

Sept. 24, 1957

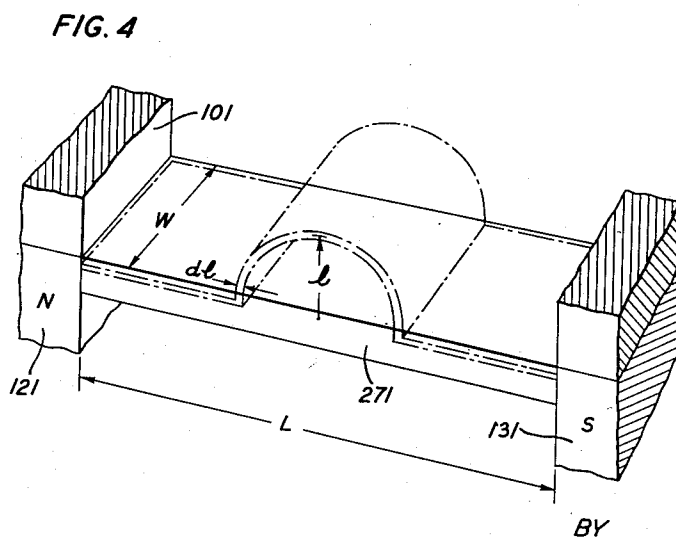
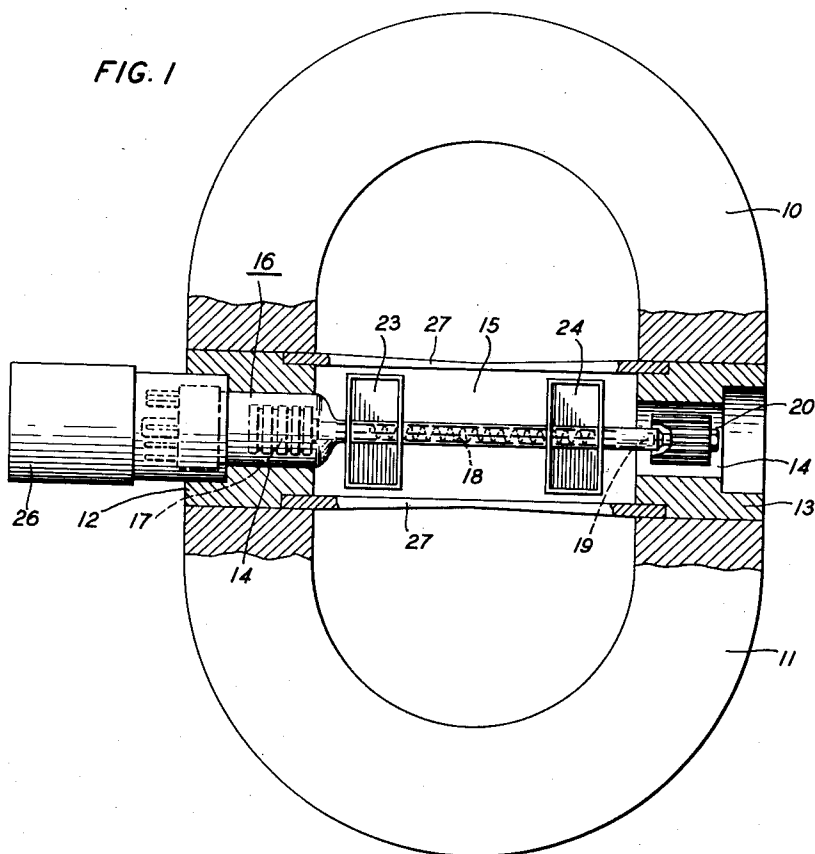
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2,807,743

TRAVELING WAVE TUBE APPARATUS INCLUDING MAGNETIC STRUCTURES

Filed Dec. 29, 1951

3 Sheets-Sheet 1



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FIG. 2

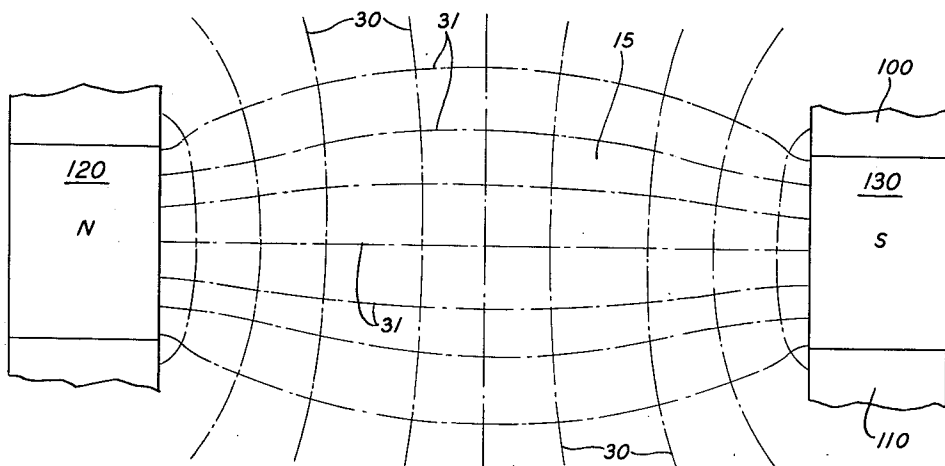
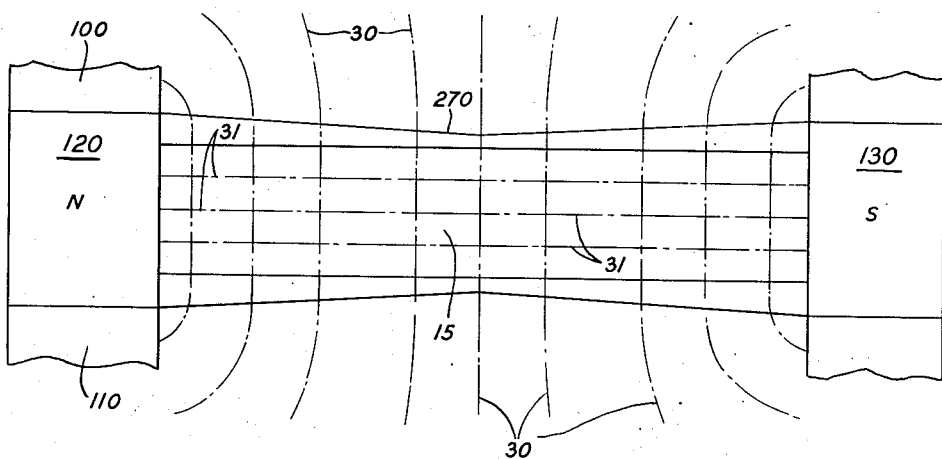


