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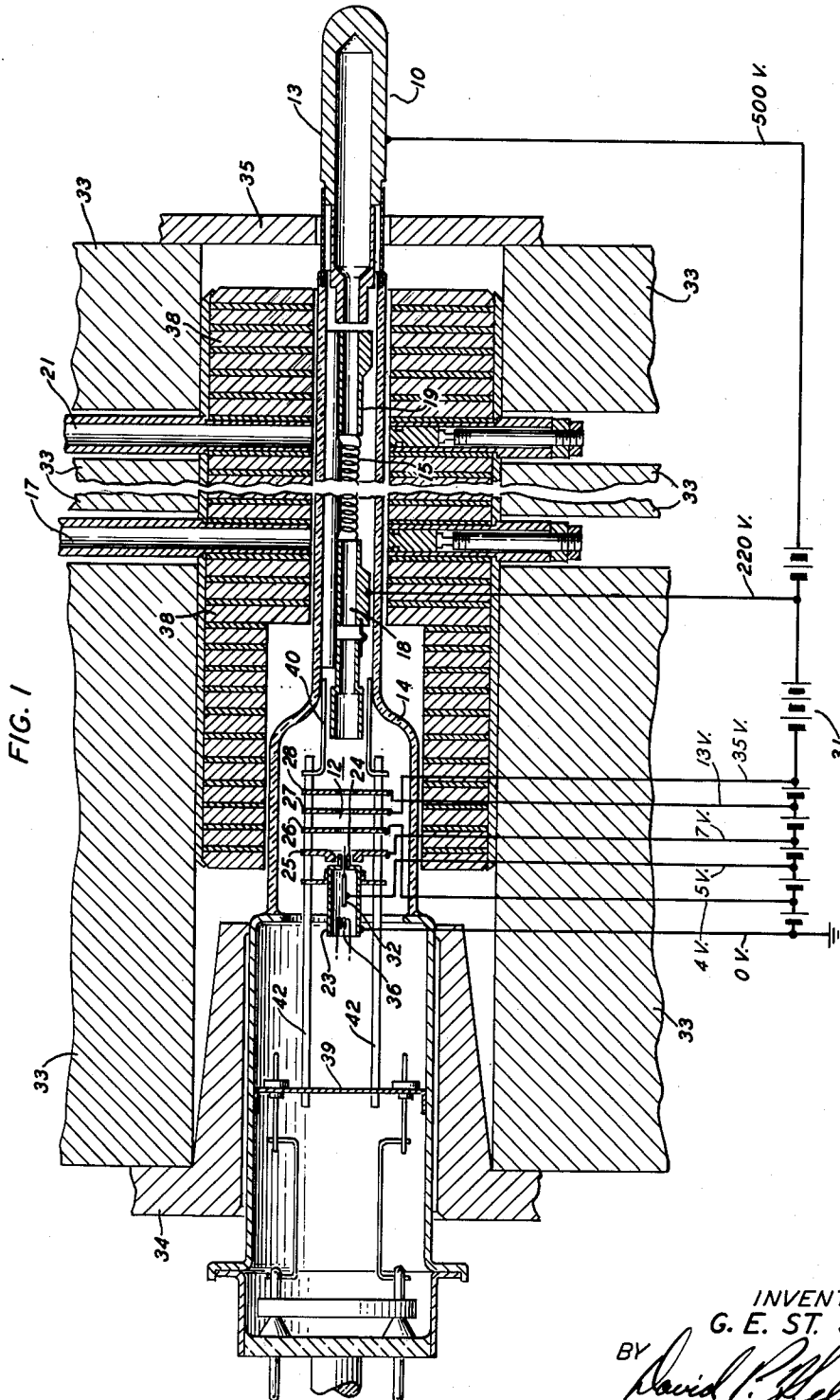
G. E. ST. JOHN

