Aug. 15, 1961 R. L. JEPSEN 2,996,639

ELECTRON DISCHARGE APPARATUS OF THE BEAM TYPE

Original Filed Oct. 5, 1953 2 Sheets-Sheet 1

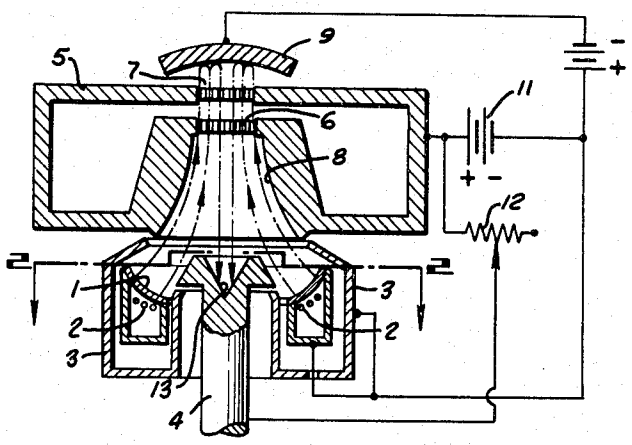


FIG_1

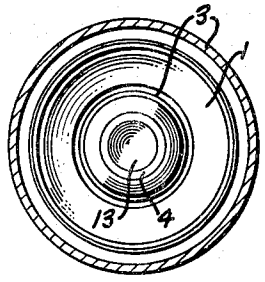


FIG_2

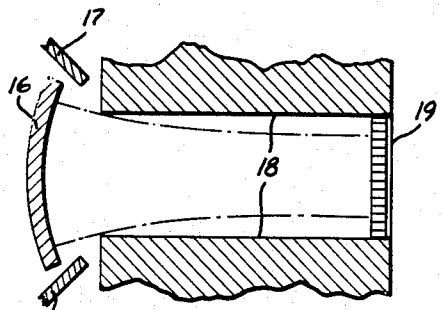


FIG_3

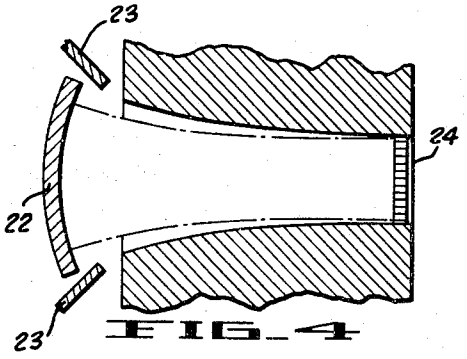


FIG_4

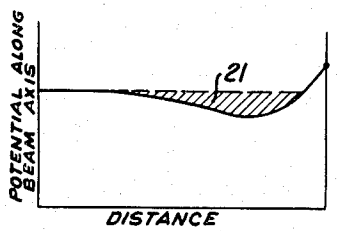


FIG_3A

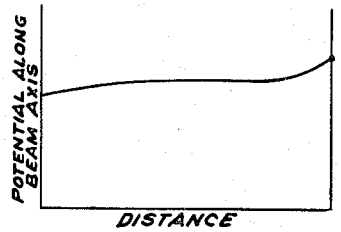


FIG_4A

INVENTOR.
ROBERT L. JEPSEN

BY Paul B. Hunter

ATTORNEY

Aug. 15, 1961 R. L. JEPSEN 2,996,639

ELECTRON DISCHARGE APPARATUS OF THE BEAM TYPE

Original Filed Oct. 5, 1953 2 Sheets-Sheet 2

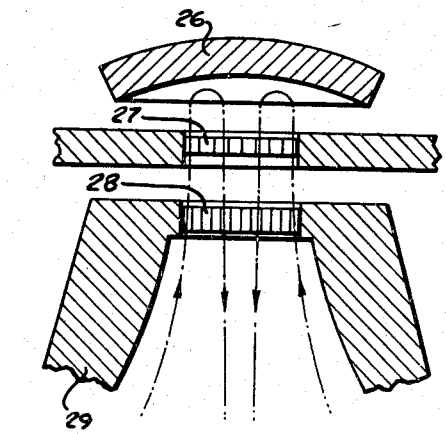


FIG. 5

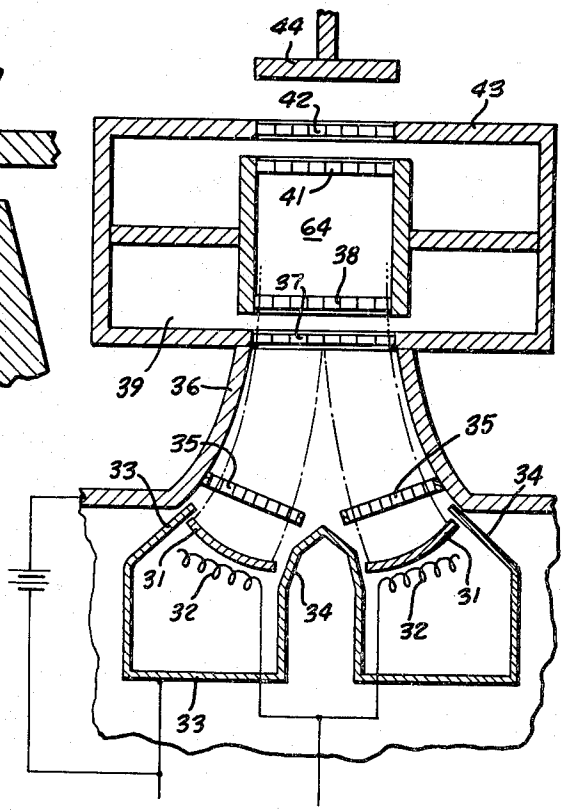


FIG. 6

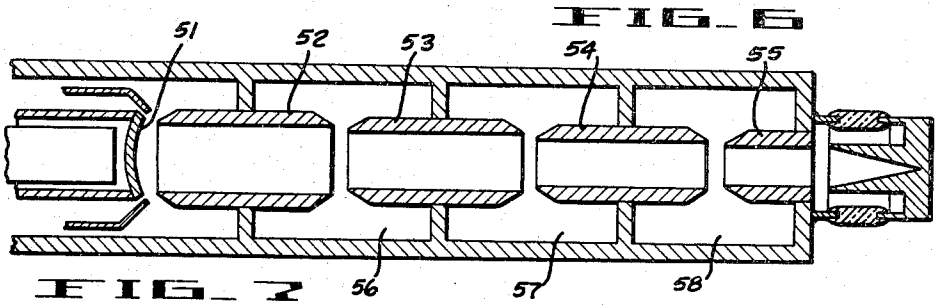


FIG. 7

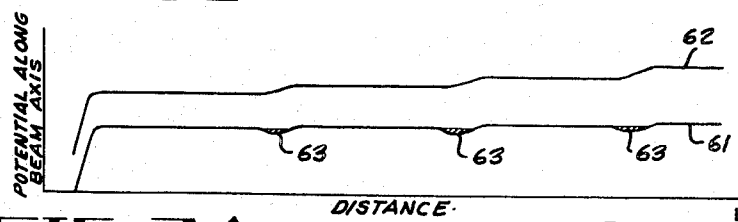


FIG 7A

INVENTOR
ROBERT L. JEPSEN

BY Paul B. Hunter
ATTORNEY

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ELECTRON DISCHARGE APPARATUS OF THE BEAM TYPE

Robert L. Jepsen, Los Altos, Calif., assignor to Varian Associates, San Carlos, Calif., a corporation of California

Original application Oct. 5, 1953, Ser. No. 384,018, now Patent No. 2,888,599, dated May 26, 1959. Divided and this application Apr. 13, 1959, Ser. No. 805,999
1 Claim. (Cl. 315—5.19)

This invention relates, generally, to ultra high frequency electron tube devices or apparatus and the invention has reference, more particularly, to novel apparatus of this type which removes ions from the beam paths through the devices, such as klystrons, traveling wave and other electron beam tubes, to thereby substantially eliminate perturbations of the beams thereof, and also to novel velocity modulation tubes of the reflex klystron type which are so contsructed as to prevent reflected electrons from returning to the cathode region. This application is a division of my United States patent application Serial No. 384,018, filed on October 5, 1953, entitled "Electron Discharge Apparatus," which has now issued as Patent No. 2,888,599 on May 26, 1959.

