

June 7, 1966

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LOW-NOISE ELECTRON GUNS

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2 Sheets-Sheet 1

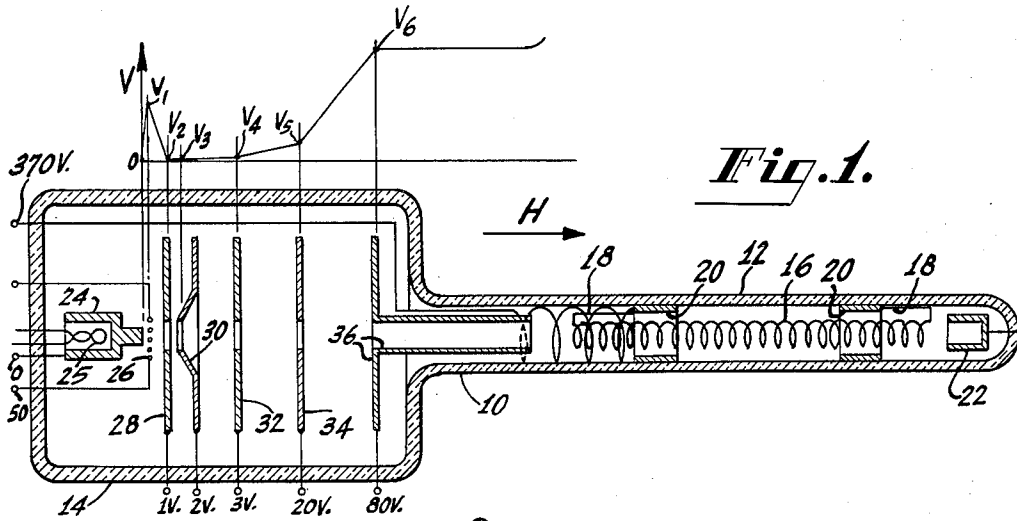


**Fig. 1.**

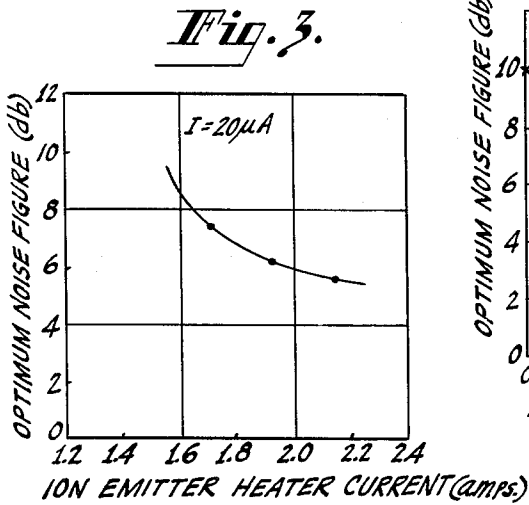
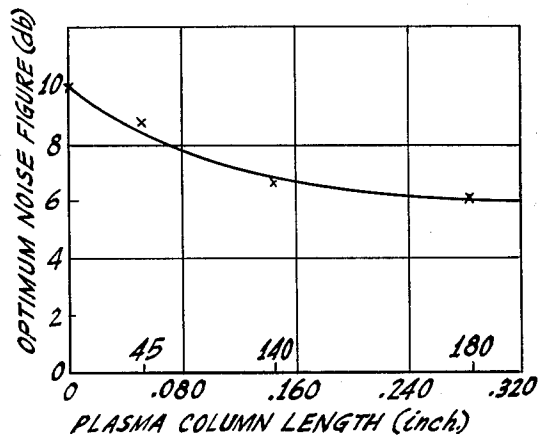