FIG. 3



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FIG. 6

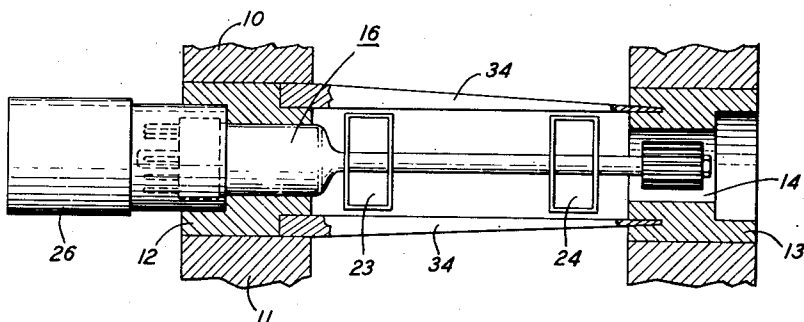


FIG. 5

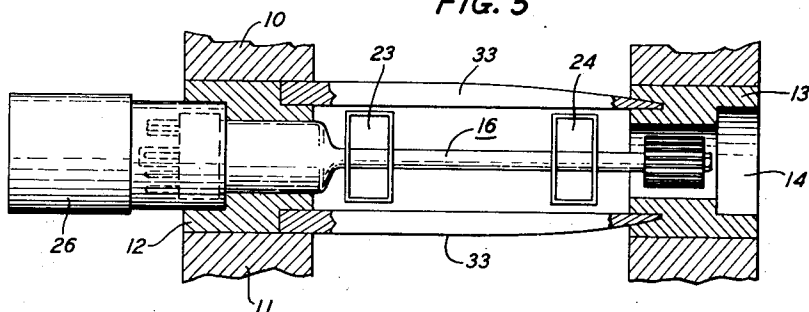
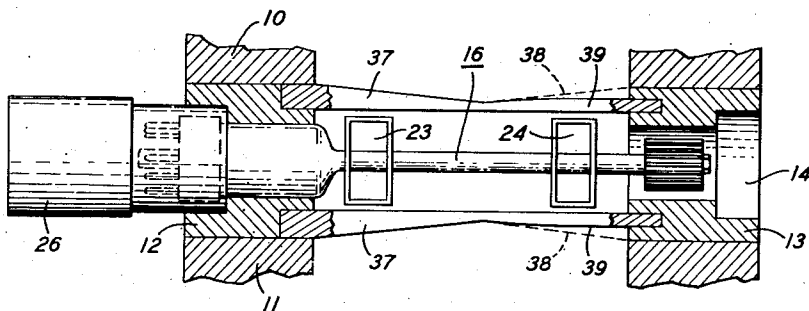


FIG. 7



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TRAVELING WAVE TUBE APPARATUS INCLUDING MAGNETIC STRUCTURES

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Application December 29, 1951, Serial No. 264,096

17 Claims. (Cl. 315—3.5)

This invention relates to apparatus including magnetic structures and more particularly to such apparatus including magnetic structures for traveling wave tubes wherein the magnetic fields produced by such structures cooperate in the operation of the associated traveling wave tubes.

In traveling wave tubes, an electron beam is projected into an interaction space, generally defined by a helix. A signal to be amplified is introduced into the interaction space, as by being applied to the helix, as is known in the art, and amplification occurs due to the interaction of the electromagnetic fields of the signal and the beam. In order to attain proper operation of the traveling wave tube, the magnetic field should restrain the beam in a generally cylindrical form so that it does not impinge on the helix of the transmission circuit. When a magnetic field is established in the elongated air gap between the pole pieces of traveling wave tube apparatus, the flux lines will bow out near the center of the gap and the field will be weakest in this region. Also the field may deviate from an axial path due to non-homogeneous fields, which non-homogeneous fields may be caused either by stray fields or by imperfections in either the permanent or electromagnet producing the field. In this center region, therefore, the diameter of the electron beam is the greatest and the beam tends to contact the helix.

It is one object of this invention to prevent the radial spreading of the electron stream and the impingement of the electrons of the electron stream on the helix of the transmission circuit at the center of the elongated air gap.

In accordance with one feature of this invention, means are provided to maintain a uniform field distribution so that neither the field nor the electron stream will tend to bow out at the center of the elongated air gap.

When a signal is applied to the transmission circuit, however, the electrons will be bunched in the stream in accordance with the signal applied to the helix as the signal grows along the transmission circuit. This axial bunching, due to a velocity modulation of the electron stream, is accompanied by a radial debunching due to the mutually repellent charges on the electrons. This space charge debunching causes the electron beam to spread at the collector end of the interaction space.

