Aug. 8, 1961

K. SCHLESINGER

2,995,676

ELECTRON GUN

Filed March 21, 1960

3 Sheets-Sheet 1

FIG. 1.

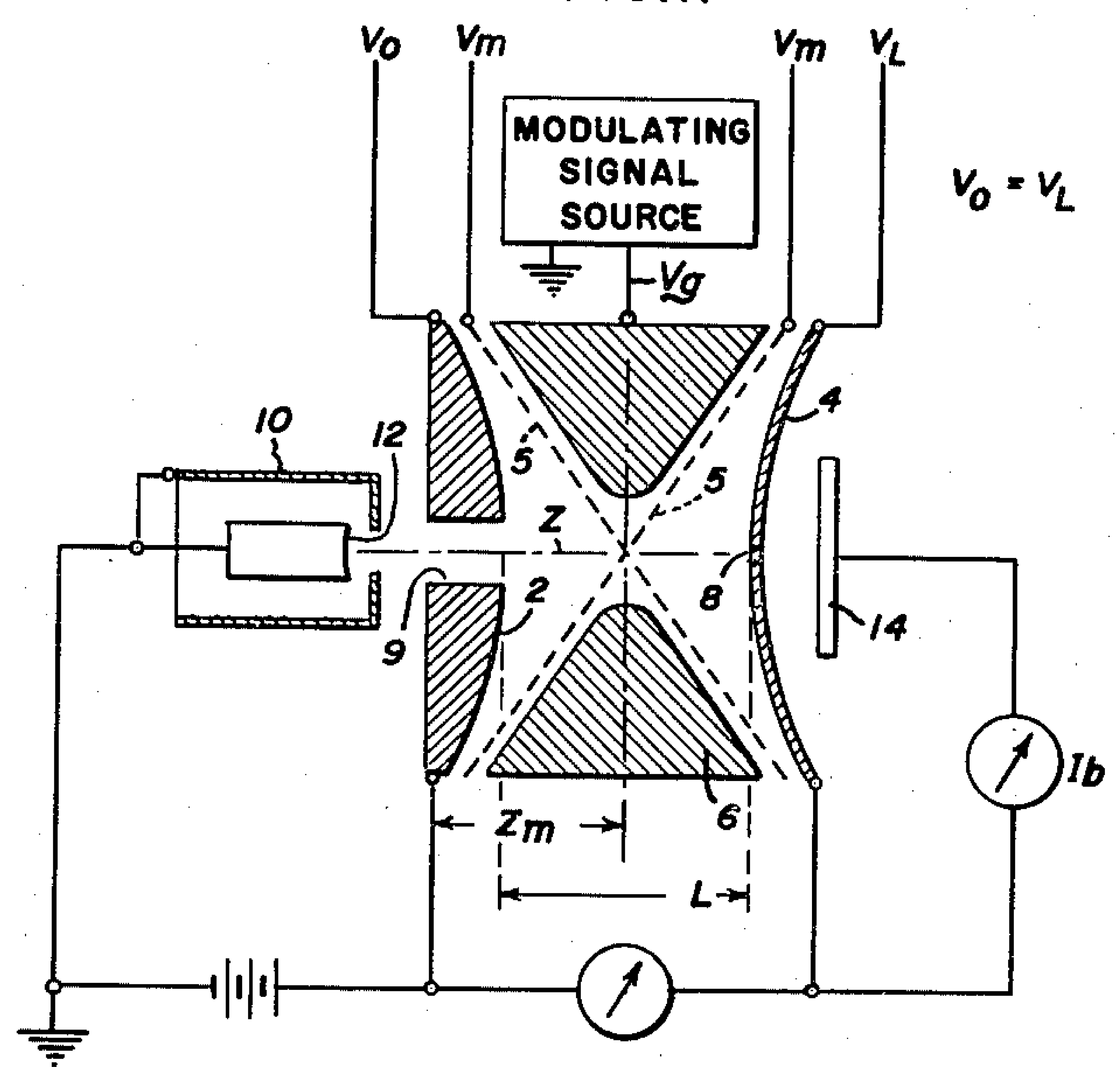
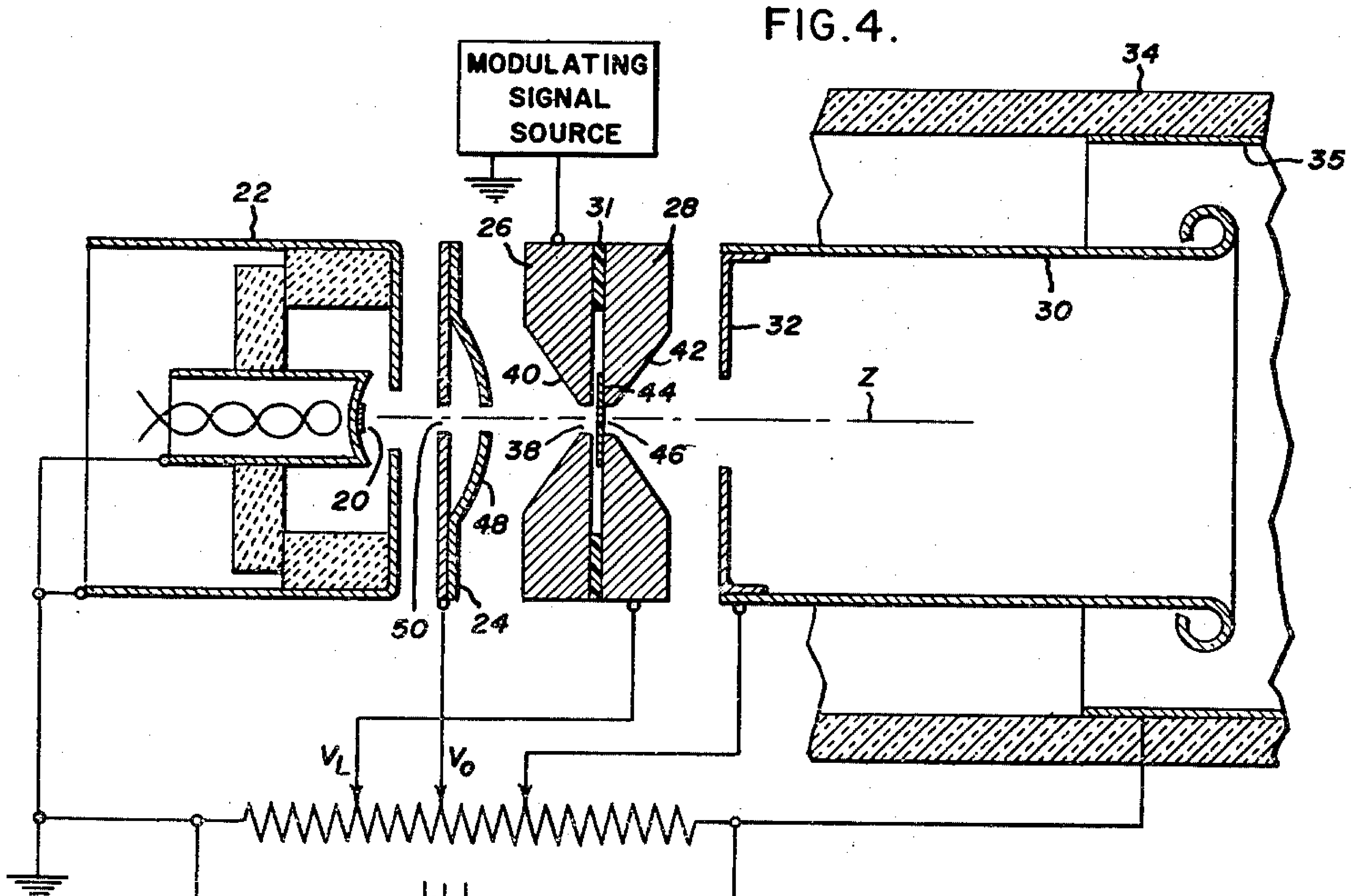