**Fig. 2.**

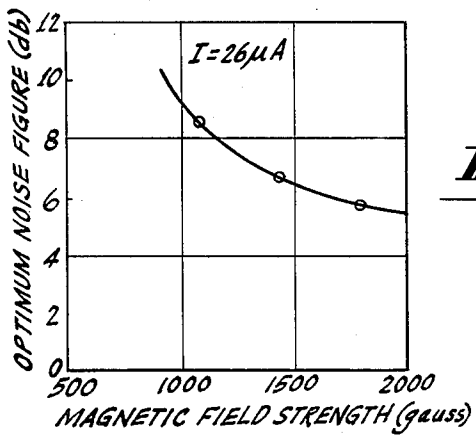


**Fig. 4.**

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2 Sheets-Sheet 2

*Fig. 5.*

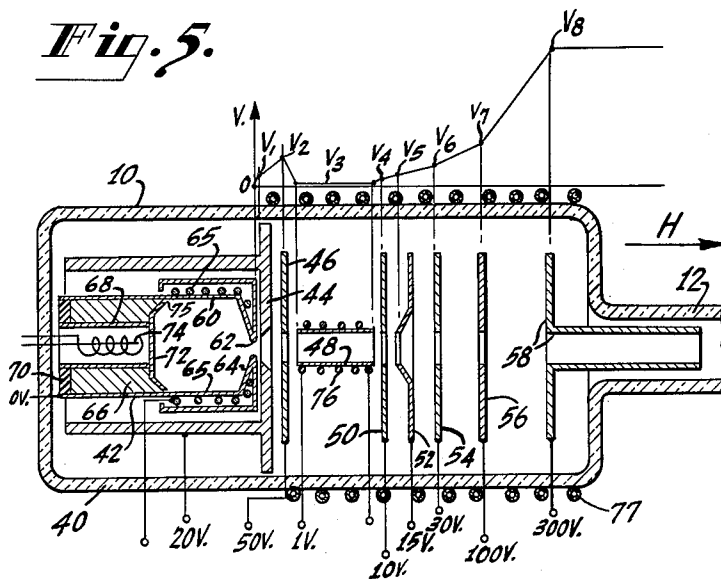
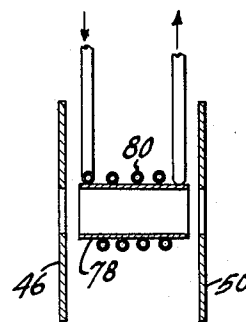


*Fig. 6.*

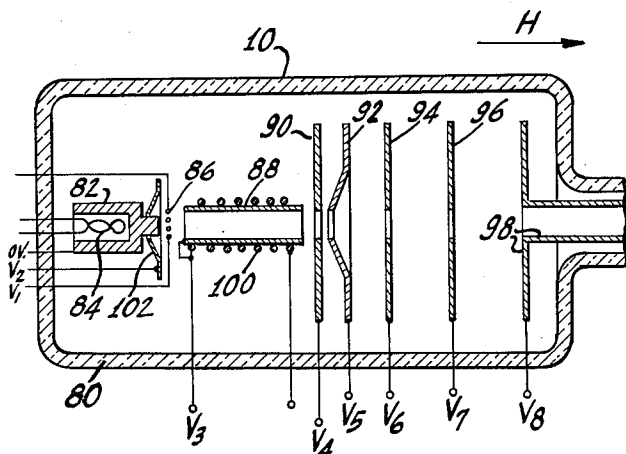


*Fig. 7.*

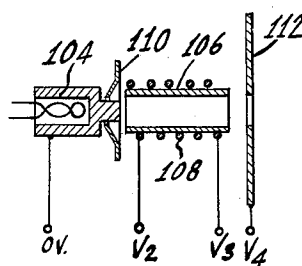


*Fig. 8.*

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1

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## LOW-NOISE ELECTRON GUNS

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19 Claims. (Cl. 315-3.5)

The present invention relates to low-noise beam tubes, and particularly to low-noise electron guns for traveling wave tubes operating at frequencies above about 1000 mc.

The noise carried by an electron beam is due primarily to random current and velocity fluctuations in the beam electrons emitted by the cathode, and is primarily a function of the cathode temperature. The minimum noise figure,  $F_{min}$ , of beam-type tubes has been calculated, for a single velocity theory, to be given by:

$$F_{min} = 1 + \gamma \frac{T_c}{2900} \quad (1)$$

where  $T_c$  is the cathode temperature in degrees Kelvin, and  $\gamma$  is a factor, near unity, which depends upon the amplitudes of, and correlation between, the current and velocity fluctuations. Thus, a lower  $F_{min}$  results if  $\gamma$  is reduced, by improving the potential profiles along the beam path in the gun region, or if  $T_c$  is reduced. The noise figure can be minimized, for a given cathode temperature  $T_c$ , by use of an exponential space charge wave transformer in the gun, as described in a paper entitled "The Exponential Gun—A Low Noise Gun for Traveling Wave Tube Amplifiers," by A. L. Eichenbaum and R. W. Peter, RCA Review, vol. XX, No. 1, pp. 18-56, 1959. For example, a beam tube having a barium-oxide-impregnated-tungsten cathode operating at a temperature of 1450° K. (1177° C.) followed by an optimum space charge wave transformer with a  $\gamma$  of about 1.0, should have a minimum noise figure,  $F_{min}$ , of about 6, or 7.8 db, by Equation (1). A cathode at 870° K. and a  $\gamma$  of about 1.0 should have an  $F_{min}$  of about 4, or 6.0 db. Due to the lack of cathodes that can provide adequate electron emission at temperatures lower than about 700° K., it appears impossible to reduce the noise figure of a beam tube having a single-velocity beam to values much lower than about 5.0 db. In regions of the gun where the space potential is several volts or more, the noise velocity fluctuations in the beam are small compared to the average velocity of the beam, and hence, the beam is substantially a single-velocity beam. However, the short region next to the cathode is a multi-velocity region which does not behave as predicted by Equation 1. It has been observed that there is a noise-smoothing action taking place in this multi-velocity region, as the electrons drift slowly therethrough, which reduces the noise figure of the tube somewhat below that predicted by Equation 1. If one attempts to accentuate this noise-smoothing effect by allowing the electrons to drift through an extended low-potential drift region, formed by an electrode at a potential of the order of 3 volts or less, at low velocities in a conventional vacuum tube, the beam becomes unstable due to space charge effects, even in the presence of strong focusing fields.

