March 17, 1953 J. F. HULL 2,632,130

HIGH CURRENT DENSITY BEAM TUBE

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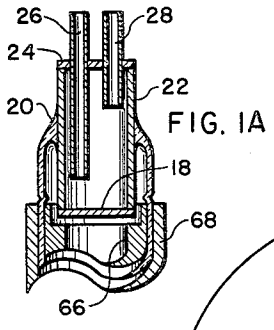


FIG. 1A

FIG. 1

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FIG. 2

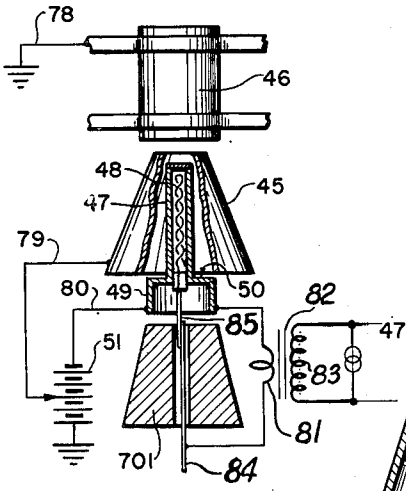


FIG. 3A

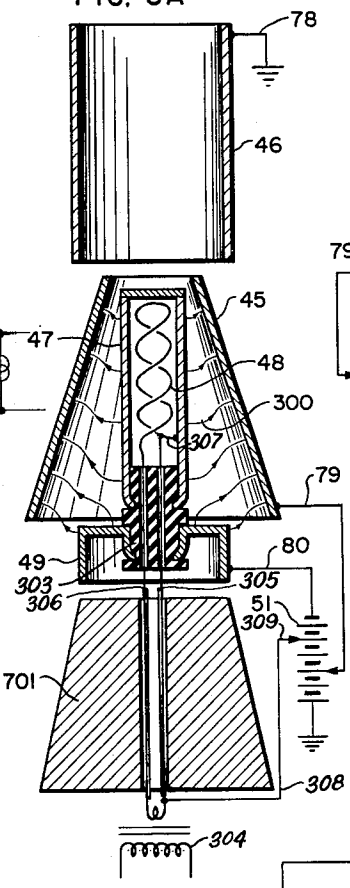
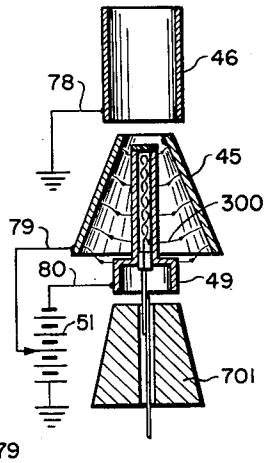


FIG. 3



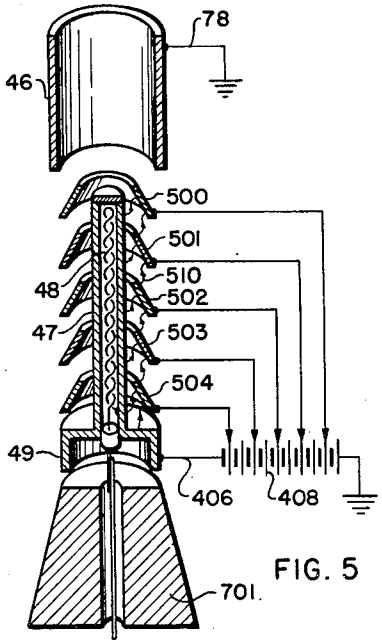


FIG. 5

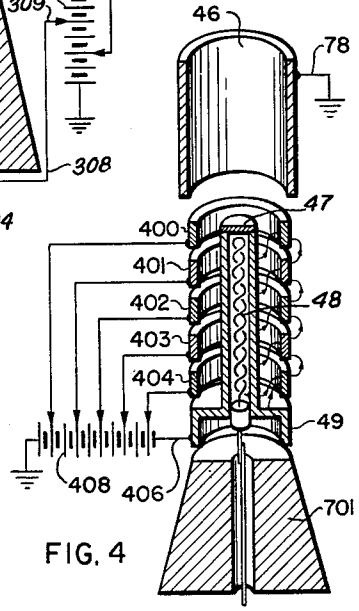


FIG. 4

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FIG. 6

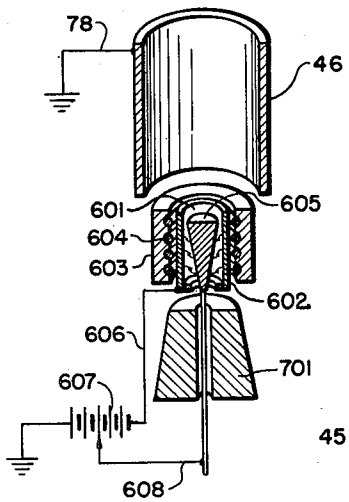
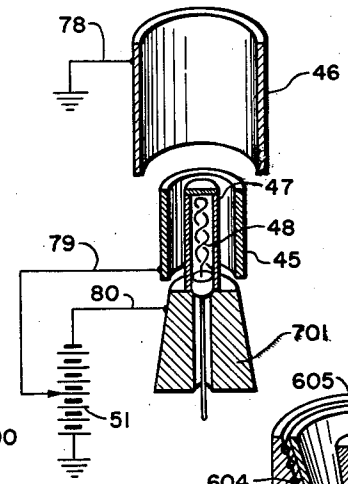


FIG. 7



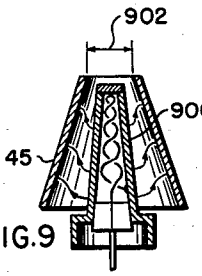


FIG. 9

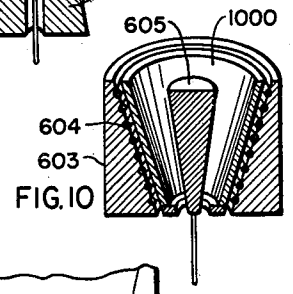


FIG. 10

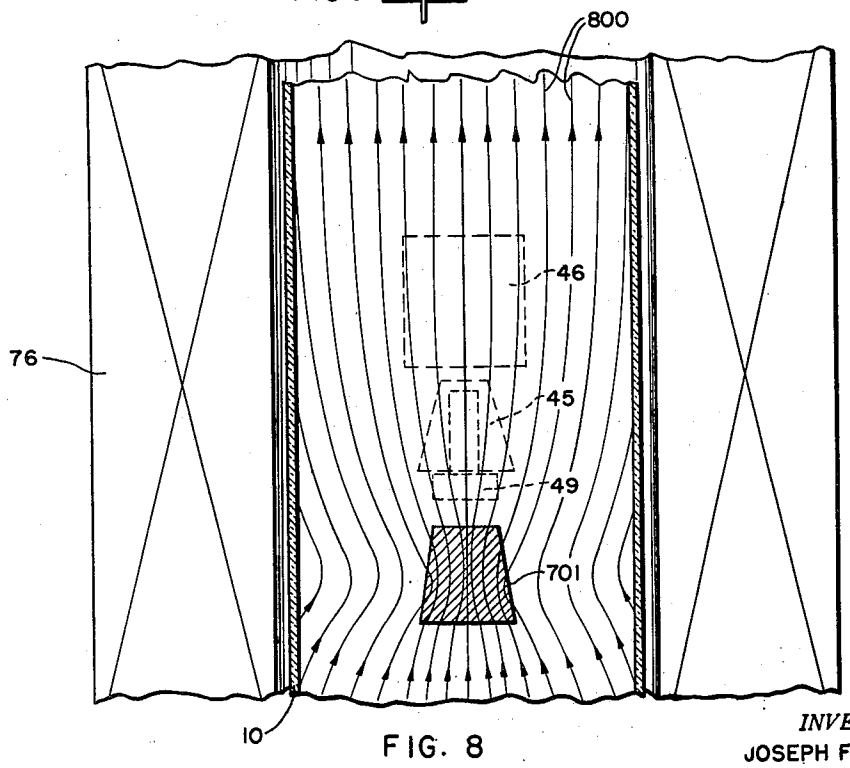


FIG. 8

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UNITED STATES PATENT OFFICE

2,632,130

HIGH CURRENT DENSITY BEAM TUBE

Joseph F. Hull, Neptune, N. J.