Several difficulties encountered in electron discharge devices such as, for example, klystrons and traveling wave tubes heretofore employed arise from an intraction between the electron beam and ions trapped along the path of the beam. These difficulties may include:

(1) Modulation of output power, frequency, and beam current at the frequency or frequencies of continuous ion oscillation. These frequencies are, typically, in the range .1 megacycle per second to 10 megacycles per second.

(2) Modulation of output power, frequency and beam current at both
   (*a*) Ion oscillation frequencies (in the megacycles per second range) and
   (*b*) Low frequencies (typically in the audio frequency range). The low frequency fluctuations are associated with the high frequency ion oscillations.

(3) Changes in output power, frequency, and beam current as the frequency of an applied modulating voltage is varied. These changes occur when the modulating frequency is near one of the frequencies of incipient ion oscillation and they may be abrupt or fluctuating.

In many heretofore existing reflex klystrons a source of trouble encountered is the occurrence of what has been termed multiple transits of the beam. Multiple transits refer to the action of the electron beam after passing through the resonator gap subsequent to being reflected back to the negatively charged reflector. After this reflection or return trip through the resonator gap, the bunched electrons have performed their useful function and their elimination from further operation on the tube is desirable. However, many of the returning electrons enter the cathode region of the reflex klystron and are turned about by the negative charge to begin a second round trip through the resonator gap. These multiple transits of the electrons produce undesirable effects in the tube such as, for example, unstable power output.

One object of the present invention is to provide a novel method and means in electron beam discharge devices for preventing the trapping of ions in the beam path.

Another object of this invention is to provide a novel method and means for draining ions out from spaces defined by grided apertures.

These and other objects and advantages of the present invention will be better understood from perusal of the following description and explanation of the drawings wherein

FIG. 1 is a schematic elevation view in section of a reflex klystron which embodies the present invention whereby multiple transits of the electrons in the tube are prevented and whereby the ions are continually drained from the re-entrant tube or drift space between the cathode and the first resonator grid to prevent the formation of an ion trap therein.

FIG. 2 is a section view of the reflex klystron of FIG. 1 taken along section line 2—2.

FIG. 3 is a section view of a portion of a reflex klystron of the type heretofore employed wherein ions are trapped in the drift space or re-entrant tube portion of the tube between the cathode and the first resonator grid.

FIG. 3(*a*) is a plot of the potential along the beam axis versus the distance along the re-entrant tube space for the reflex klystron shown in FIG. 3 showing the formation of an ion trap.

FIG. 4 is a section view of a portion of a reflex klystron which embodies the present invention wherein the walls of the re-entrant tube space between the cathode and the first resonator grid are so formed as to prevent the formation of ion traps therein as occurs in the klystron of FIG. 3. This novel feature is utilized in the klystron of FIG. 1.

FIG. 4(*a*) is a plot of the potential along the beam axis versus the distance along the beam path in the re-entrant tube space of FIG. 4 showing how the formation of ion traps is prevented.

FIG. 5 is a section view of a portion of a reflex klystron substantially identical to that shown in FIG. 1 which embodies a novel additional feature to the klystron of FIG. 1 whereby the ions in the resonator gap space are also continually drained therefrom to prevent the formation of an ion trap between the grids.

FIG. 6 discloses in section view a two-cavity klystron employing an annular shaped beam of electrons wherein a novel method and means is provided for continually draining ions from the re-entrant tube or drift space between the accelerating grid and the first resonator grid to prevent the formation of an ion trap therein.

FIG. 7 shows in longitudinal section view a portion of a three-cavity velocity modulation tube which embodies the novel invention for preventing the formation of ion traps at the resonator gaps as occurred in heretofore employed velocity modulation tubes of this type.

FIG. 7(*a*) is a plot of the potential along the beam axis versus the distance along the beam path for the novel beam device shown in FIG. 7 and also includes a plot of the beam potential along the axis of a beam versus the distance along the beam path for the heretofore employed klystrons of this general type to more clearly illustrate the improvement brought about by the invention disclosed in FIG. 7.