FIG. 4.



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ELECTRON GUN

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FIG. 2.

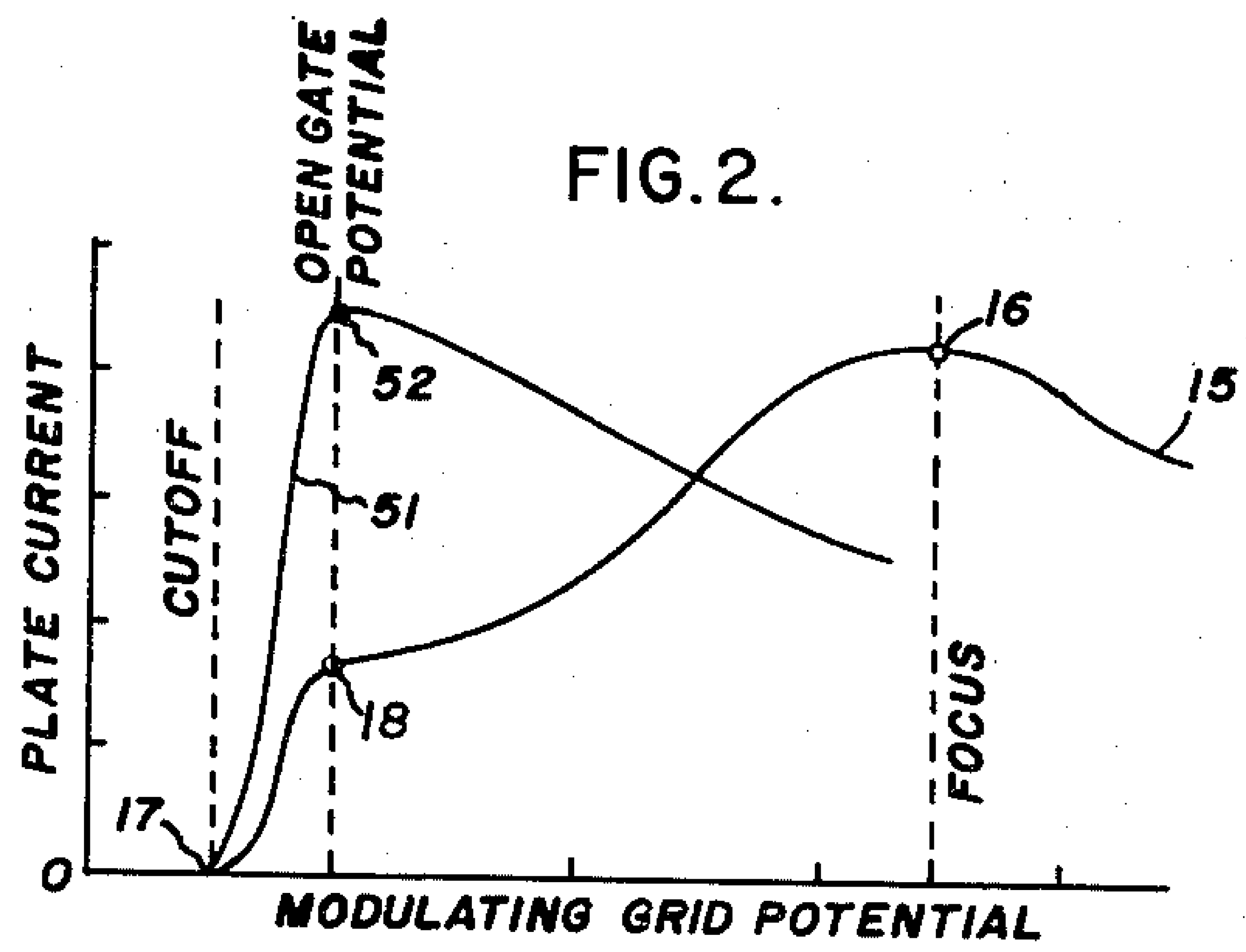
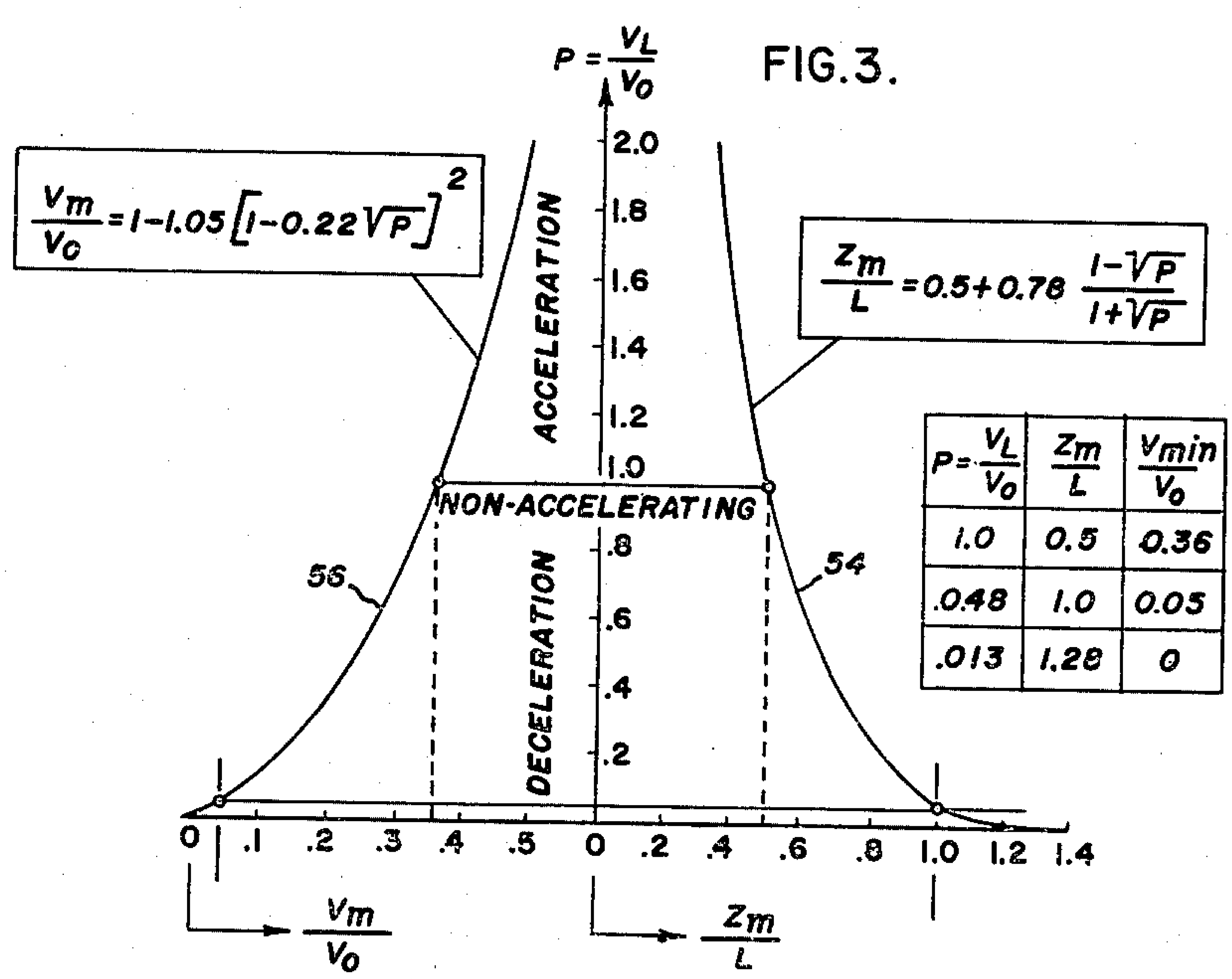
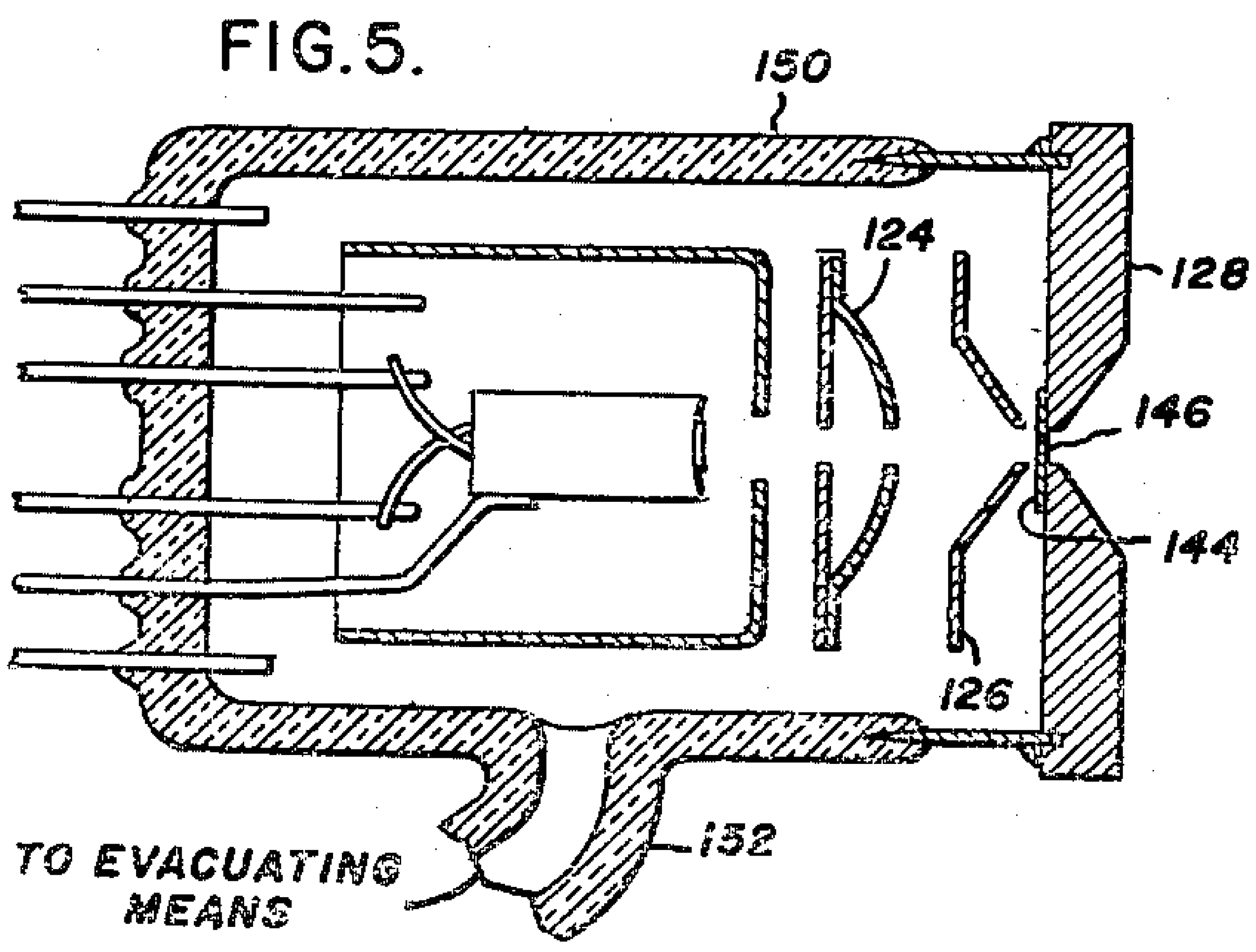


FIG. 3.



