

Oct. 15, 1946.

A. E. ANDERSON

2,409,179

ELECTRON BEAM RELAY

Filed Dec. 5, 1941

3 Sheets-Sheet 1

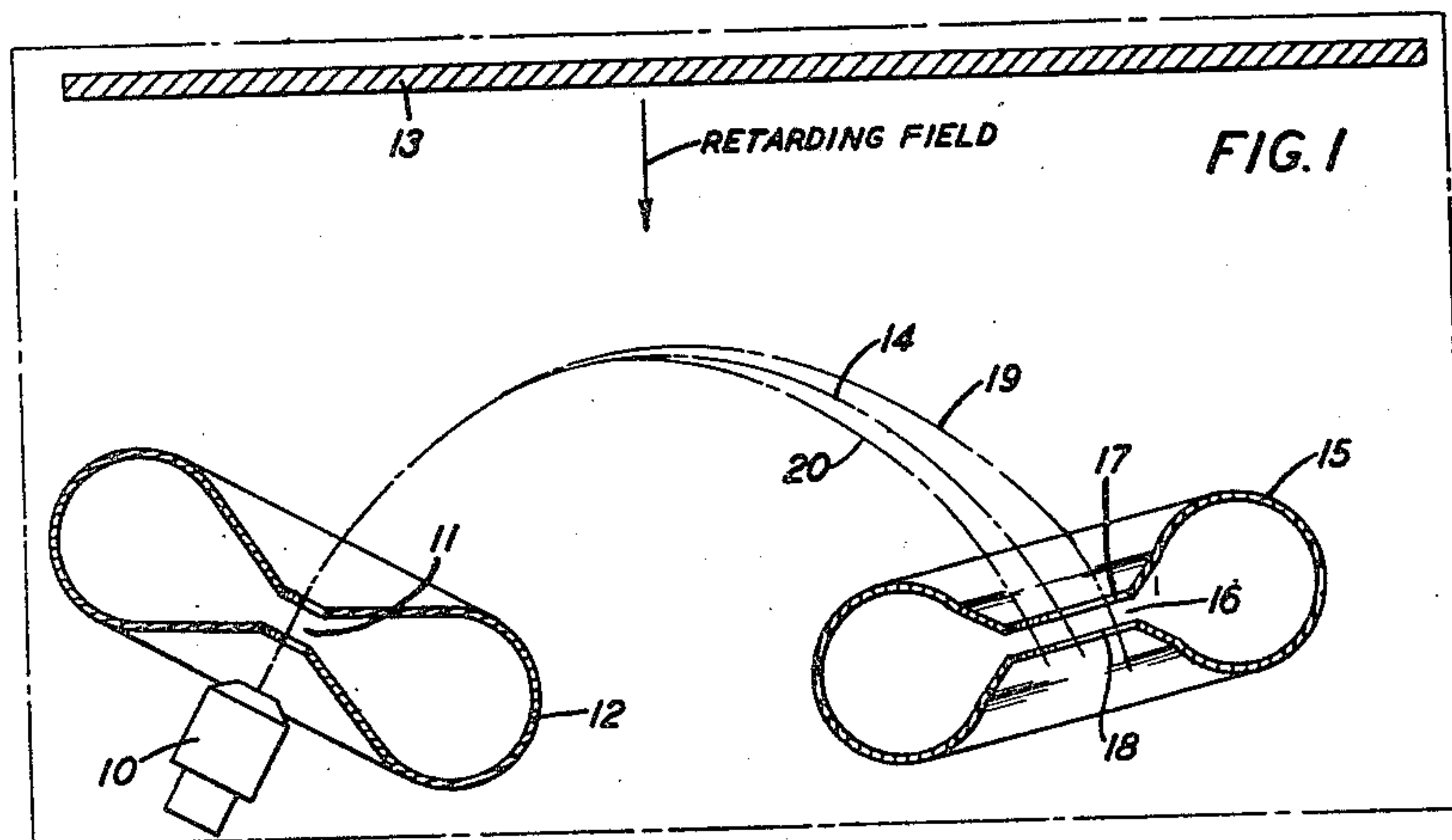
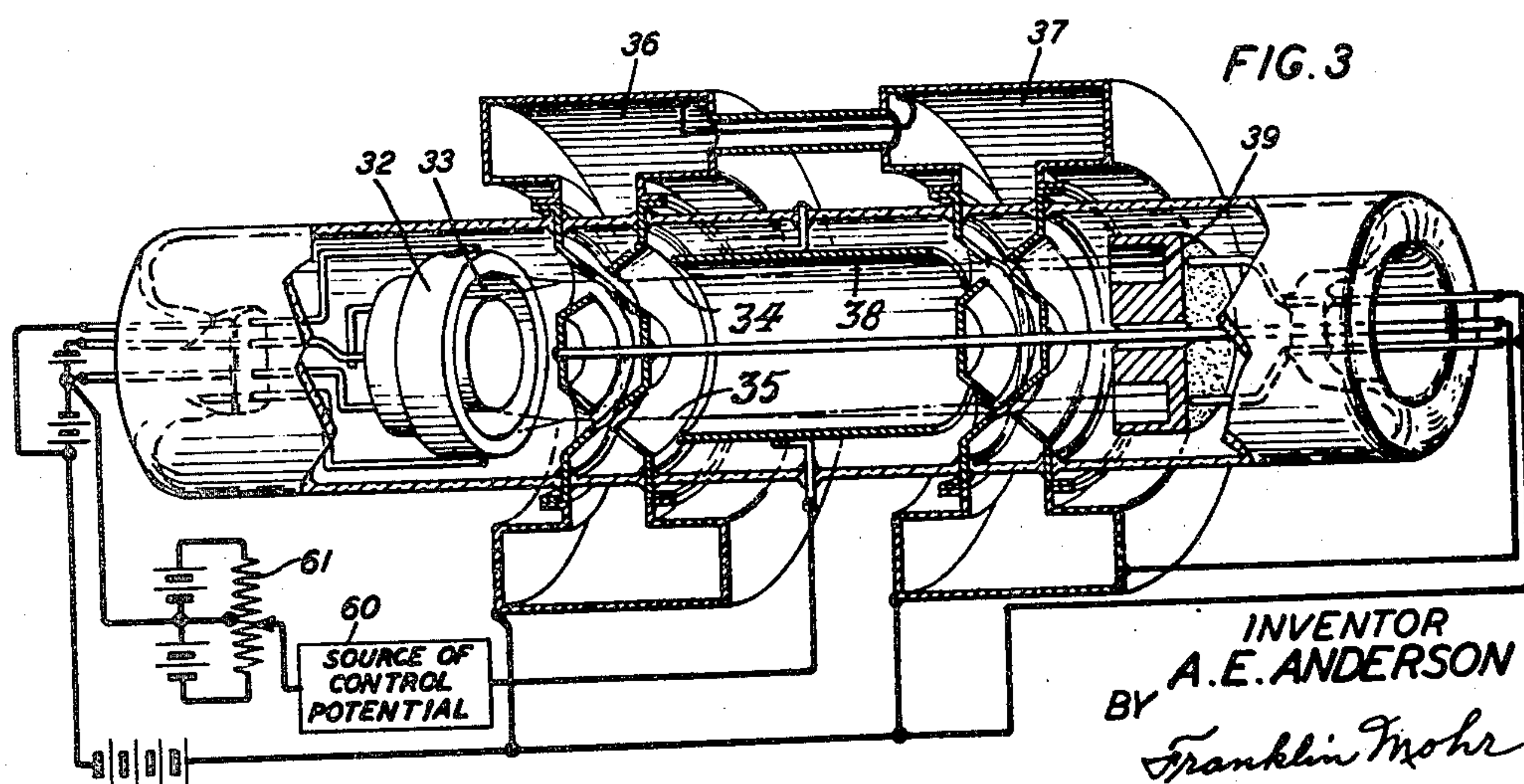
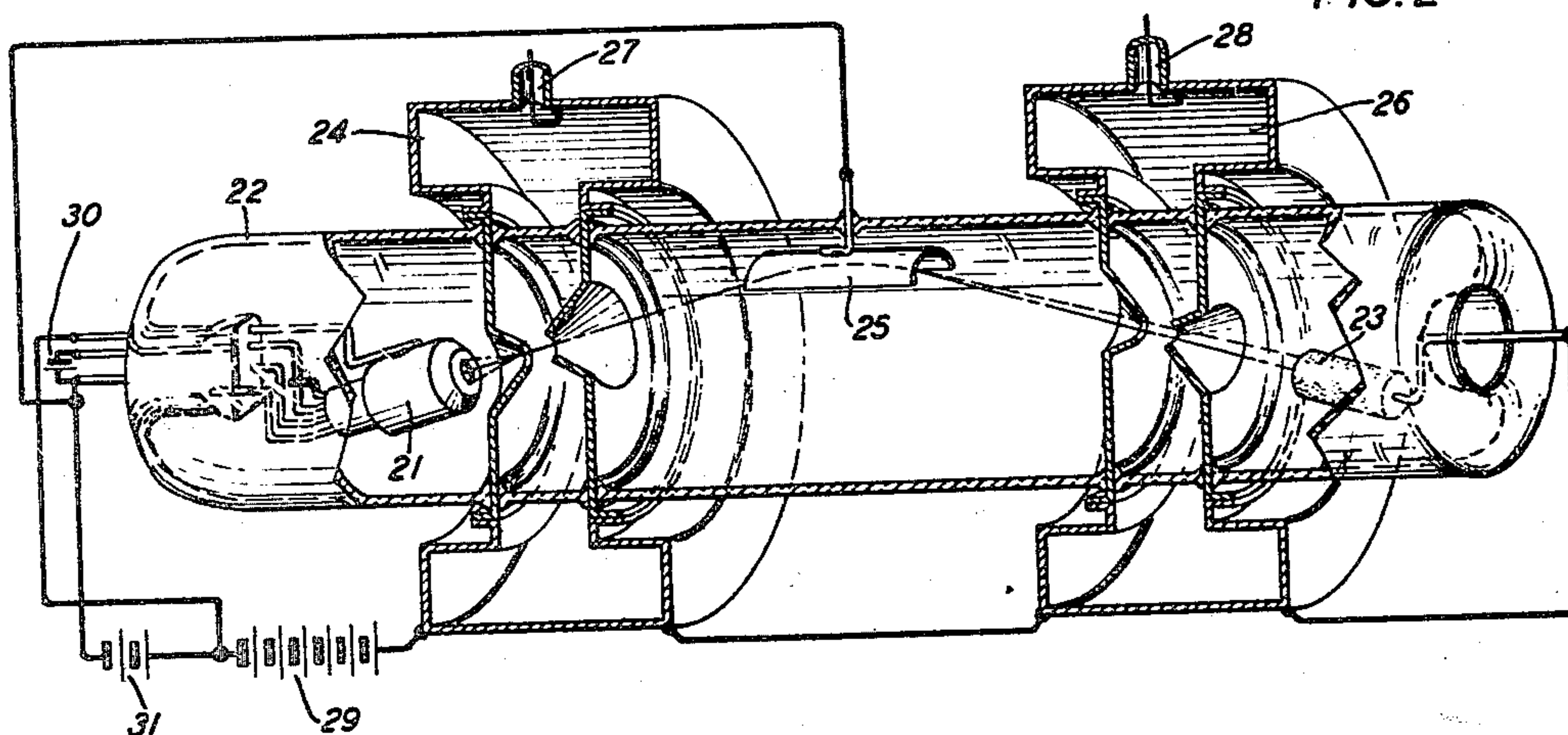