A further object of this invention is to prevent the radial debunching of the axially bunched electrons and the impingement of the electrons on the helix of the transmission circuit at the electron collector end of the elongated air gap.

Additionally, maximum amplification occurs when the electron beam is close to the helix of the transmission circuit for best interaction between the electromagnetic fields of the electron stream and the signal applied to the transmission circuit. Further, it is advantageous to reduce the size of the permanent magnet or electromagnetic field coils necessary to produce the required magnetic fields to prevent electrons impinging on the helix of the transmission circuit due to the bowing out of the electron

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stream at the center of the elongated air gap or the radial space charge debunching of the electrons at the collector end of the air gap. The saving in size of magnetic field structure by a reduction in the field required can be seen from the fact that the permanent magnet needed to produce a field of 600 oersteds is one-half the size, by volume, of the permanent magnet required to produce a field of 800 oersteds.

A general object of this invention is to improve the performance of traveling wave tubes. More specifically, it is an object of this invention to improve the performance of traveling wave tubes by producing a magnetic field of optimum characteristics for cooperation with the traveling wave tube.

A further object of this invention is to prevent the impingement of electrons on the transmission circuit either midway in the circuit or adjacent the electron collector. Thus, it is an object of this invention to attain an axially symmetrical magnetic field along the path of the projected electron beam of the traveling wave tube.

Another object of this invention is to maintain the electron beam in close proximity to the helix of the transmission circuit for best interaction of the electromagnetic waves of the electron beam and the signal being simplified without impingement of the beam on the helix.

A still further object of this invention is to provide improved magnetic circuits producing magnetic fields for utilization in electron beam apparatus.

In the specific illustrative embodiments of this invention described herein, a pair of U-shaped magnets having like poles adjacent each other and pole pieces positioned between the like poles provide the longitudinal magnetic field to focus the electron beam projected into the interaction space of the traveling wave tube, which is positioned with the electron gun and electron collector assemblies of the traveling wave tube each within one of the pole pieces and properly aligned with the magnets. A flux guide of magnetic material extends between the pole pieces and encompasses the traveling wave tube. This flux guide may entirely encompass the traveling wave tube or may, in accordance with this invention, comprise a pair of plates positioned to either side of the traveling wave tube, the width of the plates being sufficiently large to produce a uniform field in the interaction space, as by being larger than the separation between them.

In specific illustrative embodiments of this invention, the cross-sectional area of the flux guide is varied between the pole pieces in a prescribed manner to obtain optimum field characteristics. In one specific illustrative embodiment employing flux plates to attain a uniform rectilinear magnetic field free of axial deviations that would cause the radius of the electron beam to expand midway between the pole pieces and impinge on the transmission circuit, the thickness of the flux guide plates is greatest adjacent the pole pieces and decreases linearly to a minimum midway between the pole pieces. Specifically in this illustrative embodiment of this invention, the thickness of the flux guide plates is t_0 midway between the pole pieces and increases linearly on either side of this midway point towards the pole pieces, the thickness t at the pole pieces being given by the expression

$$t = L/\mu\pi + t_0 \quad (1)$$

where L is the distance between the pole pieces and μ is the permeability of the magnetic material of the guide.

In the above specific illustrative embodiment of this invention, the impingement of electrons on the helix of the transmission circuit midway between the pole pieces is prevented by producing a uniform rectilinear field with no axial deviation or bowing out in that vicinity. The impingement of electrons on the transmission circuit adjacent the collector due to radial debunching is prevented

by employing a large enough magnetic field in the elongated air gap. In this specific embodiment, the field is uniform between the pole pieces. However, as the magnetic field required to prevent radial debunching is larger than that required elsewhere to prevent impingement of electrons on the transmission circuit, permanent magnets of smaller sizes can be employed in other specific illustrative embodiments of this invention wherein the flux guide extending between the pole pieces and encompassing the elongated air gap and the transmission circuit is thickest adjacent the electron gun, where the electron beam is unmodulated, and varies in thickness along the transmission circuit to be thinner adjacent the electron collector where the electron beam is modulated by axial bunching.

In another specific illustrative embodiment of this invention, the flux guide comprises two plates on opposite sides of the transmission circuit, the width of the plates being larger than the separation between them and the thickness of each of the plates at any point being

$$t = t_k + t_0(1 - e^{-\alpha(S-Z)}) \quad (2)$$

where $t_k + t_0(1 - e^{-\alpha S})$ is the thickness of the flux guide plate adjacent the pole piece encompassing the electron gun, t_k being a constant thickness utilized to add mechanical strength to the varying thickness $t_0(1 - e^{-\alpha(S-Z)})$, α is a constant depending on the characteristics of the traveling wave tube, S is the distance, from the electron gun end of the guide, at which $t = t_k$, and Z is the distance along the flux guide plate measured from the electron gun end for the point at which the thickness is being calculated.

The above variation in the thickness of the flux guide is exponential as the magnetic field variations along the beam path introduced by such plates can compensate for the current modulation introduced by the axial bunching. Considering any electron in the beam towards which bunching is occurring in a device whose operation falls within the small signal approximation, it appears to that electron as if the current is being increased exponentially and the amount of radial space charge debunching would follow a similar expression. For devices deviating from the small signal approximation, modifications of this flux guide thickness equation would be optimum. However, I have found that the desired magnetic field for these devices having substantially exponential current variations can be approximated if the thickness of the flux guide, instead of varying exponentially, varies linearly from the pole piece encompassing the electron gun to that encompassing the electron collector. This approximation enables greater facility in the machining and fabrication of the flux guide. In either specific embodiment, however, by employing flux guides in accordance with this invention whose thickness varies, being greatest adjacent the electron gun and decreasing towards the electron collector, the electron beam can pass in close proximity to the helix of the transmission circuit along the whole length of the circuit without impinging on the helix, thereby attaining the maximum interaction between the electron beam and the signal applied to the helix.

