

Jan. 1, 1957

R. W. PETER
ELECTRON BEAM TUBES

2,776,389

Filed Nov. 1, 1950

2 Sheets-Sheet 1

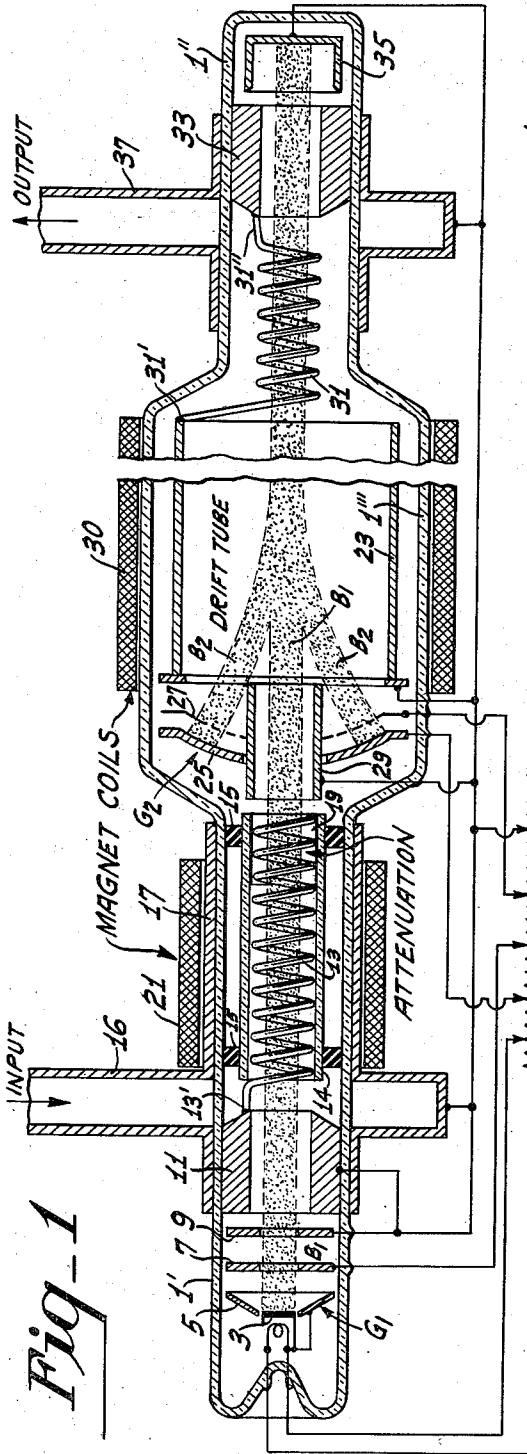


Fig-1

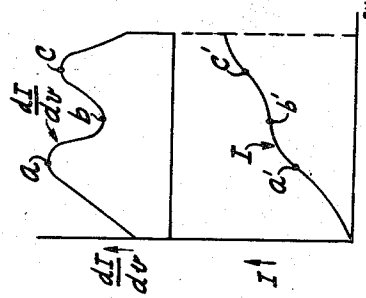


Fig-2

Fig-4

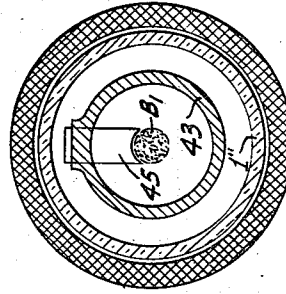
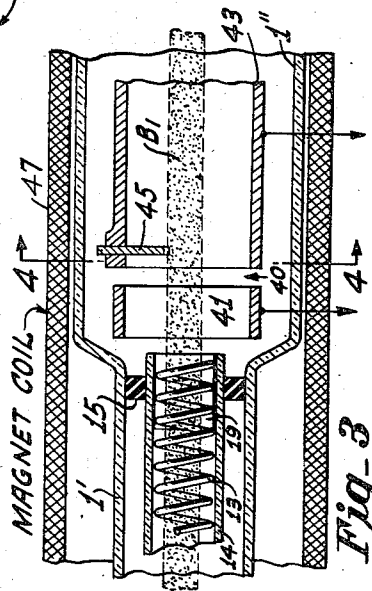