FIG. 2



INVENTOR
A. E. ANDERSON
BY Franklin Mohr
ATTORNEY

Oct. 15, 1946.

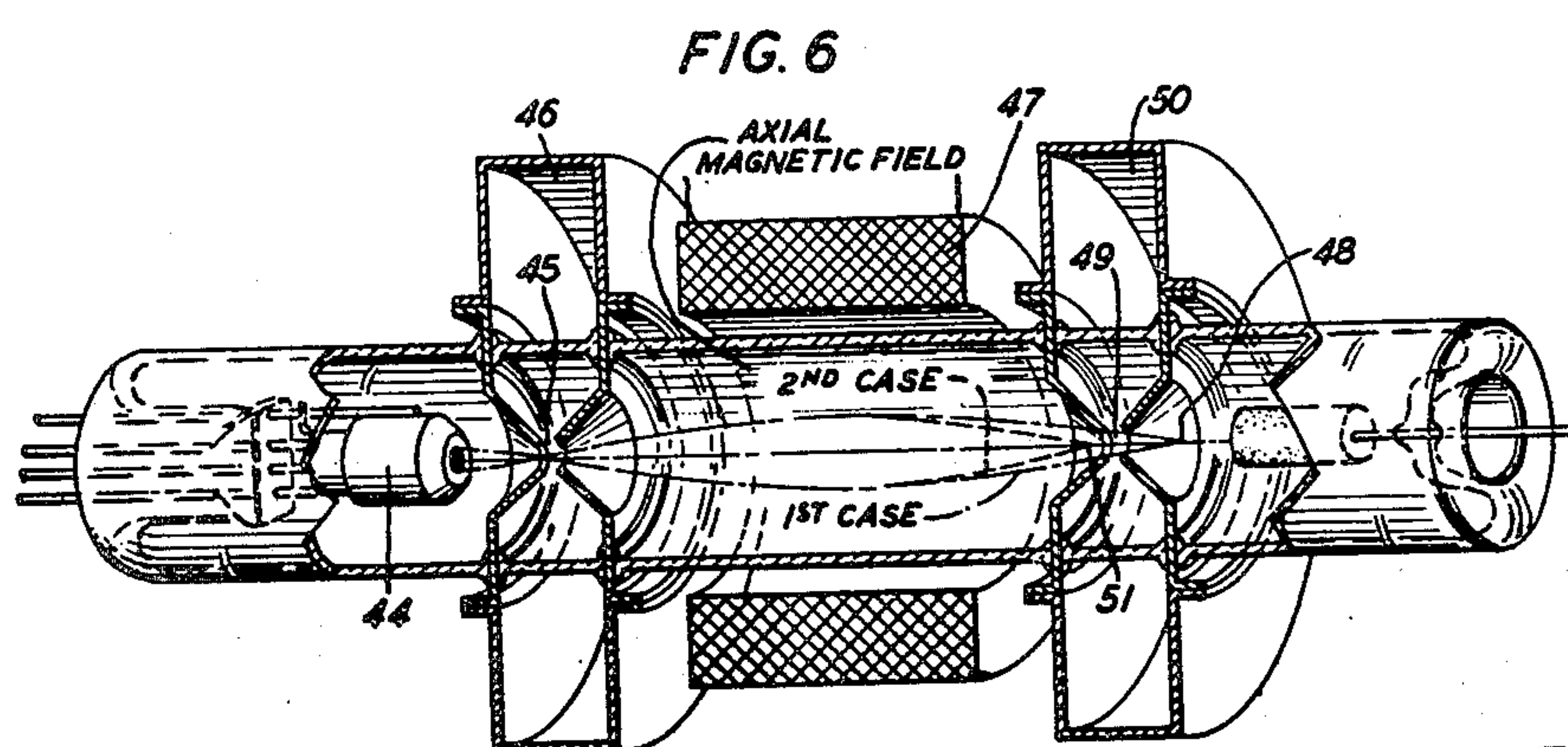
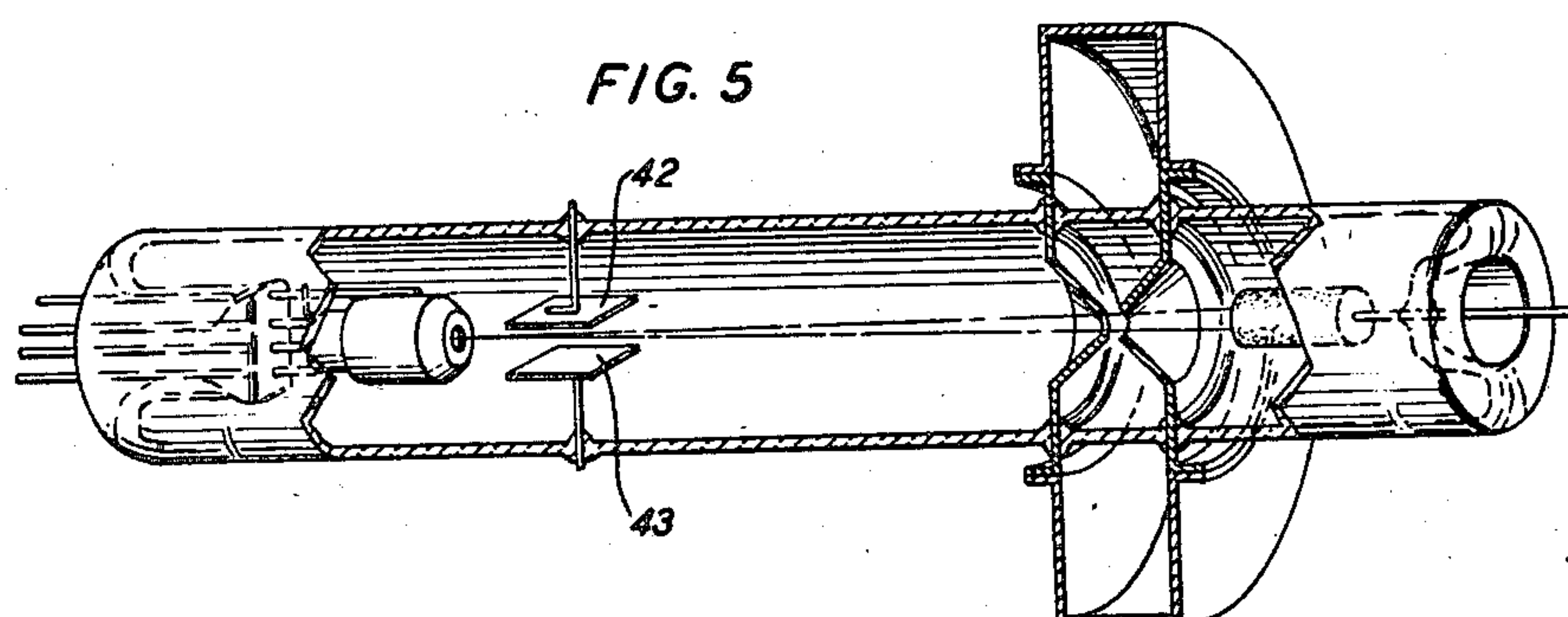
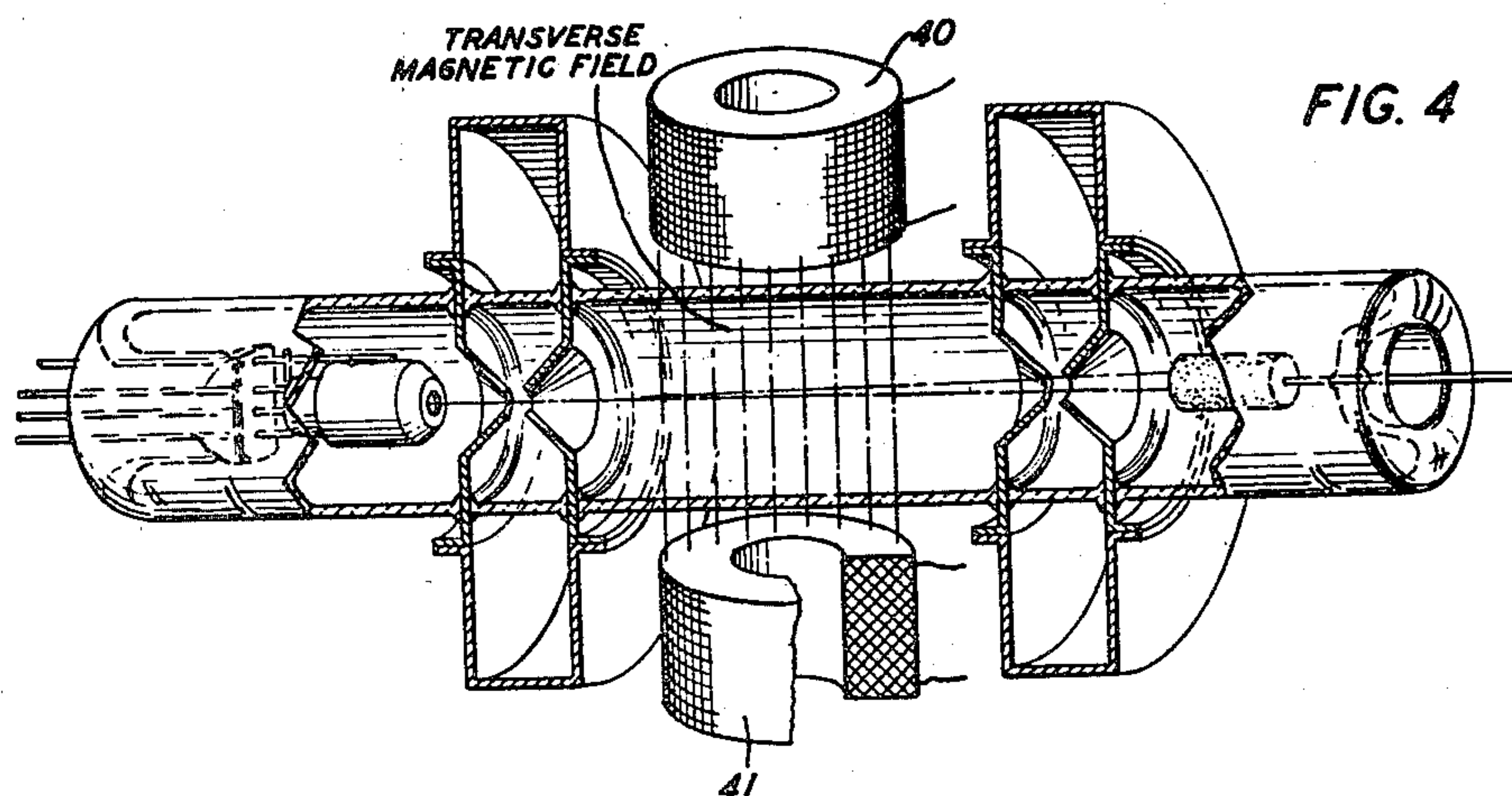
A. E. ANDERSON

