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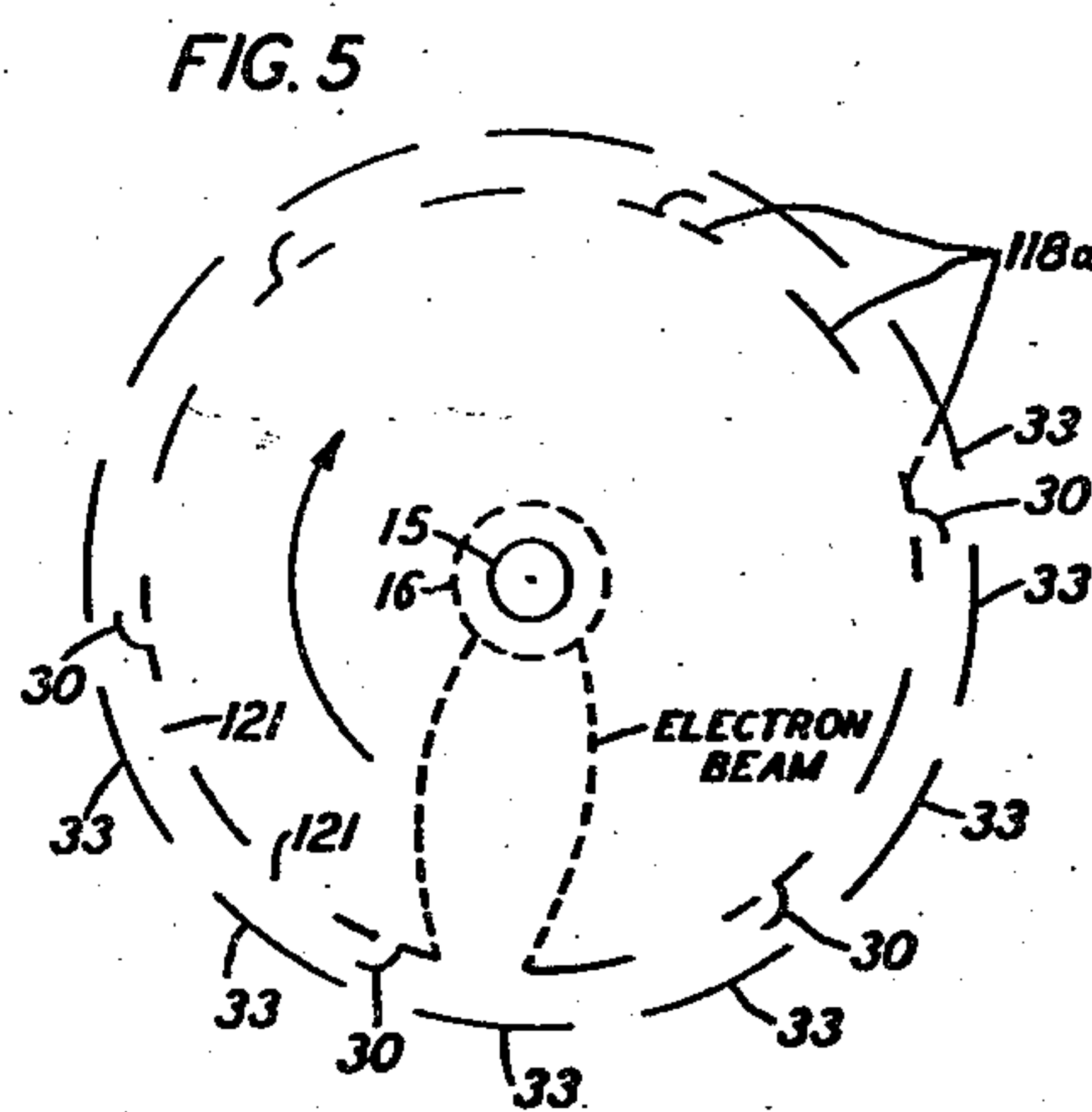