The object of the present invention is to provide an improved low-noise electron gun for low-noise beam tubes.

A more specific object of the invention is to provide a low-noise electron gun including a stable, noise-reducing multi-velocity drift region of substantial length.

Another object is to provide a novel beam tube having a relatively low-temperature electron source, followed by a low-velocity plasma drift region, and then a high-vacuum RF interaction region.

A further object is to provide a beam tube having a

2

low-temperature space-charge-neutralized hollow cathode for producing a low-temperature electron stream, an extended low-velocity plasma drift region, a space charge wave transformer, and a high-vacuum RF interaction region.

These and other objects are achieved, in accordance with the present invention, by providing a plasma, or neutral mixture of electrons and positive ions, having a relatively low electron temperature, not greater than about 1500° K., and preferably below 1000° K., in a low-potential drift space or region of substantial extent in which the electrons drift at very low velocities, and extracting the electrons from the plasma and forming a low-noise electron beam therewith.

In the accompanying drawings:

FIG. 1 is an axial sectional view of a beam tube of the traveling wave type incorporating the present invention;

FIGS. 2, 3 and 4 are graphs showing the effect of varying the plasma column length, ion emission and magnetic field, respectively, on the noise figure, in the tube of FIG. 1;

FIG. 5 is a view similar to FIG. 1 of another embodiment of the invention;

FIG. 6 is a fragmentary view of a portion of FIG. 5, showing a modification thereof; and

FIGS. 7 and 8 are views similar to FIGS. 5 and 6, respectively, showing two other embodiments of the invention.

FIG. 1 shows a traveling wave tube comprising a dielectric envelope 10 including a helix portion 12 and an electron gun portion 14. The helix portion 12 contains a conventional traveling wave helix 16, RF coupling means 18 and 20 for coupling the helix to external transmission lines (not shown), and a collector 22. The gun portion 14 contains a low-noise electron gun comprising a thermionic cathode 24 having a heater 25, an ion-emitter electrode 26, a plasma-anchoring electrode 28, accelerating electrodes 30, 32 and 34, and an accelerating drift tube electrode 36. The cathode 24 is a barium-oxide-impregnated-tungsten cathode, sometimes called an "L" cathode. The ion-emitter 26 is a zig-zag or double-hair-pin-shaped filament coated with a material known as  $\beta$ -eucryptite, having the formula  $\text{Li}_2\text{OAl}_2\text{O}_3\text{SiO}_2$ , which emits positive lithium ions when heated to temperatures above about 1000° C. (1273° K.), as by a current passing through the filament or by radiation from the cathode 24. The ion-emitter 26 is mounted very close, about 8 mils, from the emissive end surface of the cathode 24, so that the positive ions will neutralize the space charge of the electrons from the cathode and prevent the formation of a potential minimum or virtual cathode in the region between these two electrodes. Under these conditions, the electron emission from the cathode 24 is not space-charge-limited, and therefore, a relatively large electron current can be drawn with a moderate accelerating potential on the ion-emitter 26. With the cathode operating at a temperature of about 1500° K., the minimum noise factor,  $F_{min}$ , should be about 8 db for a single-velocity beam. The tube is provided with means such as a solenoid (not shown) for establishing an axial magnetic focusing field along the beam path, as schematically indicated by the arrow H.

A traveling wave beam tube constructed as shown in FIG. 1, with each of electrodes 26, 28, 30, 32 and 34 spaced from the following electrode by distances of 20, 95, 135 and 155 mils, respectively, was tested for low-noise with the cathode 24 operated at about 1500° K., and with various potential distributions along the gun electrodes, one example of which is shown in FIG. 1. In this example, the accelerating potential  $V_1$  on the ion-emitter 26 was 50 volts positive with respect to the

cathode (at zero volts); low positive potentials  $V_2$ ,  $V_3$ , and  $V_4$  of 1, 2 and 3 volts, respectively, were applied to electrodes 28, 30 and 32; successively higher potentials  $V_5$  and  $V_6$  of 25 and 80 volts, respectively, were applied to electrodes 34 and 36; and the potential on the helix 16 was 370 volts. These potentials are indicated on the external leads in FIG. 1. The electron current was varied by varying the potential  $V_1$  of the ion-emitter 26. The ion-emission was varied by varying the ion-emitter heating current.

The tests on this beam tube disclosed that if the electrodes 28, 30 and 32 beyond the ion-emitter 26 were operated at positive potentials below that of the ion-emitter 26, the positive ions emitted by the latter would not only neutralize the space charge of the electrons between the cathode and the ion-emitter, as intended, but also would drift with the electrons beyond the ion-emitter and thus form a plasma drift region in the space between electrodes 26 and 36. Moreover, it was found that if the positive potentials on electrodes 28 and 30, and preferably also 32, were very low (of the order of 1 to 3 volts) the plasma drift region produced a substantial reduction in the noise figure of the tube. Most of the positive ions emitted by the ion-emitter 26 into the plasma drift region are trapped in that region by the positive electrodes 26 and 36 at the ends of the region and the axial magnetic field.

