this coupling region is adjusted to provide optimum coupling between the wave guide 140 and the inner electrode 126 and also to be sufficiently small as not to create any significant disturbance in the radial electric field configuration in this region. For conventional amplifier applications, output energy can be abstracted from the inner electrode 126 at the collector end in a corresponding fashion. Alternatively, for backward wave applications output energy will be abstracted by way of wave guide connection 140 in the way now well known for such applications.

The tubes shown in Figs. 1 and 2 have each made use of the wave circuit of the inner of the pair of electrodes forming the annular passage for the cylindrical electron beam in accordance with one aspect of the invention. For some applications, however, it may be desirable to employ an electron beam system of the kind described above in a way to utilize the outer of the pair of the electrodes forming the annular passage for the cylindrical electron beam. Fig. 3 illustrates an embodiment of this kind.

Fig. 3 shows the electron source end of a traveling wave tube 210 which embodies an electron beam system in accordance with the invention in a manner to utilize as the wave circuit the outer of the two electrodes defining the annular longitudinal path of electron flow. In many respects, the electron beam system of this tube resembles that of the tube shown in Fig. 2. Accordingly, for purposes of simplicity, elements shown in this figure corresponding to elements shown in Fig. 2 are designated by reference numerals which are one hundred larger than corresponding elements of the tube shown in Fig. 2. The annular cathode 214 provides an electron beam which is formed into a cylindrical annular beam for projection past the aperture 222 in the shielding structure 217. Across the aperture 222 there is set up a magnetic field which imparts a rotational component to the beam. An electrostatic lens formed by electrodes 228 and 229 serves to converge the annular beam emitted into an annular beam of relatively smaller inner and outer diameters whereby the density of the stream is increased. This compressed annular beam is thereafter projected along an annular passage formed between electrodes 225 and 226. The inner electrode 226 is a cylindrical rod which extends along the longitudinal axis of the tube, and can be for convenience attached at one end to the shielding structure 217. The outer electrode 225 which, in this case, also serves as the elongated portion of the envelope of the tube extends disposed around the inner electrode 226. The outer electrode 225 comprises essentially a hollow circular wave guide whose inner walls are cor-

rugated to provide transverse slots 245 for reducing the phase velocity of waves propagating therealong. As has been indicated above, this outer electrode serves as the slow wave circuit along which travels the electromagnetic waves for interaction with the electron beam. A conventional hollow wave guide coupling connection is provided at the electron source end of this wave circuit. This coupling connection comprises a section of hollow wave guide 240 which is provided with a glass window 242 through which input energy can be supplied, or output energy abstracted, as the particular tube application demands. One end of outer electrode 225 extends into the wave guide 240 for coupling thereto and the depth of the transverse slots 245 increases with progress downstream for improving the band width characteristics of the coupling. A longitudinal slot 243 serves as a radio frequency choke for concentrating the flow of energy from the guide 240 for travel downstream along the wave circuit. Coupling connection can be provided at the collector end of the wave circuit in an analogous fashion. The operation is essentially as described for the tube shown in Figs. 1 and 2.