Fig-3

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2 Sheets-Sheet 2

Fig-5

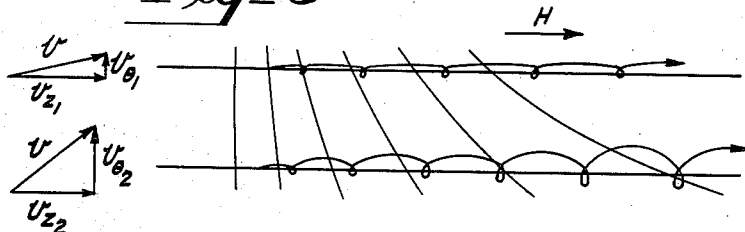


Fig-6

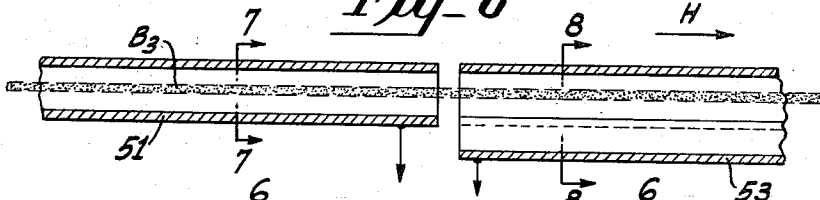


Fig-7

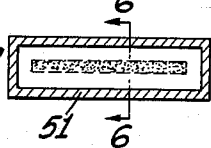


Fig-8

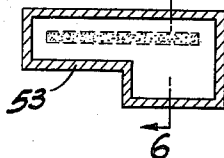


Fig-9

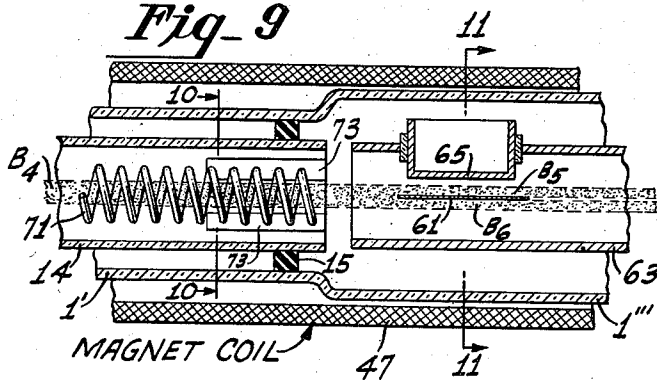
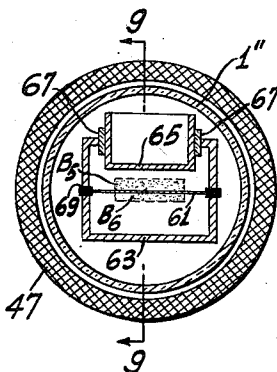


Fig-11

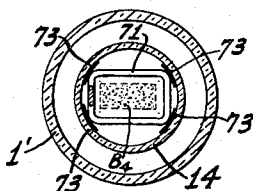


Fig-10

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2,776,389

ELECTRON BEAM TUBES

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5 Claims. (Cl. 313—80)

This invention relates to improvements in electron beam tubes of the so-called "traveling-wave" and "growing-wave" types primarily adapted for use as amplifiers at very high frequencies. Electron tubes constructed in accordance with the invention are characterized by their high gain and low noise factor when used as amplifiers.

In a conventional traveling-wave tube an electromagnetic signal wave is coupled to one end of a wave-guiding means which may be in the form of a relatively long metal helix enclosed within an elongated envelope. The helix is designed with such diameter and pitch that the axial velocity of a wave traveling along the turns of the helix is a small fraction, say one-tenth, of the velocity of light. An electron beam is projected along the helix, either inside or outside, at a velocity approximately equal to said axial wave velocity. Under such conditions, the electron beam and the traveling wave interact to cause the amplitude of the wave to increase exponentially, and hence, produce amplification of the signal. The amplified signal is utilized by suitable circuit means coupled to the output end of the helix. Since the axial wave velocity along the helix does not vary much with frequency, the traveling-wave tube is inherently a wide-band amplifier. That is, a particular tube can be used as an amplifier over a wide band of frequencies. Instead of a metal helix, the wave-guiding means of the tube may be a loaded waveguide, folded waveguide, baffle-loaded coaxial line, waveguide partly filled with dielectric, or other structure capable of reducing the axial velocity of a wave therealong to practical electron velocities. The noise factor of a traveling wave tube is mainly determined in the first part of the tube where the beam is modulated by the input signal applied to the helix. The rest of the tube amplifies the signal and the beam noise equally, i. e., the noise factor is substantially the same for any length of tube beyond a minimum length.