Application November 28, 1947, Serial No. 788,698

19 Claims. (Cl. 315—3)

(Granted under Title 35, U. S. Code (1952), sec. 266)

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This invention relates to thermionic tubes of the pencil beam type.

Recent developments in pencil beam type tubes have indicated the versatility of the tubes of this type, and the possibility of using this type of tube not only as ultra-high frequency power and voltage amplifiers, but also as ultra-high frequency oscillators. The most recent application of the pencil beam type tubes (hereafter referred to as beam tubes) to the ultra-high frequency techniques is currently known as "traveling wave tubes" which may be used as ultra-high frequency amplifiers. The latter application of the beam tubes has especially accentuated the importance of these tubes because of the previously encountered difficulties with the amplification of any ultra-high frequencies. Moreover, the versatility and the high degree of usefulness of the beam tubes in the ultra-high frequency field has become especially apparent after the development of the multiplex amplifier circuits which render the beam tubes useful as ultra-high frequency amplifiers for complex multi-channel signals.

It has become apparent in the course of the development of the traveling wave amplifiers that optimum results and high power outputs are most easily obtainable with hollow electron beams, which are in the form of hollow circular cylinders, and have high electron current density in the beam. In the prior beam tubes it has been difficult to obtain high current density in the beams because of the configuration of electrodes and cathodes; in the beam tubes now in use the emissivity of the cathodes and the space charge within the gun electrodes, or space charge of the beam have been the most serious limiting factors in obtaining high current density in the beams. Since the power output of the beam tubes depends upon the cathode-anode current, and the latter is a direct function of the electron density in the beam, it is obvious that maximum electron beam density is necessary if one is to obtain high power output from the tubes of this type.

This invention discloses hollow pencil beam tubes in which higher beam electron current densities in parallel beams are obtainable than in the tubes of this type now in use by constructing specially shaped electrodes for producing accelerating electrostatic fields, and by combining its action with the action of a strong magnetic field, the two producing a hollow electron beam with high current density. The increased density is obtained in such a manner that the cathode surfaces do not act any longer as a limiting factor in obtaining high current densities, which is the case in the hollow beam tubes currently in use. In the disclosed tubes the only substantial ultimate limiting factor upon the current density in the beam at a given acceleration potential is the electron space charge in the beam, and the concomitant interelectron repulsive forces. Because exceptionally high electron current densities, of the order of 1 to 4 amperes per square centimeter, are being discussed, it must

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be understood that a magnetic field is necessary to maintain the focus of the beam.

It should be noted that in the prior art high beam current densities have been obtained, which are even higher than 4 amperes per square centimeter. However these higher densities exist only at the focal points of the converging beams, and, as such, are not applicable or suitable for the purpose at hand since only parallel, and preferably hollow-beams can accomplish any useful purpose in the traveling wave tubes. Accordingly, hereafter, when electron beams are spoken of it will be understood that only electron beams of substantially uniform cross section along their axes are being spoken of, or beams which are equivalent to a parallel beam of light, being devoid of focal points, or scalloping.

Leon Brillouin, in an article appearing in Phys. Rev. 67, 260–265, (1945), entitled "A theorem of Larmor and its importance for electrons in magnetic fields" (see also L. M. Field, Reviews of Mod. Phys., vol. 18, #3, July 1946, page 361, "High current electron guns") has suggested the use of an ordinary non-oscillating magnetron interaction space without an end hat on the cathode as a source of hollow electron beam. In his proposal a portion of the rotating electron cloud is forced out of the open end of the interaction space primarily by mutual repulsion of the electrons. This mutual repulsion force due to electrostatic field created by the electrons, and minor electrostatic field fringe effects tending to impart to the electrons axial acceleration, is insufficient for producing high current density beam and this force has been neglected in the electron guns disclosed in this application. In the guns disclosed here the beam, and its high density, are obtained by utilizing properly directed electrostatic and magnetic fields which produce the necessary large axial acceleration of electrons. The greater the axial acceleration of the electrons in this invention, the greater the current density obtainable in the beam before the beam space charge limits the current.

It is therefore an object of this invention to provide hollow beam electron tubes with high current density in the beam, the maximum ultimate density at a given acceleration potential being limited only by the electron space charge in the beam and the resulting inter-electron repulsive forces.

It is an additional object of this invention to produce hollow electron beam tubes with high beam current density, which enhances the power capabilities of such tubes, this high density being obtained by providing special electron-extracting, beam-forming, electron-accelerating and beam-focusing electrodes, and by combining the action of these electrodes with the properly directed magnetic field so that the beam is the end product of the simultaneous action of the electrostatic and magnetic fields upon the electrons.

It is still another object of this invention to provide hollow electron beam tubes with high

beam current densities in which this high density is obtained by combining the action of the electrostatic and magnetic fields on electrons in the optimum manner and by creating an interaction between the combination of these two fields and the electrons emanating from a large electron-emitting surface.

It is an additional object of this invention to provide hollow electron beam tubes in which the electron beam is of uniform cross section, thus being equivalent to a parallel beam of light, and, therefore is devoid of any detrimental "scalloping" and node points, which are often present in the known beam tubes.

It is also an object of this invention to apply the electron guns of the above type to a traveling wave tube.

These and other objects will become apparent from the description of the following figures in which:

Figure 1 is a vertical isometric, partially cross-sectioned view of a traveling wave tube;

Figure 1–A is a vertical cross-sectioned view of a detail clarifying the relative positions of some of the elements at the top end of the tube illustrated in Fig. 1;

Figure 2 is an enlarged side view, partly in section, of the cathode of the electron-extracting and beam-forming electrode and of the accelerating electrode used in the tube of Fig. 1;

Figure 3 is a vertical, cross-sectional view of the structure illustrated in Fig. 2;

Figure 3–A is an enlarged vertical cross-sectional view of the elements of Figure 3, but with a modified cathode end-hat structure;

Figure 4 is a vertical, cross-sectional view of a modified type of the electron-extracting and beam-forming electrode surrounding the centrally mounted and indirectly heated cylindrical cathode;

Figure 5 is a vertical, cross-sectional view of another modification of the electron-extracting and beam-forming electrode surrounding the centrally mounted cathode;

Figure 6 is a vertical, cross-sectional view of a centrally located electron-extracting and beam-forming electrode surrounded by an inverted cylindrical cathode above which is mounted an electron accelerating and beam-focusing electrode;

Figure 7 is a vertical, cross-sectional view of the cathode, electron-extracting and beam-forming, accelerating electrode, and a magnetic field concentrator and shaper mounted within the tube;

Figure 8 is the same vertical, cross-sectional view as that in Fig. 5 with the direction of the magnetic flux illustrated in this figure; and,

Figures 9 and 10 are vertical cross-sections of the cathode-electrode combination used in the tube illustrated in Fig. 1.