Each of the electron beam systems of the various tubes described above has utilized a magnetic field for imparting a rotational component to the electrons as they exit from the shielding structure. Alternatively, however, each of these beam systems can be modified to employ an electrostatic field to impart the desired rotational component to the electrons. In the tube 310 of which the electron gun end is shown in Figs. 4 and 5, there is incorporated such an electron beam system. In other respects, the tube 310 is essentially similar to tube 110 shown in Fig. 2. Accordingly, elements of tube 310 corresponding to elements of tube 110 are designated by reference numerals two hundred larger than such elements of tube 110. To achieve the electrostatic field configurations desired, conductive vanes 350 are attached to the portions 320 and 318 of the structure 317 for extension across the aperture 322 as illustrated in Fig. 5. Because of the absence of the magnetic flux, it is less important to employ the structure 317 for magnetic shielding and instead this structure is useful primarily in establishing the desired electric fields. Successive vanes extend alternately from portions 320 and 318 of the structure 317 to form an interlaced or interdigital circular pattern. Lead-in conductors from a suitable voltage supply connected separately to portions 320 and 318 establish a potential difference therebetween which causes a corresponding potential difference between successive vanes. Accordingly, there exists in each of the regions 351 between adjacent vanes and through which the electron beam is projected a tangential electric field whose direction reverses between adjacent regions but which is always normal to that of electron motion. As the electrons penetrate such regions, there is imparted to them a rotational component, the direction of such rotation reversing for electrons passing through adjacent regions. Effectively, there is set up in the region beyond the aperture 322 two counter-rotating electron beams. However in operation this difference in rotation will usually have little effect and for present purposes the two beams can be treated as one. Thereafter, this beam of rotating electrons is converged in any of the ways set forth above into a relatively higher density beam for projection along the annular passage 327 formed between the two cylindrical electrodes 325 and 326. It can readily be seen that this electrostatic arrangement for achieving the desired electron rotation can readily be employed in the electron beam systems of the tubes shown in Figs. 1, 2 and 3.

It should also be evident at this point that the various improvements incorporated in the electron beam systems described can be utilized either singly or in combination. Similarly, it should also now be evident that electron beam systems incorporating such improvements can find

application in a variety of electronic devices. Accordingly, it is to be understood that the various embodiments described are merely illustrative of the principles of the invention. Various other arrangements can be devised by a worker in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In combination, an electron source for forming an annular electron beam of relatively large cross section, a structure partially enclosing said source and having an annular aperture for the passage therethrough of the annular beam of electrons and severed for maintaining D.-C. isolation between the two opposite surfaces of the annular aperture, means for imparting a rotational component to the electrons in said beam as they pass through said aperture, a pair of electrodes positioned external to the structure and aligned with the beam for forming therebetween a longitudinal annular passage for the beam, electrode means interposed between said structure and said pair of electrodes for converging the annular beam of relatively large cross section into an annular beam of relatively smaller cross section, connection means for maintaining a D.-C. electric field between the opposite surfaces of the annular aperture, and connection means for maintaining a D.-C. electric field between said pair of electrodes.

2. In combination, an electron source for forming an annular beam of electrons, a shielding structure partially enclosing said source having an annular aperture for the passage therethrough of the annular beam of electrons and severed for maintaining D.-C. isolation between the two opposite surfaces of the aperture, means for imparting a rotational component to the electrons in said beam, a pair of electrodes positioned external to the shielding structure and aligned with the beam for forming therebetween a longitudinal annular passage for the beam, means for converging the annular beam of electrons emitted from said source into an annular beam of relatively smaller cross sectional area for projection through said longitudinal annular passage, connection means for maintaining a D.-C. electric field between said opposite surfaces of the aperture, and connection means for maintaining a D.-C. electric field between said pair of electrodes.

3. In combination, an annular cathode for forming an annular electron beam of relatively large cross section, a structure shielding said cathode and having an annular aperture for the passage therethrough of the annular beam of electrons and severed for maintaining D.-C. isolation between the two opposite surfaces of the aperture, means forming a radial magnetic field across said aperture for imparting a rotational component to the electrons in said beam, a pair of electrodes positioned external to the shielding structure and aligned with the beam for forming therebetween a longitudinal annular passage for the electron beam, and means between said annular cathode and pair of electrodes for converging the electrons emitted from said cathode into a cylindrical beam of relatively small cross section for travel through the annular passage between the electrodes.

4. In combination, an electron source for forming an annular electron beam, a structure shielding said source and having an annular aperture for the passage therethrough of the annular beam of electrons and severed for maintaining D.-C. isolation between the two opposite surfaces of the aperture, electrostatic means for imparting a rotational component to the electrons in said beam in their passage through the aperture, a pair of electrodes positioned external to the shielding structure and aligned with the source for forming therebetween a longitudinal annular passage for the beam, and electrode means interposed between said source and the pair of electrodes for forming the electron beam emitted from said source into a cylindrical annular beam for travel through said passage.