The conventional traveling wave tube described above does not have a high enough back-insertion loss in operation, or forward attenuation when cold, because the input and output circuits are too closely coupled by the wave-guiding helix.

A growing-wave amplifier tube has been proposed by C. W. Hansell, in a copending application Serial No. 83,697, filed March 26, 1949, now Patent No. 2,684,453, dated July 20, 1954, assigned to the same assignee as the present application, in which the helix of the conventional traveling-wave tube described above is replaced by a second electron beam projected along the conventional electric fields along a relatively long path by a conductive shield. The two beams are given slightly different initial direct-current velocities and the signal to be amplified is applied to the beams by suitable beam modulating means. As the electrical disturbance or wave produced by the modulating means travels along the beams its amplitude grows exponentially, due to space charge interaction between the beams, in a manner somewhat

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analogous to the interaction between the single beam and the traveling wave in a conventional traveling-wave tube. The difference in initial direct-current energy of the two beams is converted into additional high frequency or signal energy. The amplified signal energy is extracted from the beams by any suitable means, such as a short helix, or a cavity resonator, inductively coupled to the beams ahead of the collector. This two-beam growing-wave amplifier tube is known to give very high gain per unit tube length and high back-insertion loss, but also to have a high noise factor.

The present invention is predicated upon an appreciation of the fact that the beam noise in this growing-wave tube builds up to relatively high values before the two beams become signal-modulated, resulting in high noise-to-signal ratios in the output system, and that any reduction in the amount of noise introduced into the beams during the modulation thereof will reduce the noise factor of the tube.

The primary object of the present invention is to provide an improved high frequency amplifier tube, and one characterized by its high gain and low noise factor.

Another object is to provide novel means for producing an electron beam comprising a plurality of groups or components having different axial velocities, for use in a growing-wave amplifier tube, for example.

In one embodiment of the invention, a two-beam growing-wave tube is provided wherein one of the beams is modulated with a signal, by means of a relatively short helix traveling-wave section designed for low noise factor coupled to the beam, prior to the mixing of the two beams and amplification due to space charge interaction between the beams in a relatively long drift space. In other words, the second beam is added to or mixed with the modulated beam at a point where the signal-to-noise ratio of the latter is already high enough to tolerate some additional noise due to the introduction of the second beam. In another embodiment of the invention, an electron beam of substantially uniform velocity is modulated by a relatively short low noise traveling wave section and then converted into a beam having two different axial velocity components for amplification in a relatively long drift space.

In each embodiment of the invention, an electron stream of substantially uniform velocity is signal modulated by a relatively short low-noise traveling-wave section, then a different velocity is introduced in the stream, the resulting two-velocity stream passes through a relatively long field-free drift space in which the signal is amplified due to space charge interaction between the different velocity components of the stream, and then amplified signal energy is extracted from the stream.

The invention is described in greater detail in the following description, taken in connection with the accompanying two sheets of drawings, wherein:

Figure 1 is a longitudinal section of an electron tube embodying the invention;

Figure 2 is a graph for use in explaining the invention;

Figure 3 is a fragmentary section of a modification of the tube of Fig. 1;

Figure 4 is a transverse section taken on the line 4—4 of Fig. 3;

Figure 5 is a diagram for use in explaining the operation of the structure of Fig. 3;

Figures 6, 7 and 8 are sections of another modification; and

Figures 9, 10 and 11 are sections of a third modification of the tube of Fig. 1.

Figure 1 illustrates the invention embodied in a beam tube comprising an elongated glass envelope 1 having input and output end portions 1' and 1'', respectively, joined by an intermediate enlarged amplifier portion 1'''.