In a further specific embodiment of this invention, a uniform rectilinear field is attained over a first portion of the air gap by having the thickness of the flux guide vary linearly from a maximum adjacent the pole piece encompassing the electron gun to a point substantially midway between the pole pieces and then vary in accordance with an exponential curve superimposed on a linear variation from the midpoint to the other pole piece. The uniform rectilinear field, as pointed out above, prevents electrons impinging on the helix due to a bowing out of the electron stream midway between the pole pieces and the deviation from a rectilinear field introduced by the superimposed exponential variation in flux guide thickness counteracts the debunching forces tending to cause the electrons to spread radially adjacent the electron collector.

It is one feature of this invention that a flux guide extend from the pole piece encompassing the electron gun assembly of a traveling wave tube to the pole piece encompassing the electron collector assembly of the traveling wave tube, a longitudinal magnetic field being provided between the two pole pieces. Further in accordance with a feature of this invention, the thickness of the flux guide varies in a prescribed manner to obtain optimum interaction of the electron stream and the electromagnetic wave guided by the helix of the transmission circuit.

It is a further feature of this invention that the flux guide be a pair of plates of magnetic material, the width of the plates being sufficiently large to produce a uniform field in the interaction space, as by being larger than the separation between the two plates.

It is a further feature of certain specific illustrative embodiments of this invention that the thickness of the flux guide vary between the ends directly adjacent the pole pieces and the middle point between the pole pieces to attain uniform magnetization of at least a portion of the flux guide. Specifically, it is a feature of these specific embodiments of this invention that the thickness at the midway point be t_0 and increase linearly towards the pole pieces, the thickness t at the pole piece being given by the expression.

$$t = L/\mu\pi + t_0$$

where L is the distance between the pole pieces and μ is the permeability of the magnetic material of the guide.

It is a further feature of certain specific illustrative embodiments of this invention that the thickness of the flux guide be greatest directly adjacent the pole piece encompassing the electron gun of the traveling wave tube and decrease towards the pole piece encompassing the collector electrode of the traveling wave tube. Specifically it is a feature of certain of the embodiments that the variation be exponential and, in one specific embodiment, that the thickness at any point be given by

$$t = t_k + t_0(1 - e^{-\alpha(S-Z)})$$

where t_k is a constant thickness to add mechanical strength to the flux guide, if desired, $t_k + t_0(1 - e^{-\alpha S})$ is the thickness adjacent the pole piece encompassing the electron gun, α is a constant depending on the characteristics of the traveling wave tube, Z is the distance along the flux guide measured from the electron gun end, and S is the distance at which $t = t_k$.

A complete understanding of this invention and of the various features thereof may be gained from consideration of the following detailed description and the accompanying drawings, in which:

Fig. 1 is a side view, partially in section, of one specific illustrative apparatus in accordance with this invention showing particularly the pole pieces, the traveling wave tube, the flux guide, and their relative positions in the apparatus;

Fig. 2 is a side view of the air gap defined by the pole pieces of the apparatus of Fig. 1 showing the flux paths and equipotential surfaces in the absence of a flux guide;

Fig. 3 is a side view of the air gap defined by the pole pieces of the apparatus of Fig. 1 together with the flux guide in accordance with this specific embodiment of this invention, showing particularly the flux paths and the equipotential surfaces attained by the employment of a flux guide in accordance with this invention;

Fig. 4 is a perspective view of one flux guide plate of width w and length L showing particularly the path of an element of flux partially through the flux guide and partially through air;

Fig. 5 is a partial side view, partially in section, of another specific illustrative apparatus in accordance with this invention;

Fig. 6 is a partial side view, partially in section, of another specific illustrative apparatus in accordance with this invention; and

Fig. 7 is a partial side view, partially in section, of another specific illustrative apparatus in accordance with this invention.

Referring now to Fig. 1 of the drawing, there is shown one specific illustrative embodiment of this invention wherein the magnetic field for focussing the electron stream is provided by a pair of U-shaped magnets 10 and 11 having like poles adjacent each other and pole pieces 12 and 13 interposed between the like poles, the pole pieces defining an elongated air gap 15. A traveling wave tube 16 extends through apertures 14 in the pole pieces and across the elongated air gap 15. The traveling wave tube, as is known in the art, comprises an electron gun assembly 17, a helix transmission circuit 18, and an electron collector assembly 19 around which may be positioned a heat radiator 20. The electron gun assembly 17 is positioned within the aperture 14 in pole piece 12 so as to be encompassed by the pole piece 12, the internal magnetic shield of the electron gun assembly 17 being advantageously aligned with the inner edge of the pole piece 12. Similarly, the electron collector assembly 19 is positioned within the aperture 14 of the pole piece 13 so as to be encompassed by the pole piece 13. The traveling wave tube 16 may be of the general type described in application Serial No. 168,202, filed June 15, 1950 of C. C. Cutler, the shield around the electron gun assembly being there disclosed as external to the tube envelope.

Input and output wave guides 23 and 24 extend within the elongated air gap 15 transverse to the axis of the traveling wave tube 16 and provide a coupling of the high frequency signal to the transmission circuit of the traveling wave tube 16, as is known in the art. Advantageously, the wave guides 23 and 24 may also provide support for the traveling wave tube 16, which may also advantageously be supported within the apertures 14 in the pole pieces 12 and 13. A plug or socket 26 may also be employed to provide connections to the terminals extending through the base of the traveling wave tube 16.