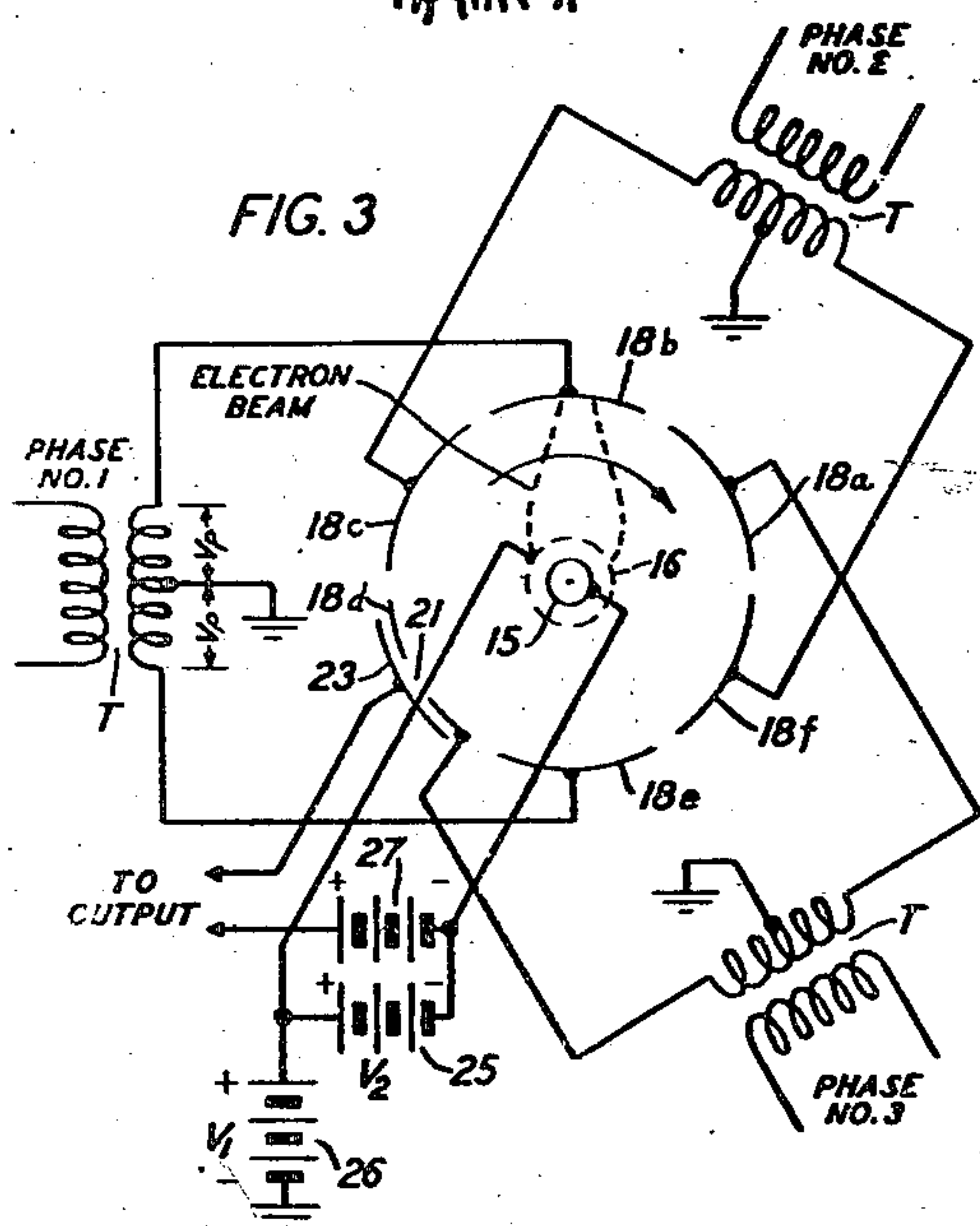
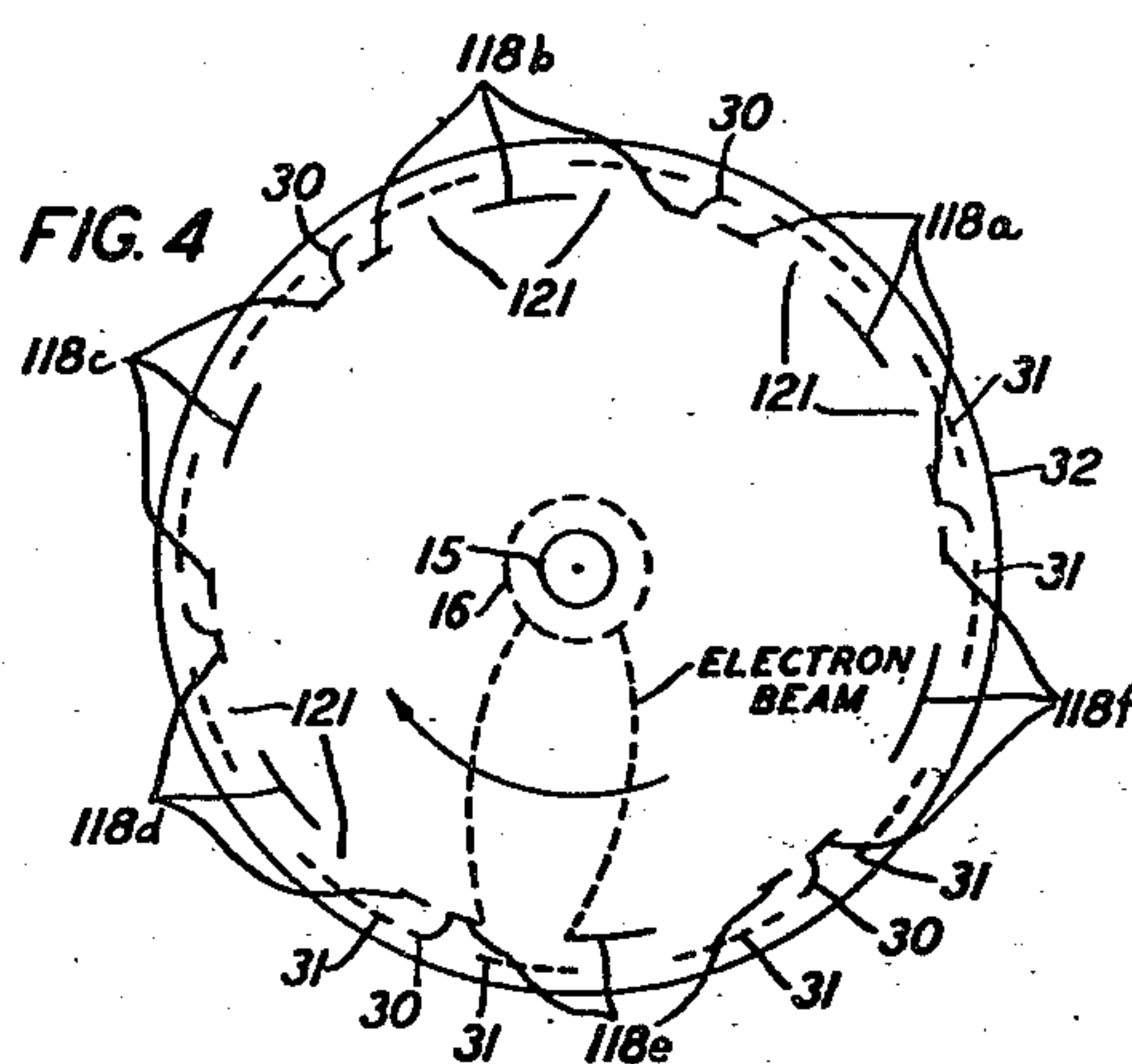
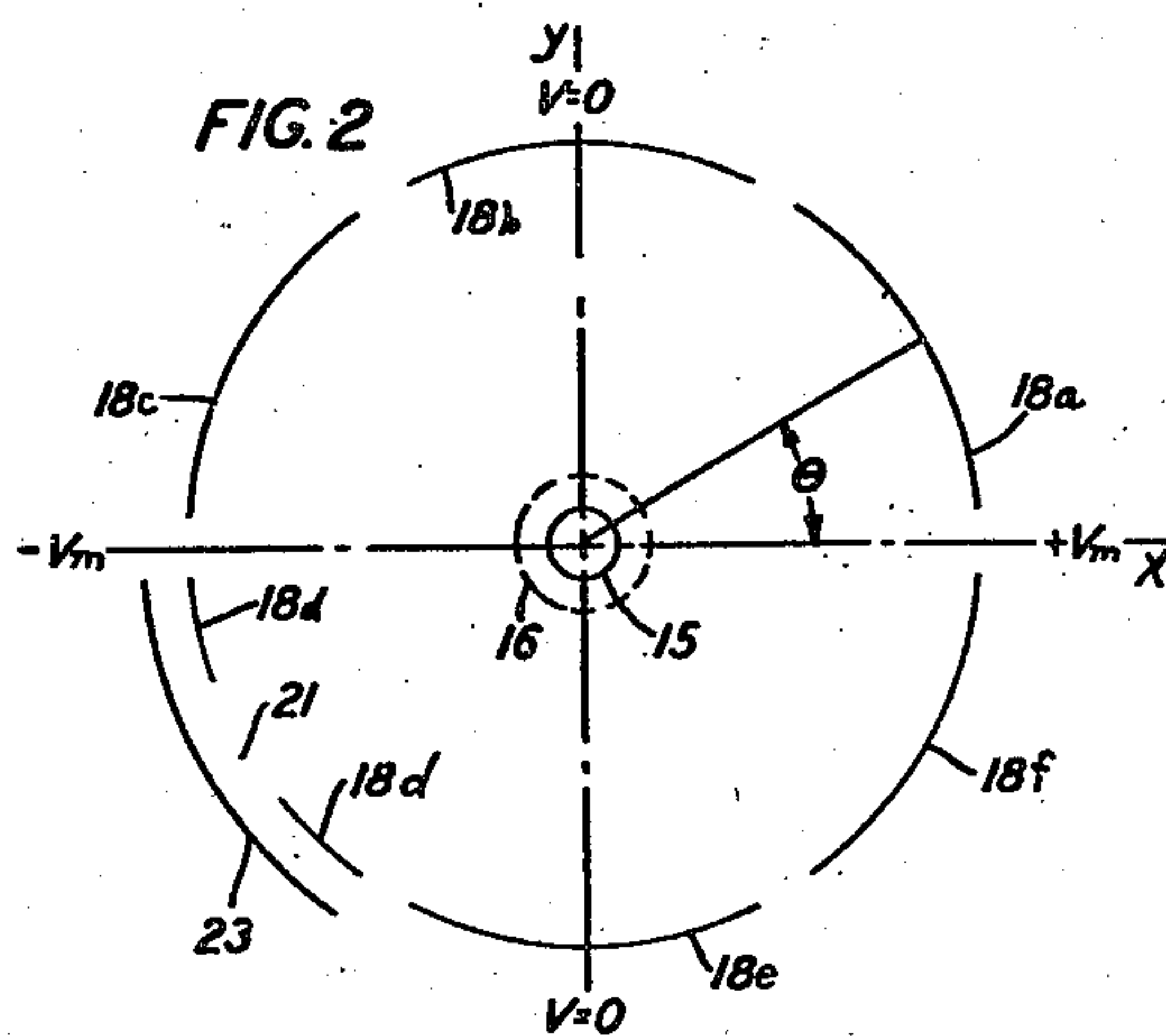