Referring to Figs. 1, 2, and 3, they disclose an electron pencil beam tube comprising an evacuated glass vessel 10 cemented to a base 12 equipped with prongs 14, 15, 16, and 17 for making the necessary connections with the beam-forming electrodes of the tube. The upper portion of the glass vessel 10 is provided with a hollow target-anode 18, and a conventional glass seal 20 between the target-anode 18 and the glass vessel 10, this seal interconnecting these two elements so that the target-anode is supported by the glass vessel 10.

The outer protruding portion 22 of the target-anode is provided with an end-washer 24 which

is soldered to the outer protruding portion 22 of the anode. Washer 24 is provided with two openings which are used for inserting two pipes 26 and 28 through the washer and into the hollow portion of the anode. These pipes are normally connected to a water supply which is used for cooling the target-anode. The bottom portion of the glass vessel 10 is provided with the usual glass press 30 which terminates in a glass cross-shaped member 32 provided with four extensions which are used for supporting and stabilizing all of the beam-forming electrodes of the tube. These electrodes are also supported by means of horizontal straps 34, 35, 36, 37, 38, and the vertical insulating tubes 39 and 40; the insulating tubes themselves are supported by metallic rods 41 and 42 which extend through these tubes. Rods 41 and 42 are also used for supplying the potentials to an electron-extracting and beam-forming electrode 45 and an electron-accelerating and beam-focusing electrode 46 respectively. These electrodes are illustrated on an enlarged scale in Fig. 2. The electron-extracting and beam-forming electrode 45 represents a right, hollow, truncated metallic cone. The cone angle of electrode 45 has an optimum value of between 30° and 60°; the reason for this is explained later in the description of operation of the tube. Electrode 45 surrounds a cylindrical, indirectly heated cathode 47 which is provided with the usual heater element 48, the latter being connected to the secondary 81 of a transformer 82, the primary 83 of which is connected to an alternating source of potential. Since one end of the heater coil 48 is connected to the cathode cylinder, the closed circuit of the heater is: centrally mounted rod 84, jumper 85, heater coil 48, metallic cylinder 47, cathode hat 49, and secondary 81 of transformer 82. The same circuit is also illustrated in Fig. 1. The outer surface of this cylindrical cathode is coated with an electron-emitting mixture of the oxides of barium and strontium. While the use of well-known barium and strontium oxides, according to well known techniques, is mentioned here, other oxides and composite surfaces of more recent origin also may be used with corresponding increase in the ultimate maximum beam current density with the accelerating voltage being sufficiently high to prevent beam space charge limitation. Similarly, at a given beam current the relative emission density of the cathode can be made lower with the concomitant increase in the life of the cathode. The new electron-emitting surfaces, to mention a few of them, are thoria, molybdenum-and-thoria powder mix, and tungsten-and-thoria powder mix. The lower portion of the cathode is provided with a hat 49 which consists of an inverted, cup-shaped, metallic member with the flat portion 50 of this cup acting as an electron-repelling element which prevents drifting of the electrons into the space surrounding the lower level of the cathode and electrode 45. Hat 49 may comprise a metallic continuation of the cathode cylinder 47 so that, in this type of construction, the hat and the cathode are at the same potential. However, hat 49 may also be insulated from the cathode cylinder 47 and connected to a negative source of potential with respect to cathode 47 as is shown in Figure 3–A in order to accentuate the electron-repelling properties of hat 49. The accelerating electrode 46 is mounted directly above, and in coaxial relationship with, the continuation of the coinciding axes of the cylindrical cathode 47 and cone-

shaped electrode 45. Electrode 46 comprises a hollow, metallic cylinder connected through lead 78 to ground, and therefore to the positive side of a source of relatively high D. C. potential 51 which may be in the order of one thousand or twelve thousand volts. The value of the cathode-anode voltage depends primarily on the geometry of the electrodes 45 and 46, the magnetic field strength, and only to a secondary extent on the size of cathode 47. The accelerating electrode, besides accelerating the electrons, exerts an electrostatic, beam-focusing action. The glass vessel 10 of the beam tube is surrounded by the segmented solenoids 74, 75, and 76, which are connected to two sources of direct current potential 54 and 55. These solenoids furnish the necessary magnetic field for producing and maintaining the previously mentioned hollow beam.

The tube disclosed in Fig. 1 is especially useful as a "traveling wave tube" in which the electron beam is velocity-modulated by longitudinal electric fields, a component of which is parallel to the axial component of the direction of travel of the electrons. As is known in connection with the traveling wave tubes, a wave guide or other input circuit, including a portion of a helix, are used for velocity-modulating the electron beam within the tube. This wave guide constitutes an input circuit for the tube, the connections of the wave guide to the tube including a helix inserted within the tube, this helix surrounding the electron beam. Only a few turns of the helix are shown in Fig. 1 due to lack of space. The actual number of turns is of the order of from 50 to 500, and the length of the small diameter portion of the tube is of the order of 5 to 10 times the length of the larger diameter portion. The number of helix turns per centimeter length, and all other linear tube dimensions, such as diameter of the helix, total length of the tube, the dimensions of the wave guide input-output circuit, and the gun dimensions, can not be specified since they all depend on the wave length, or the mean wave length of the band width of wave lengths propagated along the input wave guide. Proportioning of the above dimensions is known in the art and need not be discussed in this specification. The input wave guide is placed in the proximity of the accelerating electrode 46 and the helical coil within the tube extends from that region to the region which is in the vicinity of the target-anode 18, where a similar wave guide output circuit is connected to the helix. The operation of the traveling wave tubes is known in the art and may be summarized briefly as follows: The radiation propagated along the input wave guide velocity-modulates the electron beam with the concomitant bunching of the electrons in response to the ultra-high frequency intelligence signal propagated along the input wave guide. The modulation of the electrons by the intelligence signal extends somewhat beyond the immediate region of the wave guide to the region of several initial turns of the helix positioned within the tube where it is gradually attenuated so that it does not have any effect on the electron beam from then on. Throughout the modulation region, the velocity-modulated electron beam gradually begins to be bunched by the input signal appearing on the helix. This region occupies approximately the lower third of the helix length. From then on the velocity-modulated electron

beam acts as an ultra-high frequency generator and a source of ultra-high frequency with respect to the remaining portion of the helix, and there is a transfer of energy from the beam to the helix with gain in power level of the intelligence signal. This region will be called the amplification region of the helix, and consists of approximately the upper two-thirds of the length of the helix. The velocity-modulation region of the helix is often electrically separated from the amplification region by a coating of aquadag 29, 30, and 31 on a plurality of helix supporting rods 26, 27, and 28. This coating is several inches long, and introduces very high electrical attenuation to the energy propagated along the helix, electrically isolating the input from the output. The output portion of the helix is coupled to the output wave guide so that the same intelligence signal appears in the output wave guide but in an amplified form. The intelligence signal may be either a simplex or multiplex signal.

