

Oct. 15, 1946.

J. A. MORTON

2,409,222

ELECTRON DISCHARGE DEVICE

Filed July 19, 1941

4 Sheets-Sheet 1

FIG. 1

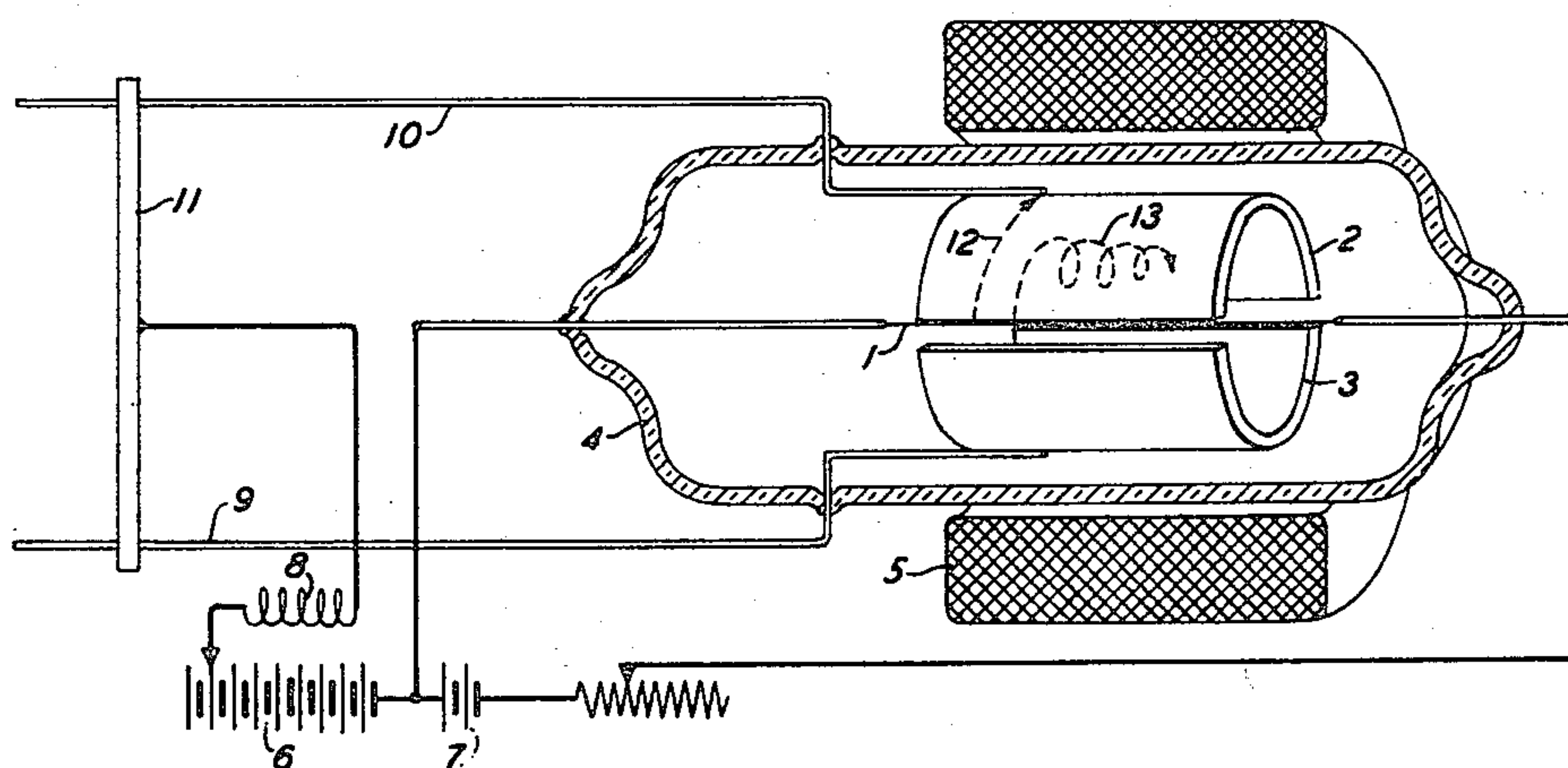
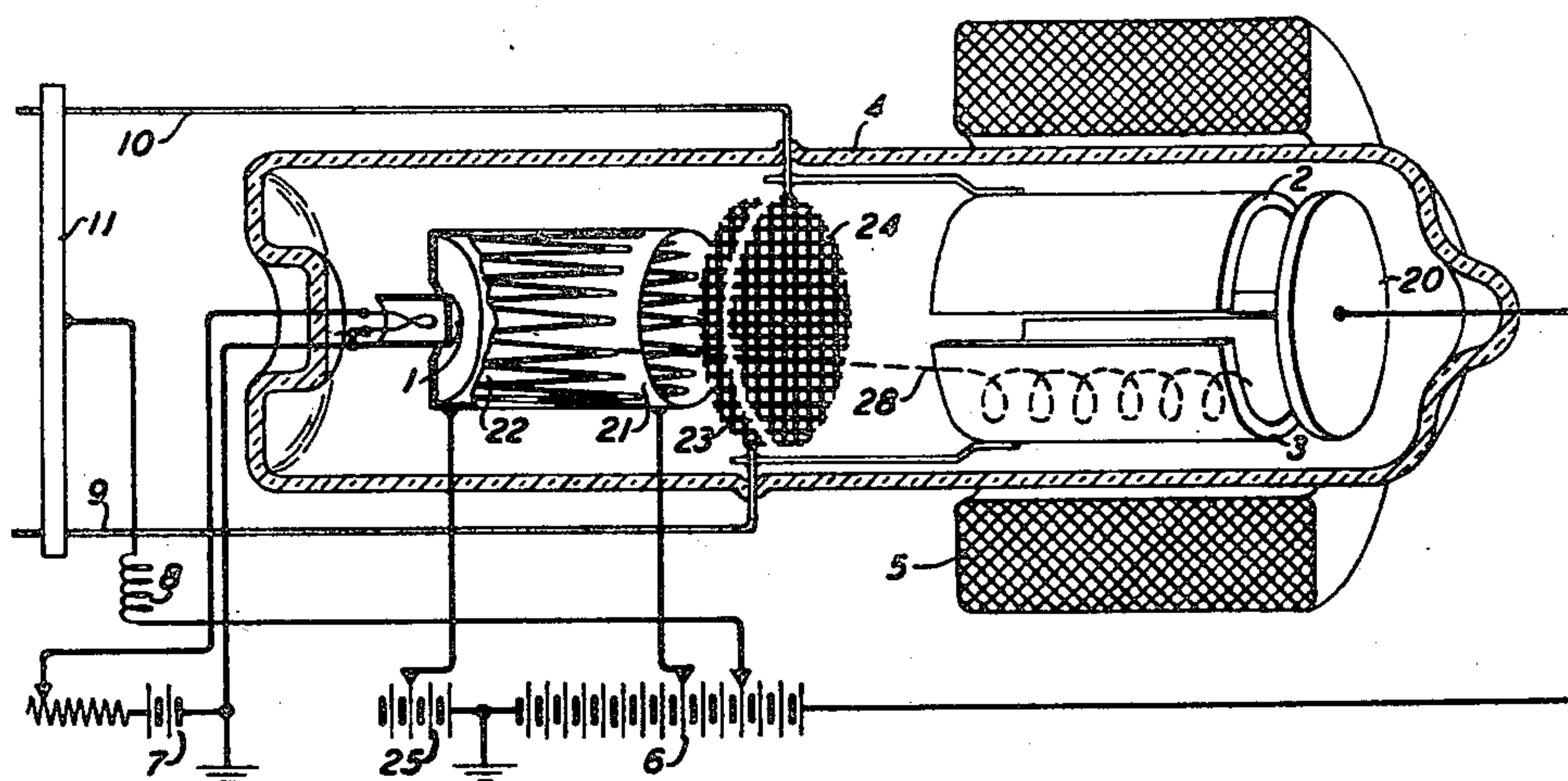


FIG. 2



INVENTOR
J. A. MORTON
BY *E. V. Krizga*
ATTORNEY

Oct. 15, 1946.

