Aug. 15, 1961 A. L. EICHENBAUM 2,996,640

VARIABLE BEAM ELECTRON GUN

Filed Nov. 20, 1958 3 Sheets-Sheet 1

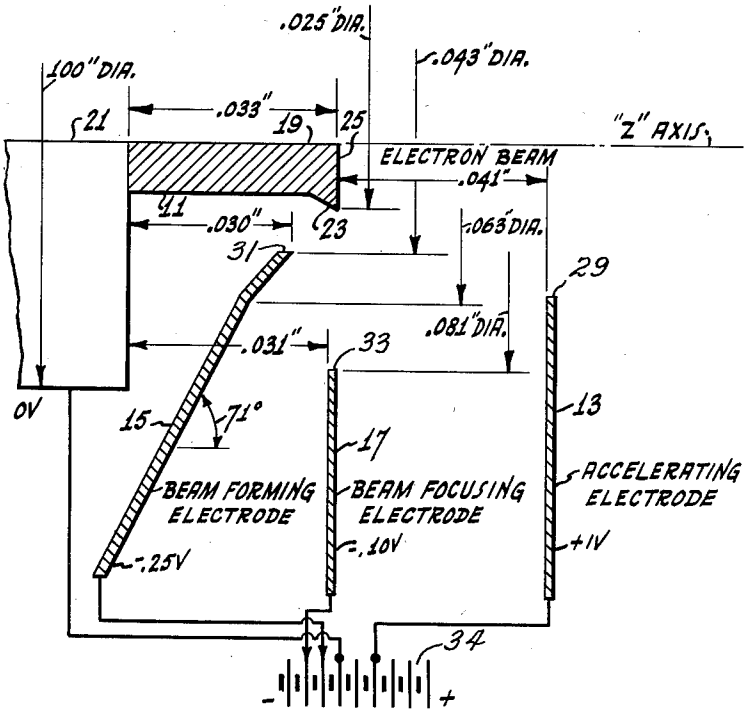


Fig. 1.

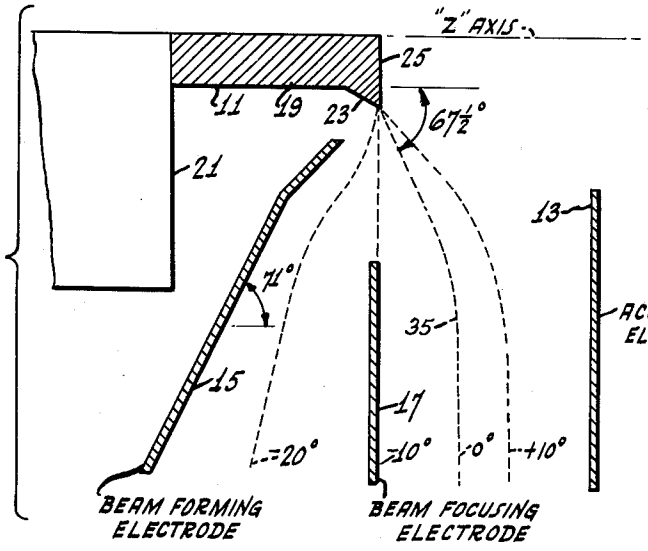


Fig. 2.

INVENTOR.
ARIE L. EICHENBAUM
BY
L A Larsen
ATTORNEY

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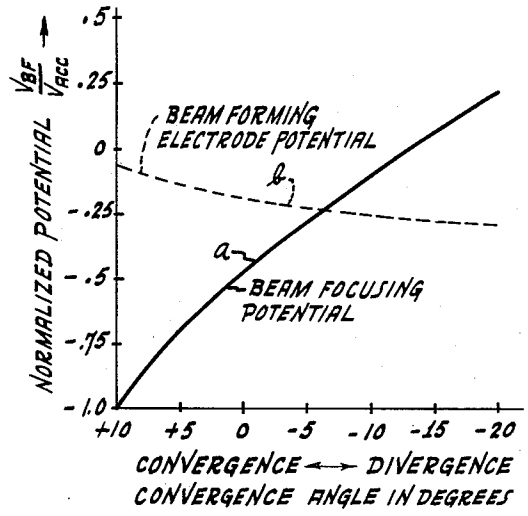


Fig. 3.