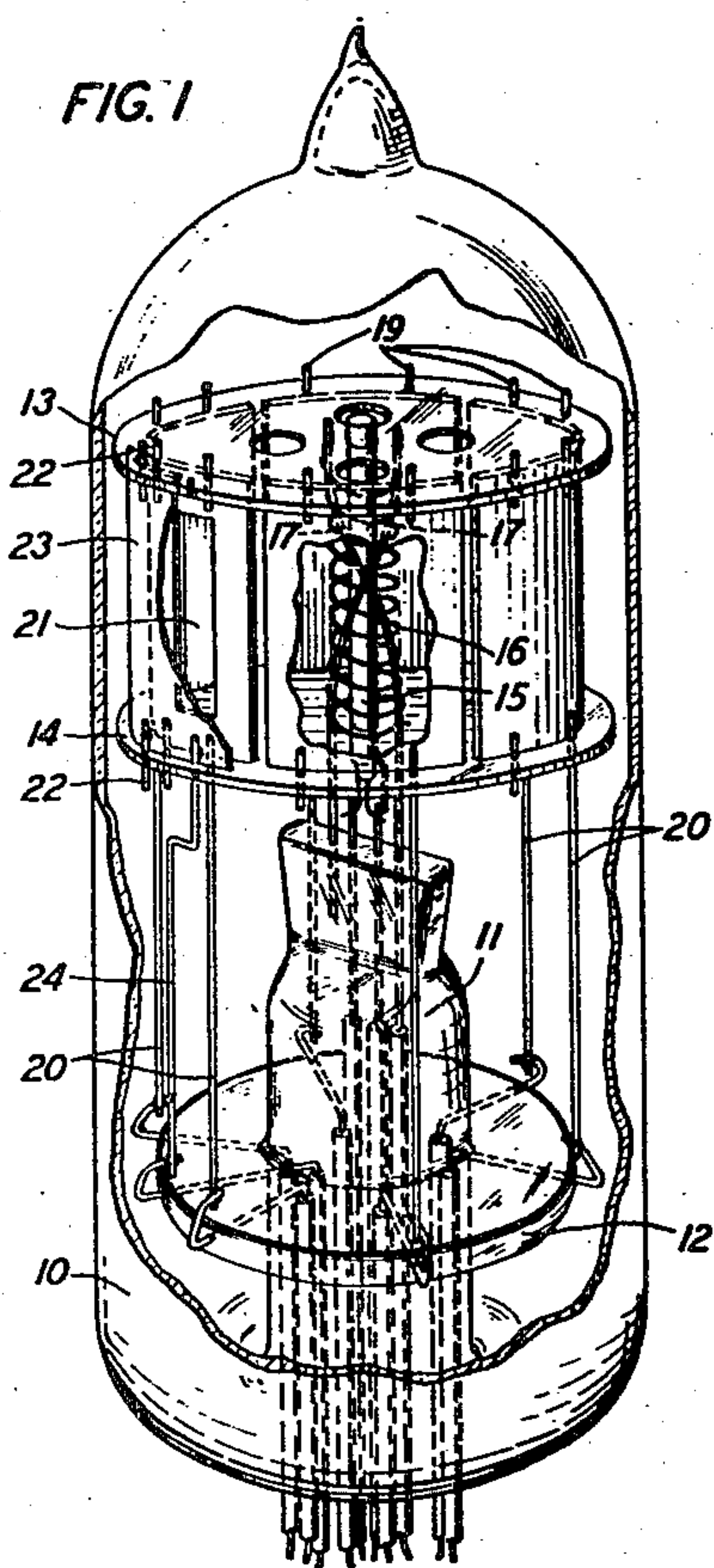
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2,433,403