$P=\frac{V_L}{V_0}$	$\frac{Z_m}{L}$	$\frac{V_{min}}{V_0}$
1.0	0.5	0.36
.048	1.0	0.05
.013	1.28	0

FIG. 5.



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3 Sheets-Sheet 3

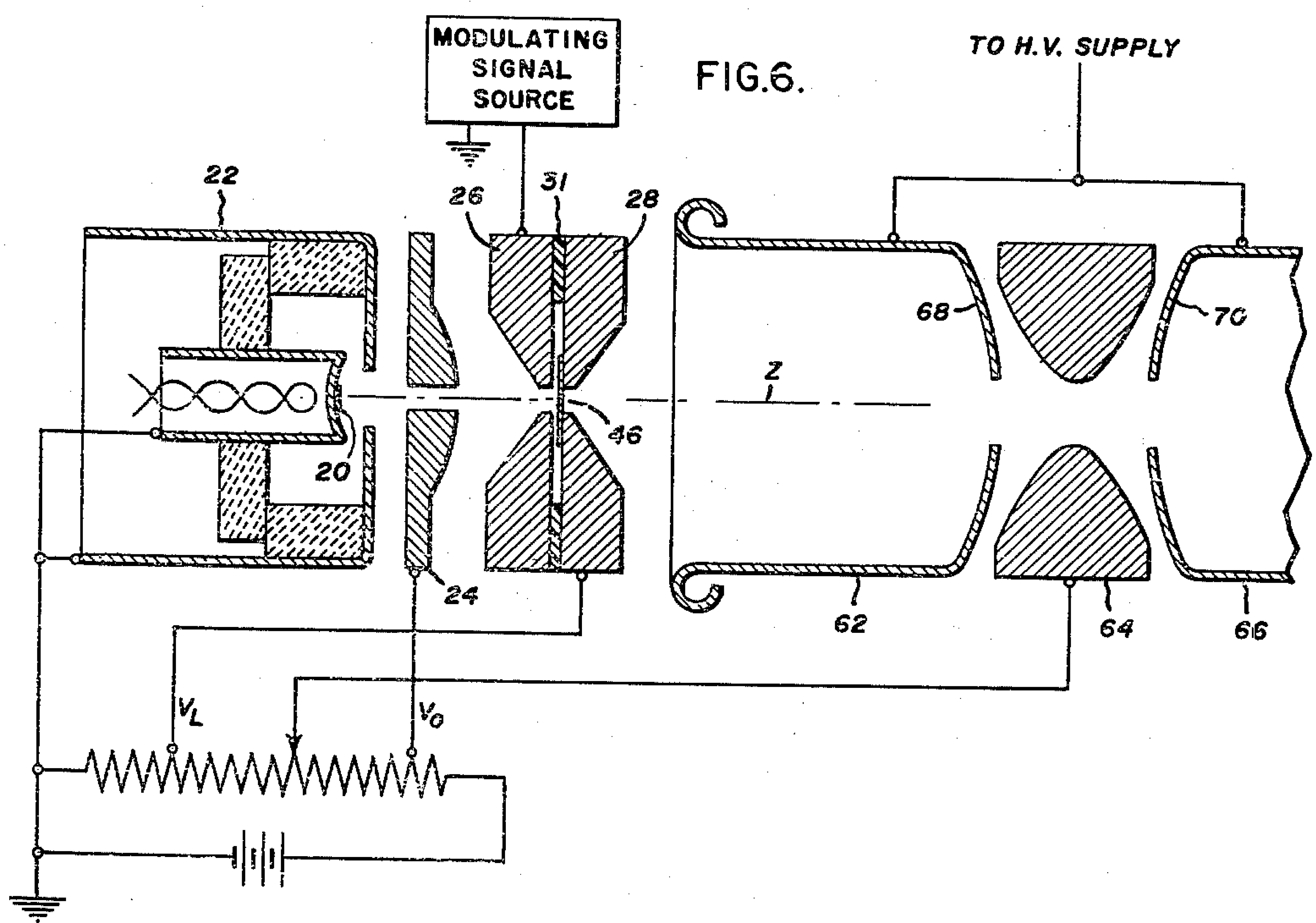

FIG.6.

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2,995,676

ELECTRON GUN

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Filed Mar. 21, 1960, Ser. No. 16,523

13 Claims. (Cl. 315—15)

The present invention relates to improvements in electron guns for cathode ray tubes and the like.

A principal object of the invention is to provide an electron gun particularly adaptable for use with electron beam intensity modulation signals of the order of a few volts, such as are conveniently obtainable from transistorized circuitry.

Another object is to provide an electron gun capable of delivering a modulated electron beam which can be readily focused to provide high resolution, and with little change of resolution with beam current.

Another object is to provide an electron gun capable of delivering an electron beam of high intensity through an opening of very small size with controlled small exit-divergence and smoothly modulatable in intensity to virtually complete cut-off by control signals of relatively small magnitude.

Another object is to provide improved means for efficiently intensity modulating an electron beam emanating from a cathode of relatively large area and focused on an aperture of relatively small area.

Another object is to provide improved means for efficiently generating an electron beam of relatively high local intensity over a small cross-section, from an emission source operated at no more than a moderate level of emission density.

Another object is to provide improved means for controlling the divergence of an electron beam exiting from a defining aperture without incurring excessive spot-magnification.

Another object is to provide electron beam generating means particularly suitable for use in cathode ray tubes and providing minimum variation in luminescent screen spot size with beam intensity.

These and other objects of the invention will be apparent from the following description and the accompanying drawings; wherein:

FIG. 1 is a schematic diagram of an electron beam forming apparatus illustrating certain aspects of the present invention;

FIG. 2 is a graph of certain characteristics of the apparatus of FIG. 1;

FIG. 3 is a graph of certain relationships of the structure of FIG. 1 applicable to the present invention;

FIG. 4 is a fragmentary axial sectional view of one embodiment of a cathode ray tube constructed according to the invention; and

FIG. 5 is an axial sectional view of another embodiment of an electron gun constructed according to the present invention.