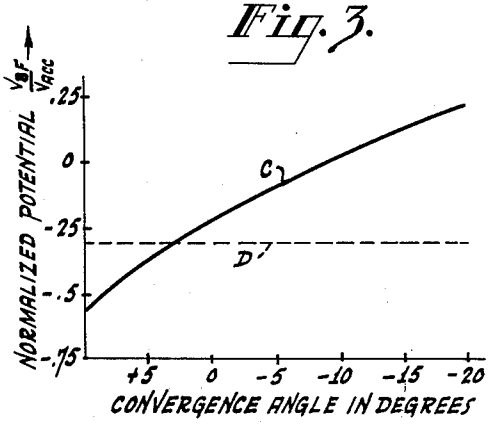


Fig. 4.

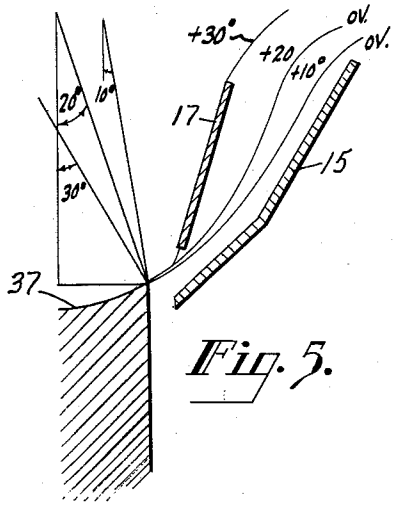


Fig. 5.

INVENTOR.
ARIE L. EICHENBAUM
BY
L A Larsen
ATTORNEY

Aug. 15, 1961 A. L. EICHENBAUM 2,996,640

VARIABLE BEAM ELECTRON GUN

Filed Nov. 20, 1958 3 Sheets-Sheet 3

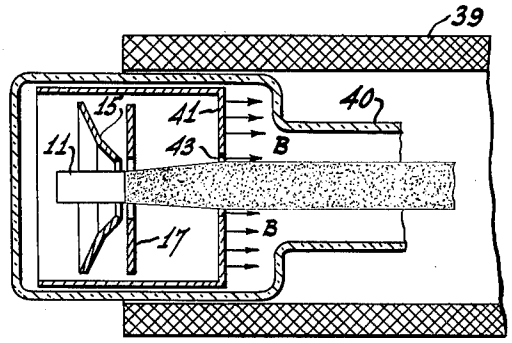


Fig. 6.

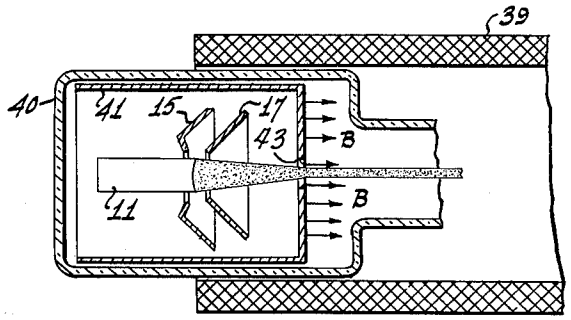


Fig. 7.

INVENTOR.
ARIE L. EICHENBAUM
BY
L A Larsen
ATTORNEY

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VARIABLE BEAM ELECTRON GUN

Arie L. Eichenbaum, Princeton, N.J., assignor to Radio Corporation of America, a corporation of Delaware

Filed Nov. 20, 1958, Ser. No. 775,195
9 Claims. (Cl. 315—15)

This invention relates to electron guns, and particularly to a novel and improved means for controlling the trajectory and shape of high density electron beams.

High density electron beam-type amplifiers and oscillators generally require electron guns which provide electron beams having uniform density, laminar rectilinear flow, and a prescribed divergence or convergence angle. As presently known, most electron beam-type microwave amplifiers, such as the traveling wave tube and the klystron, employ a Pierce type of electron gun. The Pierce type electron gun uses shaped electrodes having a specified geometry to control the flow and focusing of the electrons in the tube thus producing a uniform rectilinear electron flow. According to the Pierce principle, an ideal electrode arrangement provides a zero equipotential surface disposed at approximately a 67½° angle with respect to the normal to the cathode emitting surface at the periphery thereof. (Refer to "Vacuum Tubes" by K. R. Spangenberg, 1948, pages 450–458.) The predetermination of the electrode arrangement in the electron gun generally fixes the shape of the electron beam so that the beam is initially convergent or divergent at a fixed angle.