2,409,179

ELECTRON BEAM RELAY

Filed Dec. 5, 1941

3 Sheets-Sheet 2



INVENTOR
BY A. E. ANDERSON

Franklin Mohr
ATTORNEY

Oct. 15, 1946.

A. E. ANDERSON

2,409,179

ELECTRON BEAM RELAY

Filed Dec. 5, 1941

3 Sheets-Sheet 3

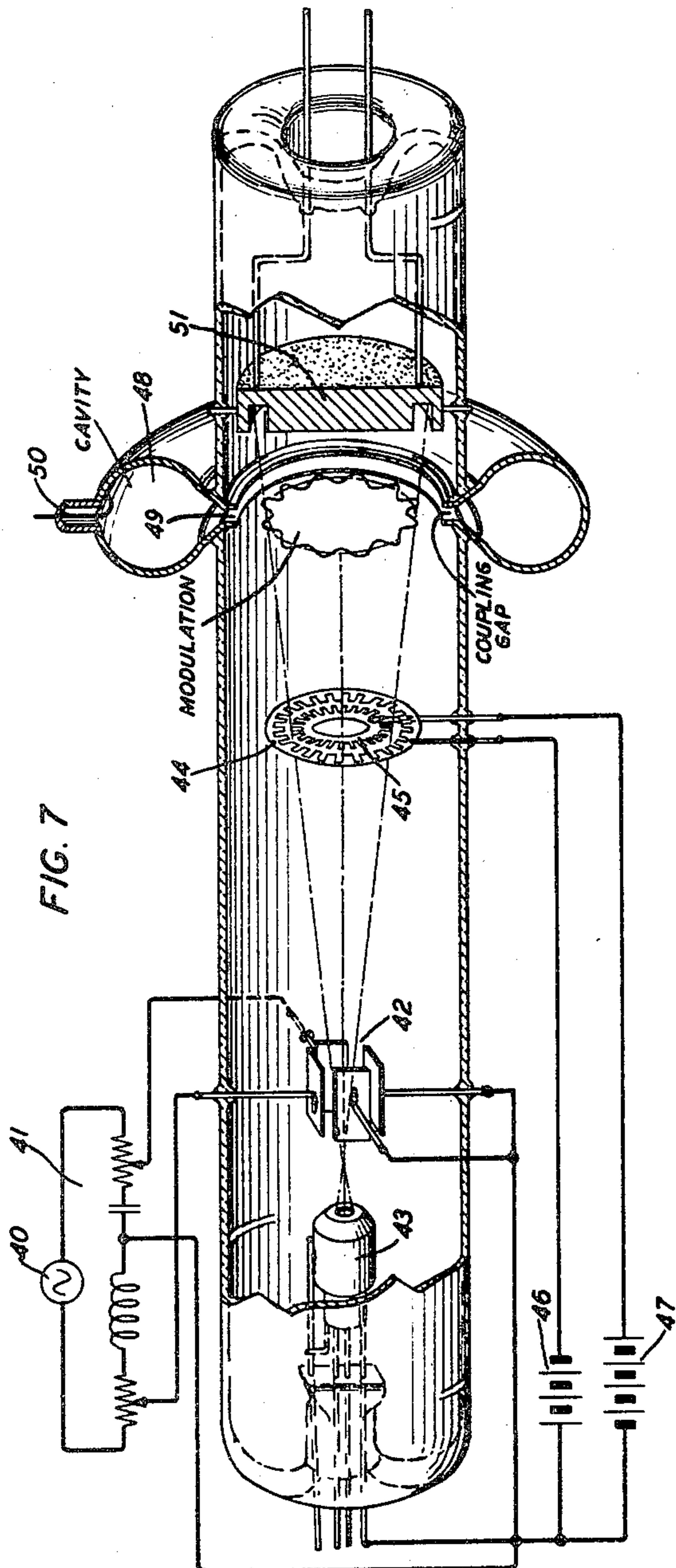


FIG. 9

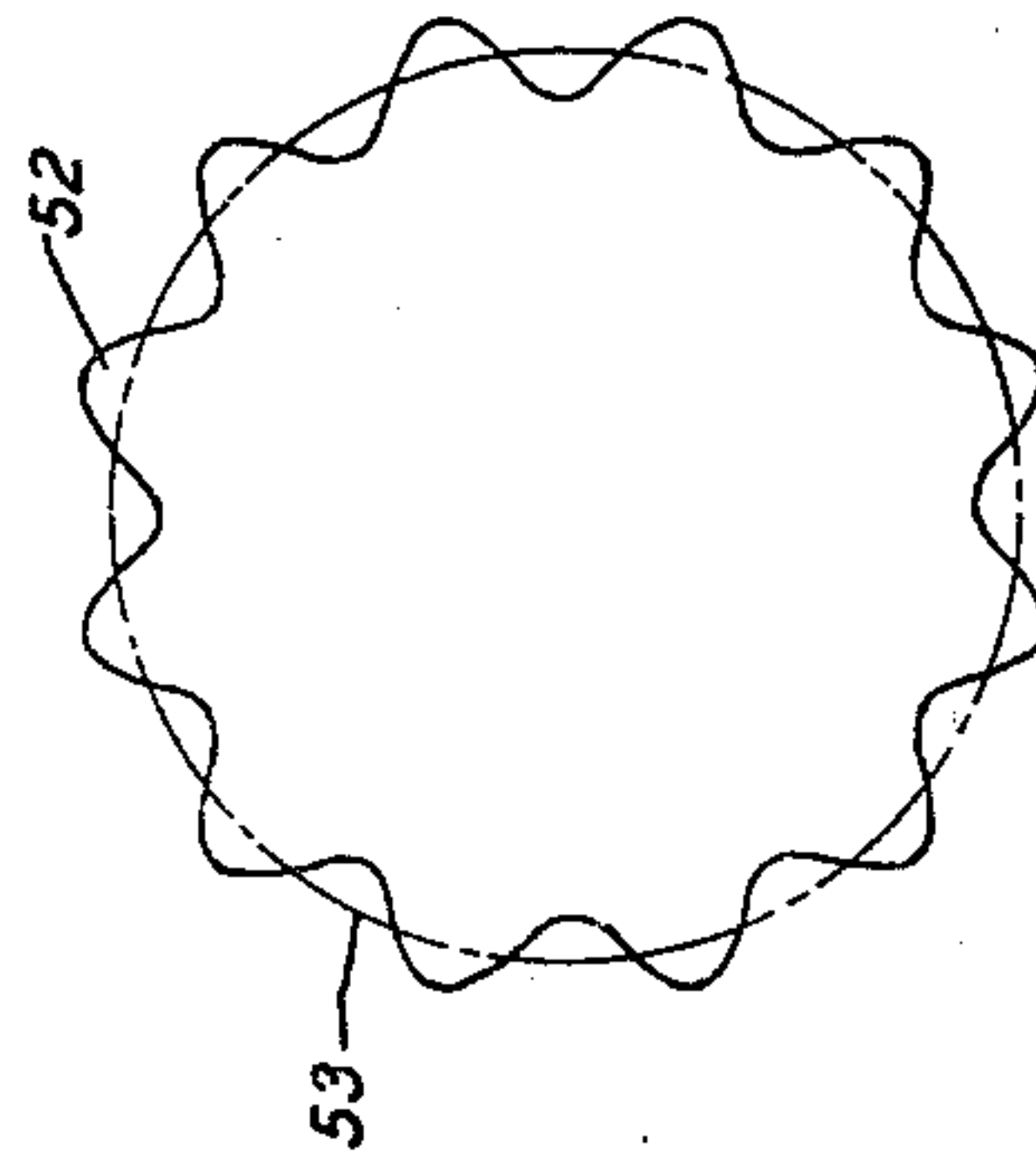
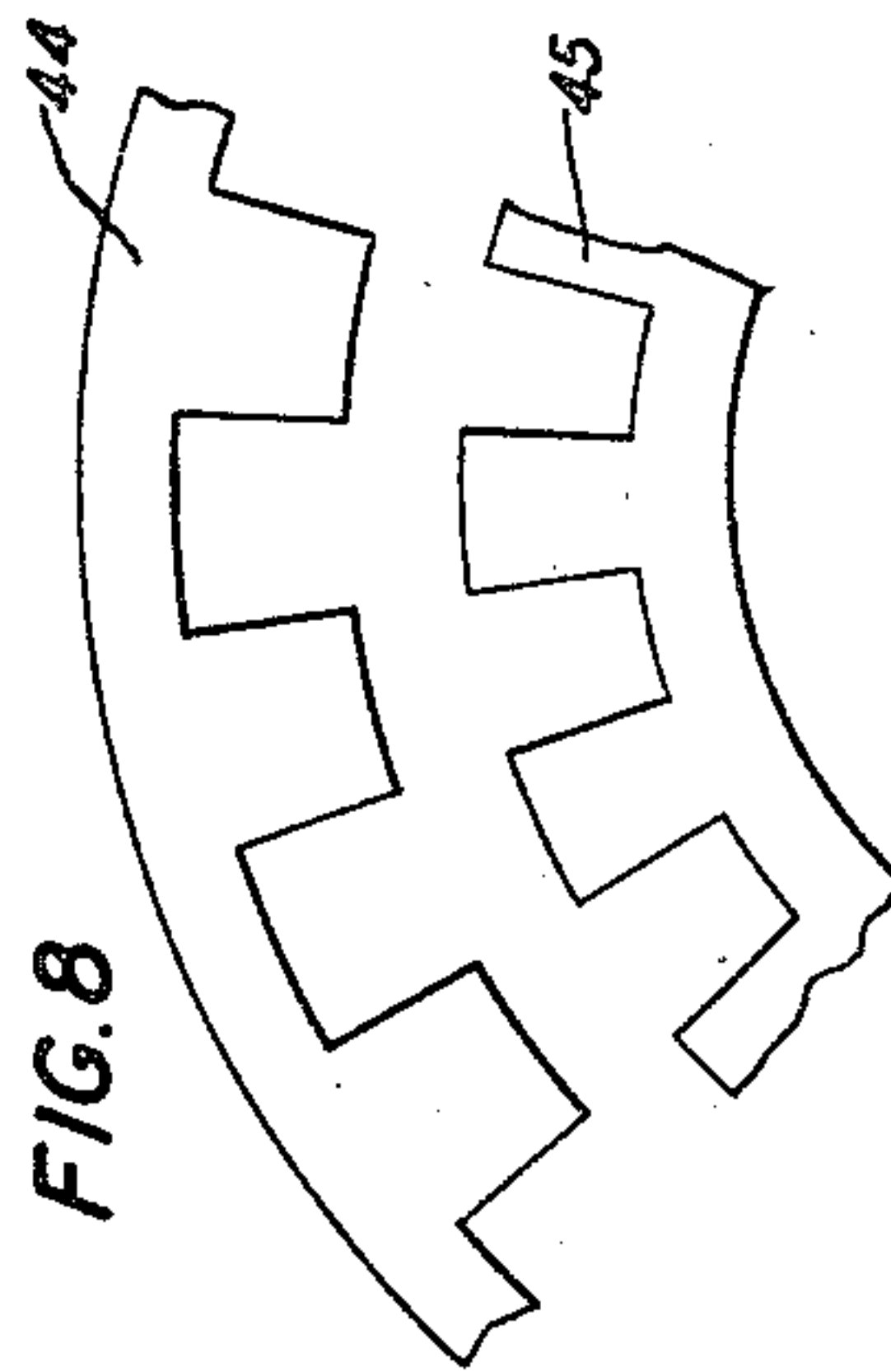