J. A. MORTON

2,409,222

ELECTRON DISCHARGE DEVICE

Filed July 19, 1941

4 Sheets-Sheet 2

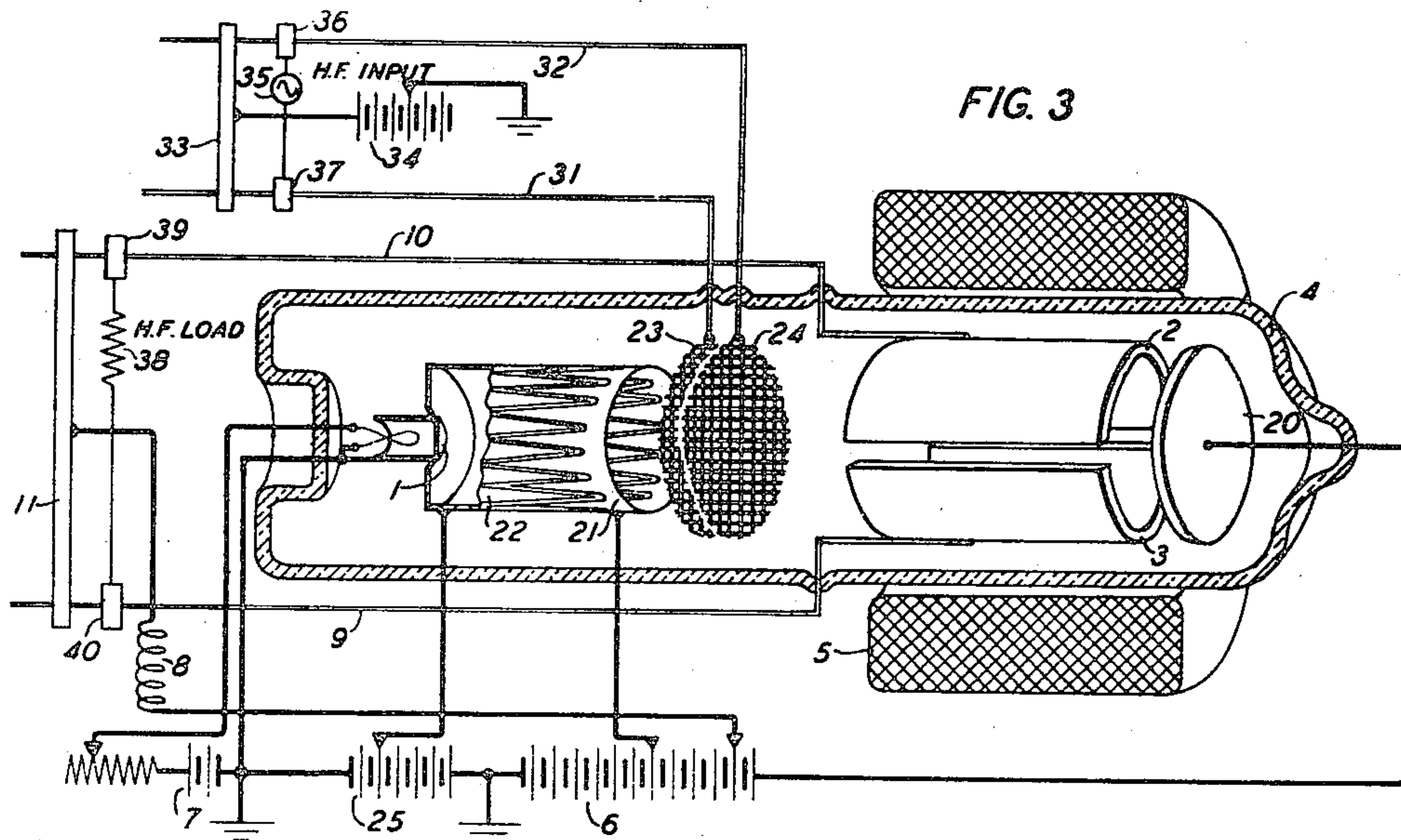


FIG. 3

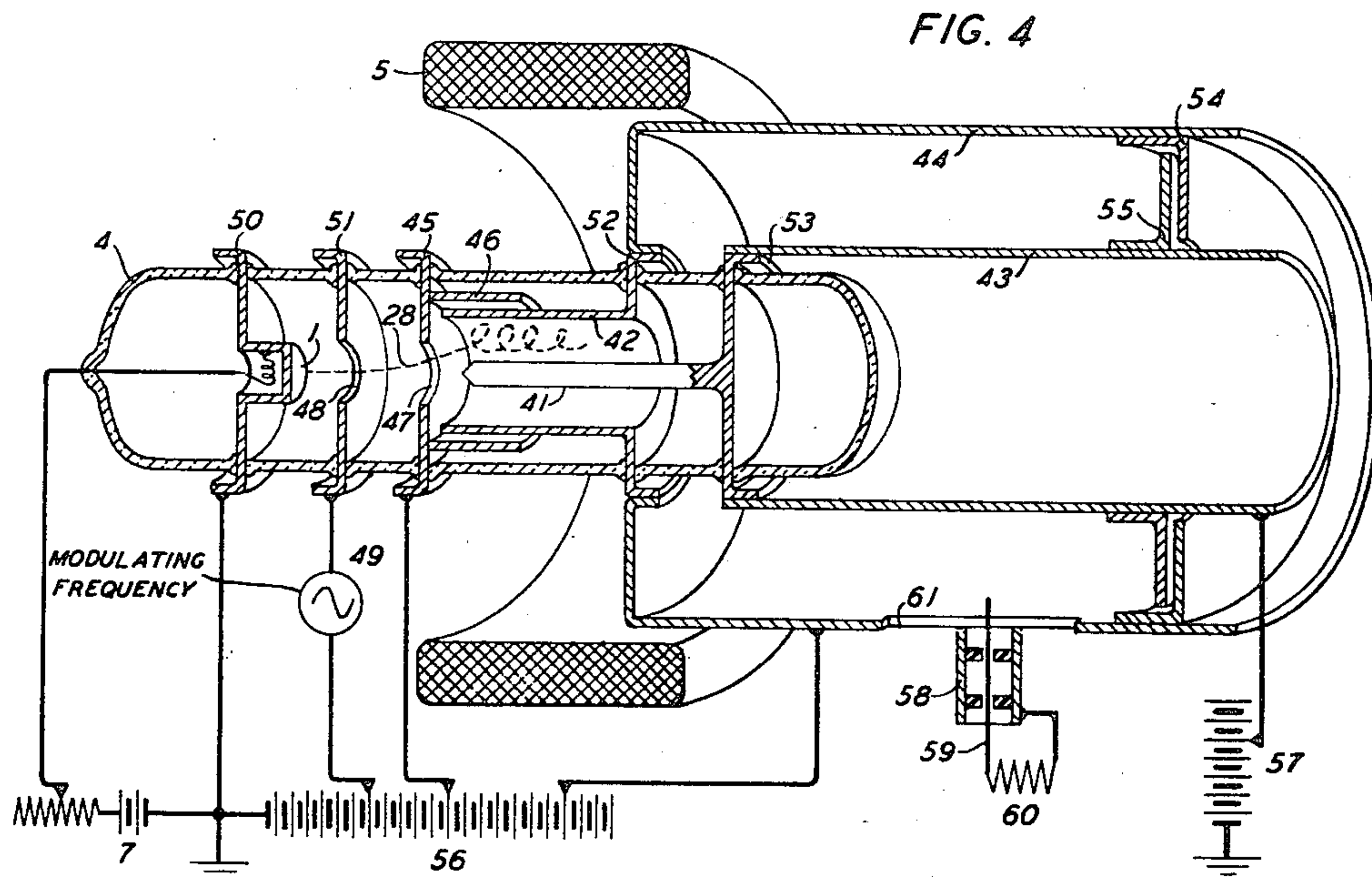


FIG. 4

INVENTOR
J. A. MORTON

BY *E. V. Briggs*

ATTORNEY

Oct. 15, 1946.