It is desirable to have an electron gun which allows simple control external to the electron tube for shaping an electron beam. An external adjustable control to vary the initial divergence or convergence of an electron beam may also be advantageous in reducing the noise figure of an electron tube.

An object of this invention is to provide a novel and improved electrode configuration for an electron gun.

Another object of this invention is to provide an improved electron gun having a control external to the electron tube which can vary the initial divergence or convergence of the electron beam.

Another object is to effect a reduction in the noise figure of an electron tube.

According to the invention, a beam-focusing electrode is positioned between the conventional beam-forming and accelerating electrodes of a Pierce-type electron gun. The configuration of the electrodes is such that when the voltage of the beam-focusing electrode is varied, the initial angle of divergence or convergence of the electron beam is controllably changed. Means external to the electron tube are provided for adjusting the voltage of the beam focusing electrode thus affording a convenient control for modifying the shape of the electron beam.

The invention will be described in greater detail with reference to the drawing wherein:

FIG. 1 is a transverse sectional view of an electron gun according to the invention, cut in half, showing the configuration of electrodes required for an electron beam which may be varied from 10° convergent to 20° divergent;

FIG. 2 is a transverse sectional view of an electron gun, cut in half, showing the same configuration of electrodes as in FIG. 1, including zero equipotential surfaces for several convergence-divergence angles as measured in an electrolytic tank;

FIGS. 3 and 4 are graphs including curves indicating the voltages applied to the beam-forming and beam-focusing electrodes of the electron gun to produce a particular convergence-divergence angle of the electron beam;

FIG. 5 is a transverse sectional view of an electron gun, cut in half, showing the configuration of electrodes required for an electron beam which may be varied from 10° convergent to 30° convergent; and

FIGS. 6 and 7 are partial sectional views of electron tubes positioned in a magnetic field and incorporating electron guns similar to those illustrated in FIGS. 1 and 5, respectively.

Similar elements are indicated by similar reference characters throughout the drawing.

An embodiment of this invention is shown in FIG. 1, in half section, wherein an electron gun comprises a cathode electrode **11**, an accelerating electrode **13**, a beam-forming electrode **15**, and a beam-focusing electrode **17**. The various elements of the electron gun structure are supported as a unit within a tube envelope. The cathode **11** consists of a narrow cylindrical portion **19** joined with a broader cylindrical portion **21**, the narrow portion **19** being solid whereas the broad portion **21** is hollow. The solid cylindrical cathode portion **19** flares outwardly at one end to form a frustoconical portion **23** having as a base a transverse surface which is coated with a thermionic emitting material to provide a cathode emitting face **25**. The emitting face **25** lies in a plane substantially perpendicular to the longitudinal axis of the cathode **11**, hereinafter designated the Z axis. A heater filament (not shown) is positioned within the hollow cylindrical section **21** for supplying heat to the cathode **11** to cause emission of electrons from the cathode emitting face **25**. During operation of the tube, a high density electron beam which may be initially convergent or divergent is projected along the Z axis from the emitting face **25**.

The accelerating electrode **13** is an annular electrode in the form of a disk having a centrally located aperture **29**, which is larger in area than the emitting face **25**, to allow passage of the electrons emitted from the cathode face **25**. The accelerating electrode **13** is spaced from the emitting face **25**, preferably at a distance greater than the diameter or width of the face **25**, along the Z axis in the direction of electron beam, and is mounted concentric to the Z axis. The position and the voltage of the accelerating electrode **13** are factors in determining the shape of the electron beam and the total current drawn.

Fixed closely adjacent to the narrow portion **19** of the cathode **11** is the beam-forming electrode **15** which is generally conical, in the example shown in FIG. 1, and has a relatively small central aperture **31**. The electrode **15** is so positioned that its aperture **31** is spaced behind the cathode face **25**, as shown in FIG. 1. The beam-forming electrode **15** is shaped in such a manner as to produce a required zero potential surface adjacent to the cathode emitting face **25**.