FIG. 8



INVENTOR
BY A. E. ANDERSON

Franklin Mohr
ATTORNEY

UNITED STATES PATENT OFFICE

2,409,179

ELECTRON BEAM RELAY

Alva Eugene Anderson, New York, N. Y., assignor
to Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application December 5, 1941, Serial No. 421,736

2 Claims. (Cl. 315—5)

1

This invention relates to amplifiers, oscillators, harmonic generators, detectors and the like, especially for operation at ultra-high frequencies, and relates more particularly to devices involving energy interchanges between a beam of moving charged particles, for example electrons, and hollow bodies resonant to electromagnetic waves.

An object of the invention is to avoid energy losses caused by the beam striking the walls of the resonating chamber.

Another object of the invention is to abstract energy from a velocity varied stream of charged particles without the necessity of first developing electron density variations.

A feature of the invention is the use of variable deflection of an electron beam for the purpose of systematically altering the magnetic coupling between the beam considered as a current and the conductive wall of an associated internally resonant hollow body.

Another feature is the variation of such coupling by axial variation of the focal point of a focussed electron beam.

Another feature is the deflection of an electron beam with respect to a normal or initial position of symmetry with reference to the electric field pattern associated with a resonator for the purpose of harmonic wave generation.

A further feature is harmonic generation by radial vibration of a rotating beam in the vicinity of an annular aperture in a toroidal resonator.

A still further feature resides in the use of electrodes, in one case resembling in appearance a pair of toothed gears in juxtaposition, for imparting a radial vibration to a rotating electron beam.

The harmonic generating system disclosed herein employing radial vibration of a rotating beam is claimed in my copending application Serial No. 506,928, filed October 20, 1943, assigned to the same assignee as the present application.

In accordance with the invention a beam of moving charged particles is directed into the immediate vicinity of a gap in a hollow resonator, the region adjacent to the gap being characterized by a standing electromagnetic wave pattern having an electric component which varies materially from point to point. The magnitude of the magnetic coupling established between the beam considered as a current and the conductors constituting the boundary of the resonator is a function of the geometry of the system. In other words, the magnitude of the energy interchange effective between the beam and the res-

2

onator depends upon their geometric relationship or relative position. The coupling is in general varied by any relative motion between the beam and the resonator. By varying the coupling at a rate corresponding to the resonant frequency of the resonating chamber, the beam is enabled to energize the electromagnetic field in the resonator. In accordance with one embodiment of the invention the desired deflection of the beam is secured by first impressing a succession of velocity variations upon the particles in the beam and then directing the beam at an angle into a substantially constant direct current electric field thereby causing the particles to travel in trajectories of different curvatures effecting a suitable lateral motion of the beam. Various other more or less conventional arrangements may also be employed to secure the desired deflection.

The invention is described in greater detail hereinafter in reference to a number of embodiments illustrated in the accompanying drawings while the scope of the invention is indicated in the appended claims.

In the drawings:

Fig. 1 is a diagram useful in explaining certain embodiments of the invention;

Figs. 2 to 7, inclusive, illustrate a variety of embodiments of the invention;

Fig. 8 is a fragmentary view of a component of the system shown in Fig. 7; and

Fig. 9 is a diagram useful in explaining the operation of the system of Fig. 7.