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Preferably, these three portions are cylindrical in shape to facilitate the mounting of focusing magnet coils and apertured input and output waveguides thereon. Mounted coaxially within the outer end of input portion 1' is a first electron gun G₁ made up of a cathode 3 surrounded by a cathode shield 5 and two apertured accelerating electrodes 7 and 9. In operation, the electron gun G₁ projects an electron beam B₁ of substantially uniform velocity, determined by the direct-current potentials applied to the cathode 3 and accelerating electrode 9, along the longitudinal axis of the tube. A tubular electrode 11 positioned beyond the gun G₁ is connected to the axially-extended end portion 13' of a relatively short modulating helix 13 which extends coaxially along the remaining length of envelope portion 1'. The helix 13 may be mounted within a glass tube 14 supported within the envelope portion 1' by insulating rings 15. The envelope portion 1' is adapted to extend through an apertured input waveguide 16 of rectangular section extending transversely of the axis of helix 13 with the axially-extended portion 13' of the helix within and parallel with the transverse electric field of the waveguide, and the tubular electrode 11 capacitively coupled to the waveguide through the glass envelope wall as shown. A tubular shield 17, surrounding the helix 13 and connected to the waveguide 16, may be provided.

In operation, an input signal applied to waveguide 16 induces traveling waves along the helix 13 for modulating the substantially uniform velocity electron beam B₁ from gun G₁. The major portion of wave energy on the helix is converted into signal energy in the beam. In order to absorb and prevent reflection of residual waves at the output end of the modulating helix 13, the helix may be terminated by means of a resistive material 19, which may be in the form of a coating on the inner wall of tube 14, in contact with several turns of the helix at that end. A magnet coil 21 may be provided around the major portion of the modulating helix 13 to produce an axial magnetic field for focusing the electron beam.

The intermediate or amplifier portion 1''' of the envelope contains a second electron gun G₂ and a relatively long elongated drift tube 23, axially aligned with the first electron gun G₁ and the modulating helix 13. The gun G₂ is conveniently made in annular form comprising a concave ring cathode 25 and concave grid accelerating electrode 27 arranged around the beam path from gun G₁ to project a hollow converging second beam B₂ toward said beam path. A tubular shield 29 is interposed between the first beam and the gun G₂ in the space between the helix 13 and drift tube 23.

In the operation of the tube, the electrons of the two beams are mixed together after the first beam has been completely modulated by the input signal, and in a region, near the entrance to the drift tube 23, where the signal-to-noise ratio in the first beam is high enough to tolerate additional noise due to the addition of the second beam. The beam from the second gun G₂ is projected into the drift tube 23 and toward the first beam at an initial velocity slightly different from the velocity of the first beam, by applying different direct-current potentials to the two cathodes 3 and 25. By space charge interaction between the electrons of two beams, the signal wave grows in amplitude along the drift tube 23, as in the Hansell growing wave tube referred to above. The drift tube 23, envelope portion 1''' and magnet coil 30 are shown broken in Fig. 1 to indicate increased length of this portion of the tube. In practice, the length of this intermediate portion would be long compared to the modulating coil 13 or the output coil 31. A magnet coil 30 may be provided around the drift tube 23 and intermediate portion 1''' of the envelope for focusing the two beams. The converging magnetic field in the region of the second gun G₂ assists in contracting the hollow beam and mixing the two beams.

Amplified signal energy is extracted from the com-

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posite beam by any suitable inductive output means coupled to the beams beyond the drift tube 23. The output means illustrated comprises a relatively short metal helix 31 coaxially surrounding the beam path in the output portion 1'' of the envelope. The helix 31 may be connected at one end to the drift tube 23 as shown at 31', or may be floating. The other end 31'' of helix 31 is extended axially and connected to a tubular electrode 33. The beam is collected by a cup-shaped collector 35 located beyond the electrode 33. The portion 1'' of the envelope is adapted to extend through an apertured output waveguide 37, similar to the input waveguide 15, extending transversely of the axis of output helix 31, and similarly coupled to the extended portion 31'' and to the tubular electrode 33.

The various electrodes of the tube are provided with suitable mounting means most of which have been omitted for the sake of simplicity, since the details thereof are not a part of the present invention. The elements are provided with leads through the envelope wall as shown schematically in the drawing, for application of desired operating potentials thereto. In operation, the two cathodes are connected to different low-voltage points on a direct-current power source S. The first accelerating electrode 7 is preferably connected to an intermediate positive voltage point on the source S. All of the other electrodes can be maintained at the same high positive voltage of the source S. However, in some cases it is desirable to apply somewhat different potentials to certain electrodes, for example, the accelerating electrode 27 of the second electron gun.