FIGURE 6 is an axial sectional view of another embodiment of an electron gun constructed according to the invention.

Briefly the present invention provides an electron gun in which a narrow and intense electron beam is generated from a relatively large area and relatively low emission density source by focused and intensity modulated transmission through a defining aperture which forms a virtual cathode. The electron supply to the defining aperture is in the form of a collimated beam of electrons derived from a cathode having an emission area substantially larger than the defining aperture. Between the source of the collimated relatively large-area beam and the defining aperture is provided means for both focusing the beam at the aperture and modulating its intensity. The focusing and modulating means is basically a hyperbolic electrostatic lens which focuses by continuous deceleration, and is so constituted as to project the beam crossover through an annular intensity-control or gate electrode into the defining aperture. Further according to the invention, this focusing of the beam crossover at the defining aperture is made to occur at substantially the same modulation-voltage as that providing maximum current transfer through the intensity control or gate electrode. As a result of such coincidence, smooth intensity modulation of the beam at the output side of the defining aperture from a high intensity to substantially complete cut-off is obtainable from small magnitude modulating signals of the order of a few volts, and with desirably high transconductance.

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For a better understanding of the present invention, it is instructive to consider first some fundamentals of hyperbolic lenses. It is known that to provide minimum-aberration focusing of an electron beam symmetrical with a reference axis Z and whose electrons are moving with substantially uniform axial velocity, the radial component of field strength should be exclusively and directly proportional to the radial distance from the axis of the beam. The coefficient of such proportionality can be expressed as an absolute constant, *c*, hereinafter referred to as the refractive power of the lens constituted by such a field. It is also known that such requirements for minimum-aberration focusing are satisfied by an electrostatic field having equipotential surfaces which are coasymptotic hyperboloids of revolution rotationally symmetrical about the electron beam axis. The asymptotic surface of such a family of hyperboloids can be shown mathematically to be a double cone of apex angle 109°24′.

Turning to FIG. 1, there is shown in schematic form a hyperbolic lens system of symmetrical form which is instructive in understanding certain aspects of the present invention. The confronting surfaces of electrodes 2 and 4 constitute surfaces having the shape of biparted hyperboloids coaxial with reference axis Z and having a common asymptote indicated by the dotted lines 5 which is a double cone coaxial with axis Z and having an apex angle of about 109°. Midway or symmetrically disposed between electrodes 2 and 4 is an annular gate electrode 6, the inner surface of which is an unparted hyperboloid of revolution about axis Z coasymptotic with electrodes 2 and 4. The potential V_0 of electrode 2 equals the potential V_L of electrode 4, and this condition, together with the lesser potential V_g and symmetrical position of electrode 6 enables the three electrodes to form a symmetrical non-accelerating hyperbolic lens whose electrostatic field is characterized by equipotential surfaces which are families of hyperboloids coasymptotic with the double cone 5. The apex of the asymptotic cone 5 of the lens denotes the location of what is hereinafter referred to as the "saddle point" or gate of the lens. Denoting the axial spacing of electrodes 2 and 4 as L, the spacing Z_m of the saddle point of the lens from electrode 2 is, in the lens shown in FIG. 1, $L/2$.

A small coaxial aperture 8 is provided in electrode 4 to serve as a defining aperture for electron output from the lens, and electrons are admitted to the lens through an opening 9 in electrode 2 in the form of a beam of area large relative to the area of aperture 8. Collimation of the beam for passage through the opening 9 is conveniently effected by an apertured collimating electrode 10 spaced in front of the axially disposed large area cathode 12. A collector plate 14 is situated opposite the output side of the defining aperture 8, for collection of current emerging therefrom.

The current through the defining aperture 8 can be intensity modulated by application of a control signal to the electrode 6, and will produce a current to collector plate 14 which varies with control signal voltage in the manner shown generally in graphical form by curve 15 in FIGURE 2.

The point 16 on curve 15 of FIG. 2 denotes the condition of maximum current through aperture 8, and corresponds to the electron beam being focused at aperture 8 by the symmertical hyperbolic lens of FIG. 1. Point 17 in FIG. 2 denotes the current cut-off condition, and point 18 on curve 15 denotes the "open-gate" potential of gate electrode 6 at which full transfer of current through the central opening in electrode 6 occurs. It will be evident from curve 15 of FIG. 2 that the modulation potential for "open gate" operation is greatly different from that for optimum focus or current transfer through aperture 8, and hence the symmetrical hyperbolic lens of FIG. 1 leaves much to be desired as a device for efficiently generating a modulated electron beam at aperture 8.

Hyberbolic lens fields can also be developed when electrodes of the type shown in FIG. 1 are disposed in non-symmetrical fashion, provided the ratio, P, of V_L to V_o is properly related to Z_m to L. I have discovered that an approximate expression for the Z coordinate of the saddle point of the electron lens shown in FIG. 1 is

$$Z_m=\frac{L}{2}\left[1+\frac{V_o}{cL^3}(1-P)\right]$$

where V_o is the bias of electrode 2, P is the voltage step-up ratio of V_L to V_o, V_L is the bias of electrode 2, L is the axial spacing of the opposed surfaces of electrodes 2 and 4, Z_m is the axial spacing of the saddle point from the opposed face of electrode 2, and c is the constant corresponding to the refractive power of the lens field. It can also be shown mathematically that a collimated electron beam entering the opening 9 will theoretically be focused at the limiting aperture 8 when the refractive power c has the approximate value:

$$c_f=0.64\frac{V_o}{L^3}(1+\sqrt{P})^2$$

The approximate position of the saddle point or gate for such a focus condition is then given by the expression:

$$\frac{Z_m}{L}=\frac{1}{2}+0.78\left(\frac{1-\sqrt{P}}{1+\sqrt{P}}\right)$$

and the approximate potential V_m of the saddle point is given by the expression

$$\frac{V_m}{V_o}=1-1.05[1-0.22\sqrt{P}]^2$$

The approximate relationships of

$$\frac{Z_m}{L}\text{ to P and }\frac{V_m}{V_o}$$

corresponding to the two equations immediately above are shown graphically in FIGURE 3. Curve 54 in FIG. 3 relates the voltage ratio P to various values of $Z_{m/L}$, and curve 56 relates P to the ratio of saddle point potential V_m to V_o. It will be evident from FIG. 3 that when $Z_{m/L}=0.5$, P is 1, while when $Z_{m/L}$ approaches 1, P becomes quite small.