Extending between the pole pieces 12 and 13 and attached thereto are a pair of plates 27 of magnetic material encompassing the air gap 15 and the transmission circuit defined by the helix 18 of the traveling wave tube 16. These plates are flux guides, in accordance with my invention, for attaining a magnetic field in the air gap 15 of optimum characteristics for cooperation with the traveling wave tube 16 and specifically for focussing the electron stream projected along the helix 18. In the specific illustrative embodiment of my invention depicted in Fig. 1 the flux plates are particularly shaped, in accordance with one feature of my invention, to attain a rectilinear and uniform magnetic field which will not bow out at the center of the elongated air gap 15 nor deviate from the axial direction and thus will prevent electrons impinging on the helix 18 at the center of the transmission circuit. Thus in accordance with this feature of my invention, each flux plate 27 is thickest adjacent the pole pieces 12 and 13 and decreases linearly towards the midpoint between the pole pieces.

The effect of the flux guides 27 can easily be seen with reference to Figs. 2 and 3 in connection with the following explanation. The equipotential surfaces between a pair of finite parallel pole pieces 120 and 130 are contour surfaces 30, as seen in Fig. 2 in the absence of flux guides in accordance with this invention. Since the lines of flux 31 between the pole pieces 120 and 130 make orthogonal intersections with the equipotential surfaces 30, the flux lines 31 bow outward near the center of the air gap 15 and the field is weakest in this region, thereby allowing the electron beam to expand radially and impinge on the helix of the transmission circuit. Because of the length of the elongated air gap 15 prior techniques to correct for this bowing out, such as making the pole pieces large with respect to the air gap length and shaping the pole pieces, are inapplicable. Fur-

ther these prior techniques do not correct for the deviations of the field from the longitudinal axis caused by non-homogeneous stray fields or by imperfections in the magnet giving rise to irregularities in the field.

Referring now to Fig. 3, a uniform field distribution is shown to exist between the pole pieces 120 and 130 wherein the equipotential surfaces 30 are parallel planes perpendicular to the axis of the air gap 15 and the potential of any plane is proportional to its displacement in the air gap measured from one pole piece. This uniform field distribution is attained, in accordance with my invention, by connecting the finite pole pieces 120 and 130 by a flux guide 270 which is advantageously a hollow cylinder of magnetic material and so proportioned as to be uniformly magnetized. Then as the magnetic potential distribution in the flux guide 270 is uniform, the equipotential surfaces extend into the air gap 15 as parallel planes, and a uniform field distribution in the air gap 15 is attained. Uniform magnetization in the flux guide 270 is obtained, in accordance with one feature of this invention, by sectional area compensation for the leakage flux. The potential drop along the cylindrical flux guide 270 is then the same as at the axis of the cylinder and, as every equipotential surface is a perpendicular plane, a uniform field distribution is attained, and the flux lines 31 are straight lines between the poles 120 and 130.

While a cylindrical flux guide 270 is theoretically best suited for attaining a uniform field distribution, the large openings that would be required in the cylindrical surface for passage of the input and output wave guides, such as wave guides 23 and 24 of Fig. 1, mitigate against its employment. Even where coaxial terminals are employed for coupling the high frequency wave to the transmission circuit a cylindrical flux guide prevents the traveling wave tube being accessible to inspection. I have found, however, that a cylindrical flux guide can be replaced theoretically by two infinite parallel plates and that it is sufficient in actual practice if the two plates merely be wide with respect to their separation, the separation being needed to accommodate the wave guides. Thus the flux guide plates 27 in the specific embodiment of Fig. 1 may advantageously be employed in place of a cylindrical flux guide.

In accordance with another feature of this invention, the thickness of the flux guide plates in this specific embodiment varies linearly from a thickness t_0 at the point midway between the pole pieces to a thickness at the pole pieces given by the expression

$$t = L/\mu\pi + t_0$$

where L is the distance between the pole pieces and μ the permeability of the magnetic material of the flux guide. The derivation of this expression can be best understood with reference to Fig. 4 which is a perspective view of a flat plate of width w and total length L extending between pole pieces 121 and 131. In such a uniformly thick plate having a magnetomotive force applied between its ends, the flux will diminish from the ends to the center of the plate because of surface leakage and this leakage will be symmetrical about the midsection of the plate. The sectional area compensation required for uniform magnetization corresponds to a thickness shape varying proportionally to the flux distribution. Such a plate comprises a uniform section sufficiently thick at the midsection for mechanical strength, the thickness being identified as t_0 , and a leakage shell varying from maximum thickness at the ends to zero thickness at the center. In calculating this leakage shell a few simplifying assumptions are made. These assumptions are that the leakage flux is normal to the surface and that the leakage paths between these symmetrical regions are semicircular. Also when the magnetic conditions are such that a uniform field exists within the flux guide, that is, within the elongated air gap, the absence of any transverse components predicates the

absence of leakage flux from the interior surfaces of the flux guide.

Referring now again to Fig. 4, the path of an element of flux of width w is shown partly through the plate and partly through air. The radius of the semicircular path of the flux in air is l and the length of surface through which this element of flux passes is dl . Leakage problems are most conveniently approached in terms of the permeance of the various paths, the permeance being the reciprocal of the reluctance and thus the ratio of the flux to the magnetomotive force of the path. Denoting the elementary sectional area through the plate as dA and the surface leakage area by $w dl$ between two regions separated by a distance $2l$, the permeance dK_s of the path of element of flux is

$$dK_s = \frac{1}{\frac{L-2l}{\mu dA} + \frac{l\pi}{w dl}} \quad (3)$$

where μ is the permeability of the magnetic material of the plate. The quantity of flux ϕ through the metallic path is

$$\phi = \mu H dA \quad (4)$$

H being the magnetic field intensity or the magnetomotive force per unit length of the path between the pole pieces, and the quantity of flux ϕ through the leakage path is

$$\phi = H 2l \frac{w dl}{l\pi} \quad (5)$$

where $H 2l$ is the magnetomotive force existing between the points of emergence of the flux through the surface of the plate.