In order to modulate the first beam with a minimum of noise in the beam, the modulating wave-guiding means is designed for relatively low noise factor. It is known that this can be done, for example, by making the interaction factor C, between the beam and the signal fields, high. The interaction factor C is defined by the relation:

$$C^3 = K \frac{I_0}{4V_0}$$

where

$$K_1 = \frac{E_z^2}{2P\beta^3}$$

E_z is the electric field in the Z (or axial) direction acting on the beam, P is the signal power input to the tube,

$$\beta = \frac{\omega}{v_p}$$

ω is the angular frequency of the signal, v_p is the axial phase velocity along the wave-guiding means, I₀ is the beam current, and V₀ is the beam accelerating voltage. For a given beam and signal, the interaction factor C is, therefore, a function of K₁, which in turn is determined primarily by E_z. One way to achieve high interaction factor would be to employ a hollow beam in close proximity to the wave-guiding means. In the case of a wave-guiding means in the form of a metal helix, the interaction factor can be made high by choosing the diameter b and pitch p of the helix for a signal wavelength λ so that

$$\frac{2\pi b \cdot 2\pi p}{\lambda \cdot b}$$

is about 2, for a solid beam of small diameter.

The invention in pre-modulating a single-velocity electron beam or stream in a growing wave tube at a low noise level before introducing a different velocity is not limited to the use of two separate beams from two separate cathodes. It is also possible to modulate an electron beam or stream of substantially uniform velocity from a single cathode, and then introduce different axial velocity components in the same stream for subsequent growing wave amplification, instead of mixing a second electron stream with a first stream as in Fig. 1.

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Growing wave amplification by space-charge interaction between the electrons of a single electron stream will not occur in a single-velocity stream, or even in every stream having a distribution of velocities. Instead, the stream must have a velocity distribution including at least two predominant groups or classes of different average axial velocity components. This is shown graphically in Fig. 2, wherein the abscissa is velocity, the lower curve is the current-velocity distribution, and the upper curve shows the rate of change of current with velocity,

$$\frac{dI}{dv}$$

In order to obtain amplification the

$$\frac{dI}{dv}$$

curve must have at least two distinct maxima *a* and *c* with an intermediate minimum *b*, which means that the current-velocity distribution must have at least three inflection points *a'*, *b'*, and *c'*, as indicated in Fig. 2.

Figures 3 and 4, 6-8, and 9-11 show three different structures which may be used to convert a single-velocity electron stream to a composite stream having an axial velocity distribution including two electron groups or classes of different average velocities.

Figure 3 shows one form of asymmetrical lens structure which may be substituted for the second gun G₂ and shield 29 in Figure 1, to impart to a single electron stream the desired velocity distribution. This lens structure comprises a short-focus cylindrical electron lens 40, formed by a ring 41, a drift tube 43 and an asymmetrical electrode 45 mounted within the drift tube 43 at one side of the lens 40 and extending inwardly toward the electron stream, as shown in Figs. 3 and 4. Since there is only one electron stream, a single magnet coil 47 is provided along substantially the entire length of the stream. The remainder of the structure may be the same as that shown in Fig. 1.

In the operation of the tube shown in Fig. 1 modified as shown in Fig. 3, the drift tube 43 and electrode 45 are maintained at the highest positive potential, like the tube 23 in Fig. 1, and the ring 41 is operated at a different potential. The asymmetrical electric field produced by electrodes 41, 43 and 45 causes the upper portion of the electron stream in Figs. 3 and 4 to be deflected transversely relative to the axial magnetic field of magnet coil 47, and the magnetic field causes the deflected electrons to execute spiral paths. As a result, a part of the initial energy of these electrons is converted into rotational energy. An electron having an initial velocity *v* in the axial direction now has an axial component *v_a* of reduced velocity and a rotational component *v_o* at right angles thereto. Fig. 5 shows the velocity components and paths of two electrons which have been deflected transversely by different amounts, and therefore, have different axial velocity components *v_{a1}* and *v_{a2}* and different rotational velocity components *v_{o1}* and *v_{o2}*.