The effective length of the plasma column was varied by varying the potentials  $V_3$ ,  $V_4$ , and  $V_5$  of electrodes 30, 32 and 34. FIG. 2 shows the effect of varying the plasma column length on the optimum noise figure, in db. As can be seen, the noise figure for zero length (no plasma drift region) was about 10 db, which included about 8 db of beam noise and an additional 2 db of noise due to interception on the ion-emitter 26. However, FIG. 2 shows that a plasma column of 70 mils length reduced the noise figure by about 2 db, and a long plasma column (several hundred mils) produced about 4 db noise reduction (to 6 db).

The tests on the traveling wave tube of FIG. 1 showed that the optimum noise figure was also a function of the plasma density and magnetic field strength (for optimum column length), as shown in FIGS. 3 and 4. The results shown in FIG. 2 were obtained with optimum ion emission and magnetic field strength. As shown in FIG. 4, the noise figure was still decreasing at a magnetic field of 2000 gauss, the limit of the test equipment used. The following conclusions were reached:

- (1) The noise figure decreases with increasing plasma column length;
- (2) The noise figure decreases with increasing plasma density;
- (3) The noise figure decreases with increasing magnetic field, at least up to 2000 gauss; and
- (4) The noise figure decreases with decreasing electron drift velocity in the plasma drift region.

In a conventional low-noise gun, the electrodes 30, 32, 34 and 36 of FIG. 1 are usually biased at optimum potentials to serve as a space charge wave transformer interposed between the cathode 24 and the helix 16. In the tests described above, the plasma column was extended far into the normal transformer region, thus reducing its effectiveness. Moreover, the operating temperature (1500° K.) of the L-cathode was considerably higher than other low temperature cathodes that could have been used. Therefore, much lower noise figures (than 6 db) are attainable by use of a low-velocity plasma drift region under optimum conditions of cathode temperature, plasma column length, plasma density, magnetic field strength, and space charge wave transformation.

An improvement over the arrangement of FIG. 1 would be produced by merely lengthening the gun and providing one or more additional electrodes, to separate

the plasma drift region from the space charge wave transformer.

FIG. 5 shows the gun portion of a low-noise microwave beam tube incorporating a preferred embodiment of the invention. The remainder of the tube (not shown) could be the same as that shown in FIG. 1. The envelope 10 comprises a helix portion 12 and gun portion 40. The gun portion contains a low-noise electron gun comprising a thermionic hollow cathode 42, apertured accelerating electrodes 44 and 46, a noise-reducing plasma drift tube 48, and apertured accelerating electrodes 50, 52, 54, 56 and 58. Electrode 44 also serves as a magnetic shield for the cathode 42. The hollow cathode 42 comprises a hollow cylindrical or tubular cathode member 60 of a metal, such as tungsten, having a relatively high electron work function. The end of cathode 42 adjacent to electrode 44 is closed except for a relatively small aperture 62 by an end flange 64, which may be inclined as shown in the drawing. The ratio of total available electron emissive area 65 of the cathode member 60 to the area of the aperture 62 is preferably at least 1000 to 1. The cathode member 60 may be heated to electron emitting temperature by an external heater coil 65. The other end of the cathode member 60 contains a reservoir of an alkali metal compound, which may be a mass of cesium dichromate and silicon powder in an annular chamber formed by the cathode member 60, an inner tube 68, an end closure 70, and a deflector plate 72. The cesium compound may be heated by a separate heater 74 located within the tube 68. The deflector plate 72 is a disc having its periphery spaced a small distance from the cathode member 60 to provide a narrow annular slit 75 for dispensing cesium vapor to the hot surface of the tungsten cathode member 60.

In the operation of the beam tube of FIG. 5, the cesium vapor performs two functions. The primary function of the cesium is to reduce the effective work function of the tungsten cathode surface, which reduces the cathode temperature required for adequate thermionic electron emission. In the absence of cesium, the bare tungsten surface would have an electron work function of about 4.5 volts, which would require an operating temperature of about 1900° K. to produce an electron current density of 100  $\mu\text{a./cm.}^2$ , for example. In the cathode of FIG. 5, the cesium vapor provides a partial coating of cesium atoms on the tungsten surface, which reduces the effective work function thereof. The optimum operating temperature of the tungsten cathode in the presence of cesium for low-temperature operation depends upon the fraction coverage of the cesium on the tungsten surface, which is determined by the cesium supply rate from the cesium dispenser and the rate of escape of cesium from the hollow cathode 42 at any given temperature. The optimum fractional coverage of cesium on tungsten is about 55%. For a net cesium arrival rate of  $10^{15}/\text{cm.}^2/\text{sec.}$ , for example, the optimum cesium coverage of 55% occurs at a cathode temperature of about 760° K. (487° C.). At this temperature, the temperature-limited electron emission from the cesiated-tungsten cathode is about 100  $\mu\text{a./cm.}^2$ , and the minimum noise figure for a single-velocity beam would be about 3.6 or 5.6 db, for  $\gamma=1.0$  in Equation 1.