5. In combination, an electron source for forming an

annular electron beam, a conductive structure, a conductive member for forming with said structure an annular aperture for the travel of electron flow past said structure, said structure and said member forming the outer and inner surfaces, respectively of said aperture, a plurality of conductive elements extending alternately from said inner and outer surfaces and across said aperture in an interleaved pattern, connection means for maintaining said inner and outer surfaces at different D.-C. potentials, a pair of electrodes aligned with said source for forming therebetween a longitudinal annular passage for the electron beam, and connection means for maintaining the electrode means at different D.-C. potentials.

6. In combination, an annular cathode whose emissive surface is substantially a spherical zone for forming a conical annular beam of electrons, a shielding structure partially enclosing said cathode and having an annular aperture for passage therethrough of the annular beam of electrons and severed for maintaining D.-C. isolation between the two opposite surfaces of the aperture, connection means to said two opposite surfaces for applying a potential difference therebetween, means for imparting rotational components to the electrons of said beam in their passage through said aperture, a pair of electrodes positioned external to the shielding structure and aligned with the beam for forming along the interspace between the electrodes a longitudinal annular passage of cross-sectional area small relative to the emissive surface of said cathode, means between said cathode and said pair of electrodes for converging the conical annular beam emitted from the cathode into a cylindrical annular beam for passage through the longitudinal annular passage, and connection means for maintaining a potential difference between said pair of electrodes.

7. An electron beam system comprising an electron source, a structure for magnetically shielding said source and having an annular aperture for the passage of the electron flow therethrough, means for creating transverse electric and magnetic fields across said aperture for imparting a rotational component to the electrons emitted from said source, a pair of electrodes aligned with the electron source and said annular aperture for forming an annular passage for electron flow therealong, and electrode means for forming the electrons emitted from said source into an annular beam for projection through said passage.

8. An electronic device which utilizes the interaction between an electron stream and an electromagnetic wave traveling along a wave transmission circuit characterized in that the means for forming and projecting the electron stream comprises an electron source for forming an annular beam of electrons, a structure shielding said source and having an annular aperture for passage therethrough of the annular beam of electrons, said structure being severed for providing D.-C. isolation between opposite surfaces of said aperture, connection means for applying D. C. potential across said opposite surfaces, means for imparting a rotational component to the electrons in said beam as they exit through said aperture, a pair of electrodes positioned external to the shielding structure and aligned with the beam for forming therebetween a longitudinal annular passage for the beam, and in that the wave transmission circuit along which the electromagnetic wave travels comprises one of said pair of electrodes.

9. An electronic device which utilizes the interaction between an electromagnetic wave traveling along a wave transmission circuit and an electron stream comprising an electron source providing an annular beam of electrons, a structure shielding said source and having an annular aperture for exit of said electron beam, means for imparting a rotational component to electrons in said beam as they traverse the aperture, a pair of electrodes defining along the interspace therebetween an annular passage aligned with said electron source for projection therethrough of the electron stream, means between said source and the passage formed between said pair of elec-

trodes for converging the beam emitted from said source into a beam of relatively smaller cross section for traversal of said passage, and coupling means in radio frequency energy exchange relationship with one of said pair of electrodes.

10. In an electronic device, an electron source for forming an annular beam of electrons, a collector electrode in target relationship with said source for defining therebetween a path of electron flow, a structure shielding said source and having an annular aperture for passage of said electron stream, means for imparting a rotational component to electrons in said beam as they traverse said aperture, connection means for supplying a potential difference across opposite surfaces of said aperture, a pair of electrodes disposed along the path of electron flow for forming a passage for the electron flow, means for converging the beam originating from said source into a cylindrical annular beam of relatively smaller cross sectional area for projection through said passage, and coupling means in radio frequency energy exchange relationship with one of said pair of electrodes.