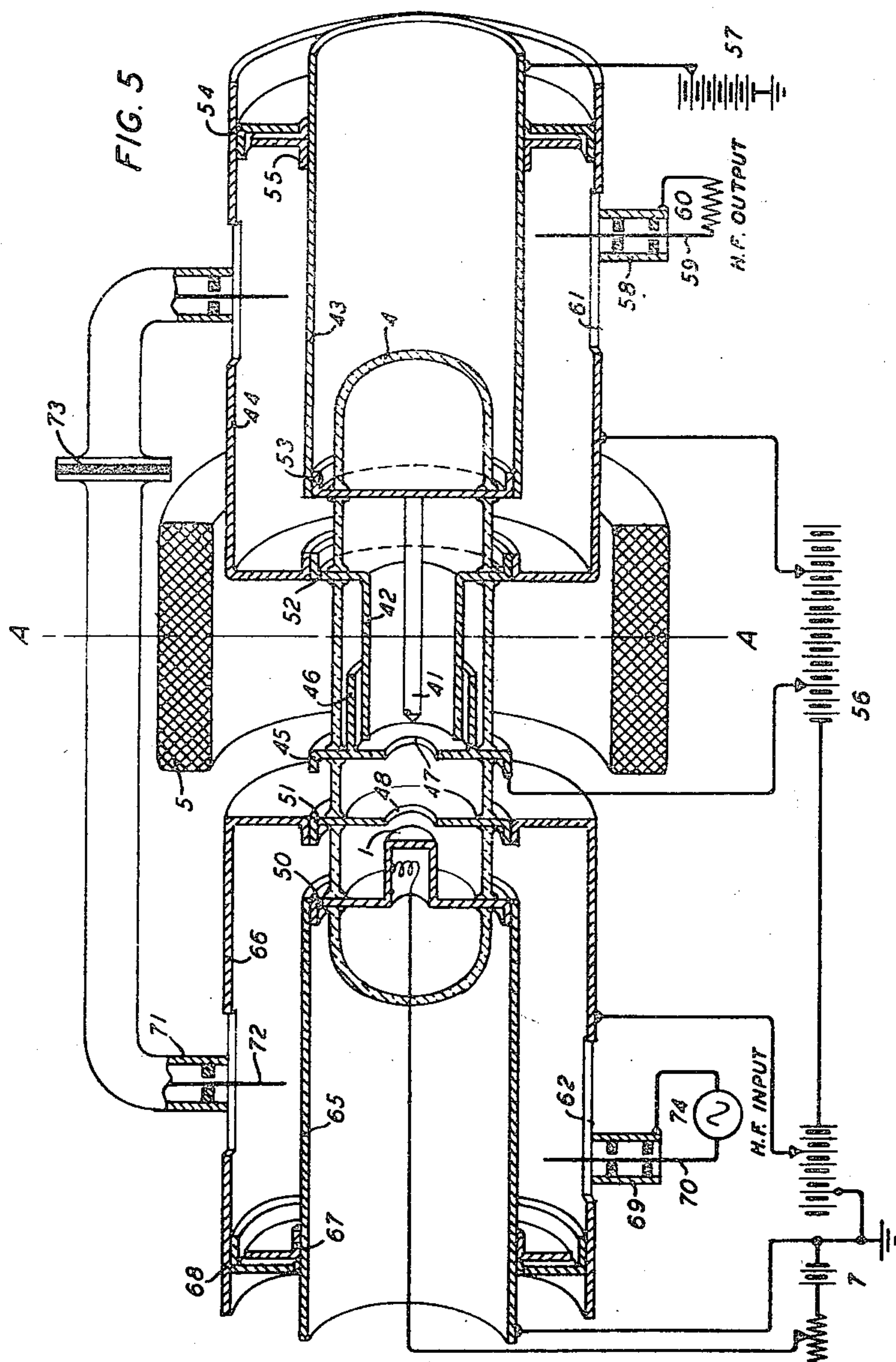
J. A. MORTON

2,409,222

ELECTRON DISCHARGE DEVICE

Filed July 19, 1941

4 Sheets-Sheet 3



INVENTOR
J. A. MORTON
BY *E. V. Briggs*
ATTORNEY

Oct. 15, 1946.

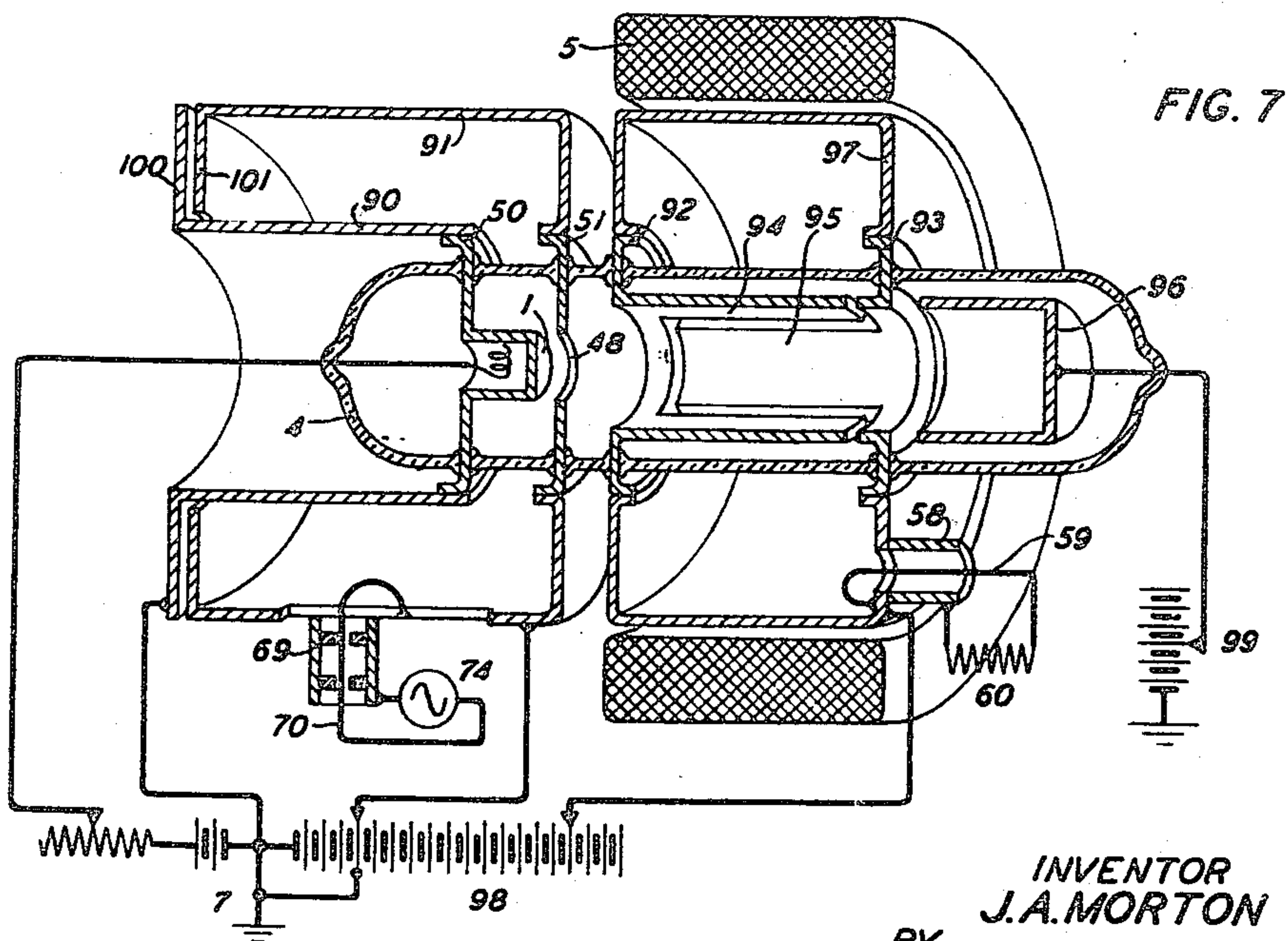
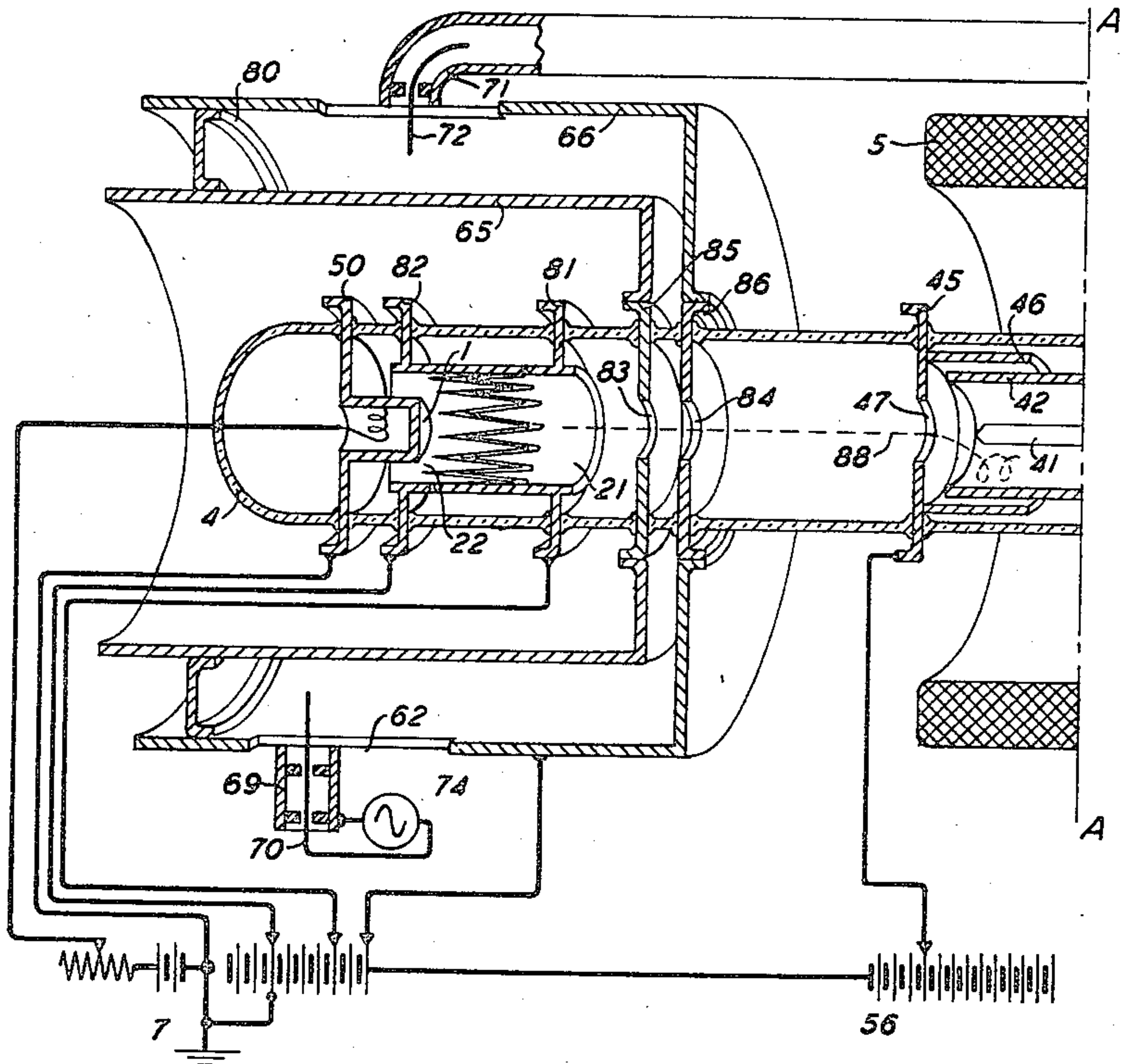
J. A. MORTON

