

Jan. 14, 1947.

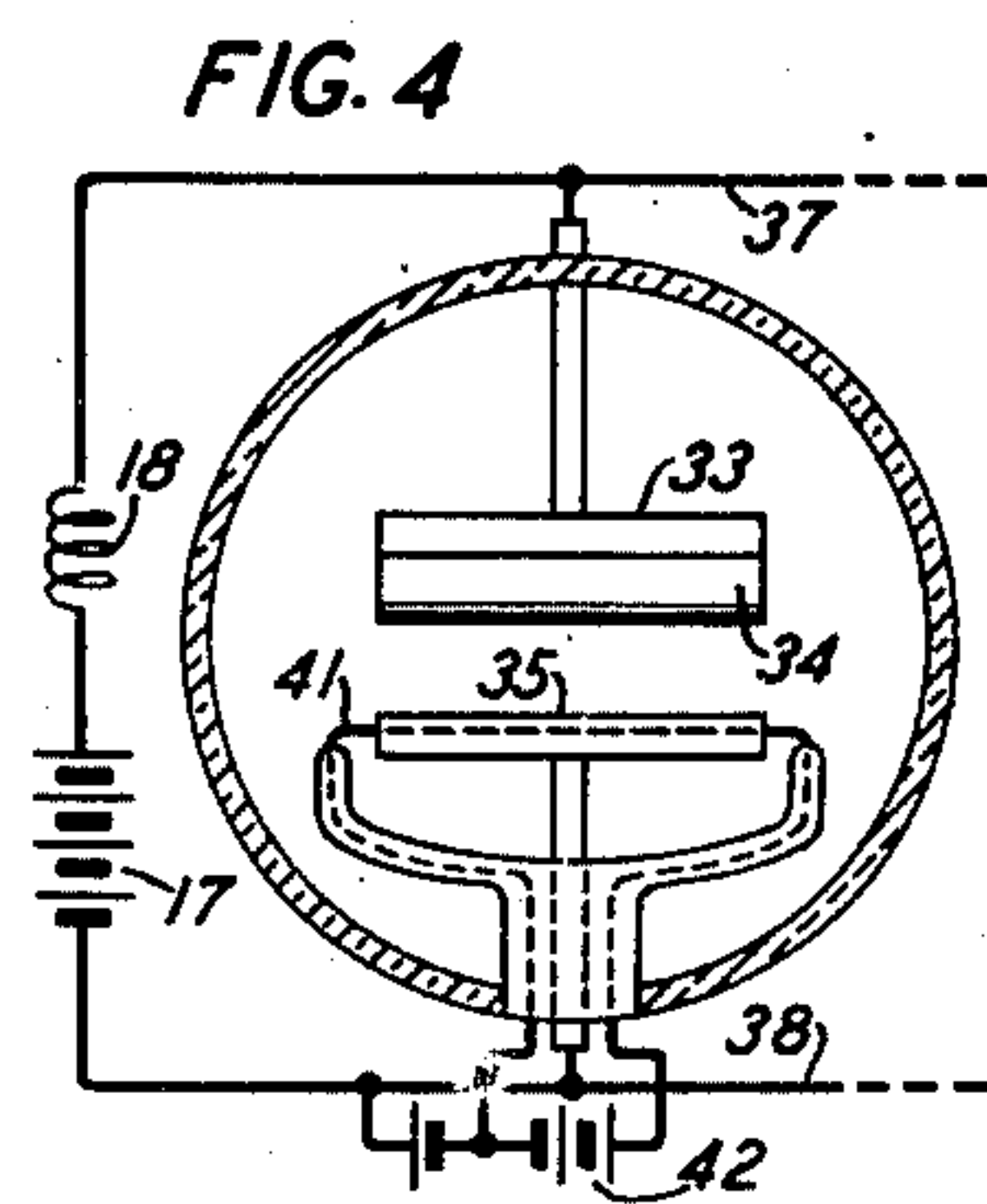
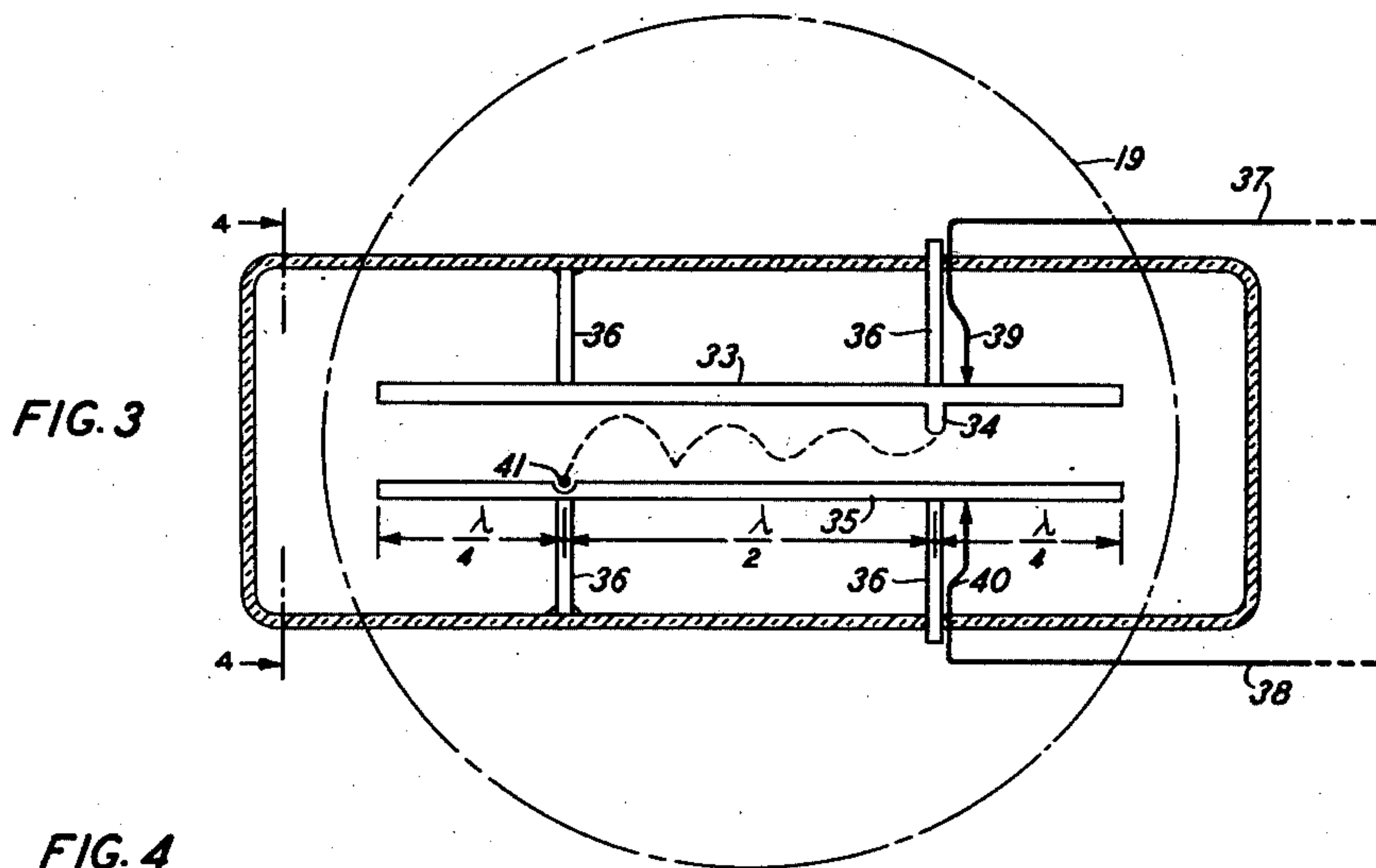
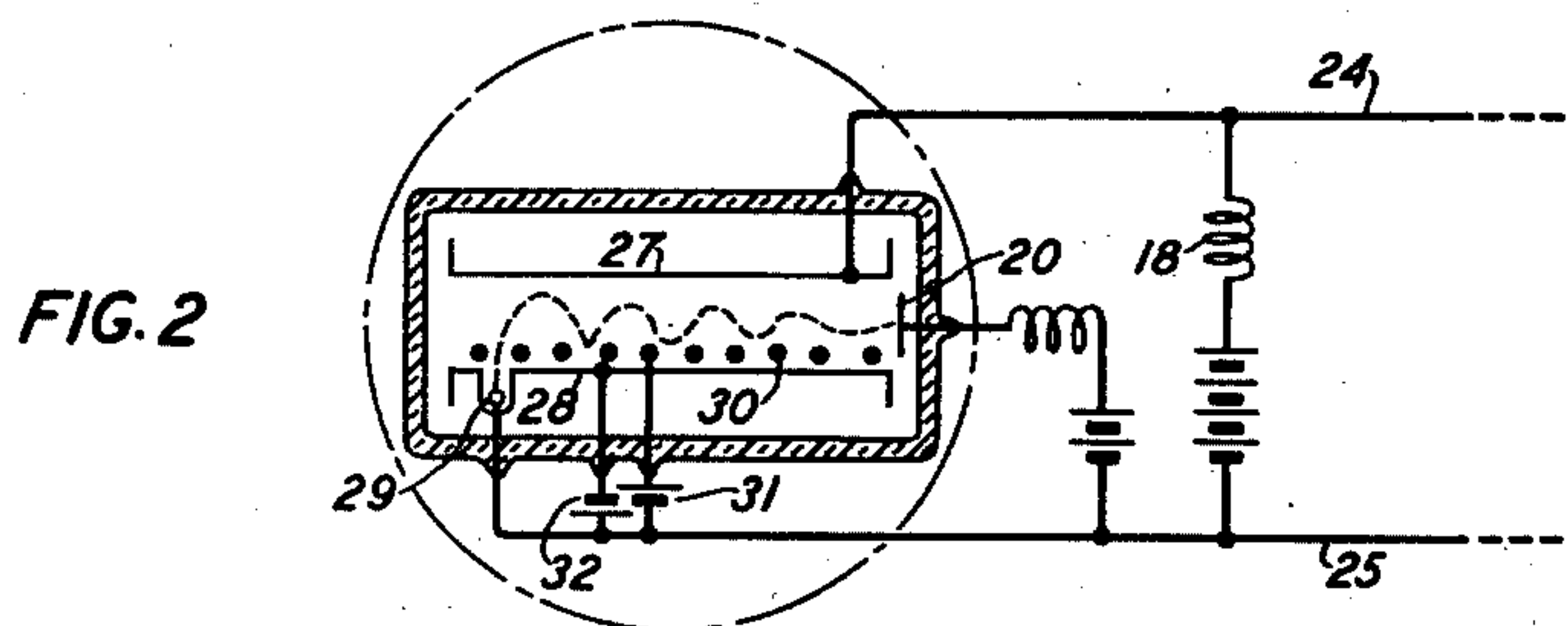
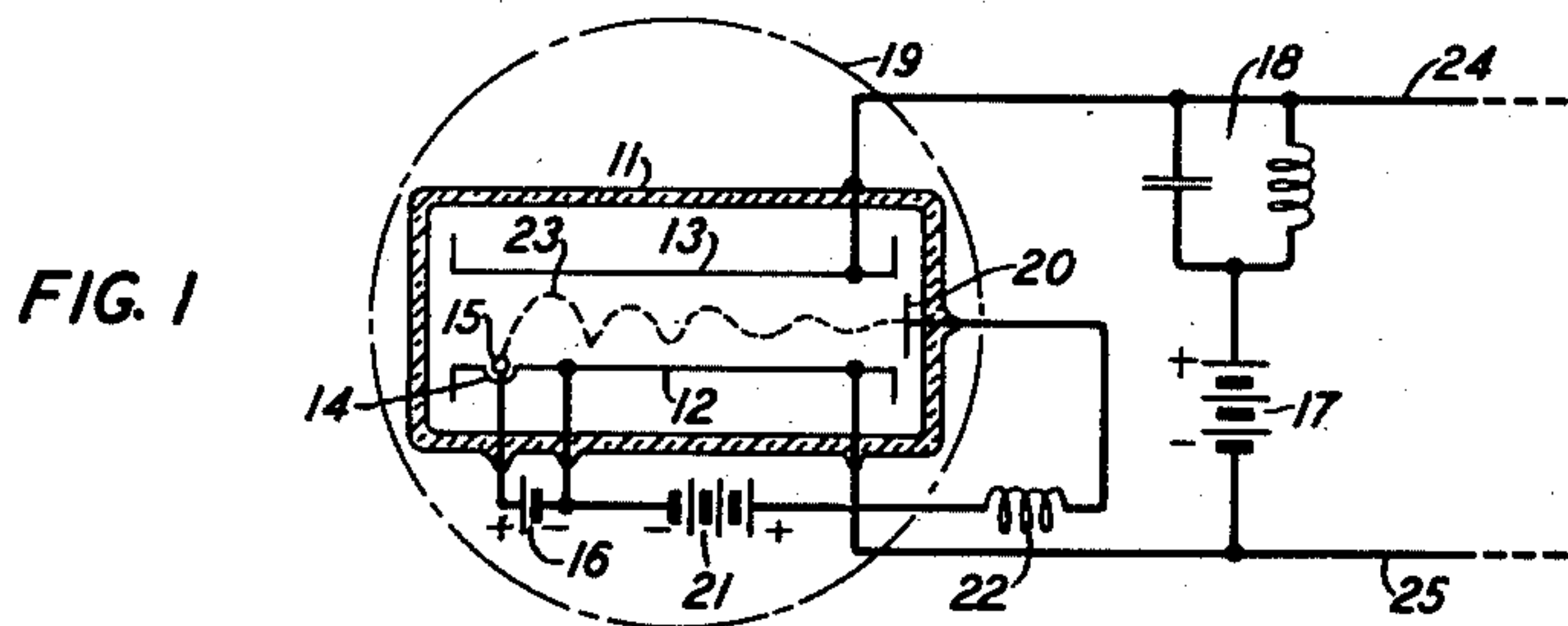
J. R. PIERCE