As the same flux ϕ flows through the entire path Equations 4 and 5 may be equated; thus

$$\mu H dA = H 2l \frac{w dl}{l\pi} \quad (6)$$

From Equations 3 and 6, by substituting for dA in Equation 3

$$dK_s = \frac{2w dl}{\pi L} \quad (7)$$

Equation 7 shows that the permeance for all paths of similar elemental area is invariable. Consequently, the leakage shell thickness varies linearly with distance, being zero at the middle of the plate and maximum at the ends. The permeance looking through the end of the shell is equal to the total surface permeances, i. e., the permeance for surface leakage, and is

$$K_s = \int_0^{L/2} \frac{2w dl}{\pi L} = \frac{w}{\pi} \quad (8)$$

The flux guide consists of a thickness of uniform section t_0 in parallel with the leakage shell and has a permeance K at its ends which is the sum of the permeance of the shell and of the section of uniform thickness t_0 ;

$$K = \frac{w}{\pi} + \frac{\mu w t_0}{L} \quad (9)$$

and the flux through the end of the plate is

$$\phi = \mu A H = H L \left(\frac{w}{\pi} + \frac{\mu w t_0}{L} \right) \quad (10)$$

The cross-sectional area of the flux guide plate at the pole pieces

$$A = t w \quad (11)$$

where t is the thickness of the plate at the pole pieces. Substituting Equation 11 in Equation 10 and combining terms gives the expression for t

$$t = L / \mu \pi + t_0$$

which is Equation 1 above. This expression gives the thickness required at the pole pieces to accommodate the surface shell, the thickness of which is zero at the midpoint as there is no surface leakage at that point, as well

as the constant thickness t_0 . As the thickness of the flux guide at its midpoint and at its ends is known and the thickness varies linearly between the end points and the midpoint, the thickness at any point along the flux guide can be determined.

In one specific embodiment constructed in accordance with the embodiment of this invention depicted in Fig. 1, a field H of 800 oersteds was employed in the air gap. This is also the field in the flux guide. This produces a magnetization of 21,000 gauss. in the flux guide. The flux guide plates 27 were of cold rolled steel having a permeability of 26.3 at the field intensity of 800 oersteds and an incremental permeability at the operating point (B, H) on the magnetization curve of 2.0. In this embodiment L was 8.356 inches, giving an indication of the length of the air gap 15, the plate separation was 2.5 inches to accommodate the wave guides 23 and 24, and the width w of the plates 27 was made 4.5 inches to be large with respect to the separation. For rigidity t_0 was made 0.100 inch and the maximum plate thickness adjacent the pole pieces was calculated to be 0.201 inch.

In the above-described embodiment the flux plates 27 were varied in thickness to attain a uniform rectilinear magnetic field in which the magnetic flux lines within the air gap 15 were all straight lines parallel to the axis so that neither the field nor the electrons would spread out radially adjacent the center of the elongated air gap 15, causing the electrons to impinge on the helix 18 of the traveling wave tube 16. Impingement of the electrons on the helix adjacent the electron collector, due to the space charge radial debunching of the axially bunched electrons, is prevented by employing a large magnetic field. This field, however, is only required to be so large at the collector end of the air gap. At other portions of the air gap this large a field prevents the electrons from being projected closely adjacent the helix in order to attain optimum interaction of the electromagnetic fields of the electron beam and the electromagnetic wave guided by the helix. Thus in other specific embodiments of this invention, the flux guide encompassing the transmission circuit of the traveling wave tube and the elongated air gap between the pole pieces is thickest adjacent the electron gun, where the electron beam is unmodulated, and may decrease constantly to be thinnest adjacent the electron collector or receiver, where the electron beam is velocity modulated.

Referring now to Fig. 5, traveling wave tube apparatus similar to that of the embodiment of Fig. 1 is depicted, like parts being identified by the same reference numeral, but the thickness of the flux guide cylinder or plates 33 varies exponentially from the pole piece 12 encompassing the electron gun, where it is thickest, to the pole piece 13 encompassing the electron receiver. An exponential variation in thickness provides an increased field to counteract the effect of the radial debunching due to the exponential increase in electrons in the electron bunch that has been created by the velocity modulation due to the interaction with the signal coupled to the helix 18. In one specific embodiment of my invention in accordance with the embodiment of Fig. 5, the thickness of the flux guide at any point is equal to a minimum thickness t_k added for mechanical strength and an exponentially varying thickness, which has a value t_0 directly adjacent the pole piece encompassing the electron gun. The thickness t_k may be zero if the exponentially varying thickness is at all points of sufficient mechanical strength. Specifically in this embodiment the thickness t at any point may be given by the expression

$$t = t_k + t_0 (1 - e^{-\alpha(S-Z)}) \quad (12)$$

where $t_k + t_0 (1 - e^{-\alpha S})$ is thus the thickness of the flux guide directly adjacent the pole piece encompassing the electron gun and $t_0 (1 - e^{-\alpha(S-Z)})$ is the varying thickness, α being a constant depending on the characteristics of the traveling wave tube, Z the distance along the flux guide

measured from the pole piece encompassing the electron gun and S the distance at which $t=t_k$.

This exponentially varying thickness may be approximated by a flux guide 34 in the specific embodiment depicted in Fig. 6 whose thickness decreases linearly from the pole piece 12 encompassing the electron gun to the pole piece 13 encompassing the electron receiver, thereby greatly facilitating the milling of the flux guide cylinder or plates.