2,409,222

ELECTRON DISCHARGE DEVICE

Filed July 19, 1941

4 Sheets-Sheet 4



INVENTOR
J. A. MORTON
BY
E. V. Briggs
ATTORNEY

UNITED STATES PATENT OFFICE

2,409,222

ELECTRON DISCHARGE DEVICE

Jack A. Morton, Upper Montclair, N. J., assignor
to Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application July 19, 1941, Serial No. 403,119

19 Claims. (Cl. 315-5)

1

This invention relates to high frequency electronic devices of the so-called magnetron type.

An object is to secure improved efficiency of operation and higher energy output from such devices at very high frequencies.

Another object is to make less critical the operating adjustments required.

Another object is to pregroup the electrons and avoid losses occasioned by the collection of energy-absorbing electrons on the plates of the magnetron.

Another object is to provide such a device in which the cathode is removed from the region of the high frequency field, thus avoiding electron bombardment and the instabilities of so-called back heating.

Another object is to make the device applicable to amplifier as well as oscillator circuits.

Another object is to utilize the magnetron, with its characteristic of providing repeated interactions between the electrons and the high frequency field, as a unilateral amplifier.

Another object is to incorporate with the device efficient non-radiating circuits.

Another object is to provide such a device readily adaptable to operation at various frequencies and easily coupled to external circuits.

Another object is to avoid the limitations of excessively small tube and circuit elements such as are encountered in very high frequency operation of magnetrons of conventional type.

Another object is to adapt the magnetron to use in a circuit where the generation of a large amount of output power is to be controlled by a small amount of control energy.

The so-called magnetron is a well-known type of device for the generation of high frequency energy. It usually incorporates essentially a cathode, an anode surrounding the cathode and a static magnetic field parallel to the axes of the cathode and anode. The electron path is deviated from a straight line by action of the magnetic field which is superposed upon the electric field between the cathode and the positively charged anode. The two fields are at substantially right angles, though to produce desired axial movement of the electrons either the magnetic field is tilted so that the angle is slightly different from a right angle or a supplementary axial electric field is provided. In either case the electrons are constrained to follow a curved spiral or helical path due to the combined action of the fields. The electrons move also in a high frequency field produced by a high frequency circuit connected either between the cathode and

2

anode, between sections of the anode or between separate electrodes adjacent to the anode. Some of the electrons enter the high frequency field at a period of the cycle to absorb energy and be accelerated so as to strike the anode and be removed from the interaction space. Other electrons enter the high frequency field at a period of the cycle to give up energy and be retarded so that their path avoids the anode and they continue along a helical path giving up energy to the field and the associated high frequency circuit during periods of interaction in successive cycles. Due to the preponderance of energy-giving periods of interaction between electrons and the high frequency field on account of the early elimination of energy-absorbing electrons the net result is the generation of energy in the attached high frequency circuit.

The necessity for prompt elimination of the energy-absorbing electrons so that the effect of the energy-giving electrons will predominate introduces limitations of the conventional type of magnetron which are largely overcome by this invention. This is accomplished by introducing the electrons in a stream from a source external to the space where interaction takes place between the electrons and the electric and magnetic fields and also by converting most of the electrons into useful, energy-giving electrons by grouping them before they enter the interaction space. By these means less critical adjustment for operation is required, more efficient operation is attained, all of the electron emission may be usefully employed and also advantage is had in that there is no longer a cathode in the interaction space with the attendant difficulties due to electron bombardment of it.

The principles of the invention are applicable to magnetron structures utilizing electrodes connected to an external circuit or to structures in which the high frequency circuit is a resonant cavity or a portion of wave guide. It is also applicable to such devices used as oscillators or in amplifier arrangements.

The various features of the invention will be more fully understood from the following detailed description of the illustrative embodiments shown in the accompanying drawings.

In the drawings:

Fig. 1 illustrates for descriptive purposes a conventional type of magnetron;

Fig. 2 shows a magnetron conventional as Fig. 1 in some respects but modified to incorporate features of the present invention;

Fig. 3 is a modification of Fig. 2 to show high

3

frequency excitation from an external source such as in amplifier operation;

Fig. 4 shows a high frequency generator using a tube incorporating crossed electric and magnetic fields and a coaxial type output circuit, with modulation by space charge control;

Fig. 5 is similar to Fig. 4, but shows an amplifier arrangement with coaxial type input and output circuits with pregrouping of electrons at high frequency by space charge control;

Fig. 6 shows as a modification of Fig. 5 an amplifier arrangement similar to that of Fig. 5 except that the pregrouping of electrons is accomplished by the method utilizing electron velocity variation and drift space; and

Fig. 7 shows a magnetron arrangement according to the invention in which interleaved split plates are employed, these being tuned by a closed resonant output cavity attached thereto.