2,414,121

ELECTRON DEVICE OF THE MAGNETRON TYPE

Filed Jan. 17, 1941

5 Sheets-Sheet 1



INVENTOR
J. R. PIERCE
BY
E. V. Briggs
ATTORNEY

Jan. 14, 1947.

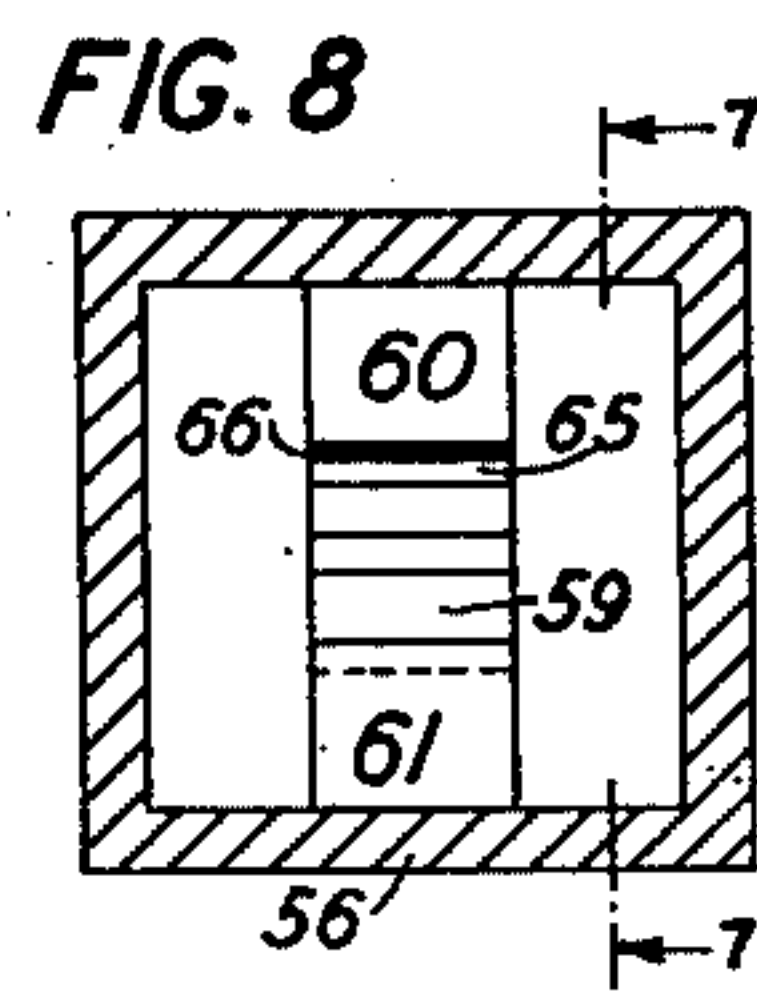
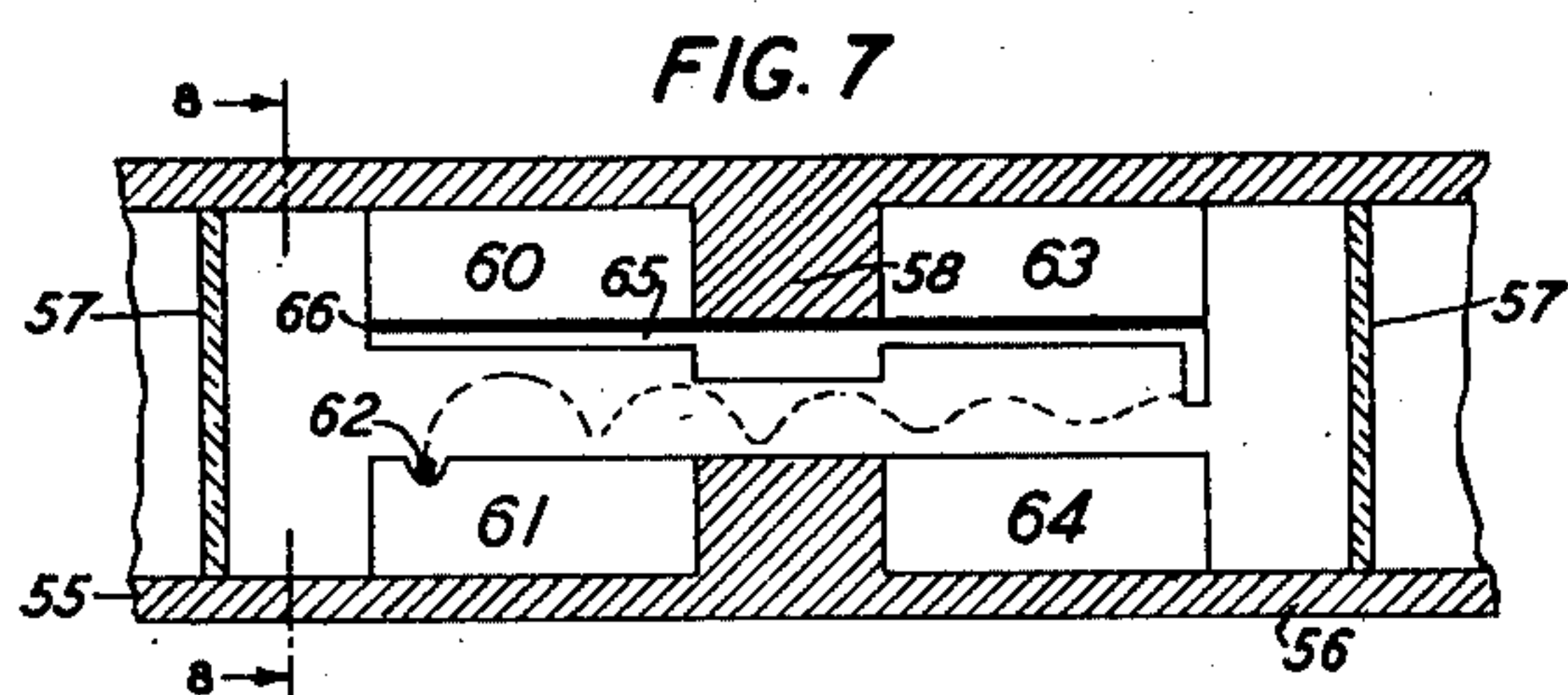
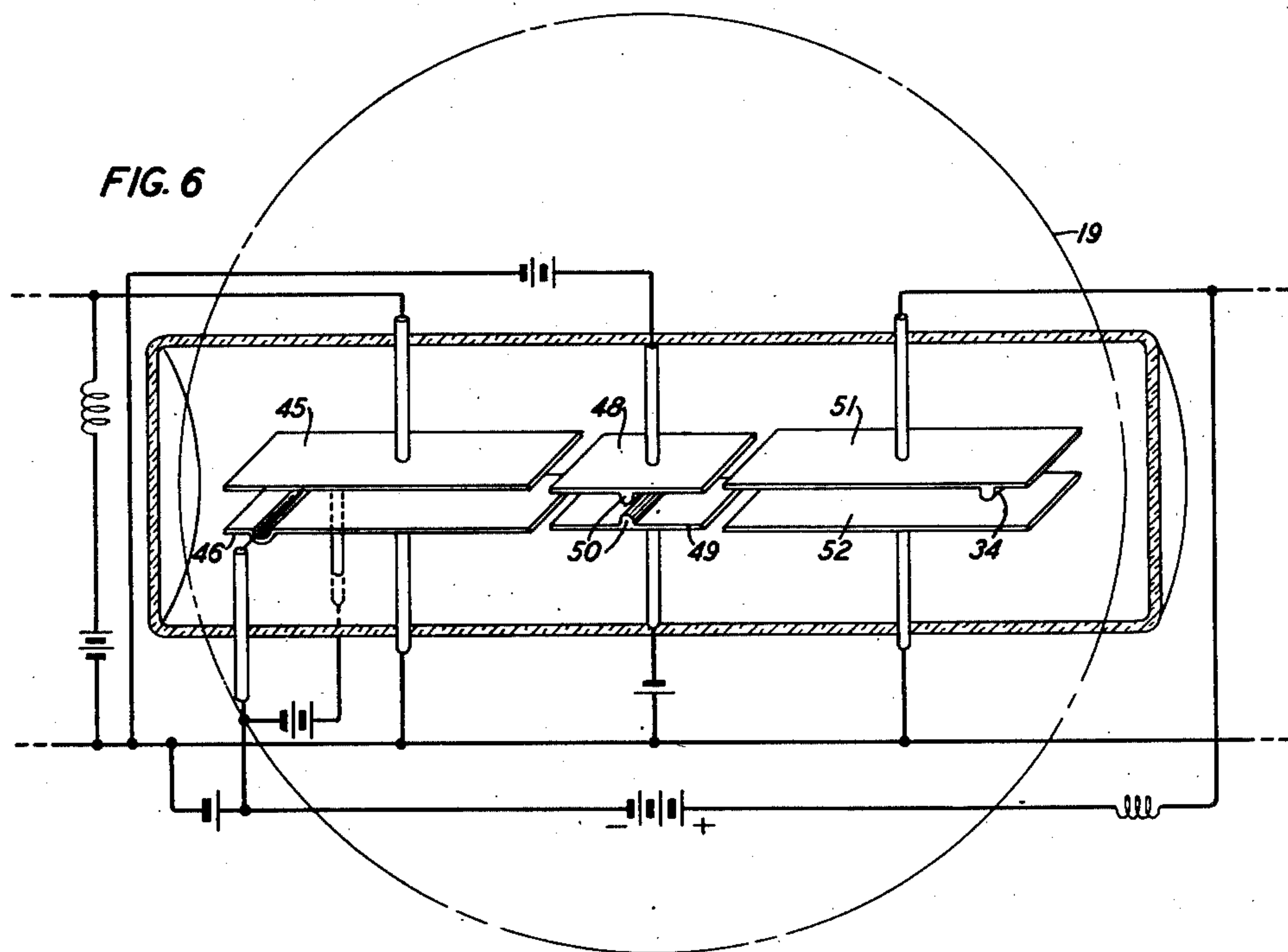
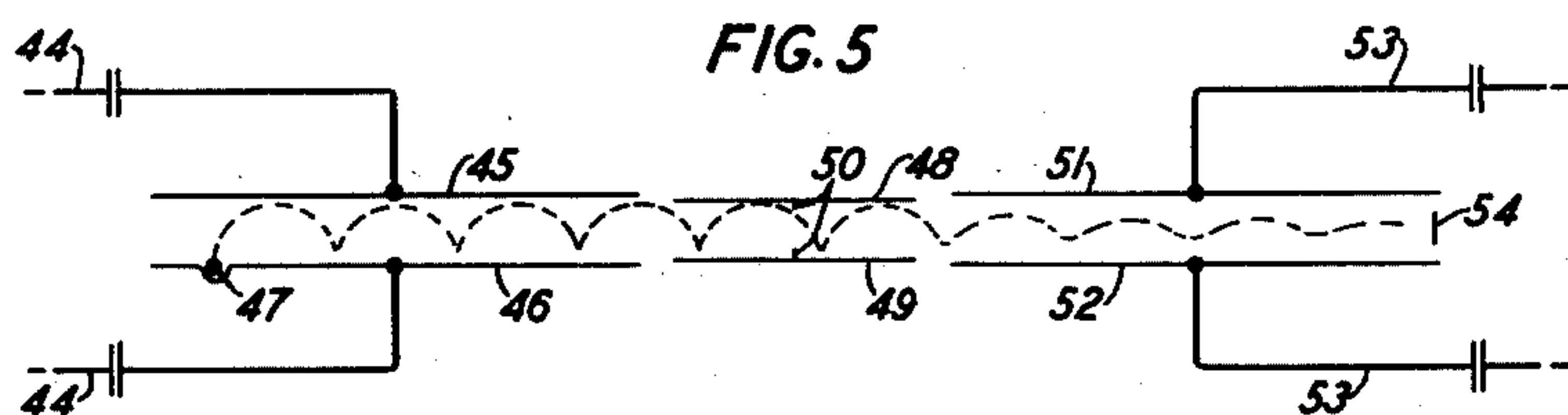
J. R. PIERCE