11. In an electronic device, an annular cathode for forming an annular beam of electrons, a structure shielding said cathode and apertured for the traversal thereof of the electron beam and including a hollow member extending axially through said cathode, means for imparting a rotational component to the electrons in said beam as they traverse the aperture, a pair of electrodes positioned external to the shielding structure for forming therebetween an annular passage for said electron flow, and coupling means extending through said hollow member in radio frequency energy exchange relationship with the inner of said pair of electrodes.

12. In an electronic device, an electron source and a collector electrode defining therebetween a path of electron flow, a structure partially enclosing said cathode and apertured for the exit therefrom of the electron stream and severed for maintaining D. C. isolation between opposite surfaces of the aperture and including a hollow member extending axially through said cathode, means for imparting a rotational component to the electrons in said beam as they exit through the aperture, a pair of electrodes disposed for defining therebetween an annular passage which forms a portion of said path of electron flow, the inner of said pair of electrodes being a helical conductor, and coupling means in a radio frequency energy exchange relationship with said helical conductor by way of said hollow member.

13. In an electronic device, an annular electron source and a target electrode defining therebetween a path of electron flow, a conductive structure for magnetically shielding said source, a hollow conductive member extending axially through said source for forming with said structure a relatively short annular aperture for passage of the electron flow, means for producing electric and magnetic fields across said annular aperture for imparting a rotational component to the electron flow, a pair of electrodes along said path of flow for defining therebetween a relatively long annular passage for the electron flow, and coupling means in a radio frequency energy exchange relationship by way of said hollow member with one of said pair of cylindrical electrodes.

14. In an electronic device an annular cathode and a target electrode defining therebetween a path of electron flow, a conductive structure for magnetically shielding said source, a hollow conductive member extending through said annular cathode for forming with said structure a relatively short annular aperture for the exit of the electron flow from said structure, connection means for applying a potential difference across opposite surfaces of said annular aperture, means for applying a rotational component to the electron flow during passage through said aperture, a pair of electrodes along said path of flow defining therebetween a relatively long passage for the electron flow, and coaxial conductor coupling means including an inner conductor which is electrically connected to the inner of said pair of electrodes and an outer conductor which is electrically connected to said hollow member for forming a wave guiding path through said hollow member.

15. In an electron beam system, an annular cathode and a target electrode defining therebetween a path of electron flow, a conductive structure for magnetically shielding said source, a conductive member forming with said structure an annular aperture for the exit of the electron flow from said structure, connection means for applying a D.-C. potential across the inner and outer surfaces of said annular aperture, means for imparting a rotational component to said electrons as they traverse said aperture, a pair of electrodes along said path of flow defining therebetween an annular passage for the electron flow, and connection means for applying a D.-C. potential across the inner and outer electrodes forming the annular passage.

16. In an electron beam system, an annular cathode and target electrode defining therebetween a path of electron flow, a conductive structure for magnetically shielding said source, a conductive member extending axially through said source and forming with said structure an annular aperture for the exit of the electron flow from said structure, connection means for applying a D.-C. potential across the inner and outer surfaces of said annular aperture, means for imparting a rotational component to the electrons as they traverse the aperture, a pair of electrodes along said path of flow defining therebetween an annular passage for the electron flow, connection means for applying a D.-C. potential across said pair of electrodes, and electrode means for forming the electrons emitted from said cathode into an annular beam of relatively large cross section for passage through said annular passage and reforming said beam into an annular beam of relatively small cross section for travel through said annular passage.

References Cited in the file of this patent

UNITED STATES PATENTS

2,064,469	Haeff	Dec. 15, 1936
2,579,654	Derby	Dec. 25, 1951
2,591,350	Gorn	Apr. 1, 1952
2,608,668	Hines	Aug. 26, 1952
2,610,308	Touraton et al.	Sept. 9, 1952
2,645,737	Field	July 14, 1953
2,687,490	Rich et al.	Aug. 24, 1954