Fig. 1 shows a conventional type of magnetron and circuit. The magnetron is of the so-called split plate type in which the plate or anode surrounding the filamentary cathode 1 is split into two sections 2 and 3 which are maintained at the same direct potential, but on account of being connected to opposite sides of the high frequency circuit composed of the lecher system 9, 10 and 11, differ in phase of high frequency potential by 180 degrees. The cathode 1 and anode 2, 3 are enclosed in an evacuated space by the envelope 4. The cathode 1 is heated by potential source 7 and the anode 2, 3 is polarized positively with respect to the cathode by the potential source 6 through the choke inductance 8 and the lecher system 9, 10 and 11 which is connected to the anode portions 2 and 3 and constitutes the high frequency circuit. A static magnetic field with lines of force parallel to the axis of the cathode and anode is produced in the space between the cathode and anode by the solenoid winding 5. This device operates in the well-known manner as has already been described briefly. Electrons from the cathode 1 are drawn toward the anode 2, 3 by the electric field due to the anode being polarized positively with respect to the cathode. The magnetic field due to coil 5, however, acts on the moving electrons so that instead of following straight paths to the anode they follow curved paths similar to those indicated by the dotted lines 12 and 13. If a path, such as 12, is followed the electron is immediately collected by one of the anode portions 2 or 3. If a path, such as 13, is followed the electron does not reach the anode immediately and after making one or more loops may return to the vicinity of the cathode. Whether, without high frequency voltage on the plate segments, the path followed is similar to 12 or to 13 depends upon the relative adjustments of the anode polarizing potential and the magnetic field due to the coil 5. In a perfectly symmetrical arrangement as shown in Fig. 1 the electron paths will lie in planes perpendicular to the axis of the tube. If the static magnetic field due to coil 5 is tilted to be at an angle to the axis of the cathode and anode or if the electrons are given a longitudinal component of direction, the paths will become helical and progress along the axis as indicated at 13 in Fig. 1. As is well known, the magnetic field must be adjusted to an intensity such that the precessional frequency of the electrons along the helical paths corresponds to the frequency of operation, i. e., the product λH should be a constant, approximately 13,000 when using the two segment plates as shown in Fig. 1, where λ is the

4

high frequency wave-length in centimeters corresponding to the frequency of operation and H is the magnetic field strength in gauss. Also, the anode voltage must be adjusted in relation to the above magnetic field strength to establish the critical grazing condition for the electrons, that is, such that with no high frequency electric field the electrons following the helical paths will just avoid striking the anode. With high frequency energy flowing in the lecher system connected to the anode portions 2 and 3 a high frequency field is superposed in the space between anode portions and the electrons interact with that field also. Electrons entering the interaction space during one phase of the high frequency field will be accelerated and constrained to pass to the anode and be collected while those entering that space during the opposite phase will be retarded and constrained to avoid collection at the anode and follow paths similar to 13. Since the retarded electrons give up energy to the high frequency field during each traversal of it and as they make more traversals of the field than do the energy-absorbing electrons which are soon collected at the anode the net result is a transfer of energy from the moving electrons to the high frequency field and a consequent sustaining of the high frequency energy in the lecher system 9, 10, 11.

Fig. 2 shows a magnetron similar to that of Fig. 1 but modified to incorporate features of the present invention. The figures are made similar to indicate clearly the added features. In Fig. 2 the enclosing envelope 4 includes an electron gun apart from the electrodes 2, 3 and the interaction space therebetween. The source of electrons 1 is now the cathode of the electron gun, and well removed from the interaction space. It is heated indirectly from potential source 7. Electrons from the cathode 1 are accelerated to the right through the grids 23 and 24 and toward collector 20 by the accelerating electrode 21, 22. This accelerating electrode is preferably, though not essentially, of the composite type as shown. The composite electrode encircles the electron path and is made up of two interleaved portions of conducting material which are insulated from each other and charged to different potentials. The surface areas of the two portions of material exposed to the electron stream vary along the direction of the electron path, the exposed areas of the two portions preponderating in opposite directions so that a uniform electrostatic field is produced in a direction depending upon the relative polarities of the two portions. The portions 21 and 22 are connected to the polarizing potential sources 6 and 25 so that 21 is the more positive causing the accelerating field to be directed from cathode 1 toward collector 20. The potential source 25 is provided in conjunction with source 6 so that electrode portion 22 may be polarized either positively or negatively with respect to the cathode 1 for the purpose of focusing the electron stream. The electrodes 2 and 3 are polarized positively with respect to the cathode by means of source 6, the connection being made through choke inductance 8, the lecher system crossbar 11 and the lecher wires 9 and 10. The high positive potential of electrodes 2 and 3 causes the electron stream to diverge after passing the grids 23 and 24 so that the electrons enter the interaction space between 2 and 3 directed at an angle to the axial magnetic field produced by coil 5. This positive diverging potential of 2 and 3 and the axial magnetic field are adjusted so

5

that the electrons travel helical paths of a precessional frequency equal to the resonant frequency of the external high frequency circuit, which in Fig. 2 is the tuned lecher system 9, 10 and 11. The grids 23 and 24 constitute a phase lens which is energized from the lecher system, and a suitable drift space is allowed between the phase lens and the field space between electrodes 2 and 3 to allow grouping or bunching of the electrons to occur.

In operation, the electron stream from the cathode 1, the path of a portion of which is indicated by the dotted line 28, is accelerated by the composite electrode 21, 22, passes through the phase lens 23, 24, is then made divergent by the high positive potential on electrodes 2 and 3 and then passes through the field, or interaction, space between electrodes 2 and 3 where the axial magnetic field causes the electrons to follow helical paths. The electrons are finally collected at the positively charged collecting electrode 20. In passing between the grids 23 and 24 of the phase lens, the electrons are subjected to a high frequency field since these grids are connected to the high frequency circuit. The electrons are accelerated or retarded depending upon the polarity of the high frequency field at the time of traversal so that velocity variations then exist in the electron stream. During traversal of the distance between grid 24 and the interaction space between electrodes 2 and 3, the electrons which have been accelerated tend to overtake those which have been retarded so that by the time the interaction space is reached the electrons of the stream are in groups. In other words, the velocity variations in the electron stream have been converted into charge density variations. Each group of electrons enters the high frequency field in the interaction space in the proper phase to contribute energy to the field and remains in that phase relation to the field as it follows the helical path, giving energy to the field each turn of the helix just as do the useful electrons following path 13 in Fig. 1. However, unlike the condition in Fig. 1, the electrons are collected at collector 20 and it is not necessary to collect at electrodes 2 and 3 energy-absorbing electrons such as follow the path 12 in Fig. 1. In the grouping process, performed by the phase lens 23, 24 in conjunction with the drift space following, electrons which would otherwise reach the interaction space at periods of the cycle such as to absorb energy from the high frequency field are moved in position along the path of the stream so as to be with the electrons reaching there at the proper periods to deliver energy to the field. Thus, in effect, most of the electrons in the stream are made useful, energy-giving electrons and it is not necessary to adjust critically so as to collect energy-absorbing electrons early in the interaction space and depend upon such collection to provide the sorting action to give a preponderance of positive energy transfer from the electron stream to the high frequency circuit. Other means of pregrouping to provide a preponderance of energy-giving electrons among those entering the interaction space will be described later.

Advantages of the arrangement of Fig. 2, therefore, are that the cathode is removed from the field of interaction, thus avoiding electron bombardment and other difficulties of electronic congestion and that more efficient operation is had on account of the transformation into energy-giving electrons of otherwise energy-absorbing electrons.

6

Obviously, the phase lens may be energized from an external source of high frequency rather than from the lecher system associated with the tube, thus providing an amplifier system. Such an arrangement is shown in Fig. 3. Pregrouping of electrons is obtained just as in Fig. 2 and the operation is generally similar with the exception that adjustments must be made to avoid the production of oscillations through plate sorting due to the collection of a portion of the electrons by the plate segments 2, 3, when there is no high frequency input. An external high frequency source 35 is shown connected to the input lecher system through the movable members 36 and 37 and the output load, indicated as a resistance 38, is shown connected to the output lecher system through the movable members 39 and 40.

Fig. 4 illustrates an embodiment of the invention utilizing a coaxial type of output circuit comprising portions of the electron tube. In this figure, 1 is an electron emitting cathode indirectly heated from source 7. The cathode is connected to and supported by the ring 50 which is sealed into the envelope 4. 48 is a control electrode which may be of any suitable form, such as an opening in the sealed-in ring 51, as shown, or a grid-like structure supported by the ring 51. 47 is a longitudinally accelerating electrode which may be of any suitable form, such as an opening in the sealed-in ring 45, as shown, or a grid-like structure supported by the ring 45. 42 is a radially accelerating anode which is connected to and supported by the sealed-in ring 52. The anode 42 also forms the continuation inside the envelope 4 of the outer conductor 44 of the external coaxial output circuit which is also connected to the ring 52. 41 is a diverging rod, so called because it is maintained at a lower potential than the anode and causes the electrons in the stream to diverge radially toward the anode 42. It is supported by and connected to the sealed-in disc 53 which also forms the continuation inside the envelope of the inner conductor 43 of the external output circuit which is also connected to the ring 53. The sleeve 46 attached to the sealed-in ring supporting the electrode 47 overlaps the end portion of member 42 and forms therewith a by-pass condenser intended to place electrode 47 and the end of member 42 at the same high frequency potential and aid in preventing radiation from the end of 42. The members 41 and 42 which constitute portions of the coaxial output circuit are also the electrodes which serve to produce the high frequency electric field in the interaction space between 41 and 42. The spaced sliders 54 and 55 with the capacitance between them close the coaxial resonant output circuit for high frequencies at a suitable position along conductors 43 and 44, insulation for biasing potentials being provided by the space separating the sliders 54 and 55. The tube, especially the portion to the right of electrode 47, is subjected to a uniform longitudinal magnetic field of an intensity such that the precessional frequency of the electrons equals the frequency of operation, this magnetic field being produced by the electromagnet 5.