2,414,121

ELECTRON DEVICE OF THE MAGNETRON TYPE

Filed Jan. 17, 1941

5 Sheets-Sheet 2



INVENTOR
J. R. PIERCE
BY *E. V. Briggs*
ATTORNEY

Jan. 14, 1947.

J. R. PIERCE

2,414,121

ELECTRON DEVICE OF THE MAGNETRON TYPE

Filed Jan. 17, 1941

5. Sheets-Sheet 3



BY

INVENTOR
J. R. PIERCE

E. V. Sniggo

ATTORNEY

Jan. 14, 1947.

J. R. PIERCE

2,414,121

ELECTRON DEVICE OF THE MAGNETRON TYPE

Filed Jan. 17, 1941

5 Sheets-Sheet 4

FIG. 13

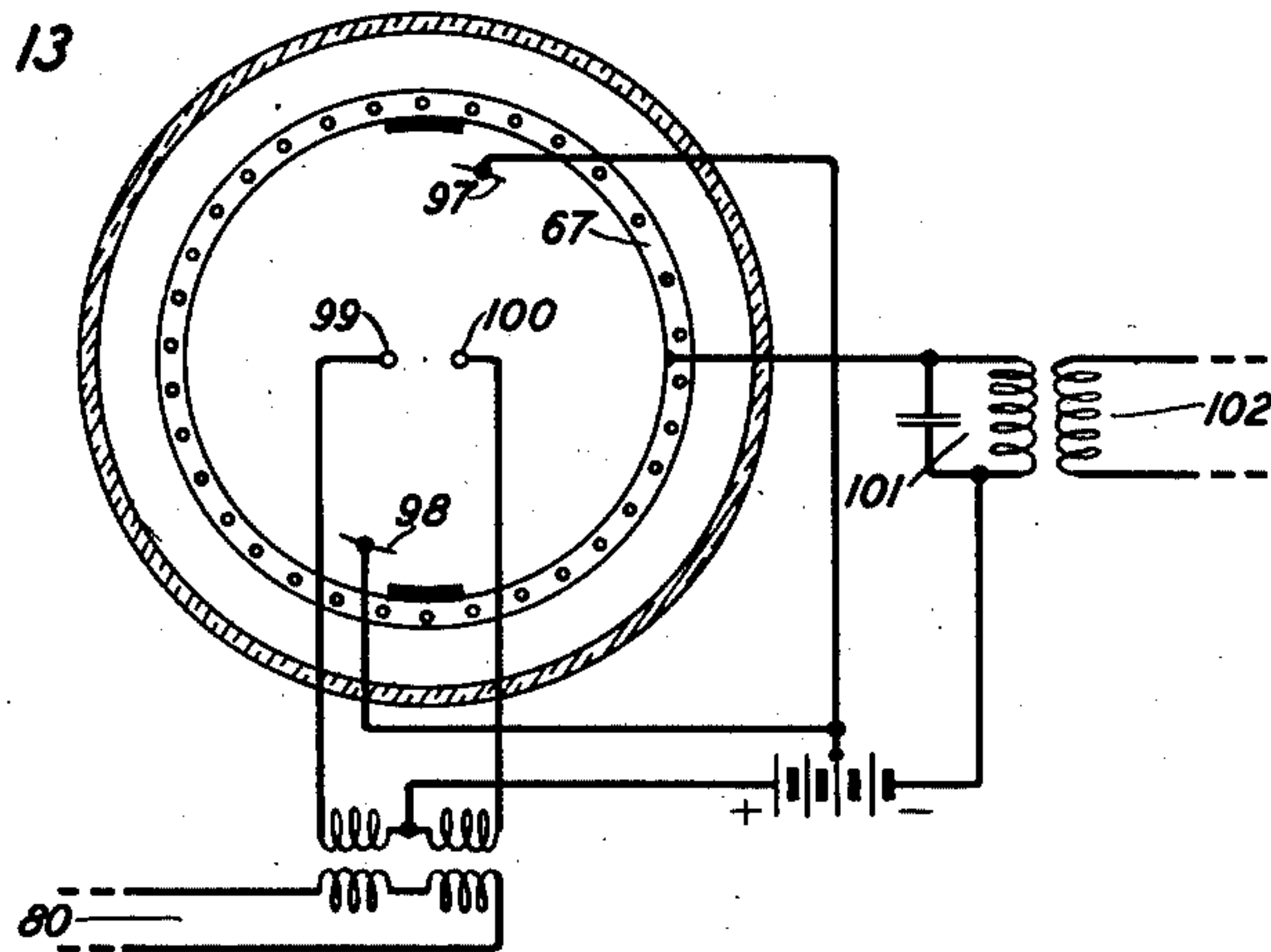


FIG. 14

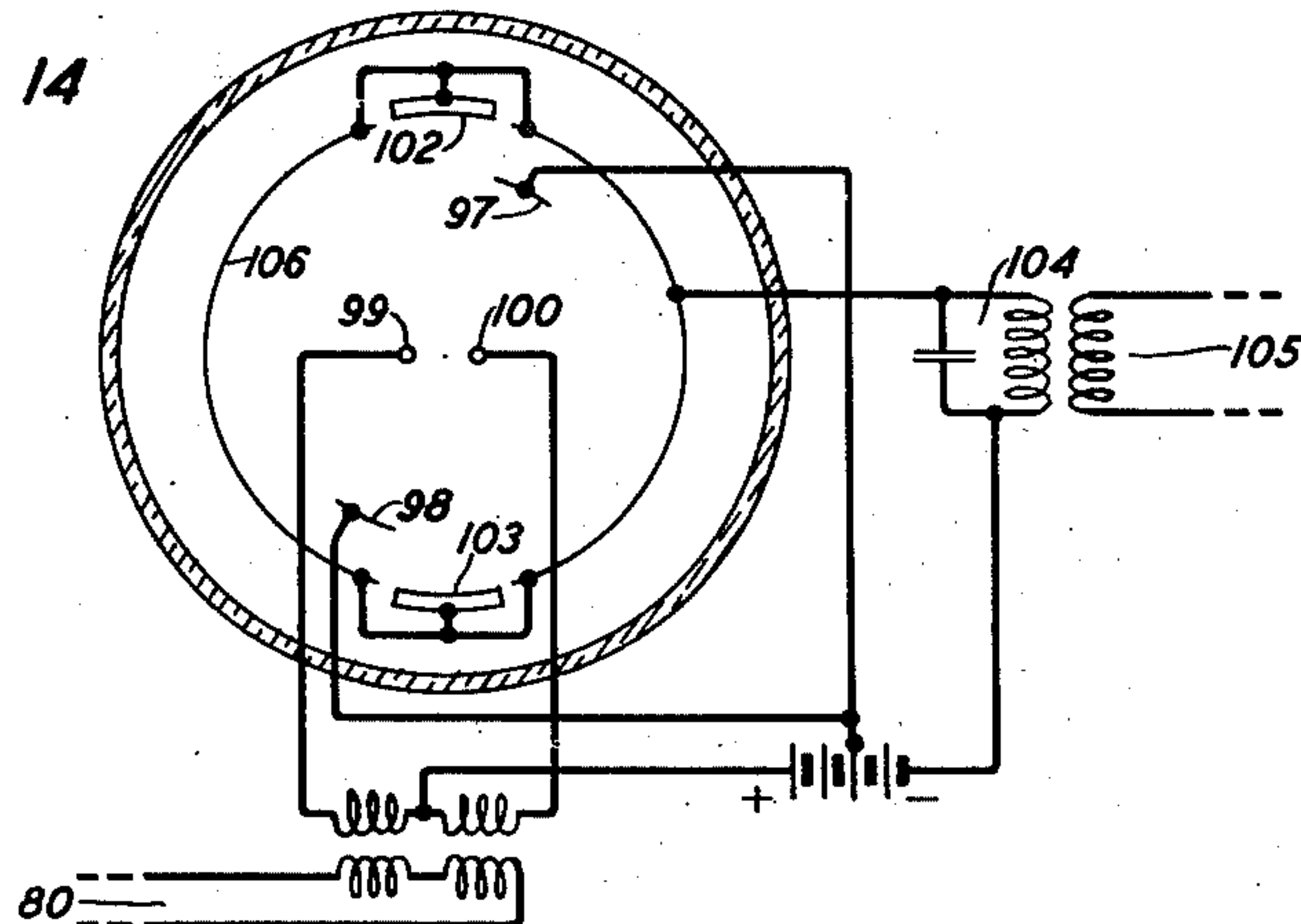


FIG. 15

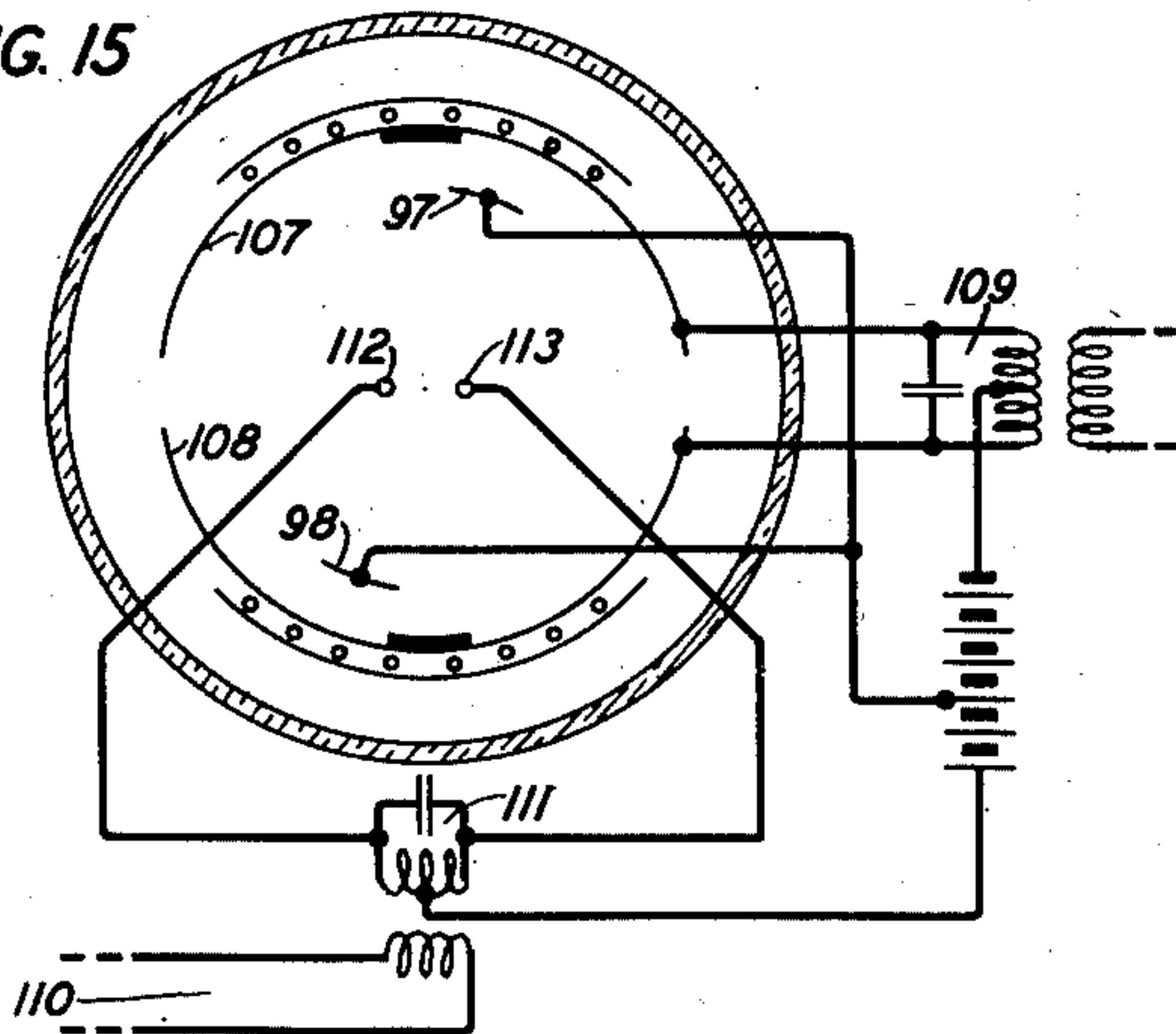
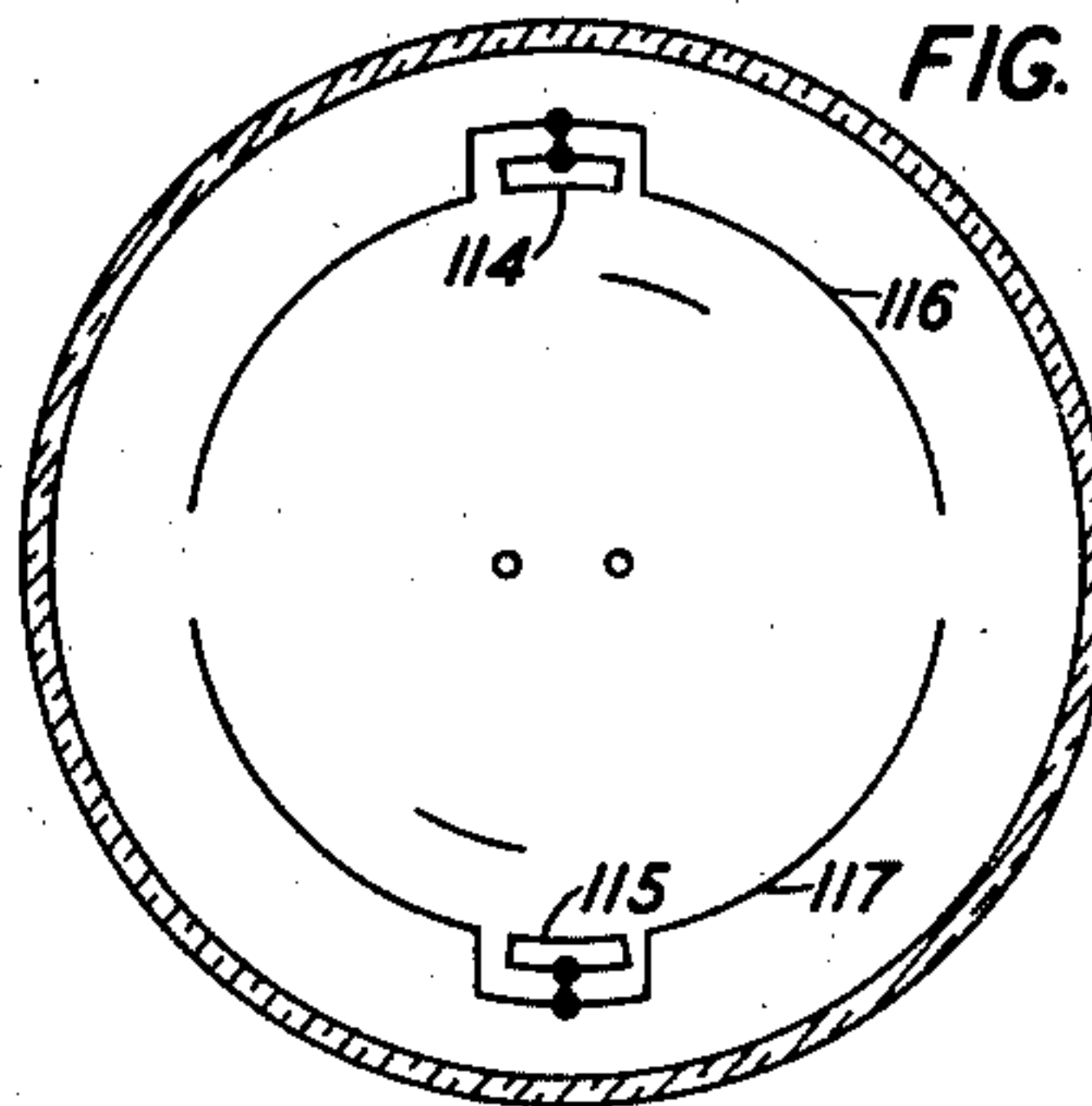


FIG. 16



INVENTOR
J. R. PIERCE

BY

E. V. Lugg
ATTORNEY

Jan. 14, 1947.