According to this invention, a beam focusing electrode **17** having a relatively large aperture **33** is mounted coaxially with and intermediate the accelerating electrode **13** and the beam-forming electrode **15**. The beam-focusing electrode **17** is preferably an annular disk which is positioned substantially in the plane of the cathode emitting face **25**. Small changes of voltage applied to the electrode **17** shifts the zero equipotential surface substantially thus varying the electron beam shape.

A source of direct current voltage **34** provides suitable potentials to each of the electrodes. In the preferred embodiment of the invention, the cathode **11** and the accelerating electrode are maintained at constant voltages, whereas the voltage applied to the beam-forming electrode **15** and beam-focusing electrode **17** may be varied.

In FIG. 2 there are shown geometrical relationships of various zero potential surfaces for corresponding convergence-divergence angles of the electron beam that were determined by measurements made in an electrolytic tank, which method is well known in the art. Thus, for a parallel rectilinear beam having a zero convergence-divergence angle, a zero equipotential surface **35** forms a 67½° angle relative to the Z axis within a beam radius

from the periphery of the cathode emitting surface **25**. With the electrode configuration illustrated, measurements indicate that at distances of about 3 beam radii from the periphery of the cathode face **25**, the zero equipotential surface **35** for zero convergence-divergence becomes arcuate and defines a larger angle than 67½° with respect to the Z axis.

The geometrical arrangement of the electrodes shown in FIGS. 1 and 2 creates zero equipotential surfaces corresponding to electron beam angles of convergence-divergence between 20° divergence and 10° convergence depending upon the potentials of the beam-forming electrode **15** and the beam-focusing electrode **17**. As illustraed in FIG. 2, the zero equipotential surface for a 20° divergent beam is represented by the line denoted as −20°. The beam-focusing electrode **17**, in this embodiment of electron gun shown by way of example, is located close to the zero potential surface for an electron beam having a 10° divergent flow denoted as −10°. It is understood that the beam-focusing electrode **17** may be positioned along any other equipotential surface provided that it is located in the approximate center of the desired convergence-divergence range, for example, from 20° divergent to 10° convergent as show in FIG. 2. The zero equipotential surface for a 10° convergent beam is denoted as +10° in FIG. 2.

The graph of FIG. 3 illustrates the voltages which are applied to the beam-forming electrode **15** and beam-focusing electrode **17** of the configuration of FIGS. 1 and 2 to produce a beam within the range of 10° convergence to 20° divergence, when the cathode is maintained at zero potential. In the example shown in FIG. 1, with a voltage on the accelerating electrode **13** of one volt positive with respect to the cathode, the beam-focusing electrode **17** is set at about .10 volt negative relative to ground, and the beam-forming electrode is set at approximately .25 volt negative relative to ground to produce a beam having a 10° divergence angle. The ordinate values of the graph of FIG. 3 represent normalized potentials

$$\frac{V_{BF}}{V_{ACC}}$$

where for a given angle of convergence-divergence, V_{BF} is the voltage applied to the beam-forming electrode **15** as indicated by a curve *a*, V_{BF} is also the voltage applied to the beam-focusing electrode **17** as read on curve *b*, and V_{ACC} is the voltage of the accelerating electrode **13**. Thus, any change in the accelerating electrode voltage requires a proportional change in the beam electrodes **15** and **17** for the same electron beam flow angle.

It is noted that the voltage applied to the beam-forming electrode **15** is varied to a smaller degree in relation to the changes in potential applied to the beam-focusing electrode **17**. While holding the beam-forming electrode **15** at a constant potential of about .30 volt negative relative to the cathode, measurements made with the electrolytic tank indicate that variations in potential from about .53 volt negative to about .22 volt positive applied to the beam-focusing electrode **17** change the angle of the electron beam from 10° convergent to 20° divergent, as shown by curves *c* and *d* in FIG. 4.

Other combinations of electrodes and applied potentials may be used for different desired ranges of electron beam convergence-divergence. As an example, a configuration of electrodes such as disclosed in FIG. 5 may be employed, wherein the cathode emitting surface **37** is concave and aids in converging the electron beam, to produce a high density electron beam in the range of 10° to 30° convergence. The beam-focusing electrode **17** and the beam-forming electrode **15** are set at smaller angles relative to the Z axis than in the arrangement of electrodes for the case of 10° convergence to 20° divergence. However, in every application of the invention, the zero potential surface for a particular electron beam angle of convergence-divergence is located between the beam-forming electrode **15** and the beam-focusing electrode **17**.