ELECTRON DISCHARGE APPARATUS

Filed Aug. 29, 1942

2 Sheets-Sheet 1



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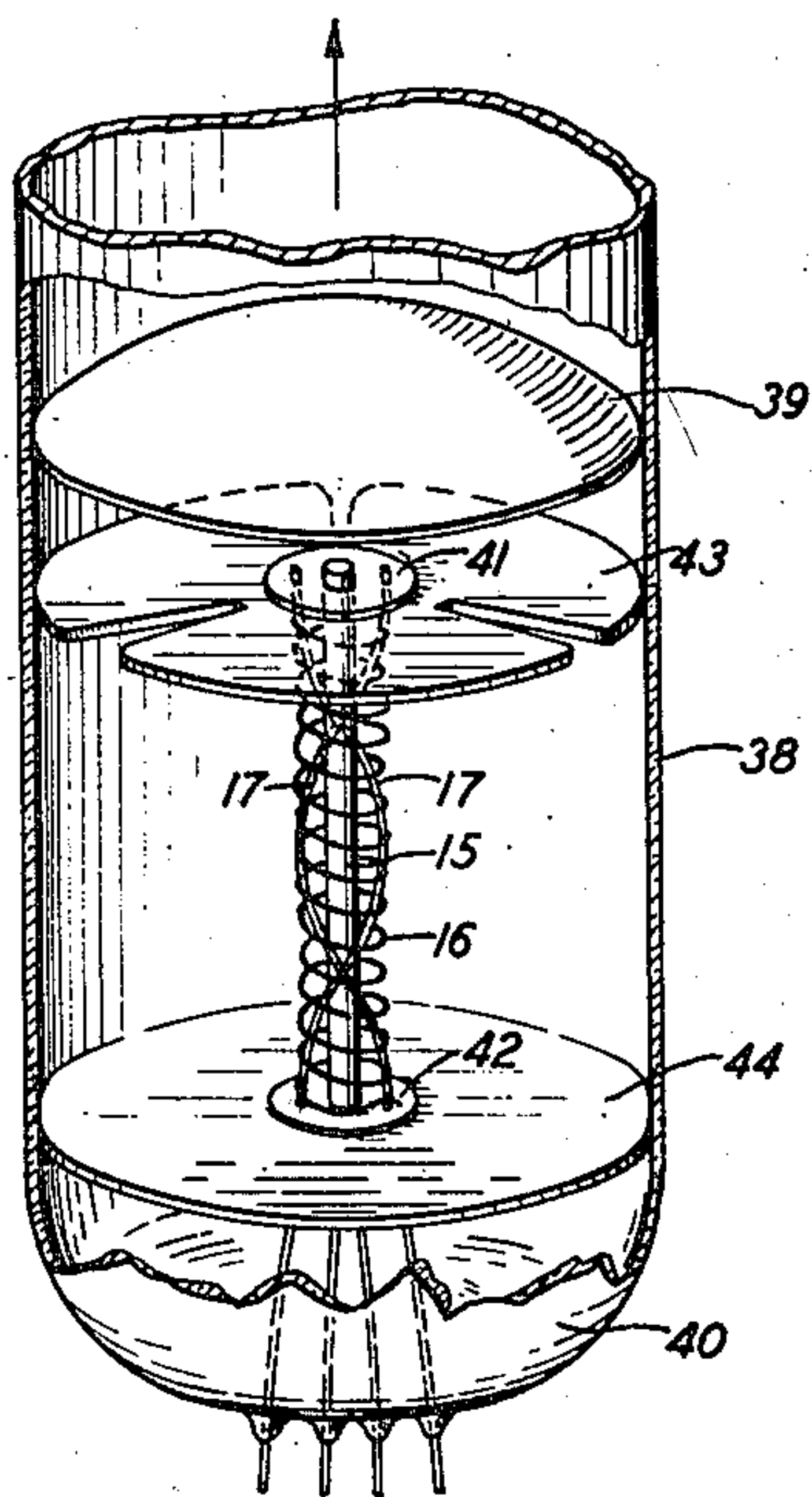
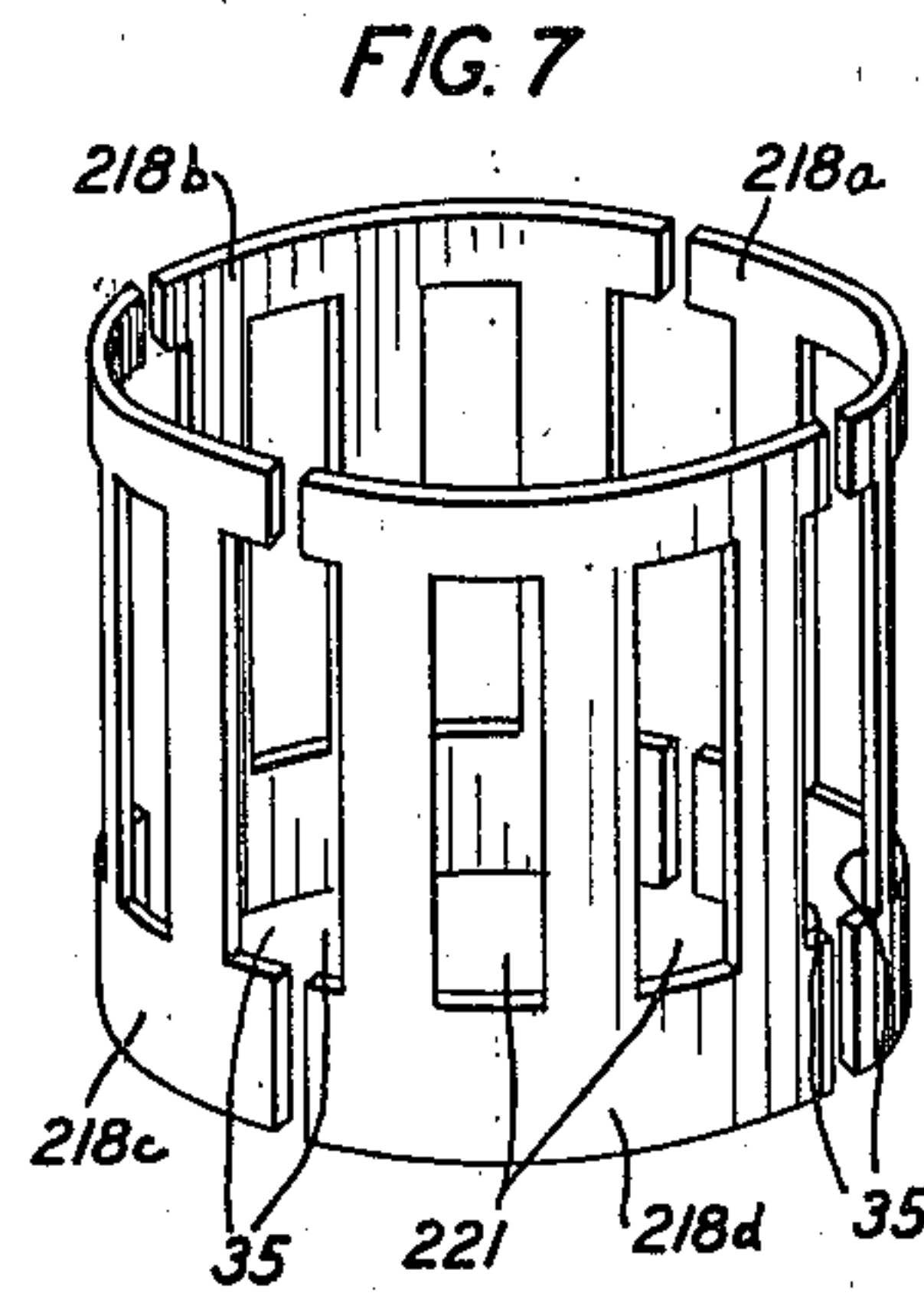
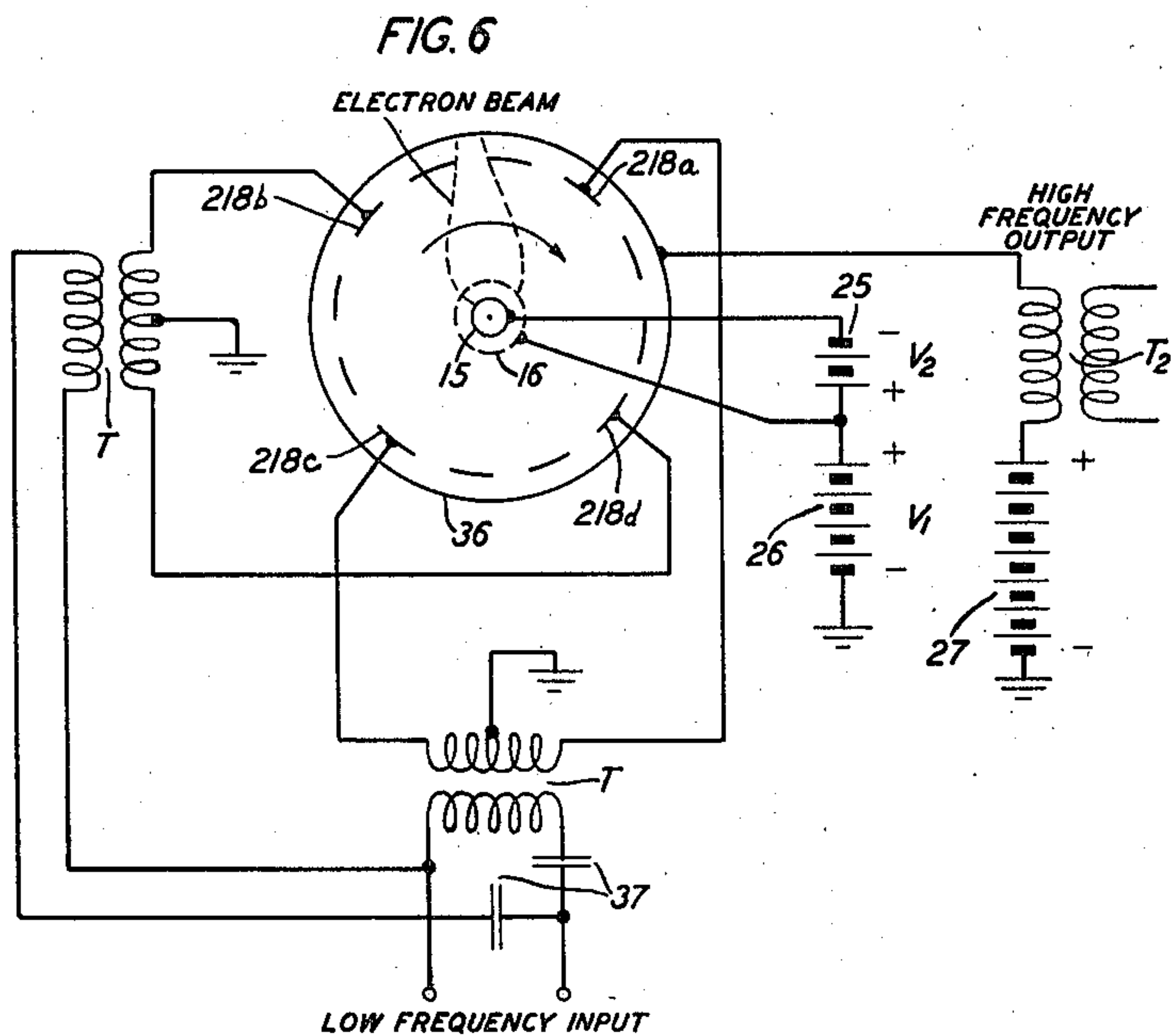
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ELECTRON DISCHARGE APPARATUS

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2 Sheets-Sheet 2



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ELECTRON DISCHARGE APPARATUS

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9 Claims. (Cl. 250—27)

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This invention relates to electron discharge apparatus and more particularly to electron discharge devices of the rotating beam type.