The above structure is disclosed in Fig. 1 with the input proper of the input wave guide surrounding that portion of the tube which is directly above the accelerating electrode 46. The wave guide 53 is provided with a coupling transformer comprising an outer ring 56, connected to wave guide 53, and an inner ring 58. Ring 58, which is in coaxial relationship with ring 56, is approximately of the same length or height as ring 56. This length is approximately one quarter of the free-space wave length of the wave propagated along wave guide. The end of the wave guide is closed or short-circuited by a metallic member 60, and the physical length of the wave guide extending beyond the center line of the tube is in the order of

$$\frac{\lambda g}{4}$$

where λg is the wave guide length of the propagated signal. The ends of the rings 56 and 58 are aligned so as to produce only a relatively narrow gap between the inner surface of ring 56 and the outer surface of ring 58, this gap being filled by the glass envelope of the tube 10. These two rings constitute the ultra-high frequency transformer, the inner ends of the rings, i. e., the ends nearer to the wave guides, being effectively short-circuited, and high voltage point appearing at that end of ring 56 which is nearest to the accelerating electrode 46. The extension 62 of the wave guide beyond the longitudinal axis of the tube constitutes a step-up transformer of the wave guide since its electrical length is made substantially equal to

$$\frac{\lambda g}{4}$$

Therefore, high R. F. voltage appears a quarter wave length away from the closed end 60; this portion of the input wave guide may thus be considered as "the open end" of this transformer, this "open end" electrically coinciding with the center line of the tube; therefore, if the input portion of helix 64 is placed in that region, effective coupling and transferring of energy from the wave guide to the helix will take place, which is indeed the case. Since helix 64 is placed coaxially with respect to the longitudinal center line of the tube, and its inner diameter is made approximately equal to the outer diameter of the hollow electron beam, a very effective coupling will exist between the

helix and the beam with the resulting velocity-modulation of the electron beam and effective transfer of the intelligence signal from the wave guide to the electron beam. At some stage along the length of helix 64, the effect of the input signal upon the beam will cease and from then on the velocity-modulated beam will begin to transfer the intelligence signal back onto helix 64 but the transfer signal will have a higher energy level than the level found in wave guide, this gain being furnished by the local source of direct current potential 51, which is the cathode-anode potential of the tube. Some energy, of course, will be contributed also by the direct current potential connected to the focusing and accelerating electrodes 45 and 46 as well as the heat energy communicated to the cathode, as is well known in connection with conventional radio or video amplifiers.

The output circuit of the velocity-modulation tube is identical to the input circuit, but it is the reversal of the former, i. e., an output transformer, including an inner ring 66 and an outer ring 53, is connected to an output wave guide 76 which propagates the radiation impressed upon it by the output transformer. The longitudinal dimensions of the helices, the impedances of the transformer and the spacing between the wave guides are so adjusted that the helix behaves, under optimum conditions, as a flat line with the concomitant minimum loss of energy in the transfer circuit itself throughout the entire process of transfer of energy from one wave guide to the other.

The operation of the beam tube is as follows: A source of potential is connected to a heater element 48 with the resulting heating of the cylindrical cathode 47 and electron-emitting oxides, which are anchored to the outer surface of cylinder 47. A positive terminal of a direct source of potential 51, having a value which is somewhat lower than the direct current potential connected to the accelerating-electrode 46 and the target-anode 13, is connected to electrode 45. Solenoids 74 and 75 are connected to a source of direct potential 54 with the resulting production of substantially uniform magnetic field throughout the length of the smaller diameter portion of the tube.

Solenoids 74 and 75 are separated only in order to leave a space for the input wave guide 54. The space between these two solenoids is small compared to their outer diameter, so that the magnetic field is substantially uniform throughout the region within the small diameter portion of the tube. Solenoid 75 is connected to a source of direct current potential 55. By means of the two independent direct current potentials 54 and 55, the magnetic field strength in the region of the helix 64 may be adjusted independent of the field strength in the region of the electron gun within the solenoid 76. A magnetic field intensity of the order of 800 gauss is required for the electron gun while a somewhat lower field strength, of the order of 500 gauss, is required for the region of the helix, where the strong radial electrostatic fields are not present. The electron-extracting and beam-forming electrode 45 accelerates the electrons simultaneously outwardly from the surface of the cathode in an approximately radial direction, and also in an axial direction, i. e., toward the apex of the cone due to the axial component of the electrostatic field. This is illustrated in Fig. 3. This axial component exists because of the conical shaping of electrode 45. If it were not for the magnetic field, the electrons would reach electrode 45 essentially along the paths 300, Fig. 3, where the configuration of the electrostatic field between the cathode and electrode 45 is illustrated by a plurality of lines 300. (For convenience the lines 300 have arrows which show a direction opposite to the conventional direction of electric field, since the direction of force on electrons is opposite to the electric field. This same reversal of convention is used in Figs. 4, 5, and 6.) Thus the tube would operate essentially as an ordinary diode. The magnetic field and the potential redistribution due to the presence of the space charge, however, cause the electrons to assume essentially circular paths concentric with the axis of the cathode. Due to the axial component of the electric field these circulating electrons receive an axial acceleration toward the apex of the cone, causing the electrons to assume helically directed paths of progressively increasing pitch toward electrode 46, which, because of the higher positive potential impressed upon it, gives an additional axial acceleration to the electrons. The initial axial acceleration of electrons within the electrode 45 may be increased by increasing the axial component of the electron field. This may be done by insulating the end hat, 49, and biasing it negatively with respect to the cathode as shown in Figure 3–A. Because of this biasing of the hat the heater circuit of cathode 47 is now insulated from the hat. This is accomplished by inserting an insulating plug 303 into the cathode cylinder 47 and hat 49, this plug acting as a mechanical means for interconnecting and holding together hat 49 and the cathode cylinder 47. The heater is supplied with the necessary heat current through a transformer 304, the primary of which is connected to two conductors 305 and 306, which complete the circuit of the heater. As illustrated in the drawing, one of the lower ends of the heater coil is connected to the inner wall of the cathode cylinder 47 by means of a jumper 307, which enables one to use one of the heater conductors, namely conductor 305, for biasing the cathode cylinder with respect to the hat. This is accomplished by means of a conductor 308, which is connected to the lower end of conductor 305 at one end and to a battery tap 309 at the other end. From the illustrated connections, it follows that battery 51 supplies all the necessary potentials, except the heater potential supplied by transformer 304; hat 49 is at the lowest potential, or most negative potential; the cathode cylinder 47 is at somewhat higher positive potential with respect to hat 49, the beam-forming and electron-extracting electrode 45 is at a much higher positive potential with respect to the cathode cylinder 47 (see conductor 73), and electrode 46 is at a still higher potential with respect to electrode 45 and also with respect to the cathode cylinder 47. The latter connection is obtained by grounding electrode 46 through conductor 73 and by grounding the positive terminal of the source of potential 51. The position and shape of electrode 46 in relation to the upper end of electrode 45 is also designed to produce the previously mentioned, well known electrostatic focusing action on the electrons, as they pass from the end of electrode 45 through electrode 46, by means of the so-called "electrostatic lens of the bi-potential concentric cylinder type." This type of electronic lens is commonly used in beam

tubes such as cathode ray tubes and storage tubes. It is important that the top end of the cathode 47 be located somewhat below the top end of electrode 45 to prevent the otherwise present electrostatic defocusing fields between the cathode and electrode 46 from nullifying the previously described focusing action of electrode 46. The hollow cylinder 58, and the helix 64 are at ground potential, being connected through lead 33 to electrode 46 which is grounded through leads 42 and 78 of Fig. 1. Because of the presence of the magnetic field in the space between the accelerating electrode 46 and the target-anode 18, the electrons will continue helical paths of enlarged but uniform pitch until they reach anode 18. In this region the pitch of the electron paths is of the order of 5 to 15 times the diameter of the beam, depending on the potentials of electrodes 46, 45, and the intensity of the magnetic field. When the electrons reach the target-anode 18 they are collected. The secondary electrons are suppressed by a potential difference of about 300 volts between the hollow cylinder helix termination 66 and the target-anode 18, supplied by a source of direct voltage 77. It is possible to obtain a hollow beam of electrons by means of the combined effects of the magnetic and electrostatic fields upon the electrons only when proper direct current potentials and the intensity of the magnetic fields are selected for operating the tube. This does not mean that the cathode-anode voltage and magnetic field parameters are critical. The variation of the two may be of the order of 100–200 percent, with any given geometry.