It is to be understood that the thickness of the flux guide may vary in accordance with this invention in other prescribed manners to attain optimum interaction of the magnetic field and electron stream depending on the characteristics of the specific electron discharge device. Thus advantageously in the specific embodiment shown in Fig. 7, the exponential variation in thickness, as shown in the specific embodiment of Fig. 3, may be superimposed on at least a portion of the flux guide of the embodiment of Fig. 1. In this embodiment the thickness of the flux guide 37 adjacent the pole piece 12 encompassing the electron gun would be given by Equation 1 above and would vary linearly to the point midway between the pole pieces. The outline 39 of the flux guide from the midpoint to the pole piece encompassing the electron receiver, however, would not increase linearly to a thickness given by Equation 1. Instead, the outline 39 would deviate from this linear line 38 by an exponentially increasing amount. Thus over the first portion of the device, a parallel magnetic field is assured obviating the impingement of electrons on the helix adjacent the center of the helix while allowing the electron stream to be in close proximity to the helix. And over the remainder of the device where axial bunching becomes of importance the field will increase exponentially to counteract the debunching of the electrons due to their mutual repulsion.

The choice of which of these specific or other embodiments of this invention will be employed to attain the optimum magnetic field conditions in the air gap for the interaction of the electron beam and the high frequency wave guided by the transmission circuit will depend on, among other things, the characteristics of the traveling wave tube, its frequency of operation, length of transmission circuit, current density and the maximum output power.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. An electron discharge device comprising an elongated electrical wave transmission circuit, electron gun means at one end of said circuit for projecting an electron stream lengthwise of and in coupled relationship with said circuit and means adjacent said circuit to supply a longitudinal magnetic field to focus said electron stream, said last-mentioned means comprising a pair of pole pieces defining an air gap in which said circuit is positioned, one of said pole pieces encompassing said electron gun means, means causing said magnetic flux to flow in said air gap and a flux guide of magnetic material extending continuously from said one pole piece to the other of said pole pieces and encompassing said air gap and said circuit, the thickness of said flux guide being greatest adjacent said one pole piece and decreasing exponentially from said one pole piece to the other of said pole pieces.

2. An electron discharge device in accordance with claim 1 wherein the thickness t of said flux guide is given by the expression

$$t=t_k+t_0(1-e^{-\alpha(S-Z)})$$

where $t_k+t_0(1-e^{-\alpha S})$ is the thickness of the flux guide adjacent said one pole piece encompassing said electron gun means, α is a constant, Z is the distance along the flux guide measured from said one pole piece, and S is the distance at which $t=t_k$.

3. An electron discharge device comprising an elongated electrical wave transmission circuit, electron gun means at one end of said circuit to direct a stream of electrons lengthwise of and in coupled relationship with said circuit, electron receiver means at the other end of said circuit and means adjacent said circuit to supply a longitudinal field to focus the electron stream, said last-mentioned means comprising a pair of pole pieces defining an air gap in which said circuit is positioned, one of said pole pieces encompassing said electron gun means and the other of said pole pieces encompassing said electron receiver means, means causing magnetic flux to flow in said air gap from one of said pole pieces to the other of said pole pieces and a flux guide encompassing said air gap and said circuit, said guide comprising a pair of plates of magnetic material positioned on either side of said circuit and extending continuously from one of said pole pieces to the other of said pole pieces, the thickness of each of said plates decreasing exponentially from said one pole piece encompassing said electron gun means to the other of said pole pieces encompassing said electron receiver means.

4. Traveling wave tube apparatus comprising magnetic members having like poles adjacent each other, a pole piece positioned between like north poles and a pole piece positioned between like south poles, said pole pieces defining an elongated air gap, a traveling wave tube positioned in said air gap and extending into said pole pieces and a flux guide of magnetic material extending continuously from one of said pole pieces to the other of said pole pieces and encompassing said air gap and said traveling wave tube, the thickness of said flux guide decreasing exponentially from said one pole piece towards said other pole piece.

5. Traveling wave tube apparatus comprising an elongated transmission circuit, an electron gun at one end of said circuit to direct a stream of electrons lengthwise of and in coupled relationship with said circuit, an electron collector at the other end of said circuit and means adjacent to said circuit to apply a longitudinal magnetic field to focus the electron stream, said means comprising a pair of U-shaped magnets having like poles adjacent each other, pole pieces between each pair of like poles, said pole pieces encompassing said electron gun and collector and defining an elongated air gap therebetween and a pair of flat plates of magnetic material extending continuously from one of said pole pieces to the other, the separation between said plates being smaller than the width of said plates and the thickness of each of said plates decreasing exponentially from said one pole piece encompassing said electron gun to the other of said pole pieces encompassing said electron collector.

6. Traveling wave tube apparatus in accordance with claim 5 wherein the thickness t of each of said flat plates of magnetic material at any point between said pole pieces is given by the expression

$$t=t_k+t_0(1-e^{-\alpha(S-Z)})$$

where $t_k+t_0(1-e^{-\alpha S})$ is the thickness of the plate adjacent said one pole piece encompassing said electron gun means, α is a constant, Z is the distance along the plate measured from said one pole piece, and S is the distance at which $t=t_k$.

7. An electron discharge device comprising an electrical conductor defining an elongated electromagnetic wave transmission system, electron gun means adjacent one end of said conductor for projecting an electron stream lengthwise of and in coupled relationship with said conductor, electron receiver means adjacent the other end of said conductor, means adjacent said conductor to apply a longitudinal magnetic field to focus said electron stream and means for preventing substantial impingement of said electron stream on said electrical conductor while allowing said stream to be closely adjacent said conductor, said last-mentioned means including a flux guide entirely

of a magnetic material extending continuously from adjacent said electron gun means to adjacent said electron receiving means, the thickness of said flux guide being greatest adjacent said electron gun means, initially decreasing towards said electron receiver means, and being minimum adjacent one of said regions where in the absence of said flux guide substantial radial electron dispersion would occur, said regions including substantially the center of said flux guide and adjacent said electron receiving means.