To provide an electron gun having a maximum divergence angle greater than 20°, the beam-forming electrode **15** is located further away from the beam-focusing electrode **17**. If a greater convergence angle than 10° is required, the beam-focusing electrode **17** may be located along the 0° or 5° convergence zero potential surface. A total range of 40° divergence to 10° convergence may then be covered with an electron gun, according to the invention, by the simple adjustment of the potentials of the beam-forming electrode **15** and the beam-focusing electrode **17**. By the use of a gun structure that produces a beam that is divergent in the region near the cathode **11**, the noise figure of the tube is substantially reduced.

In microwave beam tubes, the beam from a magnetically shielded Pierce type gun normally enters a strong axial magnetic field near a point where the radius of the beam is a minimum, so that magnetic focusing forces largely determine the beam's subsequent behavior. The initial formation of the electron beam is determined principally by the electric fields which are established according to the shapes, potentials, and arrangement of the gun electrodes.

When the electrons of a beam which enter the magnetic focusing field have a transverse velocity component, the Brillouin flow is affected and a poorly formed, scalloped beam may result. The Brillouin flow is defined as a magnetically focused electron stream in which all electrons are considered to be rotating in circles concentric with the axis with uniform angular velocity and have the same axial component of velocity. Forces acting on electrons are in balance at all radii. However, a random transverse electron velocity distribution in the beam results in a flow condition differing appreciably from this ideal picture, and the scalloping effect occurs.

The electrode configurations described herein afford the advantage of providing proper Brillouin flow when utilized in an electron tube which is positioned in a magnetic field. In each of FIGS. 6 and 7, a magnetic field is shown provided by an external magnetic coil **39** surrounding a tube envelope **40**. The gun comprises an accelerating electrode **41** in the form of a cylindrical cup of magnetic material having a central aperture **43**. The cup **41** encloses the cathode **11**, the beam-forming electrode **15** and beam-focusing electrode **17** to serve as a magnetic shield therefor. The fringing magnetic field B produced by the coil **39** in the aperture **43** deflects the electrons which pass through the aperture **43** of the accelerating electrode **41** into spiral paths to produce a constant diameter beam with Brillouin flow.

A feature of this embodiment incorporating the invention is that the location of the magnetic shield or accelerating electrode **41** is not critical because the plane of minimum beam diameter may be shifted by varying the potentials of the beam-forming electrode **15** and the beam-focusing electrode **17**. Also, by employing the desired gun design and potentials, proper boundary conditions along the edge of the beam at the cathode are established resulting in uniform emission and a well-collimated beam. Since the electrons of the beam arrive at the aperture of the accelerating electrode with a small radial velocity as a result of the adjusted flow angle, a laminar flow of electrons with a uniform current density over the cross section of the electron beam is provided upon entry into the magnetic field B causing a consequent reduction in scalloping. Also, since there is a laminar rectilinear flow of electrons towards the target, a magnetic field of lower intensity is required for focusing. Therefore, a smaller magnet of less weight and requiring less power may be employed to provide a weaker magnetic field.

It is understood that the invention is not limited to the geometries of the electrodes shown by way of example, but is applicable to various combinations of electrodes

employed in an electron gun which includes a beam-forming electrode with an aperture located behind a cathode emitting face and a beam-focusing electrode having an aperture substantially in the plane of the cathode emitting surface with means external to the tube for varying the potential of the beam-focusing electrode.

What is claimed is:

1. An electron gun for producing and shaping an electron beam comprising a cathode having an electron emitting surface with a predetermined width, a beam-forming electrode and a beam-focusing electrode, said electrodes each having a single aperture in a plane located adjacent to said emitting surface at a distance from said surface less than one half of said width, and terminal means for applying different variable voltages to said electrodes to vary the convergence-divergence angle of the beam.

2. An electron gun contained within an electron tube for projecting a variable-shape electron beam along a predetermined axis comprising a cathode having an emissive surface, a plurality of spaced apertured electrodes including a beam-forming electrode, a beam-focusing electrode and an accelerating electrode coaxially mounted relative to said axis and spaced from said emissive surface, the aperture of said beam-focusing electrode being substantially in the plane of said emissive surface and positioned between the other two of said apertured electrodes, and terminal means external to said tube for applying different potentials to said electrodes, and means for varying the potential applied to said beam-forming and beam-focusing electrodes to vary the convergence-divergence angle of said electron beam.