In one of the embodiments of the gun portion of the invention (Fig. 1) the following parameters were found to be very satisfactory for producing a hollow electron beam ¼" outer diameter and ⅛" inner diameter with no scallops:

Beam current	ma..	.400
Cathode diameter	inch..	.125
Small inner diameter of electrode 45	inch..	.250
The angle of cone 45	degrees..	40–60
The axial length of the cathode	inch..	.5
The inner diameter of accelerator 46	inch..	.375
The axial length of accelerator 46	do....	.75
Potential of electrode 45	volts..	800
Potential of electrode 46	do....	2000
Magnetic field strength in the electron gun	gauss..	800
Magnetic field strength between electrode 46 and the target	gauss..	500

Electrode 45 has an optimum angle mentioned above because if the angle were too large the electron-extracting fields would be too small to extract many electrons from the cathode in the region near the end hat 49, while if the angle were too small the axial component of the electrostatic field would be too small, and consequently the axial acceleration of the electrons would be too small.

In the prior art the known techniques of generating either solid or hollow electron beams consisted of button-type, concave or flat emitting surfaces heated by thermal radiation from a heater placed directly back of the button, the other side or the concave side of which is coated with emissive material. This button-type cathode may also be heated by electron bombardment from an electron-emitting filament on the convex or non-emitting side of the button. The beam-forming electrostatic fields are often furnished by cylindrical electrodes, one of which surrounds the button-type cathode, and the other one being placed above the first electrode. From this it follows that the electron-emitting capacity of the beam tube of this type is limited to a relatively small concave surface of the cathode, and the configuration of the electrostatic fields in the tube of this type are less favorable to the production of high density electron beams than in the disclosed tube. This is reflected at once in the electron density found in the beam tubes of this type; a typical high value is of the order 0.5 ampere per square centimeter when thoria is used as an electron emitter. The beam densities obtainable with an experimental model of the disclosed tube are in the order of two amperes per square centimeter with barium and strontium oxides acting as the electron emitter, which are less effective than thoria. Since thoria is more effective as an electron emitter than the barium-strontium oxides in the ratio of approximately two to one, it would be only reasonable to expect that a cathode made of thoria in the disclosed tube would have ultimate maximum beam current densities in the order of four amperes per square centimeter so long as higher anode voltages are provided. Thus, the current density in the disclosed tube can have an eight to one ratio as compared to the densities now obtainable with the known beam tubes.

The above figures compare the density of a solid electron-beam with the hollow electron beam obtainable with the disclosed tube. The density comparisons between the disclosed tube and the tubes capable of producing hollow electron beams would enhance the above mentioned ratios by several fold in favor of the disclosed tube since the known hollow electron beam tubes are known to be notoriously inefficient in producing high density hollow beams.

It should be mentioned here parenthetically that, as it has been stated previously, the use of the hollow electron beams in connection with the traveling wave tubes is known in the art, and it is also known in the art that the hollow electron beam is much more efficient in transferring the energy from the input wave guide to the output guide. This is because the inner diameter of helix 64 is proportioned so as to be as close to the cylindrical outer locus of the beam as possible without resulting in parasitic interception of the electrons from the beam. With this type of coupling between the beam and the helix, the electric fields produced by the helix, which are strongest next to the turns of the helix and weak at the longitudinal axis of the tube, are obviously most effective at the inner surface of the helix. Therefore, it is most advantageous to use a hollow electron beam so that the beam electrons would be under the influence of the strongest electric field for optimum interchange of energies between the field and the electrons in the input portion of the tube. The same is true for the output portion of the helix except that in the latter case the transfer of energy is from the velocity-modulated electrons to the helix. It is known in the pencil beam tube art that when the above mentioned optimum conditions are replaced with a solid electron beam, the inner electrons form a space charge which not only repels the outer electrons radially, but it also depresses the potential inside the beam so that for high density beams the inner

electrons slow down to the point of actual stoppage. These stationary electrons form a stationary space charge which limits the amount of current flow. Thus the electrons in the central portion of the beam produce simultaneously two detrimental effects: They defocus the beam, and they act as an electron-decelerating means for the entire beam.

To summarize the advantages of the disclosed tube, it discloses a most desirable type of electron beam, i. e., a hollow beam, and the density of this beam is many times higher than the density currently available with the beams of this type.

Figs. 2, 3 and 3–A disclose the use of a high permeability pole-piece 701 for shaping the path of the magnetic flux. This enables one to obtain a magnetic flux which also furnishes the radial component acting on the electrons. Therefore with the pole-piece 701, the resultant radial component consists of the electrostatic as well as the magnetic vectors. This is described more fully in connection with Figs. 7 and 8.

Fig. 4 discloses a modified form of the electron-extracting and beam-forming electrode 45. In Fig. 4 the cathode 47 is identical to the similarly numbered cathode in Fig. 2, so that the modification is restricted solely to the electron-extracting and beam-forming electrode. The latter consists of a plurality of thin-walled hollow cylinders, or metallic rings 400 through 404 of equal diameters and which are in concentric relationship with respect to the cathode and are equidistantly spaced along the axis of the tube. The rings are made of any suitable sheet metal such as nickel or tantalum. The electrical circuits between the cathode and the rings, as illustrated in the figure, consist of a conductor 406 connecting the cathode to the negative terminal of a source of potential 408 and a plurality of tapped connections between the successively higher positive potential terminals of source 403 and the rings so that ring 404 is at the lowest positive potential with respect to the cathode and ring 400 is at the highest, with positive potential increments existing between adjacent rings as one progresses from ring 404 to ring 400.

In the absence of a magnetic field parallel to the axis of the cathode, the electrons emitted from the cathode would follow paths approximately the same as the lines of electric field illustrated in Fig. 4 which reach from the cathode to the anode rings. Thus, without the magnetic field the tube would act as a diode. The magnetic field, however, causes the electrons, which are initially accelerated approximately along the radial paths toward the rings, to assume helical paths concentric about the axis of the cathode, and, in combination with the electrostatic field, cause them to assume a helical path of progressively increasing pitch toward ring 400 and electrode 46. This is especially so because of the longitudinal component of electrostatic field caused by the increasing gradient of potential from ring 404 to 400. Electrode 46, which is the electron-accelerating and electrostatic-focusing electrode, is at a higher potential than ring 400. Electrode 46, therefore, accelerates the electrons which emerge in the axial direction from ring 400, causing the electrons to continue their helical motion but with a much greater pitch. The position and shape of electrode 46 in relation to ring 400 is also designed to produce the previously mentioned, well known electrostatic focusing action on the electrons as they pass from ring 400 through electrode 46 by means of the so-called "electro-static lens of the bi-potential concentric cylinder type." This type of electronic lens is commonly used in beam tubes such as cathode ray tubes and storage tubes. By using a plurality of rings 400 to 404 with successively higher potentials applied to the rings, essentially the same shape of electrostatic field is obtained as by the use of tapered electrode 45 in Fig. 2. Therefore these two types of hollow electron beam sources, shown in Figs. 2 and 4, are essentially alike in their ability to produce hollow electron beams. Therefore the advantages of the hollow beam source of Fig. 2 over conventional hollow beam sources also apply to the source illustrated in Fig. 4.