Referring now to FIGS. 1 and 2 there is shown a reflex klystron embodying the present invention, there being shown only such parts of a reflex klystron as are necessary to illustrate the present invention. It should be understood that the beam path of the particular klystron would also be enclosed in a vacuum envelope or body and the klystron would include other elements such as, for example, an output window. The reflex klystron comprises an annular cathode 1 having a concave or recessed emitter surface, the cathode surface sloping radially inwardly and downwardly as viewed in FIG. 1 to form substantially an acute angle with respect to the axis of the klystron tube. An annular heater 2 is shown positioned on the under side of the cathode to provide the necessary heat for electron emission. An annular, substantially cup-shaped focusing ring 3 encircles the annular cathode on both its outer and inner peripheries to provide for focusing of the electron beam emitted from the cathode. Located within the center or frame opening in the annu-

lar focusing ring and cathode and in axial alignment therewith and also extending slightly above the cathode emitter surface is a metallic collector electrode 4. Positioned in axial alignment with the cathode focusing ring 3 and collector 4 is a cavity resonator 5 including a pair of mutually spaced resonator grids 6 and 7. The drift space or re-entrant tube formed by the outer wall 8 of the re-entrant portion of the cavity resonator is of substantially truncated cone configuration, the sides of which have a slightly convex shape, this particular configuration being employed for a purpose to be subsequently described. Axially aligned with the grids 6 and 7 and positioned above grid 7 is a metallic concave reflector 9.

In operation, an annular shaped beam of electrons is emitted from the cathode 1 and is focused into a beam by the focusing ring 3, the stream of electrons being accelerated toward the resonator grids 6 and 7 by the positive potential of the cavity with respect to the cathode as provided by the source of potential represented by battery 11. Because of the angle of the emitter surface of the cathode 1 with respect to the axis through the tube, the annular electron beam is directed in such a manner as to tend to form a hollow substantially conical beam, the apex of which coincides with the axis of the klystron and is located within the re-entrant tube portion 8, the sides of the beam being somewhat concave and conforming to the convex surface of the tube re-entrant portion 8. However, the electrons in the annular beam, as they approach the axis, repel each other due to space charge and this interaction between the electrons tends to bend the annular beam within the re-entrant tube portion so as to form the beam into a straight substantially hollow cylindrical beam. The electrons in this hollow cylindrical beam configuration pass through the cavity resonator gap between the grids 6 and 7 with the electrons traveling in paths perpendicular to the grids or, as stated in another way, parallel to the electric field vectors across the resonator gap. The electrons are velocity modulated by the radio frequency voltages across the gap in a well known manner and are repelled by the reflector 9 which may carry a negative potential with respect to the cathode. The electrons are turned about and again pass through the resonator gap in bunches parallel to the electric field vector across the gap to give up energy to the field in the cavity resonator. The stream of electrons continues axially through the re-entrant tube 8 and are collected on the collector 4 which is connected to a source of potential positive with respect to the cathode, the potential of which may be made variable as represented by the variable resistor 12. As noted, the returning electrons are in the form of a cylindrical beam and, since the diameter of this beam is determined in part by the diameter of the resonator grids, the collector electrode upper surface is shown having a diameter equal to or slightly larger than the diameter of the grids. Since the returned electrons are all collected on the positive collector electrode 4, few, if any, will re-enter the region of the negatively charged cathode 1 where they would be turned about and started on another trip through the tube and thus the problem of multiple transit is eliminated. A recess or pocket 13 is shown in the upper surface of the collector 4 and serves the purpose of retaining any secondary emission electrons which may be emitted from the collector by the striking electrons. A decided advantage in the use of the collector electrode for catching the electrons after they have performed their useful function in the tube is that the electrons are collected on a separate electrode, the collector, rather than on the walls of the tube and the cavity resonator, and thus the heat generated by the striking electrons does not cause expansion of the cavity resonator or other critical tube parts with a resultant change in the operating frequency of the tube.

The collector is connected to a source of potential slightly negative with respect to the potential of the cavity resonator by the variable resistor 12. The collector, because of its slight negative potential, attracts the positive ions which are produced in the re-entrant tube or drift space 8 of this klystron due to the collision of the electrons with gas molecules in the space. The collector thus continually drains the ions from the space and prevents the formation in the beam path of a deleterious ion trap. The particular configuration of the re-entrant tube walls 8 also serves to prevent the formation of an ion trap as will be more readily understood from the following description of this novel feature disclosed in FIG. 4.