Electrons emitted by the cathode 1 are accelerated and the emission is controlled in intensity by the control electrode 48. Electrode 47 injects the electrons into the space between 41 and 42 in the output circuit at a longitudinal velocity small compared to the radial velocity produced by the anode 42. The radial accelerating anode 42 is operated at a sufficiently high positive

7

potential to establish the critical grazing condition for the electrons whereas the diverging rod 41 is operated at a very low potential in order to insure that the electron trajectories become helices parallel to the axis of the tube as soon as possible. Electrons which enter the output chamber, between rod 41 and anode 42, in such a phase that their velocities have radial components in the direction of an induced electric field intensity will be accelerated and, consequently, will strike the outer anode 42 and be removed. On the other hand, electrons entering the output chamber in a phase such that their radial velocity is directed oppositely to an induced field intensity will continue to transfer energy to the induced field until they are collected by the rod 41 or the sealed-in disc 53. In such a mode of operation, the density variation grid 48 has the function only of controlling the amplitude of oscillation statically or according to the modulating signal represented as coming from the source 49. If no longitudinal sorting occurs the maximum efficiency could become only 50 per cent since half of the electrons are of unfavorable phase and are wasted. A load for the high frequency output such as indicated by the resistance 60 may be coupled to the coaxial output system as illustrated in Fig. 4 or in any other suitable manner. In Fig. 4 the central conductor 59 of the coaxial line 58, 59, connecting to the output load 60, projects into the interconductor space between members 43 and 44. 61 represents a longitudinal slot in member 44 whereby the projecting portion of 59 may be positioned from the end of the coaxial output circuit closed by sliders 54 and 55 as desired to adjust coupling impedances.

Fig. 5 illustrates a tube and circuits very similar to those of Fig. 4 but arranged to function as a unilateral amplifier. A tuned coaxial input circuit, similar to the output circuit of Fig. 4, comprising outer conductor 66, the end closure made up of sliders 67 and 68 and inner conductor 65 is connected between the control electrode 48 and the cathode 1 by the sealed-in rings 50 and 51. The control electrode 48 and its annular supporting ring 51 close and prevent radiation from the tube end of the coaxial circuit. This input circuit is energized by the high frequency to be amplified which is represented in the figure as coming from source 74 and coupled through the coaxial line 69, 70, the longitudinal slot 62 permitting the desired positioning of the projecting end of 70 along the coaxial input structure. Other features of the tube and circuit, with the exception of the feedback coaxial line 71, 72 are the same as in Fig. 4.

In operation, the electron stream from the cathode 1 is density modulated by the high frequency input voltage impressed between the electrode 48 and the cathode 1. That is, the charge density of the electron stream is varied in accordance with the high frequency input voltage. Hence more electrons enter the output interaction space, to the right of electrode 47 and between members 41 and 42, in one phase than in the opposite resulting in a net induced high frequency field. When no input signal is applied, oscillation caused by plate or anode sorting of electrons, the type of electron grouping utilized in the Fig. 4 arrangement, is prevented by operating the anode 42 at a potential low enough to avoid the critical grazing condition by a wide margin. Also, the electrode 48 may be biased negatively with respect to the cathode such that so-called class B or C operation is had and so insure that no output is

8

induced except when an input signal is applied. Furthermore, increased efficiency may be expected with class B or C operation on account of sharper grouping of the electrons.

In order to eliminate the input loading caused by the electrons in the input gap between the cathode 1 and the grid 48, the length of the gap and the biasing voltage should be made such that the electron transit time across the gap is a period within the range between the period of a whole number of cycles of the operating frequency and the period of that number increased by one-half cycle.

It is obvious that some of the output power may be coupled back to the input circuit to produce self-excitation. To illustrate this, a coaxial line comprising outer conductor 71 and inner conductor 72 is shown coupling the input and output circuits, the connections to these circuits being the same as those of the two lines 58, 59 and 69, 70 previously described. The outer conductor of the line has an insulating section 73 and is provided with flanges on each side of the insulating ring 73 to provide a path for high frequencies through the capacitance between the two flanges while insulating from each other the direct current biasing voltages on the coaxial members 61 and 66. The amount of energy transferred is controlled by adjustment of the degree of coupling as was described in connection with the input and output lines 58, 59 and 69, 70 and the phase of the energy introduced into the input circuit is determined by the length of the connecting line. The phase may be made such as to add to the input energy and provide regeneration or it may be reversed to stabilize the gain and reduce distortion. The regenerative action may be made such as to produce self-oscillation in which case the circuit becomes that of a high frequency generator and the external input circuit of the amplifier arrangement may be eliminated. High efficiency operation may be obtained through the use of regeneration to enhance the electron grouping and so place as many as possible of the electrons into favorable phase positions before they enter the interaction space in the output circuit.

The tube and circuit of Fig. 5 may be modified so that the grouping of electrons into favorable phase positions before entering the output circuit is accomplished by the velocity variation control method somewhat as shown in Figs. 2 and 3. The modification required for this is only in the input portion of the circuit and the essentials are indicated in Fig. 6 which is a modification of the portion of Fig. 5 to the left of the line AA. The portion to the right of the line AA, not repeated in Fig. 6 is the same as that to the right of line AA in Fig. 5. In other words, the tube and circuit to the right of the electrode 47 (or line AA) is the same for both Fig. 6 and Fig. 5. The input portion of the tube is quite different because in the velocity variation method of operation the electrons must enter the input gap, or interaction space, with a finite velocity and a drift space must be provided between the input and the output interaction spaces or other grouping means must be employed. In Fig. 6 the input gap, or interaction space, is between the electrodes 83 and 84 which may be openings in the conducting annular rings 85 and 86 sealed into the tube envelope 4. These electrodes are energized by the high frequency energy to be amplified which is for convenience indicated as coming from source 74 into the resonant cavity bounded by the closure mem-

ber 80, the coaxial conductors 65 and 66, the rings 85 and 86, and the electrodes 83 and 84. A high frequency field, therefore, exists between the electrodes 83 and 84 whenever the input cavity is energized. Obviously, these grids may be energized to produce the high frequency field between them in any suitable manner. Any type of resonant cavity, a coaxial system as illustrated, a lecher system or other means may be employed for the purpose.

A cathode 1 and a composite accelerating electrode 21, 22 as described in connection with Fig. 2 produce the stream of electrons which is projected across the input gap between electrodes 83 and 84, through the drift space between electrodes 84 and 47 and thence into the output interaction space between members 41 and 42. A typical path of a portion of the electron stream is indicated by the dotted line 88. After passing the grid electrode 47, the electron stream is made divergent by the high positive potential of anode 42 and the low potential on the diverging rod 41, and under the influence of the axial magnetic field produced by the electromagnet 5 the electrons are caused to follow helical paths such that the precessional frequency is the same as the frequency of operation. In a manner similar to that explained in connection with the operation of Fig. 2, the velocities of the electrons are varied as the electron stream passes through the input gap between the electrodes 83 and 84 which constitute what has been previously termed a phase lens. The electrons are accelerated or retarded in passing from electrode 83 to electrode 84, depending upon the polarity of the high frequency field therebetween at the time of traversal. Then in passing through the drift space from electrode 84 to electrode 47 the faster, accelerated, electrons tend to overtake the slower ones so that the electrons become arranged into groups and the electron stream becomes density modulated in accordance with the high frequency input before it enters the output interaction space between members 41 and 42. Thus, just as in the operation of the Fig. 5 arrangement, more electrons enter the output interaction space, beyond electrode 47 and between members 41 and 42, in one phase than in the opposite, resulting in a net induced high frequency field. Also, when no input signal is applied, oscillation caused by plate sorting is prevented by operating the anode 42 at a potential low enough to avoid the critical grazing condition by a wide margin. The high frequency input source is coupled to the input resonant system the same as shown in Fig. 5 and the feedback coaxial line 71, 72 functions just as the similar line in Fig. 5.