Fig. 4 illustrates the heater coil 42 centrally mounted within the cathode cylinder 47, this construction being identical to the one illustrated in all previous figures. The figure also illustrates hat 49 which in this particular instance, is not insulated from the cathode cylinder but constitutes a direct metallic continuation of the latter. Therefore, the relationship of the hat with respect to the cathode and the heater circuit for the heater coil 48 in Fig. 4 correspond in the construction and operation of the same elements in Fig. 2. This being the case, the heater circuit has not been illustrated in this figure.

In the description of the modifications of the beam tube illustrated in Figs. 1 through 4 it has been stressed that the electrostatic field includes a radial vector and a vector parallel to the longitudinal axis of the tube. The radial vector produces the radial acceleration of the electrons and the magnetic field converts it into the circular motion. The axial vector, which is parallel to the longitudinal axis of the tube, converts this circular motion into a helical motion so that the electrons eventually emanate from the interaction space between the cathode and the electron-extracting and beam-forming electrode. The magnitudes of the two vectors and of the magnetic field must be properly proportioned to obtain the desired helical paths since, if the radial vector is made too large and the axial vector, in an extreme case, is suppressed altogether, the interaction space is converted into that of a conventional magnetron. If the axial vector only is present, the acceleration of the electrons by the axial vector is parallel to the magnetic field. No special difficulties have ever been encountered in the prior art in creating extremely powerful radial fields which are currently used, to mention one example, in high power magnetrons. However, available geometries for the creation of the radial and axial electrostatic fields tend to favor the radial field at the expense of the axial field. To overcome this it becomes necessary to resort to the electrode configurations where the desired magnitudes of the two vectors are in the desired ratio of their magnitudes. Fig. 5 illustrates this configuration. Only the centrally mounted cathode 47, the electron-extracting and beam-forming electrode, and the accelerating and focusing electrode 46 are illustrated in this figure. The modification resides solely in the construction of the electron-extracting and beam-forming electrode which is similar to the electrode of Fig. 4 except that the rings 400 through 404 of Fig. 4 have been reshaped into a plurality of axially spaced, hollow, truncated cones 500 through 504. The electrical connections to these cones are analogous to the electrical connections to the rings shown in Fig. 4. The only difference in actions between

the electrodes of Fig. 5 and the electrodes of Fig. 4 is that the inner cone surfaces increase the axial component of the electrostatic field, as illustrated by the plurality of lines 510. The axial component of the electrostatic field in Fig. 4 is obtained solely by introducing the potential differences between the successive rings. In Fig. 5 the axial component is obtained by having the potential differences between the cones 504—508 and also by slanting the electrode surfaces. The operation of the tube illustrated in Fig. 5 is identical to the operation of the tube illustrated in Fig. 4 except that a greater axial acceleration of the electrons exists in Fig. 5 due to the greater longitudinal component of the electrostatic field.

The heater circuit for the electron gun illustrated in Fig. 5 is identical to that illustrated in Figs. 1 and 2. However, if so desired, it can be replaced with the arrangement illustrated in Fig. 3–A. If the latter is the case, then the hat is insulated from the cathode cylinder and the heater coil circuit is completed by means of two conductors such as conductors 305 and 306 and the secondary of transformer 304 illustrated in Fig. 3–A.

Figs. 4 and 5 also disclose the use of the pole-piece 701 for shaping the path of the magnetic field. As stated previously, this feature is described more in detail in connection with the description of Figs. 7 and 8.

In all prior figures the cathode is an axially mounted element with the electron-extracting electrodes surrounding the cathode. It is known in the thermionic tubes art that the electron-emmissive area can be increased still further by reversing the position of the elements, i. e., so that the cathode is the external cylindrical member, emitting electrons from its inner surface, and the other electrode is located inside the cathode. This disposition of the elements increases the emissive surface by several fold. The necessary electrostatic field is furnished by means of the axially positioned electrode, the area of which may be made rather small before introducing any limiting factors. This is illustrated in Fig. 6 where the electron-extracting and beam-forming electrode 605 is in the center and has the shape of an inverted cone. An electron-emitting surface 601 consists of a thin hollow metallic cylinder 602, the inner surface of which has been painted with an electron-emissive material. This cylinder fits inside a hollow ceramic cylinder 603, the inner diameter of which has been threaded to receive a heater winding 604. For the sake of the simplicity of the drawing, the circuit of the heater coil 604 has not been illustrated. This circuit is of conventional nature and for this reason needs no additional description or illustration.

The electron-extracting and beam-forming electrode 605 has the shape of an inverted cone with the base of the cone being somewhat below the plane defined by the upper end of the cathode cylinder 602. The remaining elements of the tube are identical to those of Fig. 1 with electrode 46 being the accelerating and focusing electrode which performs the same function as electrode 46 of Fig. 2. Cathode 602 is connected to the negative side of a source of high direct current potential 607 by the conductor 606. Electrode 605 is connected through lead 608 to an intermediate positive voltage tap on the source of potential 607 and the high positive potential side of the voltage source 607 is grounded and is therefore connected to electrode 46 through a grounded lead 78. The electric field appearing between the cathode 602 and electrode 605 is illustrated by a plurality of lines. The electric field has both a radial and a longitudinal component, as in Fig. 1. With the exception of the initial direction of the electron flow being inward toward the axis of the tube in Fig. 6 instead of outward as in Fig. 1, the operation of the tube disclosed in Fig. 6 is identical to the operation of the previously disclosed tubes. It is preferable to have the upper end of cone 605 terminate somewhat below the upper end of cathode 602 in order to avoid the presence of any strong electric fields between the upper end of the cone and the accelerating electrode 46, since they would have a disruptive effect upon the beam. Accordingly the configuration of the entire end zone involving the plane defined by the upper end of the cathode, the upper end of electrode 605, and the position of electrode 46 are such that the usual focusing and electron accelerating properties dominate this region.

The main advantage of the beam tube illustrated in Fig. 6 is that it possesses a large electron-emitting surface. For a given diameter of the beam, the current densities produced in Fig. 6 are of the order of two or three times higher than the current densities obtainable with the electron guns disclosed in Figs. 1 through 5, assuming, as before, that proper anode potentials are provided for attaining such densities.

Figs. 1 through 6 have been described thus far as having the radial component furnished by the electrostatic field. As indicated in the same figures, by an element 701, the radial component may be furnished also by the magnetic field in addition to the electrostatic field, as will be described more fully in connection with the description of Fig. 7.

Fig. 7 discloses a modification in which the magnetic field is not parallel to the axis of the tube any longer, which is especially true of the lower portion of the interaction space. The configuration of the magnetic field is illustrated diagrammatically in Fig. 8 by the magnetic lines 800. A pole-piece 701, made of ferro-magnetic material, is placed directly in the path of the magnetic field within the tube. This pole-piece is in a form of a solid truncated cone, with the axis of the cone coinciding with the axis of the tube. The pole-piece, as shown in Fig. 7, extends upward as far as the end hat of the previous figures, and, since it is connected to the cathode emitting surface, it performs the same electrostatic function as the end hats of the previous figures besides concentrating and shaping the magnetic field. Since the permeability of this pole-piece is much higher than that of vacuum, the flux will follow this path of least reluctance, as illustrated in Fig. 8. The resulting magnetic field, emanating from the pole-piece, diverges in the direction away from the cathode and hat 48.