In Fig. 1 there is shown an electron gun 10 arranged to direct a beam of electrons across a gap 11 in a resonating chamber 12. Directed at an angle to the path of the electron beam there is maintained a steady direct current electric field as, for example, by means of a negatively charged plate 13, causing the electron path to follow a substantially parabolic course indicated by a dot-dash line 14. A second resonator 15 is placed in the path of the electron beam so that a gap 16 therein is traversed by the beam substantially perpendicular to a pair of electrodes 17 and 18 which constitute the gap. By excitation of the resonator 12 the electrons of the beam may be given successively varying velocities as they pass through the gap 11. The faster electrons will then penetrate further into the retarding field and so follow paths such as one represented by the dot-dash line 19. The slower electrons will follow paths such as one represented at 20. The geometry of the system is evidently such that velocity variation of the beam

results in a movement of the beam with respect to the resonator 15 as indicated by the different positions of the curves 14, 19 and 20 spread out transversely of the gap 16.

Assuming some initial electromagnetic disturbance in the resonator 15, such as will generally occur spontaneously, any non-uniformity in the intensity of the electric field between various points along the gap 16 will give rise to a variation in the amount of energy transferred to the field per electron, depending upon the position of the electron path transversely of the gap 16. Variations in the energy transferred to the resonator will result in fluctuations in the charges present upon the electrodes 17 and 18. If the fluctuations occur at the resonant frequency of the resonator it is evident that energy will be abstracted from the electron beam to maintain the electromagnetic oscillations in the resonator. From another viewpoint the magnetic coupling between the electron beam considered as a current and the conductors forming the walls of the resonator, depends upon the geometry of the arrangement and, in particular, depends upon the position in the gap 16 which the electron beam occupies at a given time. In general, any gap between electrodes will entail some non-uniformity of the electric field and hence by moving an electron beam about in the vicinity of a gap in a resonator it is usually possible to vary the magnetic coupling and hence to establish alternating electromotive forces in the conductors of the resonator.

Fig. 2 shows a practical embodiment of an arrangement operable upon the principle which has been explained with reference to Fig. 1. An electron gun 21 is mounted within one end portion of an evacuated envelope 22. Within the opposite end portion of the envelope is provided a collector electrode 23. Between the gun 21 and collector 23 are arranged in succession an input cavity resonator 24, an electrode 25 for providing a deflecting potential and an output cavity resonator 26. If desired, the arrangement may be accommodated to a straight-walled cylindrical envelope by setting the electron gun 21 and collector 23 at an angle to the axis of the envelope as shown, and providing apertured electrodes in the resonating cavities 24 and 26 in alignment with the direct and reflected portions of the electron beam, respectively. Coupling devices 27 and 28 may be employed as input and output connections respectively and may be connected together if desired to provide feedback when the device is to be employed either as an oscillator or as a regenerative amplifier. The resonators 24 and 26 and the collector 23 may be provided with electron accelerating potentials from a battery 29. The cathode of the electron gun 21 may be heated by energy from a battery 30 and the deflecting potential for the electrode 25 may be provided by a battery 31. Other suitable sources of potentials may of course be substituted for any of the batteries illustrated herein.

In the operation of the arrangement of Fig. 2 as an amplifier, the resonators 24 and 26 may be tuned to the desired operating frequency to resonate with a wave to be amplified, the latter being impressed upon the interior of the resonator 24 through the coupling 27. A standing electromagnetic field set up inside the resonator 24 is effective at the gap to impress electron velocity variations upon the electron beam passing through the gap from the electron gun 21. In the neighborhood of the electrode 25 the electron beam is bent,

the slower electrons being deflected to a greater extent than the faster ones, as explained in connection with Fig. 1. The deflected beam in passing through the gap in the resonator 26 is variably coupled with the conductive boundary of the resonator 26, causing an alternating electromagnetic wave to be set up and resonated in the cavity of the resonator 26 from which energy may be taken off through the coupling 28.

Fig. 3 shows an arrangement generally similar to that of Fig. 2. However, instead of the electron gun 21, producing a single pencil or beam of electrons, a gun 32 is provided having an annular cathode producing a tubular beam of electrons indicated in section by dot-dash lines 34 and 35. Input and output resonators 36 and 37, respectively, are provided each having an annular gap through which the electron beam passes. Between the resonators 36 and 37 is mounted a hollow cylindrical electrode 38 to which a deflecting potential may be applied. The application of the deflecting potential in the arrangement of Fig. 3 causes the tubular beam to increase or decrease in radius thereby moving radially with respect to the annular gap in the resonator 37. A collector electrode 39 is provided, which may advantageously include an annular groove into which the tubular beam may enter, the sides of the groove serving to intercept and absorb secondary electrons produced by the impact of the beam against the electrode. A source 60 of control potentials may be inserted in the connections to the deflecting electrode 38 for superimposing a modulation or control effect. For example, the source 60 may supply audio or video signals which will modulate a carrier wave generated in the resonator 37. Or, the source 60 may supply an automatic volume control potential derived in well-known manner, for example from the output of the resonator 37.

The system of Fig. 3 may be operated to generate the carrier wave either by means of the variable electron coupling principle as in the system of Fig. 2, or by virtue of electron bunching occurring while the electron stream traverses the space enclosed by the electrode 38. In either case, the coupling may be varied by means of source 60. Adjustment of a suitable initial bias potential, either positive or negative, may be effected by means of a potentiometer arrangement 61, to deflect the electron stream initially either outwardly or inwardly to any desired extent.

Various specific arrangements for deflecting the electron beam will occur to those skilled in the art, two examples being shown in Figs. 4 and 5, respectively. Fig. 4 illustrates the use of a transverse magnetic field for deflecting an electron beam. The field may be maintained by magnetic coils 40 and 41 suitably energized and mounted outside the envelope enclosing the electron beam. Fig. 5 shows the use of electrostatic deflection plates 42 and 43 mounted inside the envelope and effective to deflect an electron beam passing therebetween. While in the arrangement of Fig. 4 the deflection of the beam is to be made variable as in the preceding arrangements by velocity variation effected by a resonator, in the arrangement of Fig. 5 the beam may be variably deflected by impressing alternating electromagnetic waves upon the plates 42, 43 either with or without an accompanying direct current biasing potential.