Fig. 7 illustrates an arrangement similar to that of Fig. 5 in that it utilizes closed resonant cavity input and output circuits and space charge control of the electron stream. It differs from Fig. 5 principally in that an interleaved four-segment plate is used, no diverging rod such as 41 in Fig. 5 is employed and the electrons are collected by a collector in the end of the tube opposite the cathode after having passed through the interaction space.

The input resonant cavity is bounded by the conducting members 90 and 91, and the sealed-in rings 50 and 51 with which are associated the cathode 1 and space charge control electrode 48, respectively. The flanges 100 and 101, which are parts of members 90 and 91, respectively, are spaced from each other to insulate the direct current biasing potential applied between cath-

ode 1 and control electrode 48 but have sufficient capacitance between them to provide a low impedance path for high frequency current, thus effectively closing the cavity at that point. The output resonant cavity is bounded by the conducting member 97, the sealed-in rings 92 and 93 and the interleaved sets of segments 94 and 95. In the figure, 94 and 95 each have two diametrically opposite segments. Obviously other numbers of segments may be used. It will be seen that the interleaved sets of segments 94 and 95 surround a tubular interaction space such as is surrounded by the plates 2 and 3 in Figs. 1, 2 and 3. They serve as electrodes to produce high frequency fields within the interaction space. A static magnetic field with lines of force parallel to the axis of the device is produced in the interaction space by the electromagnet 5 or other suitable means. The segments of 94 and 95 are maintained at a potential positive with respect to the cathode by potential source 98, the collector 96 is maintained at a lower potential positive with respect to the cathode by means of potential source 99 and the control electrode 48 may be maintained at a potential either positive or negative with respect to the cathode by the tap connection to potential source 98. Electrons leaving the cathode 1 under the control of electrode 48 pass into the interaction space surrounded by the segments of 94 and 95 under the influence of the positive potential on those segments. The electrons here encounter the static magnetic field as well as the high frequency field occasioned by high frequency energy in the output circuit. The electrons enter the interaction space with components of velocity in radial directions so that they are constrained by the static magnetic field to follow helical paths through the interaction space and thence to the collector 96.

The input circuit is energized by high frequency energy which may come from an external source such as is represented by source 74 which is coupled to the input circuit through the coaxial line 69, 70. The electron stream is density modulated by the high frequency input voltage impressed between the control electrode 48 and the cathode 1. Thus the electrons enter the interaction space in groups more or less distinctly separated, depending upon the mode of operation as discussed in connection with the operation of Fig. 5. Since, due to the grouping, more electrons enter the interaction space in one phase of the high frequency cycle than in the opposite phase, a net induced high frequency field results and high frequency energy is delivered to the output circuit in accordance with the high frequency energy impressed upon the input circuit. After the electrons have passed through the interaction space interacting with the high frequency field at each turn of the helical path and at each space between the interleaved plates they are collected by the collector 96 whether they have given energy to or absorbed energy from the output circuit, the gain of energy by the output circuit depending upon the preponderance of energy-giving electrons which in turn is dependent upon the extent of electron grouping in the input circuit. Pre-grouping of the electrons may be such that no electrons need strike the segments of 94 and 95 and all may be collected at low voltage by the collector 96. Since this collector may be made large and capable of dissipating a large amount of power the device is inherently capable of generating a correspondingly large amount of high

frequency power, thus overcoming a serious limitation of conventional magnetron structures. An advantage of the four-segment plate, illustrated in Fig. 7, is that a less intense magnetic field is required than with a two-segment plate as illustrated in Figs. 1, 2 and 3. In connection with Fig. 1 it was stated that the product λH for that two-segment structure should approximate 13,000. For a four-segment plate λH need be only half that, or approximately 6,500. A larger number of segments may be used if desired. In general, for an n segment plate λH should approximate

$$\frac{13,000}{n/2}$$

Also the arrangement of Fig. 7 like that of Fig. 5 has the advantages of non-radiating input and output circuits.

Fig. 7 illustrates primarily an amplifier arrangement with input and output circuits entirely separated and, as such, shows a form of unilateral amplifier of the magnetron type. Obviously, the input and output coaxial lines, 69, 70 and 58, 59, respectively, may be connected together through a suitable length of line for the purpose of producing self-oscillations so that the arrangement will function as an oscillation generator. Also, a feedback line may be added to interconnect the input and output cavities as illustrated in Fig. 5 for the purpose of providing regeneration or to stabilize the gain and reduce distortion.

Various embodiments of the invention illustrating devices of the magnetron type utilizing non-radiating circuits, means for efficiently introducing and controlling the electron stream and means for modulating the electron stream at high frequency before it reaches the output portion of the circuit have been shown and the utility of such devices as unilateral amplifiers as well as oscillators has been indicated. It is not intended that the scope of the invention is limited to these particular embodiments but only as defined by the appended claims.

What is claimed is:

1. A high frequency system comprising an electron tube having a longitudinal axis along the general direction of which an electron stream is directed and along which within the tube are located in substantial axial alignment and axially spaced one from another, a cathode, at least one electron control electrode, and a system of high frequency output electrodes which are portions of an electrically resonant chamber and are arranged to impress a high frequency electric field upon a space symmetrically surrounding a portion of said axis, means including the said system of high frequency output electrodes for producing a high frequency electric field in the said space symmetrically surrounding the axis, means for maintaining a static magnetic field in at least a portion of the space occupied by the said high frequency electric field such that the lines of force of the static magnetic field are substantially parallel to the said axis and perpendicular to the electric lines of force of the high frequency field, means for projecting a stream of electrons into the space occupied jointly by the two said fields with a component of direction perpendicular to the lines of force of the static magnetic field, and means including the electron control electrode for varying the charge density of the electron stream before its entrance into the space occupied by the combined said fields.

2. A high frequency system comprising an electron tube having a longitudinal axis along the

general direction of which an electron stream is directed and along which within the tube are located in substantial axial alignment and axially spaced one from another, a cathode, at least one electron control electrode, and a system of high frequency output electrodes arranged to impress a high frequency electric field upon a space symmetrically surrounding a portion of said axis, means including the said system of high frequency output electrodes for producing a high frequency electric field in the said space symmetrically surrounding the axis, means for maintaining a static magnetic field in at least a portion of the space occupied by the said high frequency electric field such that the lines of force of the static magnetic field are substantially parallel to the said axis and perpendicular to the electric lines of force of the high frequency field, means for projecting a stream of electrons into the space occupied jointly by the two said fields with a component of direction perpendicular to the lines of force of the static magnetic field, and means including the electron control electrode for varying the charge density of the electron stream at the said high frequency before its entrance into the space occupied by the combined said fields.

3. A system according to claim 2 above characterized in that the means for varying the charge density of the electron stream comprises electrodes associated with the electron path which may be connected to a high frequency electrical circuit to produce, when the circuit is energized, a high frequency field throughout a portion of the electron path whereby electrons passing therethrough are accelerated positively or negatively depending upon the phase of the field encountered.

4. In combination, an electrically resonant chamber with which when energized there is associated a high frequency electromagnetic field, means for maintaining superposed upon the high frequency field a static magnetic field of which the lines of force are substantially perpendicular to the electric lines of force of the high frequency field, means including a cathode external to the chamber for projecting a stream of electrons into the space occupied by the combined said fields, and means for varying the charge density of the electron stream before it enters the said field occupied space whereby it is enabled to deliver energy to the said high frequency field at the frequency of the charge variation.

5. A high frequency electronic device comprising an electrically resonant chamber capable of being energized to produce within itself a high frequency electric field, means for producing a static magnetic field superposed upon at least a portion of the said high frequency field such that the lines of force of the static magnetic field are substantially perpendicular to the lines of force of the high frequency electric field, and electron discharge tube means including a cathode external to the resonant chamber for projecting electrons into the space occupied by the said superposed magnetic and electric fields, such that the electrons have components of direction parallel to the lines of force of the high frequency electric field, whereby high frequency energy is generated within the chamber.