In contrast to FIG. 1, FIG. 4 shows one practical embodiment of an electron gun constructed according to the invention. The lens of FIG. 4 is extremely non-symmetrical in comparison with that of FIG. 1, and corresponds substantially to the decelerating half section of that shown in FIG. 1. Coaxially spaced along a reference axis Z are an indirectly heated relatively large area cathode 20 shown as of the Pierce type, an apertured collimating electrode 22, an anode 24, a gate electrode 26, and a meniscus electrode 28. An optical barrel electrode 30 having a centrally apertured transverse wall 32 is also provided opposite electrode 28. The foregoing

electrodes may be conveniently arranged within the neck 34 of an evacuated cathode ray tube envelope. The forward end of the barrel electrode 30 shown extends into an accelerating anode which is at luminescent screen potential and may conveniently take the form of a conductive coating 35 on the interior surface of the neck.

The gate and meniscus electrodes 26, 28 are electrically insulated from one another as by a spacer 31, and have central openings defining a throat or passage 38 coaxial with the Z axis. Gate electrode 26 is cut away, or alternatively may be formed from sheet material or the like, to provide a surface 40 which is theoretically a hyperboloid of revolution about the Z axis but which is shown as a convenient approximation corresponding substantially to such theoretical surface and comprising a cone coaxial with the Z axis and having an apex angle of about 109°. The central opening in the meniscus electrode 28 is substantially closed by a conductive diaphragm 44 carried by the meniscus electrode and having a minute coaxial defining aperture 46 which substantially coincides with the apex of surface 40. Electrode 28 also has a surface 42 which is a cone of 109° apex angle coaxial with the Z axis and substantially back-to-back with surface 40.

The surface 48 of the anode 24 facing the gate electrode 26 corresponds theoretically to a hyperboloid co-asymptotic with the surface 40, but may be for convenience an approximation of such theoretical surface, such as a parti-spherical surface, as shown in the drawing, of radius about twice the axial spacing of the anode 24 from the limiting aperture 46. The anode 24 has a flat surface facing the cathode and normal to the Z axis, and extending through the anode is a coaxial electron beam entrance passage 50 of sufficient size to accommodate the collimated electron beam from the cathode.

The anode 24 and gate electrode 26 are biased so as to form one-half of a decelerating and converging hyperbolic lens having its saddle point positioned so as to substantially coincide with the defining aperture 46.

In accordance with the invention, modulating signal voltage supplied to the gate electrode 28 of FIG. 4 controls the amount of current in the output beam emerging from aperture 46 in two ways. First it determines what portion of the current entering the lens will be forwarded through the gate electrode 26, the remainder of the current supplied to the lens being reflected back toward the anode 24 for collection thereby. Second, the modulation signal voltage varies the focal length of the lens and hence varies the position of the focal point relative to the aperture 46. According to the invention, the condition of optimum focus at aperture 46 is made to occur in substantial coincidence with maximum current transfer through the gate electrode. Thus when the gate electrode 26 is supplied with beam intensity modulating signals, an intensity modulated virtual cathode is formed adjacent aperture 46, and the electron beam emerging from aperture 46 can be smoothly varied from maximum intensity to virtually complete cutoff with a desirably large transconductance characteristic. This performance is illustrated graphically in FIG. 2 by curve 51, which it will be noted rises smoothly from cut-off to a maximum current at point 52 which is substantially equal to the current at point 16 of curve 15.

Since the virtual cathode at aperture 46 draws electrons from a cathode 20 which is relatively large compared to the size of aperture 46, the virtual cathode has a potential peak emission density many times that of cathode 20, and peak emission densities corresponding to approximately 10 amperes per square centimeter, on the equivalent spherical diode basis, have been obtained in such structures actually built and tested.

After going through aperture 46, the beam is reconverged to desired divergence angle by the lens action of the field produced betweeen the meniscus electrode 28 and the adjacent portion of the barrel electrode 30.

In one exemplary embodiment of electron gun constructed as shown in FIG. 4, the diameter of the emissive surface of the cathode 20, as well as that of passage 50 and throat 38, was about .060"; the outer diameter of surfaces 40 and 48 was about ½ inch; the radius of surface 48 was about ½ inch; the length of throat 38 was about .060 inch; electrodes 26 and 28 were axially spaced about .015 inch and diaphragm 44 had a thickness of about .005 inch with an aperture of about .015 inch; the axial spacing of surface 48 from aperture 46 was about ¼ inch; wall 32 was spaced about ⅛ inch from electrode 28 and about 7/32 inch from aperture 46 and had a central opening about ⅛ inch in diameter. With such a gun excellent operating results were obtained with bias voltages relative to the cathode of zero for electrode 22, +500 volts for electrode 24, +150 volts for electrode 28, +3000 volts for electrode 30, and a modulating signal at gate electrode 26 varying from about −10 volts to +5 volts. Under such operating conditions beam currents emerging from aperture 46 could be varied from about 1000 microamperes down to substantially complete cutoff with subtended beam angles of about 6 degrees. Excellent resolution of television pictures, exceeding 500 lines, with brightness levels of the order of 250 foot lamberts was achieved and spot size increase with current was much less than in conventional television picture tubes, by a factor of about three.

FIG. 5 shows another embodiment of my invention in which the electron gun structure is similar to that of FIG. 4 except that the meniscus electrode 128 forms a portion of a container 150 for enclosing the remaining electrodes 124, 126, etc. of the gun such that the only opening from within the container to the space outside it is the electron beam defining aperture 146. Although the aperture 146 in electrode 128 prevents the container 150 from being permanently evacuated, the entire structure itself may be housed in a larger permanently evacuated container for operating purposes. Alternatively, since the aperture 146 can be made so small in practice, for example 1 to 2 mils, that leakage through it will occur at a very low rate, the container 150 may be operated in a continuously or intermittently pumped manner, as by connection through a tubulation 152 or in other desired manner to an ionic pump or the main evacuating means of a surrounding environment, or other suitable evacuating means. If container 150 is enclosed in a continuously pumped larger chamber, and separately connected, for example, to the main evacuating means of the larger chamber, an excellent vacuum can be readily developed in container 150 even though only a lesser degree of vacuum is obtainable in the larger chamber.