The other function of the cesium in the hollow cathode 42 of FIG. 5 is to supply positive ions to neutralize the space charge of the electrons within the hollow cathode, and thereby prevent the production of an unstable potential minimum therein. Since the ionization potential of the cesium is about 3.9 volts which is lower than the work function (4.5 volts) of the uncoated portions of the tungsten surface, some of the cesium vapor atoms are ionized on contact with the hot uncoated surface portions of the tungsten cylinder 60.

If all of the electrons emitted by the cesiated-tungsten surface of the cathode member 60 could be extracted through the aperture 62 and formed into a beam, it would

5

be theoretically possible to produce a beam density in the aperture of about 100 ma./cm.<sup>2</sup> with an electron temperature less than 800° K. It has been demonstrated that most of the electrons can be extracted from the hollow cathode by using high potentials on electrodes 44 and 46. However, for lowest noise, it is preferable to avoid such high potentials, since a tenth of this beam density, or 10 ma./cm.<sup>2</sup>, is more than adequate for most low-noise applications.

FIG. 5 shows an example of a potential distribution that can be used for the various electrodes in accordance with the invention, as follows: cathode 42 at zero volts; electrode 44 at 20 volts; electrode 46 at 50 volts; drift tube 48 at 1 volt; electrode 50 at 10 volts; and electrodes 52, 54, 56 and 58 at 15, 30, 100 and 300 volts, respectively. Under these conditions, the electrons emitted by the large cathode surface are accelerated (by the field of electrode 44 fringing through the aperture 62) and formed into a relatively dense beam through the apertures of the gun electrodes. After acceleration through electrodes 44 and 46, the beam electrons are slowed down to a very low drift velocity throughout the low potential drift tube 48, and then accelerated by the succeeding electrodes. As explained above, the positive ions produced at the cathode surface neutralize the space charge of the electrons within the hollow cathode 60. Most of these positive ions are trapped within the cathode by the positive potential of electrode 44.

The space charge of the beam electrons between the aperture 62 and the drift tube 48 may be confined primarily by a strong axial magnetic field produced by the magnetic shield electrode 44 and an external magnetic field structure (not shown) indicated schematically by the arrow H.

In order to neutralize the electron space charge along the low-velocity drift region within the drift tube 48, the latter is preferably designed to supply positive ions. This may be done by making the drift tube of a high work function metal, such as tungsten, to provide positive ions by contact ionization of cesium vapor, as in the hollow cathode 60. Some of the neutral cesium vapor atoms will diffuse from the cathode 60 into the drift tube 48. The drift tube may be heated to contact-ionizing temperature by a heater coil 76. Alternatively, the drift tube 48 may be coated internally with an ion-emitting material, such as that described in connection with the filament 26 in FIG. 1. In either case, the electrons and positive ions within the drift tube form a multi-velocity, low-potential plasma drift region, which reduces the beam noise in the same manner as described in connection with the drift region in FIG. 1. The positive ions in the drift tube 48 are trapped between the higher potential electrodes 46 and 50, at each end of the drift region. The electrons are extracted from the plasma and accelerated by the increasing potentials on electrodes 50, 52, 54, 56 and 58, which potentials are chosen to provide an optimum space charge wave transformer between the plasma drift tube 48 and the RF interaction structure, which may be a traveling wave helix. It is believed that the overall minimum noise figure of the gun of FIG. 5 will not be higher than 3 db.

Very little cesium vapor will diffuse into the RF interaction region beyond electrode 58, and hence, a sufficiently low pressure (high vacuum) can be maintained in that region for normal RF operation. If necessary, the drift tube electrode 58 can be cooled to condense and trap any cesium vapor reaching that electrode. It may be desirable to cool the entire gun portion 40 of the envelope, to trap cesium vapor and thereby reduce the gas pressure in the tube, as by means of a tubular cooling coil 77 surrounding the portion 40. Also, the inner surface of the envelope portion 40 may be coated with a material which either absorbs cesium or reacts with it to reduce the gas pressure in the tube.

If the plasma drift tube 48 is operated at a somewhat higher potential, say 3 volts, it may be possible to con-

6

strain the space charge of the beam therein by means of a very strong magnetic field alone, that is, without supplying positive ions for space charge neutralization. In this case, the plasma drift tube 48 and heater 76 may be replaced by a plain metal drift tube 78, with a tubular cooling coil 80, as shown in FIG. 6, to serve as a cesium vapor trap. The drift tube 78 may be made a portion of the envelope of the tube to completely isolate the cesium vapor region from the high vacuum RF region. The drift tube 78 provides a low-potential electron drift region to reduce the beam noise.

