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J. W. KLÜVER

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ELECTRON GUN FOR REDUCING TROCHOIDAL MOTION OF ELECTRONS

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FIG. 1

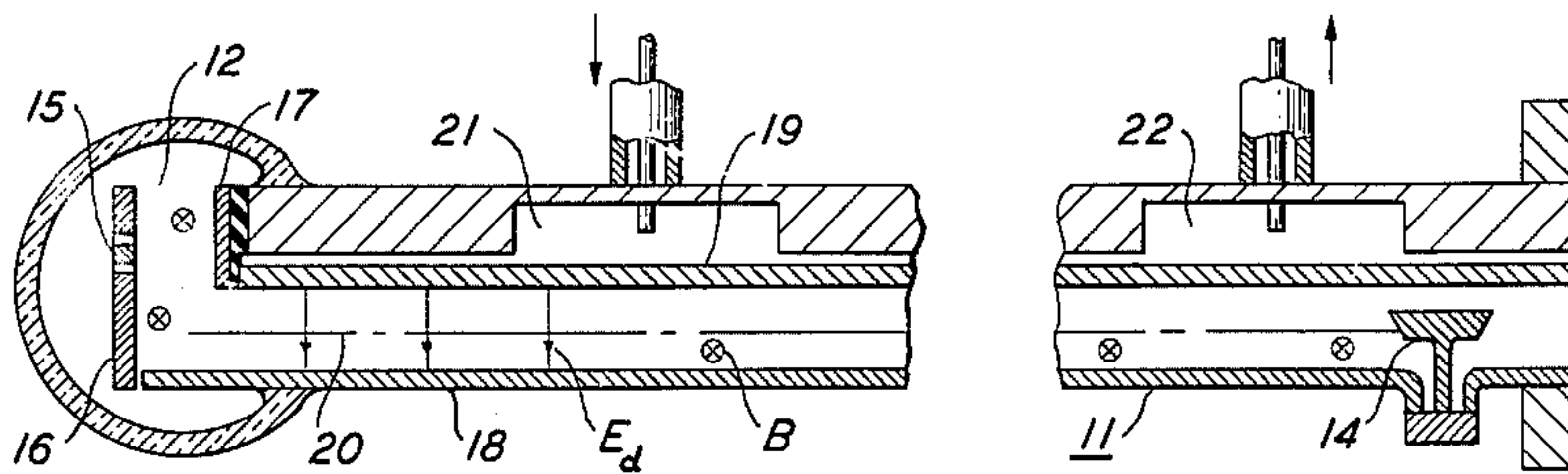


FIG. 2

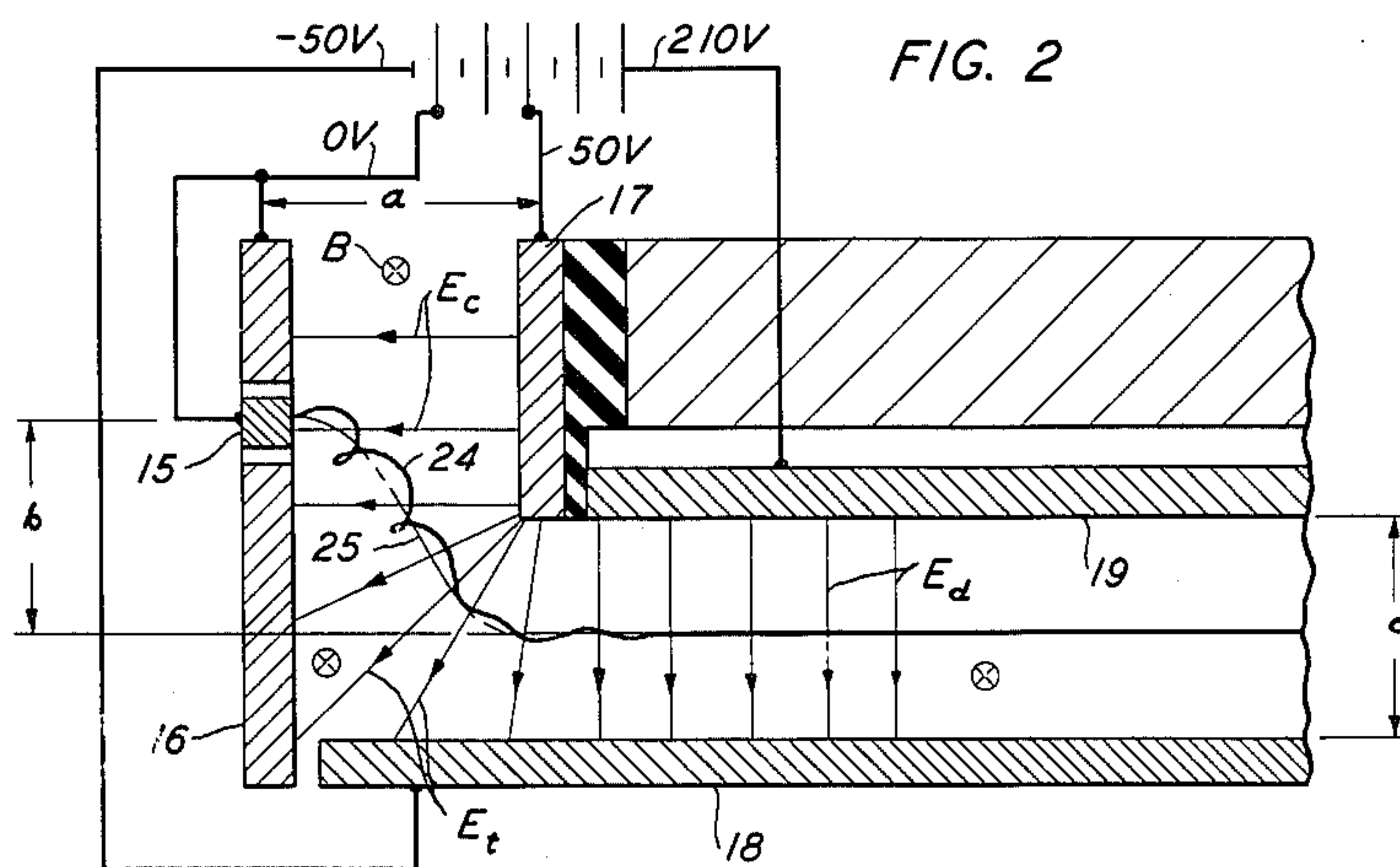
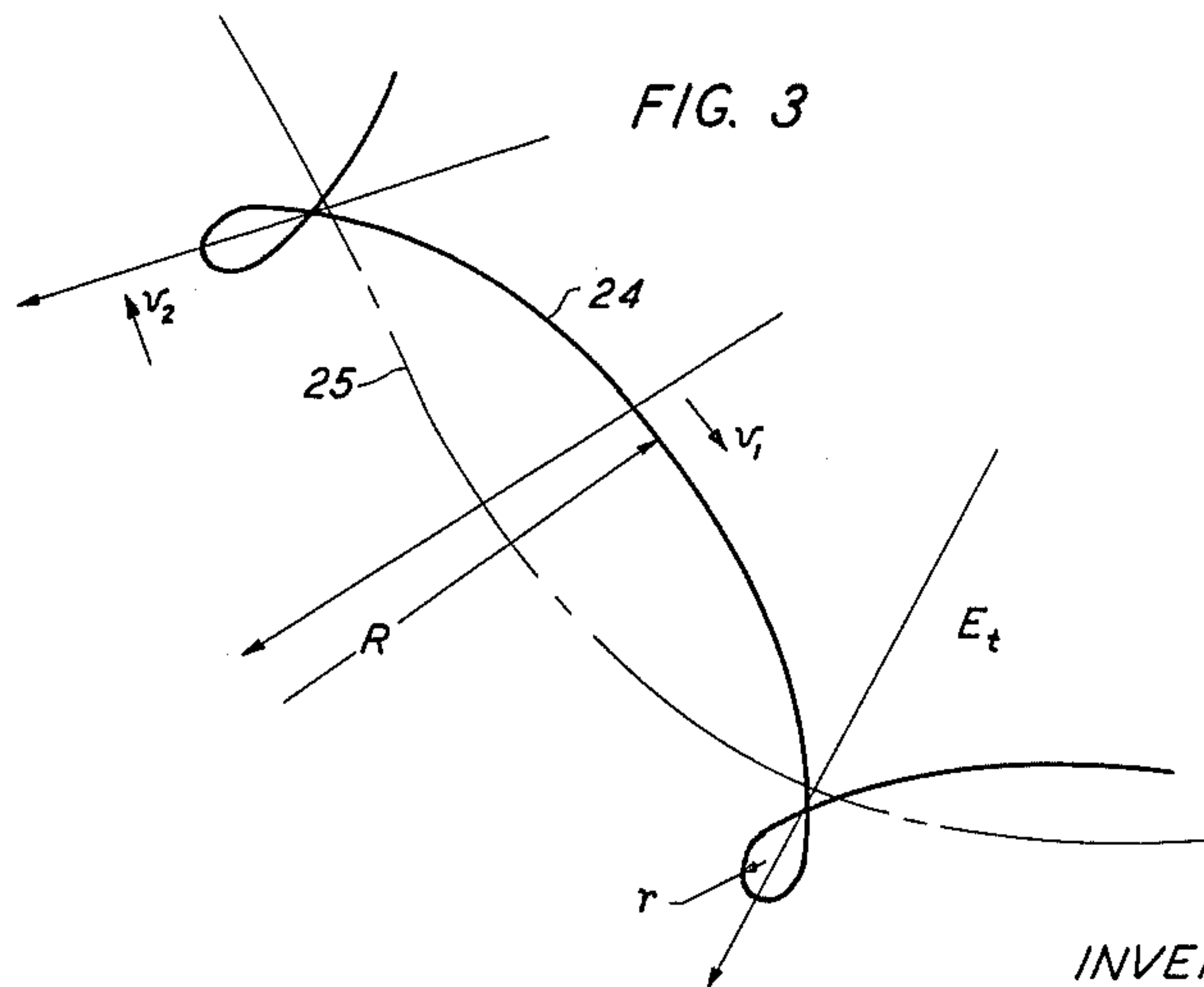