A device such as shown in FIG. 5 provides a convenient cartridge-like arrangement for generating an intensity modulatable electron beam, and since a high degree of vacuum may be readily maintained in container 150, even though container 150 itself is situated in an environment evacuated to a lesser degree, the device of FIG. 5 may satisfactorily utilize a cathode of a type, such as an oxide-coated cathode, which would otherwise be quickly destroyed in the less evacuated environment. Of course it should be noted that with use of a cartridge-like structure such as shown in FIG. 5, various desired functions such as beam reconvergence, focus to a target, and deflection across a target, must still be performed outside the container 150. However it will be appreciated that such additional conventional electrode structure as may be required for the latter functions is not subject to deterioration by such deleterious ingredients as may occur in the less evacuated enviromnent.

FIG. 6 shows another embodiment of an electron gun somewhat similar to that of FIG. 4 except that the reconvergence of the electron beam after it emerges from aperture 46 is accomplished by a symmetrical hyperbolic lens formed between the elements 62, 64 and 66. The elements 62 and 66 are cylinders having opposing end walls 68 and 70 which are theoretically biparted hyperboloids coaxial with the Z axis but in practice may be approximations to such theoretical surfaces, such as parti-spherical surfaces. Likewise the interior surface of annular element 64 is a hyperboloid of revolution about the Z axis asymptotic to a cone of apex angle about 109°. As shown the electrodes 62 and 66 have a common accelerating potential which is substantially higher than that of electrode 28, and preferably may equal or approximate the luminescent screen material. Electrode 64 has a lesser potential which may approximate the operating potential of electrode 24 by suitable spacing of surfaces 68 and 70. A reconverging lens is formed between the conical profile of electrode 28 and cylinder 62. This lens is particularly effective for reconverging the beam from aperture 46 to a very small divergence angle, because the substantial voltage ratio between electrode 62 and electrode 28 provides a strong reconverging field. Thus, because of the effectiveness of reconvergence, beams of the order of 3° divergence angle currents of 1000 microamperes have been observed in structure such as shown in FIG. 6.

It will be appreciated by those skilled in the art that the invention may be carried out in various ways and may take various forms and embodiments other than those illustrative embodiments heretofore described. It is to be understood that the scope of the invention is not limited by the details of the foregoing description, but will be defined in the following claims.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. An electron optical system comprising entrance and exit coaxial annular electrodes, means for applying an electron beam decelerating potential difference between said entrance and exit electrodes, intermediate electrode means between said entrance and exit electrodes and cooperating therewith to provide an electrostatic field therebetween in which the equipotential surfaces correspond substantially to hyperboloids asymptotic to a coaxial cone having an apex angle of 109° and having its apex substantially coincident with the coaxial opening in said exit electrode, and means for applying an electron beam intensity modulating signal to said intermediate electrode means.

2. An electron optical system comprising means for generating an electrostatic field in which the equipotential surfaces correspond substantially to hyperboloids of revolution asymptotic to a cone of apex angle 109° and coaxial with a reference axis, said field generating means including a coaxial annular first electrode through which a coaxial electron beam may be admitted to said field and a coaxial annular gate electrode, said first and said gate electrodes having confronting surfaces conforming substantially to equipotential surfaces of said field, said gate electrode defining a beam passage throat substantially coincident with said asymptotic cone apex, and means for applying intensity modulation signals to said gate electrode.

3. An electron optical system comprising means for generating an electrostatic field in which the equipotential surfaces correspond substantially to hyperboloids of revolution asymptotic to a cone of apex angle 109° and coaxial with a reference axis, said field generating means including a first annular coaxial electrode through which a coaxial electron beam may be admitted to said field, an annular exit electrode coaxially spaced from said first electrode, and an annular gate electrode coaxially disposed between the first electrode and exit electrode, said first and said gate electrodes having confronting surfaces conforming substantially to equipotential surfaces of said field, the exit opening of said exit electrode being axially located in substantial coincidence with the apex of said asymptotic cone.

4. An electron optical system comprising means for generating an electrostatic field in which the equipotential surfaces correspond substantially to hyperboloids of

revolution asymptotic to a cone of apex angle 109° and coaxial with a reference axis, said field generating means including a coaxial annular first electrode through which a coaxial electron beam may be admitted to said field and a coaxial annular gate electrode to which electron beam intensity modulating signals may be applied, said first and said gate electrodes having confronting surfaces conforming substantially to equipotential surfaces of said field, and means forming an aperture through which the electron beam can emerge from said field, said aperture being located in substantial coincidence with the apex of said asymptotic cone.

5. An electron optical system comprising means for generating an electrostatic field in which the equipotential surfaces correspond substantially to hyperboloids of revolution asymptotic to a cone of apex angle 109° and coaxial with a reference axis, said field generating means including a coaxial annular first electrode through which a coaxial electron beam may be admitted to said field and a coaxial annular gate electrode to which electron beam intensity modulating signals may be applied, said first and said gate electrodes having confronting surfaces conforming substantially to equipotential surfaces of said field, means forming an aperture through which the electron beam can emerge from said field, said aperture being located in substantial coincidence with the apex of said asymptotic cone, and means forming a convergence field in the path of the electron beam emerging from said aperture.

6. An electron optical system comprising means for generating an electrostatic field in which the equipotential surfaces correspond substantially to hyperboloids of revolution asymptotic to a cone of apex angle 109° and coaxial with a reference axis, means for introducing into said field a substantially collimated electron beam coaxial with said reference axis, said field generating means including a coaxial annular first electrode through which a coaxial electron beam may be admitted to said field and a coaxial annular exit electrode, an annular gate electrode coaxially disposed between said first electrode and exit electrode, said gate electrode and first electrode having confronting surfaces conforming substantially to equipotential surfaces of said field, said gate electrode being axially positioned closer to said exit electrode than to said first electrode, means for applying relative potentials to said first and exit electrodes such that said electrostatic field exerts a decelerating and focusing action on an electron beam admitted through said first electrode, and means for applying electron beam intensity modulating signals to said gate electrode.