3. An electron gun for projecting an electron beam comprising a cathode electrode having an emitting face, a beam-forming electrode having an aperture therein, a beam-focusing electrode having an aperture therein, the planes of said apertures being spaced from said cathode emitting face at distances less than one half of the width of said emitting face, an accelerating electrode positioned in front of and spaced from said cathode face at a distance greater than said width, means for applying different potentials to said electrodes, and means for separately varying the potentials of the beam-forming and beam-focusing electrodes to vary the convergence-divergence angle of the electron beam.

4. An electron gun in an electron tube for producing a high density electron beam comprising a cathode electrode having an emitting face, an accelerating electrode spaced from and in front of said emitting face, a beam-forming electrode disposed behind said emitting face, a beam-focusing electrode positioned between said accelerating and beam-forming electrodes, means for applying potentials to said electrodes, and means external to said tube for varying the potential applied to said beam-focusing electrode whereby the angle of convergence or divergence of said electron beam is changed.

5. An electron gun for providing an electron beam comprising a cathode electrode having an emitting face for producing an electron beam, a beam-forming electrode having an aperture closely spaced from and disposed behind said cathode emitting face, an accelerating electrode disk positioned in front of said cathode emitting face having an aperture larger in diameter than said beam-forming electrode aperture, a beam-focusing electrode positioned between said beam-forming and accelerating electrodes and having an aperture substantially in the plane of said emitting face, means for applying voltages to said electrodes, and means for varying the voltage applied to said beam-focusing electrode whereby the convergence-divergence angle of said electron beam is varied.

6. An electron gun for projecting a variable-shape electron beam along a predetermined axis comprising a cathode having an emissive surface transverse to said axis, an apertured accelerating electrode spaced from said cathode, an annular beam-forming electrode having an aperture, an annular beam-focusing electrode between said accelerating electrode and said beam-forming electrode and lying substantially in the transverse plane of said emissive surface, whereby said gun can be controlled to provide either convergent, divergent or parallel flow in the region between said cathode and said accelerating electrode by the application of suitable voltages to said beam-forming and said beam-focusing electrodes.

7. An electron gun for producing an electron beam comprising a cathode electrode having an emissive surface of approximately .025 inch diameter, the longitudinal axis of said cathode electrode passing through the approximate center of said surface at a normal to the plane of said surface, an accelerating electrode having an aperture spaced in front of said emissive surface at a distance of about .041 inch, a beam-forming electrode having an aperture surrounding said cathode, the plane of said beam-forming electrode aperture parallel to and spaced from said emissive surface at about .003 inch, a beam-focusing electrode disposed between said accelerating electrode and said beam-forming electrode having an aperture, the plane of said beam-focusing electrode aperture positioned substantially in the plane of said emissive surface, means for applying voltages to said electrodes, and means to vary the voltages of the beam-forming and beam-focusing electrodes thereby changing the shape of said electron beam.

8. A variable shape electron beam producing device comprising an electron gun having a cathode electrode with an electron emitting surface, a plurality of electrodes having apertures spaced closely from said cathode emitting surface, means for applying variable potentials to said plurality of electrodes, to vary the convergence-divergence angle of the beam, a cup-shaped accelerating electrode of magnetic material magnetically shielding said electrodes and having an aperture aligned with said first named apertures, and means for providing a magnetic field along the axis of said device for producing a uniform diameter electron beam having Brillouin flow in the region beyond the aperture in said cup-shaped electrode.

9. An electron gun for projecting a variable-shape electron beam along a predetermined axis comprising a cathode having an emissive surface transverse to said axis, an apertured accelerating electrode spaced from and in front of said cathode, an annular beam-forming electrode, and an annular beam-focusing electrode between said accelerating electrode and said beam-forming electrode, the apertures in said annular beam-forming and beam-focusing electrodes being disposed close to the plane of said emissive surface, whereby said gun can be controlled to produce various degrees of convergence or divergence, or parallel flow, in the region between said cathode and said accelerating electrode by the application of suitable potentials to said beam-forming and beam-focusing electrodes.

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