FIG. 3



INVENTOR
J. W. KLÜVER
BY
Roderick B. Anderson
ATTORNEY

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3,259,789

ELECTRON GUN FOR REDUCING TROCHOIDAL MOTION OF ELECTRONS

Johan Wilhelm Klüver, Murray Hill, N.J., 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 electron guns for use in M-type devices.

The term M-type device refers to an electron tube which uses mutually perpendicular electric and magnetic fields for constraining electron flow, as distinguished from O-type devices which use longitudinal magnetic fields for this purpose. The most attractive features of M-type devices are their inherent efficiency and capacity for high-power operation. Among their disadvantages is the difficulty of projecting a well-defined linear electron beam because of the tendency of component electrons to follow trochoidal paths.

It is well known that when a linear electron beam is injected directly into a region of crossed electric and magnetic fields, the constituent electrons are given angular velocities in addition to their translational velocities. The resulting trochoidal trajectory of each electron is the same as that generated by a spot on the spoke of a rolling wheel, which may or may not be extended beyond the wheel rim. The center of the "wheel" follows a path referred to as the guiding center which corresponds to an equipotential line of the electron focusing field.

The trochoidal electron motion tends to impair efficiency if the device is used as an amplifier or oscillator because the electron energy represented by the angular velocity cannot interact with electromagnetic wave energy and cannot be used. Further, the width of the beam is increased by the trochoidal movement which aggravates the problem of undesired beam impingement on the elements defining the beam drift region. Finally, in cyclotron wave devices, energy is put on the beam by modulating the transverse trochoidal motions of the electrons; spurious trochoidal motion limits the quantity of energy that can be put on the beam through cyclotron wave modulation.

One solution to this problem is the "Charles" electron gun which injects an electron beam along the central axis of a crossed-field drift region defined between an extended anode and sole plate. The cathode emits electrons at a 90 degree angle with respect to the central axis, while the magnetic field is directed such as to bend them toward the drift region. After injection the electrons will follow substantially linear trajectories only when the electric field intensity in the drift region is twice that in the cathode region, when an equipotential line extending from the central axis of the drift into the cathode region is substantially linear, and when the magnetic field is low enough to give a high ratio of electric field intensity to the square of the magnetic flux density in the drift region. These conditions severely limit the flexibility of the device; for example, a high beam density requires a high electric field in the cathode region; a low beam velocity, as is desired in delay lines, requires a low electric field in the drift region.

It is therefore an object of this invention to reduce trochoidal electron motion in M-type electron beam devices.

It is a specific object of the invention to make the reduction of trochoidal electron motion consistent with flexibility in the choice of electric and magnetic focusing fields in M-type electron beam devices.

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These and other objects of my invention are attained in an illustrative embodiment thereof which serves as an electronic delay line. The device includes an electron gun for forming and projecting a beam of electrons toward a collector at a relatively low velocity. The beam is focused by crossed electric and magnetic fields, both of which are perpendicular to the beam path. An extended anode and a sole plate on opposite sides of the beam produce the electric focusing field and define a drift region. Signal energy is introduced to the beam by an input coupler at one end of the drift region and is extracted from the beam by an output coupler at the other end. The time taken by the beam to transport the signal from the input coupler to the output coupler is readily determinable and represents a substantial and useful delay.