J. R. PIERCE

2,414,121

ELECTRON DEVICE OF THE MAGNETRON TYPE

Filed Jan. 17, 1941

5 Sheets-Sheet 5

FIG. 17

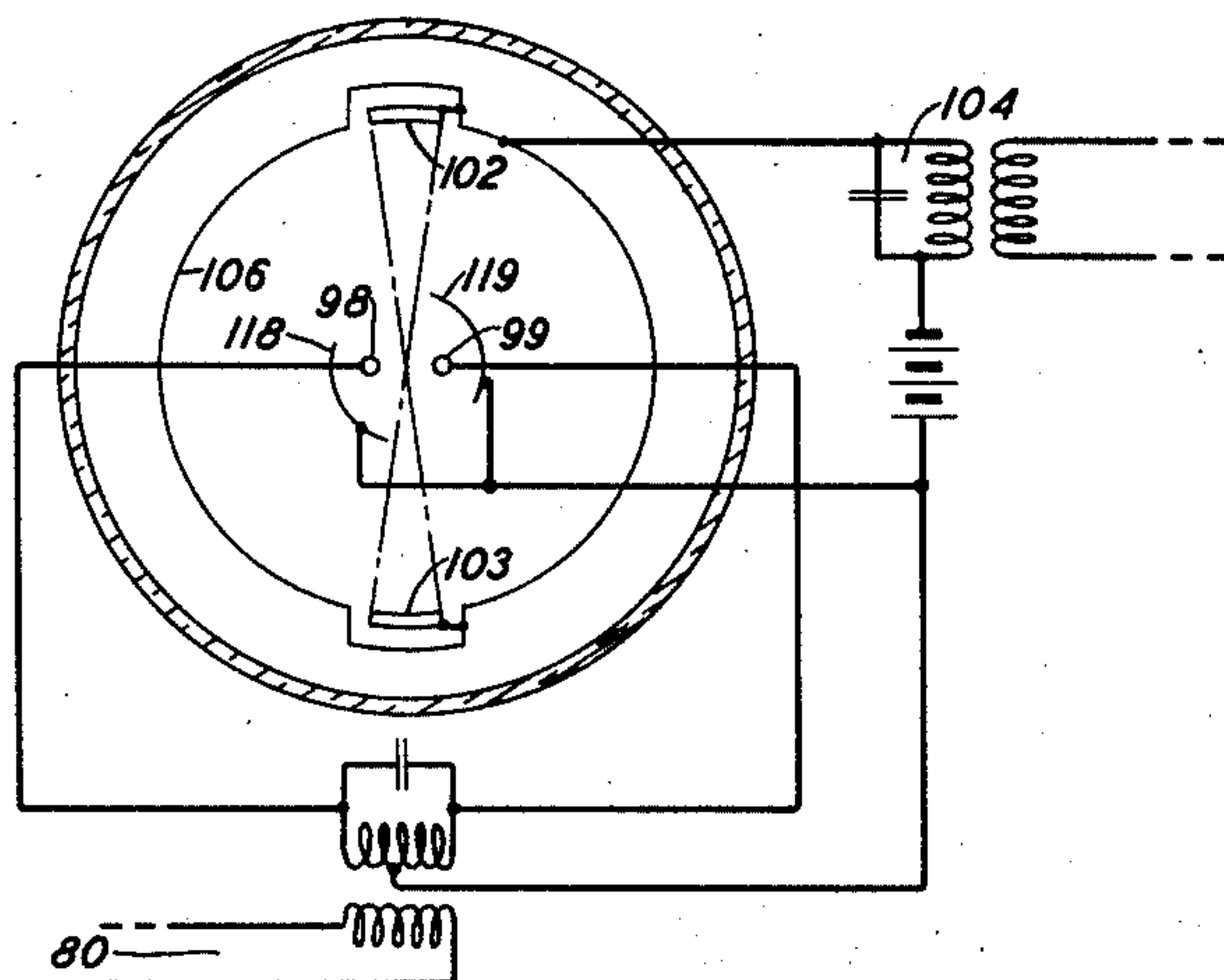


FIG. 18

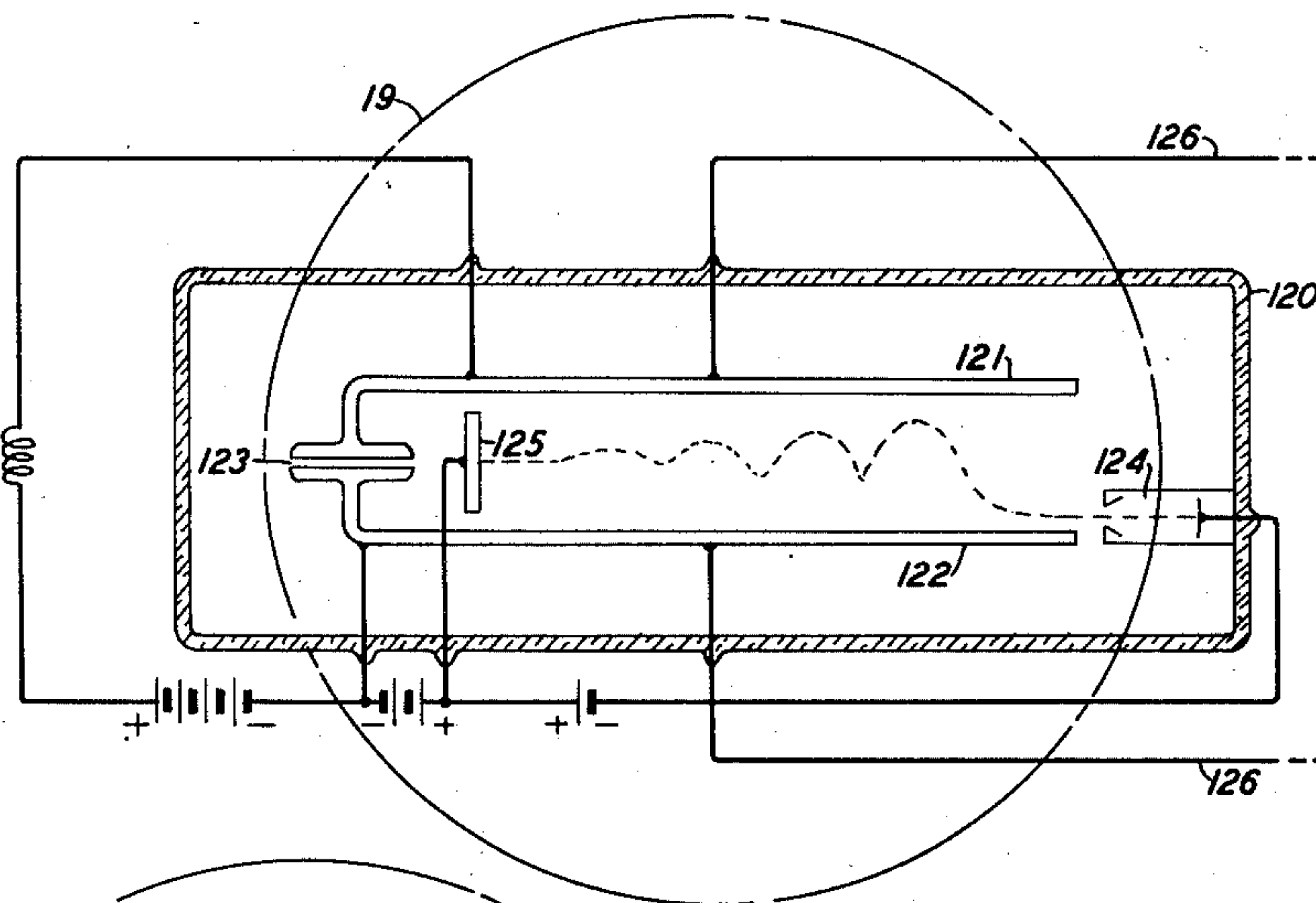
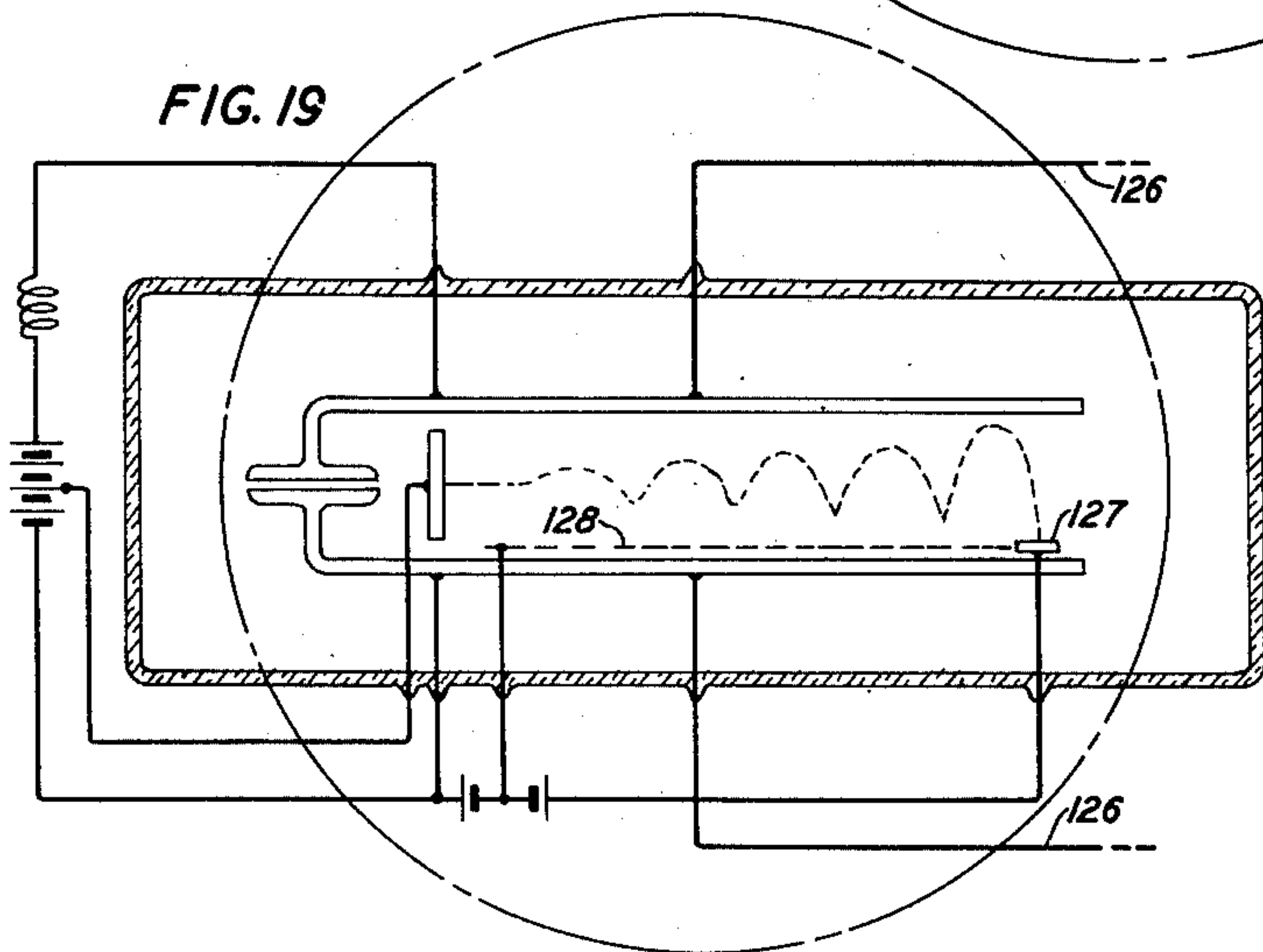