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LOW-NOISE ELECTRON GUN

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2 Sheets-Sheet 1



INVENTOR
G. E. ST. JOHN
BY *David P. Kelley*
ATTORNEY

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2 Sheets-Sheet 2

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INVENTOR
G. E. ST. JOHN
BY *David P. Kelley*
ATTORNEY

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LOW-NOISE ELECTRON GUN

Grant E. St. John, Palo Alto, Calif., assignor to Bell Telephone Laboratories, Incorporated, New York, N.Y., a corporation of New York

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5 Claims. (Cl. 315—3.5)

This invention relates to electron beam devices and more particularly to an electron gun for use in such devices.

Electron beam devices such as traveling wave tubes have proven capable of microwave amplification with reasonably high gain and stability over an exceedingly wide band of frequencies. Detracting from the significant advantages of such devices, however, is the noise resulting from the utilization of an electron beam. Considerable research on the nature of electron beams has been undertaken in an effort to reduce this undesirable noise as much as possible. In a paper entitled "The Minimum Noise Figure of Microwave Beam Amplifiers" by H. A. Haus and F. N. H. Robinson, Proceedings of the Institute of Radio Engineers, volume 43, pages 981-991, August 1955, equations are developed that lead to a theoretical minimum noise figure for a conventional traveling wave tube of approximately six decibels.

Subsequent to the work of Haus and Robinson, workers in the art discovered that certain particular electron guns sometimes yielded noise figures of less than six decibels. Investigation has indicated that these apparent contradictions of theory result from the fact that the Haus-Robinson calculations are based on the assumption that velocity variations in any given transverse plane of the electron beam are negligible by comparison to the D.C. beam velocity. This assumption is apparently valid in regions of high D.C. beam velocity, but is not valid in the region adjacent the cathode where the beam has not been accelerated.

There have been several theories advanced concerning the nature of the beam in the low velocity cathode region. Most of the recent discoveries thus far, however, have been based upon experimental findings. In the paper "Low Noise Tunable Preamplifiers for Microwave Receivers" by M. R. Currie and D. C. Forster, Proceedings of the Institute of Radio Engineers, volume 46, pages 570-579, March 1958, there is described an electron gun for use in backward-wave amplifiers that permits amplification, under certain conditions, with a noise figure of less than four decibels. The cathode of this gun is annular with a "Christmas tree" support rod of insulating material extending through the center thereof. The beam which is formed is hollow and encloses the support rod. Several accelerating anodes are attached to the support rod within the beam and corresponding anodes surround the beam. In addition, a control electrode surrounds the cathode.

A relatively large hollow beam of the type just described is somewhat limited to certain specific applications. In many traveling wave tubes a cylindrical beam of extremely small diameter is required. When such requirements exist, it is physically impossible to construct a "Christmas tree" structure of inner accelerating anodes which will be surrounded by the beam and which will not intercept a portion of the beam.

In an effort to utilize the advantages of the Currie-Forster electron gun in a device that requires an ex-

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ceedingly thin beam, electron guns have been built which have conventional planar cathodes with a beam forming electrode surrounding the cathode and a series of accelerating anodes axially spaced downstream from the cathode. Investigation has shown that this sort of gun structure may yield noise figures as low as 3.5 decibels. Although this represents a significant improvement over prior electron guns, it is desirable to produce electron beams with as low a noise figure as possible. Further, the noise figure of such an electron beam device tends to increase with increasingly higher frequencies of operation.

Accordingly, it is an object of this invention to produce an electron beam having a low noise content.

It is a specific object of this invention to produce low noise amplification in a device using a cylindrical electron beam of extremely small diameter.

These and other objects of my invention are attained in an illustrative embodiment thereof comprising an electron gun for forming and projecting a beam of electrons toward a collector. Electromagnetic waves traveling along a slow wave circuit interact with the beam and become amplified as is well known in the art. The electron gun includes an annular beam forming electrode and a plurality of annular accelerating anodes arranged axially along the beam. An annular cathode of extremely small diameter extends through the central aperture of the beam forming electrode. One end of the cathode is coated with an emissive material whereby a thin electron beam is produced when the cathode is heated.