7. An electron gun comprising means for generating an electrostatic field in which the equipotential surfaces correspond substantially to hyperboloids of revolution asymptotic to a cone of apex angle 109° and coaxial with a reference axis, means including a coaxial annular first electrode through which a substantially collimated electron beam coaxial with said reference axis may be introduced into said field and a coaxial annular gate electrode, said first and said gate electrodes having confronting surfaces conforming substantially to equipotential surfaces of said field, exit electrode means forming an exit aperture for emergence of said beam from said field, said exit aperture being located in substantial coincidence with the apex of said asymptotic cone, means for applying a bias potential V_o to said first electrode and a bias potential V_L to said exit electrode, means for applying a bias potential to the gate electrode such that the field potential V_m at said cone apex conforms substantially to the expression

$$\frac{V_m}{V_o}=1-1.05[1-0.22\sqrt{P}]^2$$

where P is V_{L/V_o}, and means for applying an electron beam intensity modulation signal to said gate electrode.

8. An electron gun comprising means for generating an electrostatic field in which the equipotential surfaces correspond substantially to hyperboloids of revolution asymptotic to a cone of apex angle 109° and coaxial with a reference axis, means for introducing into said field a substantially collimated electron beam coaxial with said reference axis, said field generating means including a coaxial annular first electrode and a coaxial annular gate electrode, said first and said gate electrodes having confronting surface conforming substantially to equipotential surfaces of said field, means for applying an electron beam decelerating bias between said first and gate electrodes, means for applying an electron beam intensity modulation signal to said gate electrode, and means forming an exit aperture for emergence of said beam from said field, said aperture being located in substantial coincidence with the apex of said asymptotic cone.

9. An electron gun comprising means for generating an electrostatic field in which the equipotential surfaces correspond substantially to hyperboloids of revolution asymptotic to a cone of apex angle 109° and coaxial with a reference axis, electrode means for introducing into said field a substantially collimated electron beam coaxial with said reference axis, said field generating means including a coaxial annular first electrode and a coaxial annular gate electrode, said first and said gate electrodes having confronting surfaces conforming substantially to equipotential surfaces of said field, means for applying an electron beam decelerating bias between said first and gate electrodes, means for applying an electron beam intensity modulation signal to said gate electrode, an evacuatable container for housing said electrodes, a meniscus electrode forming a portion of said container and having an exit aperture through which said beam may emerge from said field, said aperture being located in substantial coincidence with the apex of said asymptotic cone.

10. An electron gun comprising means for generating an electrostatic field in which the equipotential surfaces correspond substantially to hyperboloids of revolution asymptotic to a cone of apex angle 109° and coaxial with a reference axis, means for introducing into said field a substantially collimated electron beam coaxial with said reference axis, said field generating means including a coaxial annular first electrode and a coaxial annular gate electrode, said first and said gate electrodes having confronting surfaces conforming substantially to equipotential surfaces of said field, means for applying an electron beam intensity modulation signal to said gate electrode, means forming an exit aperture for emergence of said beam from said field, said aperture being located in substantial coincidence with the apex of said asymptotic cone, and means forming an electron beam converging field in the path of the electron beam emerging from said aperture.

11. An electron optical system comprising an annular first electrode through which an electron beam having a reference axis may be introduced, a coaxial annular gate electrode axially spaced from said first electrode, said first and gate electrodes having confronting surfaces conforming substantially to hyperboloids coasymptotic to a coaxial cone whose apex angle is 109°, a coaxially apertured meniscus electrode adjacent to said gate electrode on the opposite side thereof from said first electrode, means for applying a potential V_o to said first electrode and a potential V_L to said meniscus electrode, said gate electrode having an axial spacing from said first electrode such that the axial spacing Z_m of the apex of said asymptotic cone from said first electrode conforms substantially to the expression

$$\frac{Z_m}{L}=0.5+0.78\left(\frac{1-\sqrt{P}}{1+\sqrt{P}}\right)=1$$

where P is the ratio V_{L/V_o} and L is the axial spacing of said meniscus electrode from said first electrode, means for biasing said gate at a potential such that the field potential V_m at the apex of said asymptotic cone conforms approximately to the expression

$$V_{m}/V_{0}=1-1.05\,[1-0.22\sqrt{P}]^2$$

and means for applying intensity modulating signals to said gate electrode.

12. An electron optical system comprising an annular first electrode through which an electron beam having a reference axis may be introduced, a coaxial annular gate electrode axially spaced from said first electrode, said first and gate electrodes having confronting surfaces conforming substantially to hyperboloids coasymptotic to a coaxial cone whose apex angle is 109°, a coaxially apertured meniscus electrode adjacent to said gate electrode on the opposite side thereof from said first electrode, means for applying a potential V_0 to said first electrode and a potential V_L to said meniscus electrode, said gate electrode having an axial spacing from said first electrode such that the axial spacing Z_m of the apex of said asymptotic cone from said first electrode conforms substantially to the expression

$$\frac{Z_m}{L}=0.5+0.78\left(\frac{1-\sqrt{P}}{1+\sqrt{P}}\right)=1$$

where P is the ratio V_L/V_0 and L is the axial spacing of said meniscus electrode from said first electrode, means for biasing said gate at a potential such that the field potential V_m at the apex of said asymptotic cone conforms approximately to the expression

$$V_{m}/V_{0}=1-1.05\,[1-0.22\sqrt{P}]^2$$

and means for applying intensity modulating signals to said gate electrode, and means forming an electron beam converging field adjacent the exit side of the aperture in said meniscus electrode.

13. An electron gun comprising means for generating an electrostatic field in which the equipotential surfaces correspond substantially to hyperboloids of revolution asymptotic to a cone of apex angle 109° and coaxial with a reference axis, means for introducing into said field a substantially collimated electron beam coaxial with said reference axis, said field generating means including a coaxial annular first electrode and a coaxial annular gate electrode to which an electron beam intensity modulation signal is adapted to be applied, said first and said gate electrodes having confronting surfaces conforming substantially to equipotential surfaces of said field, a meniscus electrode transverse to said axis and having a coaxial aperture located in substantial coincidence with the apex of said asymptotic cone, said meniscus electrode having a convergence lens surface facing away from said gate electrode and conforming substantially to a hyperboloid asymptotic with a second cone of apex angle 109° coaxial with said reference axis, and electrode means opposite said convergence lens surface and cooperating with said convergence lens surface to form a beam converging field opposite the exit side of said aperture.

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