In accordance with the invention, inherent trochoidal electron motion is reduced by projecting the beam along a sort of S-shaped path before it is injected into the drift region. The cathode is displaced from the central axis of the drift region by a transition region in which a fan-shaped electric field is established. The electrons are emitted parallel with the central axis and are forced into the transition region by the magnetic field. They then follow a curved trajectory in the transition region and are injected into the drift region along its central axis. This particular action tends to convert angular velocity components, thereby reducing the inherent trochoidal motion. This reduces spurious beam impingement, increases the attainable delay, and increases the power limit of beam modulation.

These and other objects and features of the invention will be more clearly understood from a consideration of the following detailed description, taken in conjunction with the accompanying drawing, in which:

FIG. 1 is a sectional view of an illustrative embodiment of my invention;

FIG. 2 is an enlarged view of the electron gun of the device of FIG. 1; and

FIG. 3 is an illustration of an electron trajectory in the device of FIG. 1.

Referring now to FIG. 1, there is shown an electron beam device 11 comprising an electron gun 12 for forming and projecting a low-velocity electron beam toward a collector 14. The electron gun is shown as comprising a cathode 15 having an electron emissive coating, a beam forming electrode 16 surrounding the cathode, and an accelerating electrode 17. A sole plate 18 and an anode 19 define an extended drift region having a central axis 20. Typical values of the potentials on the various electrodes are shown in FIG. 2. In particular the anode is maintained at a positive direct-current potential with respect to the sole plate to produce an electrostatic focusing field E_d transverse to the beam path. A magnetic field B transverse to both the electric field and the beam path is formed by a magnet which, for the sake of clarity, has not been shown.

Input electromagnetic signal energy is transferred to the beam by an input resonator 21. As explained in my copending application, Serial No. 224,726, filed September 19, 1962, and assigned to the Bell Telephone Laboratories, Incorporated, wave energy can be transmitted by a very low-velocity M-type electron beam if the beam is modulated in the cyclotron mode. Accordingly, resonator 21 is resonant at the cyclotron frequency as is required for cyclotron mode modulation. Signal energy is then transmitted by the low-velocity beam to an output resonator 22 which is substantially identical to the input resonator. The time period of signal transmission by the low-velocity electron beam constitutes an appreciable predetermined delay of the signal which can be useful in a number of known systems. Input and output signal

waves are conveniently transmitted by coaxial cables as shown by the arrows.

According to my invention, cathode 15 is displaced from the axis of the drift region for the purpose of reducing trochoidal velocity components of the emitted electrons. Referring to FIG. 2, whenever an electron is injected into a crossed-field region it tends to follow a trochoidal trajectory such as path 24, which is generated by a spot on a wheel, the center of which moves along a line referred to as the guiding center, which is represented by path 25. The trochoidal motion is substantially reduced, or eliminated, by projecting the electrons through three electric field regions: a cathode region defined by an electric field E_c which is substantially parallel with central axis 20; a transition region defined by a fan-shaped electric field E_t ; and the drift region defined by electric field E_d . These fields are produced by the voltages shown for the various electrodes. The emitted electrons are initially directed downwardly by the magnetic field to flow at right angles to the electric field. As the electron flows through the transition region, the guiding center path 25 inherently follows a curvilinear line toward the drift region to thus remain perpendicular to field E_t .

One reason that the fan-shaped field E_t reduces trochoidal motion is that the electric field intensity is higher at the top of each trochoidal cycle than at the bottom. Referring to FIG. 3, the velocity v_1 at the top of any trochoid is higher than the backward velocity v_2 at the bottom. These velocities, however, are directly proportional to the electric field. The fan-shaped field therefore increases the difference between v_1 and v_2 by making v_1 higher and v_2 lower than they would be in a uniform field.

Secondly, note that the angular direction of path 25 (counterclockwise) is opposite that of path 24 (clockwise). Both of these factors tend to increase the radius of curvature R of the large loop of the trochoid, and to decrease the radius of curvature r of the small loop. As R approaches infinity, and r approaches zero, trajectory 24 approaches linearity.

Another feature which straightens out the trochoidal movement is the increase of electric field intensity from the cathode region to the drift region. If E_d is higher than E_c , the potential of the electron is continuously raised as it travels through the transition region; this increase of potential energy is made at the expense of transverse trochoidal kinetic energy. A mathematical proof of the above propositions has not been included because it is necessarily quite complex.