It is a feature of this invention that a conductive probe extend through the center of the cathode and protrude slightly beyond the emitting surface.

It is another feature of this invention that the conductive probe be at a higher positive potential than the cathode. This positive potential tends to draw off electrons predominantly from the inner edge of the annular emitting surface. The beam forming electrode is also positive with respect to the cathode and so there is also relatively high emission from the outer edge of the annular emitting surface. The high percentage of edge emission from the cathode of my invention contributes to the low noise properties of the electron beam formed thereby.

It is another feature of this invention that the probe be at a different potential than the beam forming electrode. This potential difference produces an electric field across the emitting surface that is transverse to the tube axis. As a result, artificial beam velocity variations are produced which augment the advantageous effects of inherent beam velocity variations.

These and other objects, advantages, and features of my invention will be more clearly understood with reference to the following detailed description, taken in conjunction with the drawing, in which:

Fig. 1 is a sectional view of a traveling wave tube which includes an electron gun embodying the principles of this invention; and

Fig. 2 is a sectional view of a portion of the electron gun of the traveling wave tube of Fig. 1.

Referring now to Fig. 1, there is shown, by way of example, a traveling wave tube 10 having an electron gun 12 for forming and projecting a beam of electrons toward a collector 13. These elements are maintained in a substantial vacuum by an envelope 14 which is of glass or some other suitable material. Extending between the electron gun and the collector is a conductive helix 15. Electromagnetic waves are introduced into tube 10 by means of an input waveguide 17, and are caused to propagate along helix 15 by an input coupler 18. As the electromagnetic waves propagate along the helix, the

fields associated therewith interact with the electron beam to produce a net amplification of the wave, as is well known in the art. The electromagnetic waves are thereafter removed, via output coupler 19 and output waveguide 21.

Surrounding traveling wave tube 10 is a focusing magnet 33, only a portion of which is shown for purposes of clarity. Magnet 33 produces a magnetic field within tube 10 which is substantially parallel with the tube axis to constrain the beam to follow a path coincident with the tube axis and to prohibit undesired electron impingement on helix 15. Located at opposite ends of magnet 33 are pole pieces 34 and 35 which are used to align the magnetic lines of flux so that they will be precisely parallel with the tube axis. Field straighteners 38 are also included in the magnet structure to insure further a parallel condition between the magnetic field and the tube axis, as is known in the art. The field straighteners 38 are rigidly attached to waveguides 17 and 21 to keep field distortion in the input and output sections to a minimum in the event of any movement of these waveguides.

The electron gun 12 embodying the principles of my invention comprises a cathode 23 having an electron emitting surface 24, a beam forming electrode 25, a first accelerating anode 26, a second accelerating anode 27, and a third accelerating anode 28. Appropriate bias is maintained on the various electrodes by battery 31. Typical relative voltages for optimum low noise performance of gun 12 for one specific illustrative embodiment are indicated in terms of volts on the various lead wires from battery 31. The voltages indicated on each lead specify the potential of that lead with respect to the cathode, which is at ground potential. It is also to be noted that the helix 15, as indicated in Fig. 1, is biased 220 volts positively so that the helix structure also effectively acts as an accelerating anode.

In accordance with an aspect of my invention a thin probe wire 32 extends centrally through the cathode 23, extending slightly above the surface 24. The probe 32, as can be seen in Fig. 1, is biased positively with respect to the cathode 23, and thus the emissive surface 24, but is negative with respect to the beam forming electrode 25.

For illustrative purposes, the electron gun is shown as being supported on one end by a support platform 39 and at the other end by a connector 40. Connector 40 forms a sliding fit with envelope 14 to relieve thermal stresses within the gun. Electrodes 25, 26, 27, and 28 are supported by three support rods 42 of insulating material such as ceramic, each of the support rods being located at 120 degree intervals with respect to the tube axis.