According to Faraday's law, the combined effect of the electrostatic field and of that vector of the magnetic field which is parallel to the longitudinal axis of the tube will force the electrons to follow circular orbits which are in the plane perpendicular to the axis of the tube. However the magnetic field now also has a radial component because of the presence of the pole-piece 701 with the result that, according to the same Faraday's law, the electrons moving along the orbital paths will react with the radial component of the magnetic field and will be deflected upwardly, toward

the accelerating electrode 46. Therefore, in Fig. 7, in the interaction space between the cathode 47 and the electrode 45, the acceleration of the electrons in the direction of the accelerating electrode 46, i. e., along the path parallel to the axis of the tube, is furnished solely by the magnetic field. Thus the electrons given off by cathode 47 follow helical paths of gradually increasing pitch toward electrode 46. The electrons emerging from the top end of the interaction space between cathode 47 and electrode 45 are given a large axial component of acceleration due to the high positive potential of electrode 46. The operation of the remaining portion of the tube in Fig. 7 is identical to the operation of the tube disclosed in Fig. 1. Since the heater structure and its circuit are identical to those illustrated in Fig. 2, their illustration and description have been omitted here.

In Fig. 7 cylindrical electrode 45 is coaxial with the cathode 47, and therefore the electrostatic field is purely radial. It is to be noted that the modifications previously disclosed for obtaining the radial as well as the axial components of the electrostatic field can be combined with the shape of the magnetic field disclosed in Fig. 8, in which case the electrostatic field as well as the magnetic field will furnish the axial accelerating components for the electrons. This is illustrated in Figures 2 through 6 in which a magnetic concentrator and shaper is mounted below the cathode. In line with this, illustration of the gun structure in Fig. 2 has been provided with the magnetic shaper although the latter has not been illustrated in Fig. 1.

Fig. 9 discloses an additional modification of the cathode-electron extracting and beam-forming electrode combination in which the electrode has the shape of a hollow truncated cone, as in some of the previous figures, and the cathode 900 has been imparted a conical shape to increase the axial component of the electric field. It should be noted here that the divergence of the cathode cone should be proportioned so that its largest radius, corresponding to its radius at the bottom, does not exceed the radius of the opening 902 of the electrode 45. With this geometry, practically no electrons will be intercepted by electrode 45 so long as proper voltages are impressed on the electrodes 43 and 45. The remainder of the tube is identical to that illustrated in Fig. 1 and therefore needs no additional description.

Fig. 10 discloses an additional modification of Fig. 6. As in Fig. 6, the electron-extracting and beam-forming electrode 605 is in the center and has the shape of an inverted cone with the base of the cone being somewhat below the plane defined by the upper end of the cathode 1000. In Fig. 10 cathode 1000 has been imparted a conical shape with the walls of the truncated cone 1005 being approximately parallel to the walls of the central cone 605. It should be noted here that the surfaces of the two cones need not be necessarily parallel to each other or the angles of the two cones equal to each other. The two angles can be varied to a considerable extent so long as the limits are not exceeded which would result in the parasitic interception of the electrons by the electrode 605. The modification illustrated in Fig. 10 has two advantages: it increases the axial component of the electric field and at the very same time it increases, to a considerable extent, the electron-emissive surface of the cathode as compared to the surface illustrated in Fig. 6. The remainder of the tube is identical to that illustrated in Fig. 1 and therefore needs no additional description. It should be noted however, that the heater circuit in Fig. 10 will differ from that illustrated in Fig. 1 but will correspond to the heater circuit arrangement mentioned in connection with the description of Fig. 6. It will correspond to the well known heater circuit arrangements used in connection with cylindrical cathode which surrounds centrally mounted anode.

In discussing the configuration of the cathodes and beam-forming electrodes, it has been mentioned previously that the parameters, and especially the voltage of the accelerating electrode, are adjusted to produce the beam in which the electrons will travel between the accelerating electrode and the target anode along a helical path of enlarged but uniform pitch until they reach anode 18. It has been mentioned also that in this region the pitch of the electron path is of the order of 5 to 15 times the diameter of the beam, depending on the potentials of the electrodes 43—45 and the intensity of the magnetic field. It should be borne in mind that for most effective interchange of energies between the beam-modulating fields produced by the helix 66, Fig. 1, interconnecting the wave guides 53 and 70, and the electron beam, it would be desirable to have these electrons travel along the purely axial paths. Since any deviation, for example, as in this case in the helical manner, of the electrons from this axial direction of travel will, for any given direct current accelerating voltage, decrease the axial component of the electron velocity and also increase the space charge density of the beam for a given beam current density; this will require more axial radio frequency electric field for producing some percentage of modulation. Therefore, higher percentage of modulation with the smaller signal will be obtained in the beam if the electrons travel along the axial path. However this detrimental effect of the helical path of the electrons can be diminished to a relatively insignificant amount if the pitch of the helical path is made so large that it, for all practical purposes, insofar as its modulation is concerned, approaches the axial path. Hence the reason for adjusting all the parameters to make pitch of the electron path of the order of 5 to 15 times the diameter of the beam. If so desired, this pitch can be enlarged further by increasing the potential impressed on the accelerating electrode. For example, in one version of the traveling wave beam tube, with the dimensions and the electrical parameters of the tube being identical to those listed on page 12 of the specification, the potential of electrode 45 was varied between 1000 and 2000 volts and, in response to this voltage variation, the hollow beam image, as produced on the target anode, was rotated through 360°. The distance that the beam travelled between the accelerating electrode and the target anode was 8". Therefore, from this data one can compute that the number of complete rotations experienced by the electrons in the beam has been of the order of two complete revolutions at 2000 volts and three complete revolutions at 1000 volts. Since the outer diameter of the beam was of the order of ¼", the pitch was in the order of 16 times the diameter of the beam at 2000 volts and 12 times the same diameter at 1000 volts. With the pitch dimensions of the types

illustrated above, satisfactory modulations are obtainable.

It has been also mentioned previously in this specification that one of the advantages of the disclosed tube is that, in spite of the fact that especially high beam current densities are obtained, the hollow beam is devoid of any scalloping effects. Therefore, the outer locus of the beam is a cylindrical surface. It has been established experimentally that this desirable absence of the scalloping persists over wide operating conditions even when the electrode voltages are varied over a range of the order of 200%, and when the magnetic field is varied over a range of the order of 200%. The above percentages can be increased even further, if so desired, and the upper limit of such variations is reached when there is an increase in the cathode-electrodes current. The latter begins to increase when the electrode voltages are increased by several thousand volts. During the normal operation of the tube the ratio of the beam current to the electrodes current is of the order of 100 to 1, which bespeaks very well of the geometry of the disclosed tube. It is to be noted here in connection with the possible limits of variation of the electrode voltages that since the electron path is determined by the magnitude of the two vectors, i. e., the electrical and magnetic vectors, it is obvious that the limits of the variations of the electric vector are to be considered in terms of the magnitude of the magnetic vector with the latter remaining fixed while the electric vector is varied. Once the limits have been established, the value of the magnetic vector can be altered in any desired manner.

The invention described in the foregoing specification and in the claims may be manufactured and used by or for the Government for governmental purposes, without the payment to me of any royalty thereon.