Figures 6-8 show another form of asymmetrical lens which could be used to introduce different velocity groups in a single stream. In this case a ribbon beam B₃ of rectangular form is projected through two aligned drift tubes 51 and 53 spaced apart to form an electron lens therebetween. Drift tube 51 is rectangular in cross-section and drift tube 53 has an L-shaped cross-section, as shown in Figs. 7 and 8, to produce an asymmetrical electric field.

This field causes the right-hand half of the beam B₃, as seen in Fig. 8, to be deflected transversely of the magnetic field schematically indicated by the arrow H. As in Fig. 2, this converts this portion of the beam to an axial velocity less than that of the remainder of the beam.

Figs. 9-11 show another modification of the tube of Fig. 1 to produce different axial velocity components in an electron beam. In this form beam B₄ of rectangular

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cross section is physically divided into two separate parts B₅ and B₆ by means of a thin metal strip 61 lying in a plane passing through the longitudinal axis and extending across the rectangular drift tube 63. A deflecting electrode 65, which may be cup-shaped as shown, is mounted within the drift tube 63 in close proximity to the upper beam part B₅. Preferably, both the strip 61 and deflecting electrode 65 are insulated from the drift tube 63 by suitable insulation 67 and 69, respectively, to permit the application of different potentials thereto.

It will be understood that when the structure of Fig. 1 is modified as shown in Figs. 6-8 or 9-11 the gun structure G₁ will be designed to produce a beam of rectangular cross section. While the remainder of the tube structure could be the same as that of Fig. 1, better interaction between the rectangular beam and the modulating helix will be obtained by use of a rectangular helix such as shown at 71 within the glass tube 14 in Figs. 9 and 10. The attenuation at the end of helix 71 may be in the form of strips 73 of resistive material coated on the inner surface of the glass tube 14 and contacting the four corners of the helix.

The structure of Figs. 9-11 has the advantage that the lower half of the beam is completely shielded by the strip 61 from the deflecting electric field. Moreover, all of the electrons in the upper half of the beam are subjected to the same deflecting force, and hence, have the same axial velocity after passing through the deflecting field. As a result, the electron stream in the amplifying section of the tube, beyond electrodes 61 and 65, is made up of one part consisting of electrons having a predetermined velocity and another part consisting of electrons having a different predetermined velocity. These two velocities can be accurately controlled by adjustment of the relative potentials applied to the drift tube 63, strip 61 and deflecting electrode 65. Preferably, the strip 61 should be operated at a potential equal to or slightly less than the beam potential, to reduce collection of electrons by the strip 61 to a minimum.

What is claimed is:

1. An electron tube including means for producing a beam of electrons having a plurality of different axial velocity components along a given beam path in said tube, comprising electron gun means for producing a beam of electrons of substantially the same initial velocity along a first portion of said beam path, means for establishing a magnetic field axially of said beam path, and separate means for deflecting only a predetermined part of the electrons of said beam transverse to said magnetic field along a second portion of said path for causing said electrons to execute spiral paths with axial velocity components along said beam path less than the axial velocity components of the remaining part of the electrons of said beam.

2. An electron tube including means for producing a beam of electrons having a plurality of different axial velocity components along a given beam path in said tube, comprising electron gun means for producing a beam of electrons of substantially the same initial velocity along a first portion of said beam path, means for establishing a magnetic field axially of said path, and electrostatic means for deflecting only a predetermined part of the electrons of said beam transverse to said magnetic field along a second portion of said path for causing said electrons to execute spiral paths with axial velocity components along said beam path less than the axial velocity components of the remaining part of the electrons of said beam.

3. An electron tube according to claim 2, wherein said electrostatic deflecting means comprises an asymmetrical electron lens.

4. An electron tube according to claim 3, wherein said asymmetrical electron lens comprises a short-focus cylindrical electron lens through which said beam path

extends and an electrode disposed adjacent said lens and on one side of said beam path.

5. An electron tube according to claim 2, wherein said electron gun means is adapted to produce a thin ribbon-shaped beam of rectangular cross-section and said electrostatic deflecting means comprises an asymmetrical electron lens formed by a first conductive shield member of rectangular cross-section surrounding said beam path and a second conductive shield member of L-shaped cross-section surrounding said beam path and spaced axially from said first member.

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