One desirable aspect of the invention is that there are no inherently critical voltages or electrode spacings. Most of the design considerations are known in the art; for example, E_c should not be so high with respect to the magnetic field as to cause impingement on accelerating electrode 17. It has been observed empirically that the ratio of E_d to E_c can be optimized to give maximum trochoid reduction, but no specific relationship of the variables involved has been found other than the observation that E_d should be higher than E_c for maximum reduction. Of course, in a delay line, it is usually desirable to use a relatively low electric field E_d to give a slow beam velocity. With the voltages shown, a considerable reduction of trochoidal motion was attained by making the distance a between the beam-forming electrode and the accelerating electrode equal to 60 mils, the displacement b of the cathode above the central axis 90 mils, the cathode thickness of 15 mils, and the separation c between the anode and sole plate 140 mils. The magnetic flux density B in this device was 400 gauss.

It is to be understood that the embodiment shown merely illustrates the invention. Numerous modifications may be made by those skilled in the art without departing from the spirit and scope of the invention. In particular, the electron beam system described can be incorporated in a traveling wave tube which includes

a slow-wave structure positioned along the beam path for propagating an electromagnetic wave in interacting relation with the electron beam.

What is claimed is:

1. An electron beam device comprising:
 - means for defining a drift region having a central axis;
 - a cathode region displaced from the central axis and separated from the drift region by a transition region;
 - a cathode in the cathode region for emitting electrons parallel with the central axis;
 - means for producing a first electric field in the cathode region which is parallel to the central axis;
 - means for producing a second electric field in the drift region which is at right angles to the central axis;
 - means for producing a third electric field in the transition region which is substantially radial and which changes direction through substantially 90 degrees to be parallel to the first electric field at one end thereof and parallel to the second electric field at the other end;
 - and means for producing a magnetic field extending through the cathode, transition, and drift regions which is transverse to the first, second, and third electric fields.
2. Apparatus for minimizing the trochoidal motion of electrons in a cross-field focused electron beam comprising:
 - means for producing a fan-shaped electric field in which the direction of electric intensity changes from one end thereof to the other;
 - means for producing a magnetic field transverse to the electric field;
 - means for injecting the electron beam into one end of the electric field;
 - said electric field comprising means for forcing the electrons to flow along a curvilinear guiding center line in a first angular direction as, for example, counterclockwise;
 - said magnetic field being directed such as to force any trochoidal movement of the electrons to take place in a second angular direction opposite that of the first angular direction as, for example, clockwise.
3. An electron beam device comprising:
 - an elongated anode and an elongated sole plate defining therebetween a drift region having a central axis;
 - means for producing a first electric field between the anode and the sole plate;
 - an electron collector located at one end of the drift region on a central axis;
 - a cathode near the other end of the drift region and displaced therefrom for emitting electrons in a direction parallel with the central axis toward the collector;
 - beam forming electrode surrounding the cathode and extending substantially perpendicular to the sole plate;
 - an accelerating anode substantially parallel with the beam forming electrode and displaced therefrom;
 - means for producing a second electric field of lower intensity than the first field between the beam forming electrode and the accelerating anode;
 - and means for producing a magnetic field that is transverse to both the first and the second electric fields;
 - said electric fields and said magnetic field comprising means for displacing the electron beam and for causing it to flow along the central axis.
4. An electron beam device comprising:
 - means for defining a drift region having a central axis;
 - a cathode displaced from the central axis for emitting electrons parallel with the central axis in the direction of the drift region;

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the density of electron emission being a function of a first electric field through the cathode that is substantially parallel to the central axis;
 a magnetic field transverse to the path of the electrons being directed such as to exert a force on the electrons directed toward the central axis;
 said magnetic field extending along the drift region;
 and a second electric field along the drift region transverse to the central axis and the magnetic field and of higher intensity than the first field for forcing the electrons to flow substantially parallel to the central axis.
 5. An electron beam device comprising:
 an elongated anode and an elongated sole plate defining therebetween a drift region having a central axis;
 means for maintaining the anode at a positive voltage of approximately 260 volts with respect to the sole plate;
 the anode and sole plate being separated by a distance of approximately 140 mils;
 an electron collector located at one end of the drift region on the central axis;
 a cathode located near the other end of the drift region and displaced therefrom for emitting electrons in a direction parallel with the central axis toward the collector;

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said cathode being displaced from the central axis a distance of approximately 90 mils;
 a beam forming electrode surrounding the cathode and extending substantially perpendicular to the sole plate;
 an accelerating anode substantially parallel with the beam forming electrode and displaced therefrom a distance of approximately 60 mils;
 means for maintaining the accelerating anode at a positive voltage of approximately 50 volts with respect to the cathode and beam forming electrode;
 and means for producing a magnetic field of approximately 400 gauss that is transverse to the electric fields between the anode and sole plate and between the beam forming electrode and the accelerating anode.

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HERMAN KARL SAALBACH, *Primary Examiner.*

ELI LIEBERMAN, *Examiner.*

R. D. COHN, *Assistant Examiner.*