One general object of this invention is to facilitate the efficient generation of a rotating electron beam in electron discharge devices suitable for use as frequency multipliers, pulse generators, receiving and transmitting distributors for multiplex telephony, electronic switches, oscillation generators and the like.

More specifically, objects of this invention are to

Increase the operating frequency range of apparatus including electron discharge devices of the rotating beam type;

Enable the generation of an electrostatically focussed rotating electron beam;

Improve the operating efficiency of rotating beam electron discharge devices; and

Simplify the construction of such devices.

In one illustrative embodiment of this invention, an electron discharge device comprises an anode structure, which may include one or several elements, and an electrode system for producing a concentrated electron beam rotating about an axis of the anode structure. This system includes, generally, a cathode, a focussing electrode or grid encompassing and coaxial with the cathode, and a field electrode structure encompassing and coaxial with the control electrode or grid, this structure including a plurality of electrically individual elements in edge to edge relation and extending substantially parallel to the cathode.

In accordance with one feature of this invention, the elements of the field electrode structure are energized with alternating potentials in such manner as to produce an electric field substantially parallel to a diameter and rotating at a uniform rate about the cathode, and the control electrode or grid is operated at such potential relative to the cathode and field electrode structure that the electrons emanating from the cathode are concentrated into a single, radial rotating beam substantially focussed upon the field electrode structure.

The invention and the above noted and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawing, in which:

Fig. 1 is an elevational view in perspective of an electron discharge device illustrative of one embodiment of this invention, a portion of the enclosing vessel and of the anode and field electrode

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structures being broken away to show the internal construction more clearly;

Fig. 2 is a diagrammatic end view of the electrodes in the device illustrated in Fig. 1 showing the configuration and relation of the electrodes;

Fig. 3 is a circuit diagram illustrating one manner of operating the electron discharge device illustrated in Figs. 1 and 2;

Figs. 4 and 5 are diagrammatic plan views of the electrode arrangements in discharge devices illustrative of other embodiments of this invention, suitable for use as sending and receiving distributors respectively in multiplex telephone systems;

Fig. 6 is a circuit diagram of a frequency multiplier illustrative of another embodiment of this invention;

Fig. 7 is a perspective view of a field electrode structure particularly suitable for use in a frequency multiplier constructed in accordance with this invention; and

Fig. 8 is a perspective view of a high frequency oscillation generator illustrative of another embodiment of this invention.

Referring now to the drawing, the electron discharge device shown on Fig. 1 comprises an evacuated enclosing vessel 10 having a stem 11 provided with an annular flange 12 and mounting an electrode assembly. The electrode assembly includes a pair of parallel insulating members 13 and 14, such as mica discs, a cylindrical cathode 15, which may be of the indirectly heated equipotential type, extending through central apertures in the discs 13 and 14, and a helical focussing electrode or grid 16 encompassing and coaxial with the cathode. The electrode or grid 16 is carried by a pair of uprights 17 fitted in diametrically aligned apertures in the discs 13 and 14, the uprights 17 being skewed or twisted as shown so that each extends from a point at one end of the grid to a diametrically opposite point at the other end of the grid, whereby the interception of electrons by the uprights is substantially the same around the cathode.

The electrode assembly includes also a field electrode structure which includes a plurality of similar equally spaced, arcuate plate members 18a to 18f inclusive, parallel to the cathode and mounted in a cylindrical boundary coaxial therewith. The plate members 18 are mounted by short rigid wires 19 secured thereto and fitted in the discs 13 and 14, and have connected thereto individual leading-in conductors 20 extending from the flange 12.

The plate member 18d is provided with a cen-

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tral aperture or slit 21 opposite which there is mounted, by pins 22 fitted in the discs 13 and 14, an anode 23, the anode having a leading-in conductor 24 connected thereto.

During operation of the device, as illustrated in Fig. 3, the field electrode plate members are supplied by a three phase source through transformers T, the mid-points of the secondary windings of which are connected to ground. The focussing electrode or grid 16 is biased at a positive potential V_2 with respect to the cathode 15, by a battery 25 and also is biased at a positive potential V_1 with respect to the field electrodes 18, by a battery 26. The cathode 15, it will be noted, is thus biased positive with respect to the field electrodes. The anode 23 is operated positive with respect to the cathode 15 as by a battery 27.

Because of the manner of energization of the plate members 18 and the focussing electrode or grid 16, the electrons emanating from the cathode 15 are concentrated into a single radial electron beam substantially focussed upon the boundary in which the plate members 18 lie and rotating clockwise as indicated by the arrow in Fig. 3. The beam impinges upon the plate members in sequence and when it crosses the aperture or slot 21 an electron current flows to the anode 23 so that a pulse, the length of which is dependent upon the width of the aperture or slit 21 and the rate of rotation of the beam, is produced in the output circuit connected between the cathode 15 and the anode 23. The frequency of the pulses produced will be dependent upon the rate of rotation of the beam.

The manner of operation of the rotating beam producing system will be understood from the following considerations with particular reference to Fig. 2, the plate member 18 being energized in the manner shown in Fig. 3. Ideally, the potential around the field electrode structure varies according to the relation

$$V = V_m \cos \theta \quad (1)$$

where V is the potential of any point immediately adjacent this structure, V_m is the maximum potential applied and θ is the azimuthal angle around the longitudinal axis of the structure, measured, for example, from the X axis in Fig. 2. If the cathode 15 and control grid 16 were absent, this potential distribution would produce within the cylindrical boundary in which the plate members 18 lie, a plane uniform electric field E parallel to the X axis. For purposes of analysis, this boundary may be replaced by two line images within the space occupied by the grid, considered as a simple cylinder, for these would give a cylindrical equipotential surface at the position of this grid cylinder. If the potential at the grid cylinder is zero, this analysis gives for the potential V'_F at any point outside thereof

$$V'_F = \left(Er - \frac{ER_1^2}{r} \right) \cos \theta \quad (2)$$

where r and θ are polar coordinates and R_1 is the radius of the grid cylinder.