When cathode 23 is heated, as by a cathode heating element 36 non-inductively positioned within the cathode and around the inner end of probe 32, electrons are emitted from emitting surface 24, as is well known in the art; for purposes of clarity heater 36 has been only schematically depicted in Fig. 1. In accordance with the principles outlined in the aforementioned Currie-Forster paper, the use of a plurality of accelerating electrodes 26, 27, and 28, rather than a single accelerating electrode, for projecting the emitted electrons along the central axis of the tube tends to reduce the noise content of the beam. It is to be observed that these electrodes have very small central apertures therein so as to be in close proximity with all of the electrons of the beam despite the exceedingly small diameter of the beam. The voltages illustrated on the various electrodes are given to show approximate relative voltages rather than absolute voltages, as discussed above. These voltages may vary with various modes and frequencies of operation. The present invention lies in the unique cathode construction which, in cooperation with the other elements of electron gun 12, produces an electron beam having an unusually low noise content.

Fig. 2 illustrates more clearly the cathode section of the electron gun in accordance with my invention, as utilized in Fig. 1, and also various of the critical structural relationships involved. For the formation of a small-diameter electron beam, which shall be considered to be a beam having a diameter of less than .1 inch, the outer diameter c of the emissive cathode surface 24 should be also less than .1 inch and preferably less than .05 inch. The inner diameter b of the emissive surface 24 should be less than .05 inch and preferably less than .03 inch. The probe 32 in order to be entirely confined within the hollow beam which is emitted from the emissive surface 24 and primarily from the outer and inner edges 47 and 45, respectively, thereof, needs to be of very small diameter a such as preferably less than .01 inch.

In accordance with an important aspect of my invention the probe 32 extends beyond the emissive surface 24 a length e so as to create a transverse electric field across the face of the emissive surface 24 between the probe 32 and the differently biased beam-forming electrode 25, which electrode extends beyond the surface 24 by a distance d but also has a portion at an angle α extending to a plane behind the emissive surface 24.

In one specific illustrative embodiment of my invention wherein, in cooperation with the elements of the device and specific biases therefor depicted in Fig. 1, a small-diameter electron beam was produced having a lower noise content than any other analogous cathode section of which I am aware, the various elements of the cathode section, as depicted in Fig. 2, had the following specific dimensions and relative positions:

Probe 32 diameter a	inch	.005
Cathode 24 inner diameter b	do	.015
Cathode 24 outer diameter c	do	.025
Distance d of electrode 25 beyond surface 24	do	.017
Length e of probe 32 beyond surface 24	do	.005
Angle α of electrode 25 with surface 24 ..	degrees	45

There are several theoretical explanations possible of why the Haus-Robinson calculations do not apply to a low velocity electron beam in accordance with my invention. One of these theories is that certain noise parameters fluctuate with distance when velocity variations along a transverse plane of the beam are large with respect to the mean beam velocity. In the cathode section of Fig. 2, a transverse electric field is produced between probe 32 and beam-forming electrode 25. It therefore appears that one reason that this cathode section produces an unusually low noise beam is because artificial transverse beam velocity variations are produced by the transverse electric field. These artificial velocity variations tend to augment the fluctuations of the noise parameter due to inherent velocity variations. The voltage on the helix or on one of the accelerating electrodes may be varied slightly to accelerate the beam at a point at which the fluctuating noise parameter is at a minimum, the points at which the minimum occurs being determined in part by the potential difference between probe 32 and electrode 25, and the beam velocity.