8. An electron discharge device comprising a helical electrical conductor defining an electromagnetic wave transmission circuit, electron gun means at one end of said circuit to direct a stream of electrons lengthwise of and in coupled relationship with said conductor, electron receiver means at the other end of said conductor, and means adjacent said conductor to apply a longitudinal magnetic field to focus said electron stream, said field applying means including a pair of pole pieces defining an air gap in which said conductor is positioned, one of said pole pieces being adjacent said electron gun means and the other of said pole pieces being adjacent said electron receiver means, and means for preventing substantial impingement of said electron stream on said helical conductor while allowing said stream to be closely adjacent said conductor, said last-mentioned means including a flux guide entirely of a magnetic material extending continuously between said pole pieces and encompassing said air gap and said helical conductor, the thickness of said flux guide being greatest adjacent said one pole piece, initially decreasing towards the other of said pole pieces, and being minimum adjacent, one of said regions where in the absence of said flux guide substantial radial electron dispersion would occur, said regions being adjacent the center of said air gap and adjacent said electron receiver means.

9. An electron discharge device in accordance with claim 8 wherein the thickness of said flux guide is t_0 at the point midway between said pole pieces and

$$t=L/\mu\pi+t_0$$

at the pole pieces, t being the thickness at the pole pieces, L the distance between the pole pieces and μ the permeability of the material of the flux guide, the thickness of said flux guide varying linearly between said pole pieces and said midpoint.

10. An electron discharge device in accordance with claim 8 wherein the thickness of said flux guide varies linearly from said one pole piece encompassing said electron gun means to the other of said pole pieces.

11. An electron discharge device in accordance with claim 8 wherein the thickness of said flux guide varies linearly from said one pole piece encompassing said electron gun means to a point substantially midway between said pole pieces and varies substantially exponentially from said point to the other of said pole pieces.

12. An electron discharge device in accordance with claim 8 wherein said flux guide comprises a pair of plates of magnetic material positioned on either side of said circuit.

13. An electron discharge device in accordance with claim 12 wherein the thickness of each of said plates is t_0 at the point midway between said pole pieces and varies linearly to a thickness t at the pole pieces, where

$$t=L/\mu\pi+t_0$$

L being the distance between the pole pieces and μ the permeability of the magnetic material of the plates.

14. Traveling wave tube apparatus comprising a helical electrical conductor defining an elongated electromagnetic wave transmission circuit, an electron gun at one end of said conductor to direct a stream of electrons lengthwise of and in coupled relationship with said conductor, an electron collector at the other end of said conductor, means adjacent to said conductor to apply a longitudinal

magnetic field to focus said electron stream, said means comprising a pair of magnets having like poles adjacent each other, pole pieces between each pair of like poles, said pole pieces encompassing said electron gun and collector and defining an elongated air gap therebetween and means for preventing substantial impingement of said electron stream on said helical conductor while allowing said stream to be closely adjacent said conductor, said last-mentioned means including a pair of flat plates entirely of a magnetic material extending continuously between said pole pieces and encompassing said air gap and said conductor, the separation between said plates being smaller than the width of said flat plates and the thickness of said plates being greatest adjacent said one pole piece, initially decreasing towards the other of said pole pieces, and being minimum adjacent one of said regions where in the absence of said flat plates substantial radial electron dispersion would occur, said regions being substantially at the center of said air gap and adjacent said electron collector.

15. Traveling wave tube apparatus in accordance with claim 14 wherein the thickness of each of said flat plates of magnetic material is t_0 at the point midway between said pole pieces and is $t=L/\mu\pi+t_0$ at one of said pole pieces, L being the distance between the pole pieces, μ the permeability of the magnetic material of the plates, the thickness of the plates varying linearly between said thickness t at said one pole piece and said thickness t_0 at the midpoint between said pole pieces.

16. An electron discharge device comprising an electrical conductor defining an elongated electromagnetic wave transmission circuit, electron gun means at one end of the device to direct a stream of electrons along said conductor, electron receiver means at the other end of said device, means for applying a longitudinal magnetic field to focus said stream, said last-mentioned means including a first pole piece encompassing said electron gun means, and a second pole piece encompassing said electron receiver means, said pole pieces defining an air gap and means for preventing substantial impingement of said electron stream on said conductor adjacent said electron receiver means, said last-mentioned means comprising a flux guide entirely of magnetic material extending from said first pole piece to said second pole piece and encompassing said air gap, the thickness of said flux guide varying continuously between said pole pieces and diminishing adjacent said electron receiver means where in the absence of said flux guide substantial radial electron dispersion would occur.

17. An electron discharge device comprising an electrical conductor defining an electromagnetic wave transmission circuit, electron gun means at one end of said device to direct a stream of electrons along said conductor, electron receiver means at the other end of said device, and means for applying a longitudinal magnetic field to focus said electron stream, said field applying means including a first pole piece adjacent said electron gun means, a second pole piece adjacent said electron receiver means, said pole pieces defining an air gap, and means for preventing substantial impingement of said electron stream on said electrical conductor due to radial dispersion of said electron stream while allowing said stream to be closely adjacent said conductor, said last-mentioned means comprising a flux guide entirely of magnetic material of varying thickness extending continuously between said pole pieces and being of a minimum thickness adjacent one of said regions where in the absence of said flux guide substantial radial dispersion of said electron stream would occur, said regions including adjacent the center of said air gap and adjacent said electron receiving means.

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