When the potential on the grid cylinder is other than zero, say V_c with respect to the average potential of the field electrode cylinder, the field due only to the potential of the grid cylinder is

$$E' = \frac{V_c}{r} \frac{1}{\log \frac{R_2}{R_1}} \quad (3)$$

where E' is the field, R_2 is the radius of the field

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electrode cylinder and the logarithm is to the base e . The corresponding potential at any point in this field is

$$V''_F = \int_r^{R_2} \frac{V_c dr}{r \log \frac{R_2}{R_1}} \quad (4)$$

If the field electrode cylinder is at zero potential

$$V''_F = \frac{V_c \log \frac{R_2}{r}}{\log \frac{R_2}{R_1}} \quad (5)$$

Hence, from Equations 2 and 5, the total field outside of the grid cylinder is given by

$$V_F = \left(Er - \frac{ER_1^2}{r} \right) \cos \theta + V_c \frac{\log \frac{R_2}{r}}{\log \frac{R_2}{R_1}} \quad (6)$$

The potential gradient around the grid cylinder determines the angular spread of the electrons that are projected through the grid 16 from the cathode 15. From Equation 6 and inasmuch as at the grid $r = R_1$, it is seen that

$$\frac{dV_F}{dr} = 2E \cos \theta - \frac{V_c}{R_1} \frac{1}{\log \frac{R_2}{R_1}} \quad (7)$$

The gradient around the cylinder is zero when the right-hand side of Equation 7 is zero. θ is the angle at which the gradient changes sign. Hence, electrons emanating from the cathode 15 can, at any instant, pass through the grid in a region covering an angle of about 2θ . Because of the positive potential of the grid 16, the electrons have a certain energy at the grid and, therefore, the emergence angle will be slightly greater than the size noted. However, it will be appreciated that a substantial portion of the electrons emanating from the cathode are concentrated into a beam which rotates with the rotating field due to the alternating potentials applied to the plate members 18 and which is substantially focussed upon the boundary in which these plate members lie.

In the analysis given above, the ideal potential variation around the field electrode structure has been assumed. In actual devices, because of the finite number of plate members and relatively small number of phases employed, this variation is only approximated and, therefore, some distortion of the field near the field electrode members results but the effect of this distortion is to increase the focussing action when the beam is near the center of each of the plate members 18.

The beam current and the focussing are dependent upon the diameter of the focussing electrode or grid 16 and upon the potential V_1 of this electrode with respect to the plate members 18 and the potential V_2 of this electrode with respect to the cathode. In general, it is advantageous to make the grid of very small diameter. Very small grids can be used by employing a filamentary cathode, for example, a thoriated tungsten filament, and a sharp focus and large beam currents thus realized.

The optimum grid potentials will be dependent upon the size of the device. In general, the bias V_2 of the grid with respect to the cathode should be small, for example a few volts, and the potential V_1 should be of the order of five to ten times V_2 and of the order of $\frac{1}{5}$ the maximum value of V_F the alternating potential applied to the plate

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members 18. In a particular construction wherein the field electrode structure was 0.96 inch in diameter, the grid 0.093 inch in diameter and the cathode 0.055 inch in diameter, the following potentials were found to be suitable: $V_P=225$ volts, V_1 =approximately 40 volts and V_2 =approximately 5 volts.

Although in the device shown in Fig. 1 and described hereinabove, only one of the plate members 18 is provided with an aperture or slit 21, several or all of the plate members may be so constructed and individual anodes in cooperation with each aperture or slit or a single anode opposite all of the apertures or slits may be provided. Two such constructions are illustrated in Figs. 4 and 5.

In the construction illustrated in Fig. 4, which is particularly suitable for use as a twelve channel sending distributor in multiplex telephone systems, each of the plate members 118a to 118f inclusive of the field electrode structure is provided with two apertures or slits 121, similar to the aperture or slit 21 in the device shown in Fig. 1, and is provided also with a lip portion 30 overlying the opening between it and an adjacent plate member to intercept electrons passing through this opening. Mounted behind each aperture or slit 121 is a control electrode or grid 31 for controlling the current passing through the respective aperture or slit. The control grids 31 are encompassed by a cylindrical output anode 32 coaxial with the cathode.

As in the device shown in Figs. 1 and 3, the focussing electrode or grid 16 and the plate members 118 are energized to produce a rotating beam substantially focussed upon the cylindrical boundary in which the plate members lie. As the beam rotates, electrons pass through the apertures or slits 121 and the current from each slit is varied in accordance with desired signals by the corresponding control electrode or grid 31, which may be connected to a subscriber's station, so that the current to the output anode 32 is a complex current composed of the several varied currents.

In the twelve channel receiving distributor illustrated in Fig. 5, the field electrode structure is the same as that in the sending distributor shown in Fig. 4. However, in the receiving distributor, twelve output anodes 33 are provided, each being positioned opposite a corresponding one of the apertures or slits 121 and connected to a corresponding subscriber's station. As in the sending distributor, the field electrode structure in the receiving distributor is energized to produce a rotating electron beam, which revolves in synchronism with the beam in the associated sending distributor. The signal applied to the focussing grid 16 of the receiving distributor corresponds to the complex current transmitted from the anode 32 of the sending distributor and the beam current to each of the anodes 33, therefore, corresponds to the respective variable current component of the transmitted current.

Although the invention has been described thus far as embodied in three phase devices including six plate members in the field electrode structure, it will be understood that it may be utilized in other phase devices. In general, the number of plate members included in the field electrode structure will be twice the number of phases.

Also, although the devices described thus far have used a polyphase supply source for the field electrode structure, a single phase supply may be employed. One such arrangement, suitable

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for frequency multiplication, is illustrated in Fig. 6. In the device shown in this figure, the field electrode structure comprises four segments 218a to 218d, the construction of which is shown in Fig. 7, mounted in a cylindrical boundary encompassing and coaxial with the cathode 15 and focussing electrode or grid 16. Each of the segments 218 is provided with two apertures or slits 221 and with cut-out portions 35, juxtaposed cut-out portions of adjacent electrodes defining an aperture similar to the apertures 221, so that twelve similar, equally spaced apertures are provided in the field electrode structure. This structure is encompassed by a cylindrical anode 36.

The four segments 218 are energized through transformers T, from a low frequency input, the phase of which is split into two components in time quadrature by condensers 37, one component being impressed between the segments 218a and 218c and the other being impressed between the segments 218b and 218d. The focussing grid 16 is biased at positive potentials with respect to both the cathode 15 and the field electrodes and the output is taken from a transformer T₂.