I claim:

1. An electron gun comprising a cathode having an elongated electron-emissive surface; an electron-extracting and beam-forming means, said means comprising an electrode in spaced, coaxial, coextensive relationship with respect to said cathode to form an interaction space therebetween and means including said electrode for establishing a potential gradient between said electrode and cathode which varies axially over the length of said interaction space to thereby produce an electrostatic field having radial and substantial axial components substantially throughout said interaction space for accelerating the electrons emitted by said cathode along a path determined by the direction of the electrostatic field; and means comprising a source of magnetic flux furnishing a magnetic field for said interaction space for modifying the direction of said path into a spiral thereby producing a hollow electron beam emanating in an axial direction from said interaction space, said beam having a longitudinal axis in substantial coincidence with the continuation of the longitudinal axis of said cathode.

2. An electron gun as defined in claim 1 which also includes an accelerating electrode connected to a source of direct potential to place thereon a sufficiently higher positive potential than on said coextensive electrode for imparting further axial acceleration to said hollow electron beam against the decelerating effect of the space charge.

3. An electron gun as defined in claim 1 wherein said source of magnetic flux includes a means for introducing a radial component to said magnetic field for increasing the electron-extracting force acting on said electron-emissive surface.

4. An electron gun for generating an electron beam including a cathode having a cylindrical, electron-emitting surface; an electron-extracting and beam-forming means; said means comprising an electrode in spaced, coaxial and coextensive relationship with respect to said surface defining an interaction space between said electron-emitting surface and said electrode and means including said electrode for establishing a potential gradient between said electrode and said surface which varies axially over the length of said interaction space to thereby produce a resultant electrostatic field having radial and substantial axial components substantially throughout said interaction space; and means comprising a source of magnetic field for imparting a helical path to electrons in said beam.

5. A combination as defined in claim 4 in which said electrode comprises a plurality of metallic rings axially spaced along the axis of said cylindrical surface, and a source of direct potential connected between said cathode and said rings for furnishing positive potentials to the successive rings of progressively higher values, whereby there is an increment of positive potential between adjacent rings.

6. A combination as defined in claim 4 in which said electrode comprises a plurality of hollow, metallic, truncated cones in spaced coaxial relationship with respect to said cylindrical surface and uniformly spaced from each other along said axis, and a source of direct potential connected between said surface and said cones for furnishing positive potentials to the successive cones of progressively higher values whereby there is an increment of positive potential between adjacent cones.

7. In an electron beam tube, a cylindrical cathode, an electron-emitting layer on one of the surfaces of said cathode, a first, cone-shaped, electron-extracting and beam-forming electrode in spaced, coaxial and coextensive relationship with respect to said cathode, means for connecting said first electrode to a source of direct voltage to render said first electrode positive with respect to said cathode for establishing an electrostatic field having axial and radial components, a second beam-focusing and accelerating electrode, said cathode and said second electrode having a common longitudinal axis with said second electrode being positioned along said axis and in spaced relationship with respect to said cathode and said first electrode, and a source of magnetic field for producing a magnetic field having radial and axial components and extending through the space defined by said first and second electrodes.

8. In an electron beam tube as defined in claim 7 in which said cathode is a centrally mounted member with said first electrode surrounding said cathode.

9. In an electron beam tube as defined in claim 7 in which said first electrode is a centrally mounted element with said cathode surrounding said first electrode and said electron-emitting layer being on the inner surface of said cathode.

10. In an electron beam tube, a cathode having an electron-emitting surface, an electron-extracting and beam-forming electrode, said cathode and said electrode being in spaced, coaxial

and coextensive relationship with respect to each other, the space between said electrode and said electron source comprising an interaction space, a source of direct potential connected across said cathode and said electrode for establishing, through said interaction space electric field having axial and radial components, a magnetic flux source furnishing magnetic field for said interaction space, and a ferro-magnetic member in spaced, coaxial relationship with respect to said cathode and said electrode for imparting to said magnetic field a direction having axial and radial components whereby the electron path in said beam is a helical path.

11. An electron gun for generating an electron beam and including a cathode having an electron-emitting surface, in the form of a surface of revolution about an axis, in which lines normal to said surface intersect said axis, an electron-extracting and beam-forming electrode in spaced, coextensive and coaxial relationship with respect to said surface and defining an interaction space between said cathode and said electrode, a source of direct potential connected between said cathode and said electrode for establishing an electrostatic field in said interaction space, and a source of magnetic field furnishing a magnetic field for said interaction space, said source having a magnetic circuit producing axial and radial components for imparting a helical path to the electrons in said beam.

12. A traveling wave tube including an evacuated glass vessel, a cathode mounted at one end of said glass vessel, said cathode having an electron-emitting layer in the form of a surface of revolution about an axis, in which lines normal to said surface intersect said axis, an electron-extracting and a beam-forming first electrode in spaced coaxial and coextensive relationship with respect to said surface, an accelerating second electrode in an axially spaced relationship with respect to said first electrode, a first solenoid surrounding said glass vessel and said first and second electrodes, a source of direct potential connected to said first solenoid to produce from said first solenoid a magnetic field furnishing lines of force substantially parallel to said axis which permeate the space confined by said first and second electrodes, a target anode at the opposite end of said glass vessel, input and output wave guides connected to said tube and positioned between said second electrode and said target anode, a helical coil interconnecting said wave guides, said coil being positioned within said glass vessel, and a second solenoid surrounding said glass vessel and said helical coil, a source of direct potential connected to said second solenoid to produce from said second solenoid a magnetic field furnishing lines of force substantially parallel to the longitudinal axis of said helical coil.

13. A traveling wave tube as defined in claim 12 in which said cathode is an axially mounted, indirectly heated, hollow, metallic cylinder with an electron-emitting layer on the outer surface of said cylinder and said first electrode is a hollow, metallic, truncated cone in spaced, coaxial relationship with respect to said cathode.

14. An electron beam tube as defined in claim 12 in which said cathode is an axially mounted cylindrical member and said first electrode comprises a plurality of metallic rings axially spaced and surrounding said cathode, and a source of direct potential connected between said cathode and said rings for furnishing positive potential to the successive rings of progressively higher value whereby there is an increment of positive potential between adjacent rings.

15. An electron beam tube as defined in claim 12 in which said cathode is an axially mounted cylindrical member and said first electrode comprises a plurality of hollow, metallic, truncated cones in spaced coaxial relationship with respect to said cathode and a source of direct potential connected between said cathode and said cones for furnishing positive potential to the successive cones of progressively higher values whereby there is an increment of higher potential between adjacent cones.

16. An electron beam tube as defined in claim 12 which also includes a low reluctance element coaxially disposed with respect to said cathode for introducing radial components to said magnetic field for increasing the electron-extracting force of said field.

17. An electron gun as defined in claim 1 which also includes a metallic element having a disc-shaped surface of larger cross section than said cathode and disposed coaxially therewith, said metallic element connected to said cathode and partially closing off said interaction space at the end opposite to the end from which said beam emanates.

18. An electron gun as defined in claim 1 which also includes a metallic element having a disc-shaped surface of larger cross section than said cathode and disposed coaxially therewith, said metallic element partially closing off said interaction space at the end opposite to the end from which said beam emanates, and a source of biasing potential connected between said cathode and said metallic element for repelling the electrons from said metallic element and the region in the vicinity of said metallic element.

19. An electron gun as defined in claim 1 in which said cathode and said first electrode both have the shapes of truncated cones.

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