FIG. 19



INVENTOR
J. R. PIERCE
BY
E. V. Briggs
ATTORNEY

UNITED STATES PATENT OFFICE

2,414,121

ELECTRON DEVICE OF THE MAGNETRON TYPE

John R. Pierce, New York, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application January 17, 1941, Serial No. 374,816

7 Claims. (Cl. 179—171)

1

This invention relates to electronic apparatus and more particularly to electron devices of the magnetron type in which density variation of electron streams is effected by a deflection sorting of high speed electrons from the lower speed electrons of a velocity varied stream.

An object of the invention is to increase the structural size of a magnetron for a given frequency thus increasing the possibilities of cooling the structure.

Another object of the invention is to provide a magnetron in which electrons do not retrace their paths thus reducing the limitations of space charge.

An additional object of the invention is to preclude bombardment of the cathode of a magnetron by electrons which have gained energy.

A still further object of the invention is to produce effective density variation of an electron stream by subjecting the stream to an alternating electric field which may impress upon the electrons directional or velocity characteristics or both by which the electrons emitted during opposite phases may subsequently be sorted.

A further object of the invention is to provide a means for amplifying at very high frequencies.

In accordance with the invention, an electron stream emitted into the space between two conducting surfaces, one of which is at substantially the potential of the emitter and the other of which is at a relatively high potential is subjected to a cross-magnetic field of a strength sufficient to cause the electrons to proceed laterally in a series of cycloidal hops, the periodicity of which is a function of the applied magnetic field only. The electric and magnetic fields are also so established and the separation of the conducting surfaces is so predesigned that the cycloidal trajectories of the electrons under the influence of the normal forces just fail to reach the high potential surface.

A superposed alternating electrostatic field between the plates will accelerate electrons emitted during one phase of the field so that these electrons quickly reach one of the plates and are withdrawn. Electrons emitted during the opposite phase are decelerated thus yielding oscillating energy to the field. They continue in their course with transfer of energy during each cycle of their cycloidal path until they finally impinge upon a target or collector. The alternating electric field is maintained by this energy so that the device functions as an oscillator.

If, after the electrons have been subjected to such accelerating action in a region widely

2

enough spaced to prevent their striking the electrodes they are permitted to pass out of the zone of the accelerating plates successively into an electron sorting zone and an energy extracting zone, the device may serve as an amplifier. Such an amplifier may be of the ordinary thermionic type enclosed in a highly evacuated container of dielectric material or it may form an asymmetric coupling between two wave guide sections.

In a modified form of the invention, electrons emitted by a cathode which may be cylindrical are subjected to an alternating electric cross-field which deflects them in one direction or in the counter-direction depending upon the phase of the electric cross-field while those of a second group emitted during the opposite phase are deflected in the other direction. By this method the electrons of the original electron stream are sorted into two separate density-varied streams, the energy of either or both of which may be transferred to the circuits of suitably located auxiliary electrodes.

In the drawings Fig. 1 illustrates schematically an oscillator constructed in accordance with the invention; Fig. 2 shows a modification of the oscillator of Fig. 1 designed for higher efficiency; Fig. 3 presents a modification of the oscillator of Fig. 1 in which the structure of the electron discharge device is simplified; Fig. 4 is a cross section of the structure of Fig. 3 along line 4—4; Fig. 5 is a schematic diagram of an amplifier in accordance with the invention; Fig. 6 illustrates a structure designed in accordance with the schematic of Fig. 5; Fig. 7 is a longitudinal section of a wave guide repeater; Fig. 8 is a cross section taken on the line 7—7 of Fig. 7; Fig. 9 shows in section a modified form of an amplifier in accordance with the invention; Figs. 10 and 11 are schematic diagrams to assist in explaining the operation of Fig. 9; Figs. 12 to 15 inclusive, show modifications of the amplifier of Fig. 12; Fig. 16 shows a modification of the cathode apparatus of Fig. 15; Fig. 17 shows a modification having auxiliary electrodes; Fig. 18 shows a form of oscillator; and Fig. 19 shows a modification of the structure of Fig. 18.

Referring to Fig. 1, an electron discharge device comprises an evacuated container 11 enclosing a pair of parallel plate electrodes 12 and 13 of electrically conducting material. Plate 12 is recessed as indicated at 14 to provide a space for a linear cathode 15 which extends across the plate 12 in a direction perpendicular to the plane of the paper. The cathode 15 may be heated in any well-known manner as, for example, by a

source of heating current, not shown, connected to its terminals. Plate 12 may be polarized at about the same potential as cathode 15 or preferably slightly negatively with respect thereto by a source 16. An electrical current source 17 is connected in series with resonant circuit 18 between the plates 12 and 13 to render plate 13 highly positive with respect to plate 12. A magnetic field source 19 which may be a permanent magnet or an electromagnet, as indicated by the broken line circle, imposes a magnetic field perpendicular to the plane of the paper and, also, to the electric field, upon the space between the plates 12 and 13. Near the end of the discharge device and somewhat beyond the space between the plates 12 and 13 is a collector electrode 20 which is polarized positively with respect to cathode 15 by a source 21 in series with a choke coil 22. An electron emitted from the cathode 15 will be impelled by the high positive potential of plate 13 in a direction toward that plate. Because of the cross-magnetic field, however, the path of the electron will not be linear but will be curved as indicated by the dotted line 23. If the spacing between the plates 12 and 13, the magnitude of the potential source 17 and the strength of the magnetic field of source 19 be properly related the electron will not reach the plate 13 but its path 23 will be approximately cycloidal in character. The vertical component of its motion in the direction between the plates 12 and 13 will consist of a simple harmonic oscillation, the magnitude of which depends upon the strength of the applied electric and magnetic fields and the frequency of which is primarily a function of the magnetic field. The horizontal component of the motion of the electron, that is, in the direction toward the collector 20, will have an average velocity depending on both the magnetic and electric fields.

Suppose that in addition to the forces already considered, namely, the steady electric field between the plates 12 and 13 and the steady magnetic cross-field, there be applied between the plates 12 and 13 a sinusoidal electric field having an angular frequency the same as the natural frequency of the electron motion in the vertical direction. The trajectory 23 of an electron emitted from cathode 15 will now depend upon the phase of the applied alternating electric field at the instant of emission of the electron. The amplitude of the vertical component may either increase with time or may decrease depending upon the phase position of the alternating field at the time when the electron starts. If the amplitude increases the electron will, of course, abstract energy from the alternating electric field and it may reach a position such that it will collide with and be absorbed by the plate 13. This condition may be facilitated by making the spacings between the electrodes 12 and 13 approximately equal to the total vertical excursion of electrons when there is no alternating electric field so that electrons unaccelerated by the alternating field just miss the plate 13 but those which receive the greatest acceleration are quickly withdrawn from the zone of action. Suppose that an electron from the cathode 15 be emitted at an instant such that its entire vertical excursion is opposed by the alternating field. Under these circumstances, the vertical excursion of the electron will be reduced or, in other words, the electron will yield energy to the alternating field. During the next cycle the process will be repeated with the elec-

tron losing additional energy to the field until finally its vertical excursion is considerably reduced and the electron passes out from the space between the plates 12 and 13 to impinge upon and be absorbed by the collector 20. It will be apparent that those electrons which received energy from the alternating field reduce the energy of the field while those whose vertical excursions are decreased yield energy to that field. However, since the electrons which abstract energy are quickly withdrawn from the space between the plates 12 and 13 while those which yield energy to the field remain throughout their transit between the plates until they reach the collector 20, the net result will be that the field gains energy from the electrons. Consequently, any tendency to build up such an alternating electric field will be accentuated and oscillating energy will therefore be supplied by the device over its output terminals 24 and 25 or through other coupling means to a line antenna, wave guide, or other load circuit connected thereto.

Even when the amplitude of electron oscillation is reduced to zero or a very low magnitude the electrons will still have a velocity in the direction toward the collector 20 representing an energy substantially equivalent to half that they would receive from the unidirectional field in passing from their point of origination to the median plane of their vertical excursions. If the electrons were permitted to finally pass to the higher potential plate 13, a part of their energy would be wasted. This loss is avoided by introduction of the collecting electrode 20 polarized at a potential such that the electrons are slowed down substantially to a stop before they are collected.