Another possible theory is that certain cathode sections produce low noise beams because electron emission occurs primarily at the edges of the cathode. In the cathode section of Fig. 2, emission would be expected to be predominant at the outer annular edge 45 because of its proximity to beam-forming electrode 25, and also at the inner annular edge 47 because of its proximity to the positively biased probe 32. It therefore appears that the percentage of edge emission from the emitting surface 24 of Fig. 2 is large by comparison to analogous emitting surfaces of the prior art.

Since emission appears to be primarily from the concentric edges 45 and 47 of cylindrical cathode 23, one might expect two concentric annular beams to be formed.

As is well-known in the art, two modulated beams in close proximity may couple together in such a way as to excite a growing wave with resulting amplification of the modulation energy traveling thereon. This phenomenon is known as double stream amplification. Likewise, two such beams may couple together in such a way as to excite a decaying wave with resulting de-amplification. Generally speaking, it is necessary for such de-amplification that the two beams travel at different mean velocities. In the present device, two proximate beams of different velocities are formed. Inherent noise energy can be considered as being space charge modulation energy. It is therefore submitted that the low noise characteristics of my device may be due in part to double stream de-amplification of the inherent noise energy on the beam.

It is not intended that any of the foregoing explanations should limit the scope of this invention. These theories have been advanced merely as possible explanations of the unusually low noise figure realized in the present device wherein a probe 32 extends beyond the cathode surface 24, is positively biased with respect thereto, and is differently biased than the beam-forming electrode 25. In practice it has been found that with the particular voltage and dimensional relationships set out in the foregoing, the electron gun of the present invention produces less noise than many other types of guns for a thin or very small diameter beam. In particular, it has been found that the extension of the probe 32 beyond the cathode emitting surface, as herein set forth, is a major factor in reducing the noise content of the beam.

It is also to be understood that the structures discussed are presented only for purposes of illustration. Numerous other arrangements may be made by those skilled in the art without departing from the spirit and scope of this invention.

What is claimed is:

1. An electron beam device comprising electron gun means for forming and projecting a beam of electrons, means for transmitting electromagnetic waves in interacting relationship with said beam, means for constraining said beam to follow a single predetermined path of flow, said electron gun comprising a plurality of accelerating anodes and a cylindrical cathode having a central aperture, a beam-forming electrode surrounding a portion of said cathode, one end surface of said cathode being completely coated by electron emissive material thereby forming an electron emitting surface, a conductive probe

within said cathode aperture and extending beyond said emitting surface, and means maintaining said conductive probe at a higher positive potential than said cathode and at a lower positive potential than said beam-forming electrode.

2. An electron discharge device comprising an electron gun for forming and projecting a beam of electrons, means for focusing said beam, means for transmitting electromagnetic waves in interacting relationship with said beam, said electron gun comprising a plurality of accelerating anodes and a hollow cylindrical cathode having a flat end surface which is completely coated with electron emissive material, thereby forming an emitting surface, the outside diameter of said annular emitting surface being less than .1 inch and the inside diameter being less than .05 inch, a beam-forming electrode surrounding said emitting surface, a conductive probe extending through the central aperture of said emitting surface, and means for biasing said conductive probe at a lower positive potential than said beam-forming electrode and at a higher positive potential than said cathode.

3. A low noise electron gun for producing a small diameter electron beam comprising a beam-forming electrode having a central aperture therein, a cathode having a portion extending through said beam-forming electrode aperture and having a flat emissive surface with a central aperture therein, a wire probe extending through said emissive surface aperture and projecting slightly above said surface, means maintaining said probe at a positive potential relative to said cathode, means maintaining said beam-forming electrode at a different positive potential relative to said cathode, and a plurality of accelerating anodes serially positioned along the path of said beam.

4. A low noise electron gun in accordance with claim 3 wherein said beam-forming electrode is dish shaped, having a first portion adjacent said cathode and behind said emissive surface and a second portion removed from said cathode and above said surface.

5. A low noise electron gun in accordance with claim 4 wherein said beam-forming electrode second portion is in a plane further removed from said emissive surface than the end of said wire probe.

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