6. A high frequency electronic device comprising an electrically resonant chamber capable of being energized to produce within itself a high frequency electric field, means for producing a static magnetic field superposed upon at least a

portion of the said high frequency field such that the lines of force of the static magnetic field are substantially perpendicular to the lines of force of the high frequency electric field, and electron discharge tube means including a cathode external to the resonant chamber for projecting electrons into the space occupied by the said superposed magnetic and electric fields, such that the electrons have components of direction parallel to the lines of force of the high frequency electric field, whereby high frequency energy is generated within the chamber, the said electron tube means including means for varying the charge density of the stream of electrons before the electrons enter the resonant chamber at a frequency below that to which the chamber is resonant, whereby the intensity of the generated high frequency energy is modulated in accordance with the variations of the charge density of the stream of electrons.

7. In combination, an electrically resonant chamber capable of being energized to produce within itself a high frequency electric field, means for producing a static magnetic field superposed upon at least a portion of the said high frequency field, such that the lines of force of the static magnetic field are substantially perpendicular to the lines of force of the high frequency field, electron tube means including a cathode external to the resonant chamber for projecting a stream of electrons into the space occupied by the said superposed magnetic and electric fields, such that the electrons have components of direction perpendicular to the lines of force of the static magnetic field, the said electron tube means including means for modulating the electron stream prior to its entrance into the said space occupied by the superposed magnetic and electric fields, at frequencies within the range to which the said resonant chamber is resonant whereby energy at frequencies corresponding to the modulating frequency is generated within the chamber.

8. A high frequency electronic device, comprising an electron discharge tube with an evacuated envelope which includes at least a portion of a resonant coaxial high frequency system capable of being energized to produce within itself a radial high frequency electric field, means for maintaining an axial, static, magnetic field between the inner and outer conductors in a portion of the high frequency system included in the electron tube envelope, an electron emitting cathode, and means for introducing electrons into the space between the inner and outer coaxial conductors of the high frequency system such that the electrons have radial components of direction.

9. A high frequency electronic device, comprising an electron discharge tube having an evacuated envelope which includes at least a portion of a resonant coaxial high frequency system capable of being energized to produce between its inner and outer conductors a radial high frequency electric field, means for maintaining an axial, static, magnetic field between the said inner and outer conductors in a portion of the high frequency system included in the electron tube envelope, an electron emitting cathode, and means, including electric potential means, for introducing electrons into the space between the inner and outer conductors of the high frequency system occupied by the said electric and magnetic fields such that the electrons have radial components of direction, the electric potential means and the intensity of the static magnetic field being so adjusted that the stream of electrons

traversing the said space becomes charge-density modulated at a frequency to which the high frequency system is resonant whereby energy at that frequency is generated in the high frequency system.

10. A high frequency electronic device, comprising an electron discharge tube having an evacuated envelope which includes at least a portion of a resonant coaxial high frequency system capable of being energized to produce within itself a radial high frequency electric field, means for maintaining an axial, static, magnetic field between the inner and outer conductors in a portion of the high frequency system included in the electron tube envelope, an electron emitting cathode, means for introducing electrons into the space between the inner and outer coaxial conductors of the high frequency system occupied by the said electric and magnetic fields such that the electrons have radial components of direction, and means for varying the charge density of the stream of electrons before it enters the said space at a high frequency whereby energy at that frequency is generated in the high frequency system.

11. A high frequency electronic device, comprising an electron discharge tube having an evacuated envelope including at least a portion of a resonant coaxial high frequency system capable of being energized to produce within itself a radial high frequency electric field, means for maintaining an axial, static, magnetic field between the inner and outer conductors in a portion of the high frequency system included in the electron tube envelope, an electron emitting cathode, means, including electric potential means, for introducing electrons into the space between the coaxial conductors of the high frequency system occupied by the said electric and magnetic fields such that the electrons have radial components of direction, means for varying the charge density of the stream of electrons before it enters the said space at a high frequency whereby energy at that frequency is generated in the high frequency system, the electric potential means and the intensity of the static magnetic field being so adjusted that no high frequency energy is generated in the high frequency system when the said means for varying the charge density of the stream of electrons is inactive.

12. A device according to claim 11 wherein the means for varying the charge density of the stream of electrons comprises means for varying the space charge of the stream of electrons.

13. A device according to claim 11 wherein the means for varying the charge density of the stream of electrons comprises means for varying the velocities of the electrons.

14. An electronic device comprising, hollow electrically resonant input and output systems which are closed to substantially confine high frequency electromagnetic fields within, means for energizing the input system to produce a desired high frequency field therein, means for maintaining a static magnetic field having lines of force superposed upon and substantially perpendicular to lines of force of the high frequency electric field associated with the output system when it is energized, electron tube means for projecting a stream of electrons, first, through the high frequency field of the input system whereby the charge density of the electron stream is varied in accordance with the high frequency energy in the input system, and subsequently, through at least a portion of the high frequency field of the

15

output system upon which the static magnetic field is superposed with components of direction perpendicular to the lines of force of the superposed static magnetic field whereby energy in accordance with the charge density variations of the electron stream is generated in the output system.

15. A device according to claim 14 characterized in that the electron transit time through the high frequency field of the input system is a period between the period of a whole number of cycles of the high frequency field and the period of that number increased by one-half cycle.

16. A device according to claim 14 and including a feedback connection whereby high frequency energy may be transferred from the output system to the input system.

17. A high frequency electronic device comprising an electron tube having an evacuated envelope, a resonant coaxial output system, one end of which is enclosed within the envelope of the electron tube, a closure member substantially closing for high frequencies the end of the outer coaxial conductor of the output system within the electron tube, the closure member, however, being foraminate to permit the passage of electrons therethrough, means for maintaining an axial static magnetic field between the inner and outer conductors in a portion of the output system included within the tube envelope, the static magnetic field being superposed upon the radial high frequency electric field produced in the interconductor space when the output system is energized, means including electrical potential means connected to the coaxial conductors of the output system for projecting a stream of electrons through the said foraminate closure member into the space between the said coaxial conductors such that the electrons have components of direction radial with respect to the coaxial conductors.

18. A high frequency device comprising an electron tube having an evacuated envelope which encloses as electrodes the end portions of resonant coaxial input and output systems which are resonant at substantially the same frequency and are axially aligned with the ends within the tube envelope facing and spaced from each other, the outer conductors at these facing ends being substantially closed for high frequencies by conducting members which are foraminate to permit the passage of electrons therethrough, means for maintaining an axial static magnetic field between the inner and outer conductors in a portion of the output system included within the tube envelope, the static magnetic field being superposed upon the radial high frequency electric field produced in the interconductor space when the output system is energized, an electron emitting cathode connected to the central conductor of

16

the input coaxial system within the tube envelope and spaced from the foraminate member closing the end of the outer conductor of the coaxial input system such that when the input system is energized a high frequency control voltage is impressed between the foraminate member closing the input system and the cathode, electric potential means for maintaining the outer conductor of the coaxial output system and its closing foraminate member at positive potentials with respect to the cathode, and electrical potential means for maintaining the inner conductor of the output coaxial system at a potential lower than that of the outer conductor whereby electrons are drawn from the cathode through the foraminate members into the interconductor space occupied by the said superposed static magnetic and high frequency electric fields with radial components of velocity, and means for energizing the input coaxial system at a desired frequency of operation to modulate the electron stream before it enters the output system whereby energy at the input energizing frequency is generated in the output system.

19. A high frequency system comprising an electrically resonant cavity generally toroidal in shape, the boundary of which is a shell of conducting material consisting essentially of two concentric tubular portions one within the other and two annular portions connecting the two tubular portions to each other at their ends, thereby enclosing a space extending radially between the two tubular portions and longitudinally between the two annular portions, the inner tubular portion of the shell having a slit through its conducting material, the slit extending alternately in longitudinal and circumferential directions dividing the inner tubular portion into two parts, each part comprising a plurality of segments interleaved with segments of the other part such that the inner tubular portion comprises a plurality of longitudinal segments with alternate segments connected together and to the other material of the conducting shell at opposite ends of the inner tubular portion, those connected at one end being separated from those connected at the other end by the said alternately longitudinal and circumferential slit, means for maintaining a longitudinal static magnetic field within the said inner tubular portion, means for projecting a stream of electrons into the inner tubular portion with components of direction perpendicular to the lines of force of the static magnetic field and means for varying the charge density of the electron stream at the resonant frequency of the cavity whereby high frequency energy is transferred from the electron stream to the cavity.

JACK A. MORTON.