FIG. 7 shows the gun portion of another beam tube embodying the invention. The remainder of the tube could be the same as in FIG. 1. The envelope 10 comprises a gun portion 80 containing a low-noise gun comprising a thermionic cathode 82 having a heater 84, an ion-emitter electrode 86, a plasma drift tube 88, and apertured accelerating electrodes 90, 92, 94, 96 and 98. The cathode 82 may be an L cathode as in FIG. 1, but is preferably an oxide cathode which can be operated at about 1000° K. The ion-emitter 86 may be an electron-permeable filament or grid coated by  $\beta$ -eucryptite, to supply positive ions. The cathode 82 and ion-emitter 86 constitute a plasma source. The drift tube 88 is preferably also coated internally with  $\beta$ -eucryptite, for example, and provided with a heater coil 100, to supply additional positive ions in the path of electrons from cathode 82.

The beam tube of FIG. 7 as described thus far is similar to that of FIG. 1 with a plasma drift tube interposed between the ion-emitter 26 and the plasma anchoring electrode 28. In FIG. 7, the ion-emitter 86 may be operated at a sufficiently high positive potential to draw the desired electron current from the cathode 82. However, it is preferred that the ion-emitter be operated at a low positive potential  $V_1$ , and that other means be provided for accelerating the electrons from the cathode. Accordingly, an annular beam-forming or accelerating electrode 102 is provided, surrounding the cathode 82 behind the ion-emitter 86. Preferably, the inner portion of electrode 102 is inclined outwardly and forwardly, as shown, to establish an optimum accelerating electric field. Operation of the electrode 102 at a positive potential  $V_2$  higher than potential  $V_1$  of the ion-emitter 86 produces an electric field which accelerates electrons from the cathode 82 outwardly and forwardly in the axial magnetic field H, thereby causing them to execute spiral paths through the gun electrodes at low axial velocities. The drift tube 88 should be operated at a very low potential  $V_3$ , to produce a multi-velocity, low-potential, plasma drift region therein for reducing the beam noise as described above in connection with FIGS. 1 to 5. Preferably, the ion-emitter potential  $V_1$  is 1 or 2 volts higher than the potential  $V_3$  of the drift tube, in order to trap positive ions therein. The potential distribution on electrodes 90, 92, 94, 96, and 98 may be the same as on the corresponding electrodes in FIG. 5.

If an adequate supply of positive ions is provided by the coated drift tube 88 in FIG. 7, the grid 86 can be left uncoated and used as a control grid, instead of an ion-emitter.

FIG. 8 shows a modification of FIG. 7 in which the ion-emitter grid is omitted. In this case, a thermionic cathode 104 is mounted close to a plasma drift tube 106 having an internal ion producing surface and a heater coil 108. The drift tube 106 may produce ions either by contact ionization of cesium or by direct emission from an ion-emitting coating. A beam forming or accelerating electrode 110 may be provided around the cathode 104, as in FIG. 7. The other electrodes, one of which, 112, is shown, may be the same as in FIG. 7. The plasma drift tube 106 should be operated at a relatively low positive potential, of the order of 1 to 2 volts, to cause the electrons from the cathode 104 to drift through the plasma in the tube at low velocity, thereby reducing the noise figure. It will be understood that this embodiment of the inven-

tion will not produce as much reduction in beam noise as that of FIG. 5, for example, but may be preferred for some applications having less stringent noise level requirements, because of its simplicity.

Each of the embodiments illustrated includes a low-potential electron drift region of substantial length through which a stream of electrons, having relatively low initial electron temperature, drifts at low velocity for reducing the random current and velocity fluctuations constituting the beam noise. The term "low-potential," as applied to an electrode, indicates a positive bias potential on the electrode of 3 volts or less, relative to the cathode. The term "low-velocity" indicates an electron velocity produced by such a "low-potential" electrode. The term "relatively low temperature" means a temperature not greater than 1500° K. The term "low-temperature" means a temperature not greater than 1000° K.

What is claimed is:

1. A low-noise electron gun for a beam tube, said gun comprising:

- (a) means for forming a noise-reducing low-velocity drift region;
- (b) means, including separate electron and positive ion sources, for producing a plasma in said drift region having an initial electron temperature not greater than 1500 K.;
- (c) means for trapping positive ions in said drift region; and
- (d) means for extracting a beam of electrons from said plasma.

2. A low-noise electron gun for a beam tube, said gun comprising:

- (a) means for forming a noise-reducing low-velocity drift region;
- (b) means, including a thermionic cathode, for injecting a stream of electrons having an initial electron temperature not greater than 1500° K. into said drift region;
- (c) means separate from said cathode for producing positive ions in said drift region to neutralize the space charge of said electrons;
- (d) means for trapping positive ions in said drift region; and
- (e) means for extracting a beam of said electrons from said drift region.