When the field electrode elements 218 and the grid 16 are energized, there is produced a rotating electron beam focussed upon the boundary in which the field electrode elements lie. As the beam rotates it passes across the apertures in the field electrode structure so that, for each revolution of the beam, twelve current pulses are delivered to the anode 36 and the output frequency is twelve times that of the input. A greater or lesser number of apertures may be provided in the field electrode structure depending upon the harmonic of the input frequency desired in the output.

The invention may be embodied also in ultra-high frequency oscillation generators, one suitable construction for this purpose being illustrated in Fig. 8. In this figure, 38 is a cylindrical metallic wave guide having therein an evacuated section bounded by the guide and vitreous closure members 39 and 40 hermetically sealed thereto. Mounted within the evacuated section are a cathode 15 and focussing grid 16 which are maintained in coaxial relation with each other by insulating discs 41 and 42. The insulating disc 41 is mounted by an insulating spacer 43 engaging the inner wall of the guide 38 and the disc 42 is mounted by a metallic disc 44 joined to the guide 38 so that the cathode and grid are positioned coaxially with the guide 38.

As is known in the art, there may be set up in the cylindrical wave guide a simple type of oscillation in which two points at the extremities of a diameter have the maximum potential difference between them and to set up simultaneously a similar mode of oscillation in a direction at right angles to the direction of the first oscillation. The net result of these two modes of oscillation is a rotating electric field in the guide at right angles to the longitudinal axis of the guide. Such field, in the same manner as in the devices described hereinabove, would result in the generation of a substantially radial electron beam revolving about the cathode 15 as an axis. Of course, the electron transit time from the cathode to the guide wall should be adjusted so that the electrons reach the wall when the potential thereof is negative with respect to the grid 16 to provide the negative resistance characteristic requisite for the generation of oscillations.

During operation of the device, the grid 16 is biased at a relatively low positive potential with

respect to the cathode 15 and the metallic wall of the guide 38 is biased at a negative potential with respect to the grid 16. The oscillating electromagnetic energy is generated in the evacuated section of the guide and is propagated along the guide in the direction of the arrow in Fig. 8, passing through the vitreous closure member 39 with little or substantially no attenuation.

Although specific embodiments of this invention have been shown and described, it will be understood that they are but illustrative and that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. In electron discharge apparatus, means for producing an electron beam rotating about an axis and extending normal to the axis, comprising a cathode extending along said axis, a field electrode structure including a plurality of electrode members mounted side by side in a cylindrical boundary encompassing said axis, means for energizing said electrode members to produce within said boundary an electric field substantially normal to and revolving about said axis, a focussing electrode adjacent said cathode, and means biasing said focussing electrode at a positive potential with respect to said cathode and said cathode at a positive potential with respect to said electrode members.

2. In electron discharge apparatus, means for producing an electron beam rotating about an axis, comprising a rectilinear cathode extending along said axis, a field electrode structure including a plurality of plate members substantially parallel to said cathode and mounted side by side in a cylindrical boundary encompassing and coaxial with said cathode, alternating current potential means connected to said plate members for producing within said boundary an electric field substantially normal to said cathode and revolving thereabout, a cylindrical focussing electrode adjacent, encompassing and coaxial with said cathode, and means biasing said focussing electrode at a positive potential with respect to said cathode and at a higher positive potential with respect to said plate member.

3. In electron discharge apparatus, means for producing an electron beam rotating about an axis, comprising a rectilinear cathode extending along said axis, a field electrode structure comprising a plurality of pairs of electrode members substantially parallel to said cathode and mounted side by side in a cylindrical boundary encompassing and coaxial with said cathode, polyphase potential means having one phase connected between each pair of electrode members for producing within said boundary a radial electric field rotating about said cathode, a helical focussing grid encompassing and coaxial with said cathode, means biasing said grid at a potential several volts positive with respect to said cathode, and means biasing said grid positive with respect to said electrode members at a potential greater than said first potential and substantially smaller than the peak voltage of said polyphase potential means.

4. Electron discharge apparatus comprising a cathode, a cylindrical field electrode structure encompassing and coaxial with said cathode and including a plurality of plate members, said field electrode structure having an aperture therein, an anode mounted opposite said aperture outside of said field electrode structure, means for ener-

gizing said field electrode structure to produce between it and said cathode a radial electric field revolving about said cathode whereby electrons emanating from said cathode are concentrated into a radial beam rotating about said cathode, and means for focussing the electron beam upon said field electrode structure including a cylindrical grid adjacent and encompassing said cathode and means biasing said grid at positive potentials and with respect to said cathode and said field electrode structure.

5. Electron discharge apparatus in accordance with claim 4 comprising a control electrode mounted between said anode and said aperture.

6. Electron discharge apparatus comprising a cathode, a cylindrical field electrode structure encompassing and coaxial with said cathode and having therein a plurality of apertures in alignment with said cathode, alternating current means for energizing said structure to produce a radial electric field substantially normal to said cathode and revolving about said cathode, a focussing grid adjacent and encompassing said cathode, means biasing said grid at positive potentials with respect to said cathode and said field electrode structure, an anode outside of said structure and having portions opposite all of said apertures, and an output circuit connected to said anode.

7. Electron discharge apparatus in accordance with claim 6 comprising a plurality of control electrodes each opposite a corresponding one of said apertures.

8. Electron discharge apparatus comprising a cathode, a cylindrical field electrode structure encompassing and coaxial with said cathode, said structure comprising pairs of arcuate plate members mounted side by side and each having a plurality of apertures therein, means for impressing low frequency alternating potentials between said pairs of plate members phasically related to produce within said structure a radial electric field rotating about said cathode, a cylindrical anode encompassing said structure, a high frequency output circuit connected to said anode, and a focussing electrode adjacent said cathode.

9. In electron discharge apparatus, means for producing an electron beam rotating about an axis, comprising a cathode extending along said axis, a cylindrical field electrode structure encompassing and coaxial with said cathode, means for energizing said structure to produce a radial electric field rotating about said cathode whereby electrons emanating from said cathode are concentrated into a beam extending substantially radially from said cathode and revolving about said cathode, and means for focussing said beam upon said structure including a grid encompassing and coaxial with said cathode and biased at a positive potential with respect thereto.

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