In the arrangement of Fig. 6 an electron gun 44 is employed of a type producing a convergent beam arranged to have a focal point at the gap

5

45 of an input resonator 46. A magnetic coil 47 is provided to produce an axial magnetic field whereby the electron rays diverging after passing the gap 45 may be brought together at a second focal point 48, for example. The focal point 48 may be, for example, somewhat beyond the gap 49 in an output resonator 50.

In the operation of the system of Fig. 6, velocity variations impressed upon the electron beam at the gap 45 cause a variable deflection of the individual electrons in the axial magnetic field, thereby serving to shift the focal point from 48 to other positions such as the one indicated at 51, for example. Velocity variation of the electron beam thus causes the focal point to execute axial excursions, thereby continually varying the relative position of the electron beam and the conductors of the resonating chamber 50. The shifting of the focal point of the beam constitutes an alternative method of varying the coupling between the electron beam and the resonant system thereby energizing the resonating chamber 50 in accordance with the same general method that has been explained in connection with the preceding figures.

An "in phase" variation in which an increase of electron velocity is accompanied by an increase in output current is obtained by adjusting the beam to focus initially at a point beyond the gap 49, such as point 48. Conversely, an "out of phase" variation in which an increase of electron velocity is accompanied by a decrease in output current is obtained by locating the initial focal point ahead of the gap 49, at a point such as 51.

In any of the arrangements of Figs. 1 to 6, inclusive, it will be noted that if the normal position of the beam is located at an axis of symmetry of the electric field pattern at the gap, as for example, at the center of the gap in a symmetrical system, there will be two cyclic changes of coupling accompanying each cycle of the deflecting potential. The output wave will in that case have a wave form rich in harmonics, particularly the second harmonic, and will be deficient in the fundamental frequency component. Hence in such an adjustment any of the arrangements functions as a frequency multiplier. To secure a fundamental component in the output wave it is only necessary to shift the normal, or zero position of the beam to a position unsymmetrical with reference to the space pattern of the electric field.

Fig. 7 shows another adaptation of the invention particularly designed for harmonic generation but not depending upon locating the normal position of the beam symmetrically with respect to the electric field pattern. A source 40 of waves the frequency of which is to be multiplied, is connected through a quarter phase network 41 to the respective pairs of deflecting plates of a conventional beam rotating arrangement 42 operating upon the electron beam from an electron gun 43 to cause the beam to sweep over a conical surface passing between two annular electrodes 44 and 45. The electrodes 44, 45 are polarized at unequal potentials by means of batteries 46 and 47, respectively. Beyond the electrodes 44, 45 and adjacent to the path of the electron beam is mounted a toroidal resonating chamber 48 having an annular slot or aperture 49 surrounding and adjacent to the path of the rotating beam. An output coupling arrangement 50 is provided in conjunction with the resonator 48 and

6

a collector 51 is arranged for intercepting the beam after it passes the aperture 49.

In the operation of the arrangement of Fig. 7, the electron beam sweeps out a circular conical surface except for the modifying influence of the electrodes 44, 45. These electrodes have regularly spaced projections alternately arranged, as for example in the form shown in detail in a fragmentary view in Fig. 8. The shaping of the teeth in Fig. 8 is merely illustrative of various suitable forms that may be used, the effect being to deflect the beam radially inwardly and outwardly alternately, causing the beam to describe a surface of wave-like outline as shown by the line 52 in the sectional diagram Fig. 9. There the undisturbed path of the beam is indicated by a circle 53. The effect of the electrodes 44 and 45 is to cause the beam to alternately approach and recede from the aperture 49 at a rate determined by the input frequency of the source 40 and the number of teeth in the electrode 44 or 45. The effect of the relative movement between the electron beam and the boundaries of the resonator 48 as in the other applications of the invention is to generate in the resonator an alternating electro-magnetic field. In this case, it is evident that the frequency of the field will be a multiple of the frequency of the source 40, the number of the multiple being determined by the number of teeth in either electrode 44 or 45. In other words, the input frequency is multiplied by one half the number of teeth in either of the two electrodes.

In any of the systems illustrated the effects due to beam deflection may be accompanied by the ordinary electron grouping action resulting from faster moving electrons overtaking slower ones in the space between the velocity varying electrodes and the output resonator. Simple theory indicates that the two effects, electron grouping and variable coupling, will combine in quadrature relation at the output. They are therefore not in opposition and may be advantageously combined. If desired, the electron grouping effect may be minimized by using short electron paths or increased initial electron speeds. The modulation and control features described in connection with Fig. 3 may be applied to any of the deflecting mechanisms and used as adjuncts either to an electron grouping or beam deflecting system.

As the operation by means of variable coupling obtained by beam deflection is not dependent upon any electron grouping action to generate large induced electromotive forces in the output system but relies upon the extent and rapidity of deflection of the beam, the output with a given beam current may be increased by increasing the amplitude of the impressed velocity variation. Large output currents may be generated using a large induced electromotive force in conjunction with a resonator of low effective resistance. For this purpose an internally resonant hollow conductive body is well adapted.

What is claimed is:

1. Means for producing and maintaining a beam of moving electrically charged particles, an internally resonant hollow conductive body having an aperture in the path of said beam, means for bringing said beam to a substantial focus at a point near said aperture and means to vary the position of said focal point with reference to said aperture while maintaining the beam current substantially steady, said aperture being sufficiently large compared with the trans-

7

verse dimensions of the beam to freely pass substantially the whole beam throughout the normal range of variation of the position of said focal point.

2. Means for producing and maintaining an electron beam moving along a substantially rectilinear axis, an internally resonant hollow conductive body having an aperture in the path of said beam, means for bringing said beam to a substantial focus at a point on said axis near said aperture, a source of waves to be repeated, and

8

means actuated by said waves to vary the position of said focal point along said axis with reference to said aperture while maintaining the beam current substantially constant in magnitude, said hollow body being resonant to said waves and said aperture being sufficiently large compared with the transverse dimensions of the beam to freely pass substantially the whole beam throughout the normal range of variation of the position of said focal point.

ALVA EUGENE ANDERSON.