3. A low-noise electron gun for a beam tube, said gun comprising:

- (a) means for forming a noise-reducing low-velocity drift region;
- (b) means, including a thermionic cathode, for injecting a stream of electrons having an initial electron temperature not greater than 1500° K. into said drift region;
- (c) at least one beam control electrode adjacent to said cathode;
- (d) means separate from said cathode for producing positive ions in said drift region to neutralize the space charge of said electrons;
- (e) means for trapping positive ions in said drift region; and
- (f) means for extracting a beam of said electrons from said drift region.

4. A low-noise electron gun for a beam tube, said gun comprising:

- (a) means for forming a noise-reducing low-velocity drift region;
- (b) means, including a thermionic cathode, for injecting a stream of electrons having an initial electron temperature not greater than 1500° K. into said drift region;
- (c) means, including a thermionic positive ion emitting electrode interposed between said cathode and said drift region, for producing positive ions in said drift region to neutralize the space charge of said electrons;

(d) means for trapping positive ions in said drift region; and

(e) means for extracting a beam of electrons from said drift region.

5. A low-noise electron gun for a beam tube, said gun comprising:

- (a) means for forming a noise-reducing low-velocity drift region;
- (b) means, including a low-temperature hollow thermionic cathode, for injecting a stream of low-temperature electrons into said drift region;
- (c) the inner surface of said hollow cathode including portions having a given contact-ionizing work function, means for supplying alkali metal vapor atoms having an ionization potential lower than said work function adjacent to said surface, for producing positive ions in said cathode to neutralize the space charge of said electrons and for reducing the effective work function of other portions of said surface;
- (d) means for trapping positive ions in said drift region; and
- (e) means for extracting a beam of said electrons from said drift region.

6. A low-noise electron gun for a beam tube, said gun comprising:

- (a) means, including at least two low-potential axially-aligned annular electrodes, for forming a noise-reducing low-velocity drift region;
- (b) means, including a thermionic cathode, for injecting a stream of electrons having an initial electron temperature not greater than 1500° K. into said drift region;
- (c) means separate from said cathode for producing positive ions in said drift region to neutralize the space charge of said electrons;
- (d) means for trapping positive ions in said drift region; and
- (e) means for extracting a beam of said electrons from said drift region.

7. A low-noise electron gun for a beam tube, said gun comprising:

- (a) means, including a low-potential drift tube, for forming a noise-reducing low-velocity drift region;
- (b) means, including separate electron and positive ion sources, for producing a plasma in said drift region having an initial electron temperature not greater than 1500° K.;
- (c) means for trapping positive ions in said drift region; and
- (d) means for extracting a beam of electrons from said plasma.

8. A low-noise electron gun for a beam tube, said gun comprising:

- (a) means, including a noise-reducing low-potential drift tube, for forming a low-velocity drift region;
- (b) means, including a thermionic cathode, for injecting a stream of electrons having an initial electron temperature not greater than 1500° K. into said drift tube;
- (c) means separate from said cathode for producing positive ions in said drift tube to neutralize the space charge of said electrons;
- (d) means for trapping positive ions in said drift region; and
- (e) means for extracting a beam of said electrons from said drift tube.

9. A low-noise electron gun for a beam tube, said gun comprising:

- (a) means, including a noise-reducing low-potential drift tube, for forming a low-velocity drift region;
- (b) means, including a thermionic cathode, for injecting a stream of electrons having an initial electron temperature not greater than 1500° K. into said drift tube;
- (c) means comprising the inner surface of said drift

tube for producing positive ions to neutralize the space charge of said electrons; and

(d) means for extracting a beam of said electrons from said drift tube.

10. A low-noise electron gun for a beam tube, said gun comprising:

(a) means, including a noise-reducing low-potential drift tube, for forming a low-velocity drift region;

(b) means, including a thermionic cathode, for injecting a stream of electrons having an initial electron temperature not greater than 1500° K. into said drift tube;

(c) means separate from said cathode for producing positive ions in said drift tube to neutralize the space charge of said electrons; and

(d) means for extracting a beam of said electrons from said drift tube;

(e) said ion-producing means comprising:

(1) the inner surface of said drift tube having a given contact-ionizing work function;

(2) a supply of alkali metal vapor atoms having an ionization potential lower than said work function adjacent to said surface; and

(3) means for heating said surface to contact-ionizing temperature.

11. A low-noise electron gun for a beam tube, said gun comprising:

(a) means, including a noise-reducing low-potential drift tube, for forming a low-velocity drift region;

(b) means, including a thermionic cathode, for injecting a stream of electrons having an initial electron temperature not greater than 1500° K. into said drift tube;

(c) means separate from said cathode for producing positive ions in said drift tube to neutralize the space charge of said electrons; and

(d) means for extracting a beam of said electrons from said drift tube;

(e) said ion-producing means comprising:

(1) the inner surface of said drift tube comprising a material adapted to emit positive ions thermionically when heated; and

(2) means for heating said surface to ion-emitting temperature.