In the apparatus of Fig. 1, it was assumed that the majority of the electrons emitted from the cathode 15 at such times as to receive maximum vertical acceleration would be collected by the plate 13. It might transpire that certain electrons, although receiving a positive vertical acceleration from the alternating field would not be accelerated quite enough during the first cycle to strike the plate 13. However, on the excursion toward the plate 12 they would receive from the alternating electric field an additional vertical acceleration toward the plate 12 and might therefore impinge upon that plate and be withdrawn from the zone of action. The earlier these electrons are withdrawn, the less energy they will abstract from the alternating field. Those electrons which are abstracted by plate 13 give rise to a certain loss of energy from the unidirectional current source since they must be replaced by current which flows through the unidirectional circuit from that source. This loss may be avoided by so designing the apparatus that the electrons will tend to strike the more negative plate 12.

Fig. 2 discloses an apparatus involving this principle in which the parallel plates 27 and 28 are so spaced with reference to the cathode 29 that the electrons tend to be absorbed by the plate 28 rather than by the plate 27, thus reducing the unidirectional current loss involved in their collection by plate 27. An additional difficulty is encountered in this structure in the tendency of the negative plate 28 to emit secondary electrons upon the impact of primary electrons collected by the plate 28. To prevent this secondary electron effect a suppressor grid 30 may be placed adjacent the surface of the plate 28 and may be suitably polarized with respect thereto by the

5

source 31 which fixes the potential of the suppressor grid with respect to the cathode 29. The electrode 28 may be suitably polarized by a source 32. In other respects the apparatus of Fig. 2 may be similar to that of Fig. 1. The operation of this apparatus will, therefore, be evident without further explanation.

Fig. 3 illustrates a modification of the apparatus of Figs. 1 and 2 in which the upper plate 33 is provided with an integral rib 34 which serves as the collector, thus simplifying the apparatus. In this structure, the plates 33 and 35 are each made of a full wave-length for oscillations of the desired frequency. The mechanical supporting elements 36 for the plates 33 and 35 are connected thereto at nodal points in order to reduce the loss which their shunting effect may tend to introduce. The external output circuit 37, 38 may be connected by leads 39 and 40, respectively, to points on the plates 33 and 35 sufficiently far from the nodal points to give the desired coupling to the load circuit. The cathode 41 may be heated by the external source 42 of heating current as shown in Fig. 4, which represents a cross-section of Fig. 3 along line 4—4.

Fig. 5 shows schematically an amplifier involving certain principles of the invention. An input circuit 44 is connected to a pair of input plates 45 and 46. The space between these plates is subjected to unidirectional electric and magnetic fields as in the structures of the preceding figures. The spacing of the plates, contrary to that of the preceding figures, is made such that a negligible number of electrons from the cathode 47 strike them. While an acceleration and deceleration of the oscillating electrons takes place in accordance with the varying alternating electric field impressed between plates 45 and 46, no sorting of the accelerated from the decelerated electrons occurs in this region and the input circuit is therefore stable. The action of the alternating electric field on the oscillating electrons causes a certain differentiation or variation in their velocities. Thus since the electrons starting in some phase positions gain in amplitude of oscillation and those starting in other phase positions lose in amplitude of oscillation, there is a certain net gain in energy on the part of the electrons from the impressed alternating field. This energy is not returned to the field of the input plates and hence is the occasion of a resistive component in the input impedance. This is, however, a second order effect which does not substantially affect the linearity of the amplifier performance. A second pair of plates 48 and 49 is provided for effecting the sorting action between the accelerated and decelerated electrons. It may be accomplished in any of three ways or all three methods may be employed in the same structure, as illustrated. In this first method the spacing between plates 48 and 49 may be made slightly less than that between plates 45 and 46 so that the most highly accelerated electrons while able to pass through the space between plates 45 and 46 without interception are intercepted by plates 48 and 49 at the points of maximum vertical acceleration of these electrons. As an alternative or a concomitant expedient the polarizing electromotive force between plates 48 and 49 may be slightly increased over that between plates 45 and 46 to enable the most highly accelerated electrons to increase their vertical excursions sufficiently to be intercepted. A third expedient is to interpose a central barrier as, for

6

example, a pair of ribs 50 similar to rib 34 which may intercept electrons whose trajectory involves wide vertical excursions while permitting those of smaller excursions to pass. There remains of the stream of electrons thus sorted by withdrawal of the most highly accelerated, chiefly those emitted at the phases or instants of deceleration and, accordingly, these pass as a density-varied stream in the space between output circuit plates 51 and 52, the alternating electric field between which extracts energy from the density-varied electron stream in the manner already explained in connection with Fig. 1. The device thus serves as an amplifier and in response to weak alternating electromotive forces of appropriate frequency and signal modulated, if desired, which are impressed by the input circuit 44 upon the input plates 45 and 46, there are yielded to the output circuit 53 amplified electromotive forces of corresponding frequency and wave form but of greatly augmented amplitude. The electrons may finally be collected by a suitably polarized electrode 54.

Fig. 6 illustrates one embodiment of the electronic apparatus which is represented schematically in Fig. 5. The electron collector represented by 54 in Fig. 5 takes the form in the particular embodiment of Fig. 6, of integral grid 34 of the plate 51 similar to the collector 34 of Fig. 3. It will be obvious that it may be readily designed to handle comparatively large output power and that although the transconductance may be high there is substantially no reaction from the output circuit plates 51 and 52 back upon the input plates 45 and 46.

The frequency characteristic of a device such as that of Figs. 5 and 6 is dependent upon the number of hops that the electrons make. If the electrons make only a few hops they will not get far out of phase with the alternating field electromotive force even if their natural frequency and that of the field differ considerably. By increasing the number of cycles spent in the region between the input plates 45, 46 or the number of cycles spent between the sorting plates 48, 49 the device may be made very selective. This is advantageous for short wave operation. The frequency of maximum response may be adjusted by varying the magnetic field and it is to be understood therefore that in each of the systems employing a source 19 of magnetic field that the source is variable to permit such a tuning of the device to be effected.

Fig. 7 illustrates in longitudinal section along line 7—7 of Fig. 8 and Fig. 8 shows in turn a cross-section along line 8—8 of Fig. 7 of a repeater which may be incorporated as an integral structure between two wave guide sections 55 and 56. The repeater portion of the structure is preferably evacuated and sealed by means of glass or other dielectric closures 57. A conducting partition 58 separating the sections 55 and 56 is apertured as at 59 to provide an electronic repeater operating in a manner similar to the structures of Figs. 1 and 5. The steady positive potential necessary between the parallel surfaces for operation may be applied to a conducting electrode 65 insulated from the body of the wave guide by means of an insulating element 66. The electrode 65 preferably has a central raised portion which serves, like the closely spaced plates 48 and 49, to sort out the more highly accelerated electrons. It also has a rib corresponding to the rib 34 of Fig. 6 projecting inwardly from the margin of the electrode 65 most remote

7

from the cathode to collect spent electrons. The alternating electric field existing between the longitudinal central rib members 60 and 61 on the upper and lower walls of the wave guide serves to variably accelerate electrons emitted from the cathode 62. The more highly accelerated electrons are withdrawn from the zone of action in the early period following their emission or at least when they reach the zone of the central raised portion of electrode 65. Electrons which are somewhat decelerated pass on through the aperture 59 into the wave guide section 56 to yield to the opposing alternating field between the members 63 and 64 an amplified energy corresponding in frequency and wave form to that of the section 55. After their energy has been largely spent the electrons are collected at the terminal rib of electrode 65.

Fig. 9 illustrates an amplifier comprising a container 66 enclosing a cathode 67 of circular contour with two active areas 68 and 69 and heaters 70 electrically energized by a source not illustrated. The cathode 67 comprises two concentric metallic cylinders between which are placed the insulated heater units 70 aligned parallel with the axis and electrically connected in series. The cathodes are preferably constructed of some such material as sheet nickel and the active portions 68, 69 may be coated with any suitable material having high electron emitting capacity. Two auxiliary electrodes 74 and 75 for associating the output circuit with the space in which the electron courses lie are positioned within the cathode and symmetrically with respect to active areas 68 and 69. Two anodes 76 and 77 at opposite sides of a diameter joining active areas 68 and 69 are polarized positively with respect to the cathode by a source 78. An input circuit 80 is coupled by a transformer 81 to the path connecting the anodes 76 and 77. Auxiliary electrodes 74 and 75 are connected to opposite terminals of a tuned circuit 82. The tuned circuit is coupled as illustrated to the amplifier output circuit 84 which may lead to an antenna, transmission line or wave guide or other load as desired.

Referring to the diagram of Fig. 10 it will be seen that an electron starting from some position such as point 68 on the cathode will be accelerated in the general direction of the anodes 76 and 77. Assuming that an alternating electromotive force be impressed between the anodes 76 and 77 of such character as to render anode 77 more positive than anode 76 during the initial portion of the electron transit the electron will be impelled with a counter-clockwise deflection as indicated in the broken line trajectory. As it passes beyond the anodes 76 and 77 it is retarded by the adverse field between these anodes and the cathode 67 until coming to rest it begins a return transit during which it is deflected counter-clockwise. Thus it will finally have a path lying in the second and fourth quadrants. In order for this action to take place the alternating electromotive force impressed between the anodes 76 and 77 should be of the same frequency as that of the oscillation of the electrons in the electric field. This is for the reason that in the electron's downward path electrode 77 is positive with respect to 76 and the electron is attracted toward it and deflected counter-clockwise; then on its return path in order to be deflected counter-clockwise electrode 76 must be positive so the electron will be attracted toward electrode 76. If the electron starts from the

8

point 68 at an instant when the anode 76 is positive with respect to the anode 77 or under conditions a half cycle later than those of Fig. 10, its trajectory will be as indicated at Fig. 11 and its final path will lie in the first and third quadrants. The result of this deflecting action is that two oscillating groups of electrons are produced 180 degrees apart with respect to the frequency of the alternating electromotive force between the anodes 76 and 77. Remembering that the path illustrated in Fig. 11 is that of an electron starting $\frac{1}{2}$ cycle or 180 degrees later than that whose path is illustrated in Fig. 10, it may be seen that both groups will move in phase in the direction normal to their undeflected motion. That is, when an electron as illustrated in Fig. 10 is moving toward the right, an electron as illustrated in Fig. 11 is also moving toward the right. Thus, there will be an oscillating component of electron current in the direction perpendicular to the direction of undeflected motion. This will cause a current to be induced in the circuit connecting electrodes 74 and 75. Thus, power will be delivered to tuned circuit 82, the natural frequency of which is made equal to the impressed electromotive force between anodes 76 and 77. An output circuit 84 is coupled to circuit 82 to deliver amplified alternating currents of the frequency of the electromotive force impressed between the anodes 76 and 77 by the secondary winding of the transformer 81, the primary winding of which is associated with the input circuit 80. The device therefore responds to high frequency electromotive forces of low intensity impressed upon it by the input circuit 80 to deliver to the output circuit 84 amplified electromotive forces of the incoming carrier frequency and with corresponding signal modulations.