12. A low-noise electron gun for a beam tube, said gun comprising:

(a) means for forming a noise-reducing low-velocity drift region;

(b) means, including a low-temperature hollow thermionic cathode, for injecting a stream of low-temperature electrons into said drift region;

(c) the inner surface of said hollow cathode including portions having a given contact-ionizing work function, means for supplying alkali metal vapor atoms having an ionization potential lower than said work function adjacent to said surface, for producing positive ions in said cathode to neutralize the space charge of said electrons and for reducing the effective work function of other portions of said surface; and

(d) means for extracting a beam of said electrons from said drift region;

(e) said first named means including a low-potential drift tube surrounding the beam path adjacent to said cathode.

13. A low-noise electron gun for a beam tube, said gun comprising:

(a) means for forming a noise-reducing low-velocity drift region;

(b) means, including a low-temperature hollow thermionic cathode, for injecting a stream of low-temperature electrons into said drift region;

(c) the inner surface of said hollow cathode including portions having a given contact-ionizing work func-

tion, means for supplying alkali metal vapor atoms having an ionization potential lower than said work function adjacent to said surface, for producing positive ions in said cathode to neutralize the space charge of said electrons and for reducing the effective work function of other portions of said surface; and

(d) means for extracting a beam of said electrons from said drift region;

(e) said first named means including a low-potential drift tube surrounding the beam path adjacent to said cathode, and means for producing positive ions in said drift tube to neutralize the space charge of said electrons therein.

14. A low-noise electron gun for a beam tube, said gun comprising:

(a) means for forming a noise-reducing low-velocity drift region;

(b) means, including a low-temperature hollow thermionic cathode, for injecting a stream of low-temperature electrons into said drift region;

(c) the inner surface of said hollow cathode including portions having a given contact-ionizing work function, means for supplying alkali metal vapor atoms having an ionization potential lower than said work function adjacent to said surface, for producing positive ions in said cathode to neutralize the space charge of said electrons and for reducing the effective work function of other portions of said surface; and

(d) means for extracting a beam of said electrons from said drift region;

(e) said first named means including a low-potential drift tube surrounding the beam path adjacent to said cathode, and means for cooling said drift tube to reduce the gas pressure in said beam by condensation of ions and vapor atoms.

15. A low-noise electron gun for a beam tube, said gun comprising:

(a) means, including a noise-reducing low-potential drift tube, for forming a low-velocity drift region;

(b) means, including a thermionic cathode, for injecting a stream of electrons having an initial electron temperature not greater than 1500° K. into said drift tube;

(c) means, including a thermionic positive ion emitting electrode interposed between said cathode and said drift tube, for producing positive ions in said drift tube to neutralize the space charge of said electrons;

(d) the inner surface of said drift tube comprising a material adapted to emit positive ions when heated, and means for heating said surface to ion-emitting temperature; and

(e) means for extracting a beam of electrons from said drift tube.

16. A low-noise traveling wave tube comprising:

(a) means for forming a noise-reducing low-velocity drift region;

(b) means, including a thermionic cathode, for injecting a stream of electrons having an initial electron temperature not greater than 1500° K. into said drift region;

(c) means separate from said cathode for producing positive ions in said drift region to neutralize the space charge of said electrons;

(d) means, including a space-charge-wave transformer positioned beyond said drift region, for extracting a beam of electrons from said drift region;

(e) an elongated slow wave structure extending along the path of said beam beyond said transformer; and

(f) means for producing a magnetic field, having a field strength greater than 1000 gauss, along said drift region, said beam extracting means and said slow wave structure.

17. A low-noise traveling wave tube comprising a vacuum tight envelope containing:

- (a) means, including a noise-reducing low-potential drift tube, for forming a low-velocity drift region;
- (b) means, including a thermionic cathode, for injecting a stream of electrons having an initial electron temperature not greater than 1500° K. into said drift tube;
- (c) means comprising the inner surface of said drift tube for producing positive ions to neutralize the space charge of said electrons;
- (d) means, including a space charge wave transformer positioned beyond said drift tube, for extracting a beam of said electrons from said drift tube; and
- (e) an elongated slow wave structure extending along the path of said beam beyond said transformer; and
- (f) said beam extracting means being adapted to maintain a high vacuum in said envelope along said slow wave structure.

18. A low-noise electron gun for a beam tube, said gun comprising:

- (a) a relatively low temperature thermionic electron source;
- (b) electrode means for directing electrons from said source along a given beam path and for forming a noise-reducing low velocity electron drift region along a portion of said path;
- (c) means for producing positive ions in said drift region to neutralize the space charge of said electrons therein; and
- (d) means for trapping said positive ions within said drift region.

19. A low-noise electron gun for a beam tube, said gun comprising:

- (a) a relatively low temperature thermionic electron source;

(b) means including first, second and third aligned electrodes for directing said electrons along a given beam path;

(c) means for producing positive ions in the space between said first and third electrodes to neutralize the space charge of said electrons and form a plasma in said space; and

(d) means for biasing said second electrode at a low positive voltage and said first and third electrodes at higher positive voltages, with respect to said source, to form a noise-reducing low velocity electron drift region in said space and for trapping positive ions therein.

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