Fig. 12 shows a modification of the apparatus of Fig. 9 in which the cathodes 86 and 87 are provided with axially extending interior heating means 88 and with active electron emitting surfaces 89 and 90 arranged along the same cylindrical contour as the pairs of auxiliary electrodes 93 and 94 which correspond in function to electrodes 74 and 75, respectively, and are similarly connected electrically. The anodes 95 and 96 correspond to anodes 76, 77 and are connected in the same manner to the input circuit. The electrodes 91 and 92 are shielding electrodes which may be included to prevent any reaction not of an electronic nature between input and output circuits.

Fig. 13 shows another modification of the apparatus of Fig. 9 in which intercepting baffles 97 and 98 are provided with direct connections to a point in the space current source. The group of electrons of the first and third quadrants is directly absorbed by these baffles and the energy of the other group of electrons is yielded to the electric field between the cathode 67 and the anodes 99 and 100. It follows therefore that if weak incoming electromotive forces be applied to the input circuit 80, amplified electromotive forces of twice the incoming carrier frequency will be delivered by the tuned circuit 101 to the output circuit 102.

Fig. 14 is a schematic diagram of a modification of the disclosure of Fig. 13 in which the concentric cathode with its active portions is replaced by the indirectly heated cathodes 102 and 103 similar to cathodes 88 and 87 of Fig. 12. A cylindrical conducting shell 106 at cathode potential is interrupted along its opposite walls to accommodate the cathodes 102 and 103. In other respects the

apparatus and circuit are identical with those of Fig. 13.

Fig. 15 utilizes a split cylindrical cathode 107, 108 between which the tuned output circuit 109 is connected. The incoming circuit 110 is coupled to a tuned input circuit 111 connected between the anodes 112 and 113. Intercepting auxiliary electrodes 97 and 98 are connected directly to the anode current source as in Fig. 13.

Fig. 16 illustrates a modification of the disclosure of Fig. 15 in which the cathodes 107 and 108 with active electron emitting portions are replaced by indirectly heated cathodes 114 and 115 with cathode potential surfaces 116 and 117, all the elements being otherwise connected electrically as in Fig. 15.

In Fig. 17, the auxiliary electrodes 118 and 119 are formed as semicircular shielding elements and also constitute one terminal of the output circuit. The input circuit 80 is connected between the anodes 98 and 99, as in the previously described structures. The electrodes 118 and 119 encompass such a large portion of the space surrounding the anodes 98 and 99 that they serve to largely isolate and shield this region from that of the field of the output circuit lying between auxiliary electrodes 118 and 119 and the cathodes. Electrodes 118 and 119 are angularly displaced with respect to the line joining the centers of the cathodes and also act as intercepting electrodes to eliminate electrons which have been deflected clockwise.

Fig. 18 illustrates an electron discharge oscillator. Within an evacuated container 120 are disposed a pair of parallel plates 121 and 122 constituting a quarter wave-length Lecher circuit terminated at its far end in the short-circuiting condenser 123. An electron gun 124 impels electrons into the space between the plates 121 and 122 which is subjected to a cross-magnetizing field as in the case of Fig. 1. Electrons emitted during one phase are accelerated toward and absorbed by the positive plate 121 and thus withdrawn from the field. Electrons emitted during the opposite phase execute a series of cycloidal hops along a trajectory such as that indicated by the broken line delivering their energy to the oscillating field until finally they impinge upon the target 125. Alternating output energy is supplied to the output circuit 126.

Fig. 19 shows a modification of the structure of Fig. 18 in which in lieu of an electron gun a filamentary or strip cathode 127 is utilized, together with a suppressor grid 128 similar to the grid 30 of Fig. 2. In other respects, the structure and operation of this system is the same as that of Fig. 18.

What is claimed is:

1. An electron discharge device comprising a pair of parallel conducting surfaces, means for emitting electrons in the space between the surfaces at a point adjacent one of the surfaces, means for impressing a unidirectional electromotive force and an alternating input electromotive force between the surfaces, means for producing a magnetic field in the space between the surfaces of such magnitude and direction as to cause electrons proceeding towards the more positive of the surfaces to be deflected and to proceed laterally in a series of hops, the hop frequency being approximately that of the alternating input electromotive force, a second pair of parallel surfaces adjacent the end of the first pair toward which the lateral procession of electrons occurs and insulated therefrom, the sur-

faces of said second pair being spaced from each other more closely than are the surfaces of the first pair in order to intercept and abstract from the field electrons the lateral motion of which has brought them into the space between the second pair of surfaces and the energy of which has been augmented by the input electromotive force.

2. In a transmission system, a wave guide comprising an enclosing tube of conductive material, a partition across the guide at a point at which energy in the wave guide is to be amplified for retransmission, an electron emitter and an electrode capable of positive polarization with respect thereto within the enclosing tube on one side of the partition and aligned to cause a discharge of electrons transverse to the guide, means for producing a magnetic field transverse to both the guide and the electron discharge in the regions of the guide at opposite sides of the partition whereby electrons are deflected from their original direction to follow a trajectory proceeding longitudinally of the guide by a series of cycloidal hops toward the partition, an aperture in the partition of such size as to permit the passage therethrough in the course of the cycloidal hops of electrons whose transverse excursions are of lesser magnitude than the original excursions but to intercept electrons whose excursions are greater than their original excursions whereby electrons undergoing diminishing excursions may pass over into the region of the guide at the opposite side of the partition to interact with and deliver energy to a transverse electric field.

3. In combination, two pairs of conducting surfaces, the surfaces of each pair being separated by a respective intervening space and the pairs being arranged end to end so that their intervening spaces are substantially aligned, input conductors connected to one pair of surfaces to enable them to serve as the input of an electron discharge device and conductors connected to the other pair of surfaces to enable them to serve as the output of the electron discharge device, means for causing emission of electrons in the space between the input surfaces, means for impressing a unidirectional electromotive force between the input surfaces to accelerate electrons toward the more positive surface, magnetic means for deflecting the electrons to prevent incidence upon the more positive surface and to impel them in a cyclical path extending generally in a direction parallel to the surfaces, an apertured partition extending in a direction transverse to and between the two pairs of surfaces, the aperture having such restricted dimensions as to permit electrons executing diminishing cyclical hops to pass therethrough and to cause electrons executing increasing cyclical hops to be intercepted by the partition whereby only the non-intercepted electrons pass into the region between the output surfaces and means for enabling the output surfaces to abstract energy cyclically from the electrons which pass between them.

4. An electron device comprising an electron emitting cathode, a target, a pair of conducting input elements intermediate the cathode and target and one of the pair of input elements being located at each side of the direct electron path therebetween, means for impressing a varying electromotive force between the elements for deflecting the electron stream in its course in accordance with the electromotive force, a second pair of conducting elements between which the

11

electron stream passes and an integral conducting member on one of the elements of the second pair projecting from the surface of the element into the path of the stream to such an extent that the stream is at times intercepted by the conducting element depending upon the amount of its deflection whereby the stream is density-varied in accordance with the varying electromotive force impressed upon the input elements.

5. In combination, a pair of plane parallel conducting surfaces, a recess in one of the surfaces, a cathode seated in the recess, means for maintaining the cathode in electron emitting condition, means for polarizing the cathode and the recessed surface at substantially the same potential and negatively with respect to the other surface, means for subjecting the space between the surfaces to a constant magnetic field in a direction parallel to the principal dimension of the cathode and of a field strength sufficient to so deflect electrons as to prevent their absorption by the more positive surface, means for superimposing between the surfaces an alternating potential of a frequency equal to that of the successive deflections of an electron whereby electrons having the phases of their excursions opposed to the alternating field deliver energy thereto and undergo a diminution of excursion, a second pair of plane parallel conducting surfaces each substantially aligned in the plane of one of the surfaces of the first pair and at the side of the first pair in the direction toward which electrons are carried, the space between the second pair of surfaces being less than that between the first pair and an electron collecting electrode positioned to absorb and remove from the field electrons whose excursion has been substantially reduced.

6. An electron discharge device comprising three pairs of parallel conducting surfaces disposed in end-to-end relation, input terminals connected to each of the surfaces of the first pair, means for emitting electrons in the space between the first pair at a point adjacent one of the surfaces of that pair, means for polarizing the surface of each pair on that side which in the first pair is adjacent the electron emitting means negatively with respect to the respectively opposite surface, means for producing a magnetic field in the spaces between the pairs in a direction transverse to the electron discharge and of

12

such magnitude as to cause electrons proceeding toward the more positive surface of the first pair to be deflected and to proceed laterally in a series of hops of approximately the preselected frequency of an alternating input electromotive force to be impressed on the input terminals, the surfaces of the second pair adjacent the end toward which the lateral procession of electrons occurs being spaced from each other more closely than the surfaces of the first pair in order to intercept and abstract from the field electrons the energy of which has been augmented by the input electromotive force, and output terminals connected to the third pair of surfaces whereby alternating current energy may be derived therefrom in consequence of the reaction of electrons which were not abstracted by the second pair of surfaces and succeeded in reaching the space between the third pair.

7. An electron discharge device comprising a pair of separated conducting surfaces, electron emitting means within the space between the surfaces and adjacent one of them, means for polarizing the other surface to a positive potential with respect to the electron emitting means and also with respect to the adjacent surface whereby electrons are impelled in a direction from the one surface toward the other, a second pair of separated surfaces disposed in end-to-end relation to the first pair, and means for polarizing the surfaces of the second pair with respect to each other to produce a similarly directed intervening electric field, means for producing a magnetic field in the zone including both pairs of surfaces and of such direction as to be transverse both to the direction of electron discharge and to the direction in which the pairs of surfaces are aligned whereby electrons are impelled to deviate from a linear path and to follow a trajectory of cycloidal hops from the space between the first pair of surfaces to that between the second pair and an intermediate partition separating the pairs of surfaces and having an opening therethrough sufficiently large to permit passage of electrons the excursions of which are decreasing but to cause the partition to intercept those electrons the excursions of which equal or exceed their initial excursion.

JOHN R. PIERCE.