In heretofore existing reflex klystrons wherein attempts were made to prevent the beam from returning into the cathode region after passing through the resonator gap, one example of which employs a spike in the center of the reflector to produce an umbrella-shaped reflected beam, the electron beam does not travel parallel to the electric field vectors across the resonator gap during both passages thereacross and, therefore, the optimum interchange of energy between the beam and resonator field does not occur. In this present invention, the electron beam travels parallel to the electric field vectors across the resonator gap on both passages therethrough to give the maximum energy exchange even though the electron beam does not re-enter the negative cathode region on its return trip through the klystron.

Referring to FIG. 3 there is shown a portion of a reflex klystron tube of the heretofore employed type including the cathode 16, the focusing ring 17, the walls 18 forming the cylindrical re-entrant or drift space and the first resonator grid 19. The outer periphery surface of the beam emitted from the cathode and focused by the focusing ring is shown in dotted lines. It is noted that at the entrance to the re-entrant tube space the beam occupies substantially the entire opening, the beam occupying a progressively smaller portion of the cylindrical drift tube space as it proceeds toward the resonator grid 19. The beam may spread again as it approaches the grid 19 but, in any case, the beam occupies a smaller proportion of the drift space at some point within the space defined by walls 18 than at the left-hand end of the drift space. This particular relationship between the walls of the drift tube space and the beam shape produces an ion trap within the drift tube. The amount of potential depression within a drift tube due to the passage of an electron beam through the drift tube depends on the beam voltage, on the beam current, on the distribution of current across the beam, and on the geometry of the drift tube. In particular, increasing the diameter of a cylindrical drift tube, keeping all other quantities constant, results in an increased potential depression.

This ion trap is better illustrated in FIG. 3(*a*) which is a plot of the potential along the beam axis between the entrance to the re-entrant tube 18 and the resonator grid 19. The ion trap is formed where the potential curve drops below the positive value which is present at the left-hand end of the re-entrant tube or drift space due to the space charge effects of the electron beam. This ion trap is represented by the cross-hatched area 21. The positive ions in excess of the number necessary to fill the trap or, in other words, to balance the decrease in positive potential of the beam will drain out the left-hand end of the re-entrant tube. The present inventors have devised a novel drift tube structure which prevents the formation of ion traps, this novel structure employed in FIG. 1 is being shown in FIG. 4.

Referring to this FIG. 4 and also to FIG. 4(*a*) it will be noticed that the drift tube space, rather than being of a cylindrical shape, is now of an approximately truncated cone shape with convex walls, the walls tapering toward the right-hand or grid end. The cathode 22 and focusing ring 23 may be of the same construction as shown in FIG. 3 and the beam produced thereby of the same shape as that in FIG. 3. The drift tube walls are so shaped with relation to the beam perimeter that as the beam progresses toward the resonator grid 24 it occupies

a progressively increasing portion of the drift tube space. This particular relationship between the drift tube walls and the electron beam prevents the formation in the beam path of any ion traps. This is better illustrated in FIG. 4(*a*) which shows a plot of the potential along the beam axis between the left-hand end of the re-entrant tube and the resonator grid. As can be seen there is no depression or decrease in the positive potential along this drift space length so that substantially all of the positive ions formed in the drift tube space drain out the left-hand end thereof.

It is this particular feature of the re-entrant tube portion of the klystron in FIG. 1 which aids in preventing the formation of ion traps in the re-entrant tube space of this tube as mentioned above.

Referring to FIG. 5 there is shown therein in section view a portion of a reflex klystron tube of the type shown in FIG. 1, there being disclosed only the reflector electrode **26**, the two resonator grids **27** and **28** and a portion of the walls **29** defining the re-entrant tube and cavity resonator. It will be noted that the second resonator grid **27** is thinner than the first resonator grid **28** and also that the openings or interstices defined by the vanes of the grid **27** are substantially larger than those of the first resonator grid. This particular type of second resonator grid permits a portion of the negative field produced by the reflector electrode **26** to penetrate through this grid into the resonator gap space between the two grids, thus providing for the draining of positive ions from the resonator gap to the reflector and thereby preventing the formation in the resonator gap of an ion trap.

In FIG. 6 is disclosed still another novel structure for use in electron beam apparatus for draining ions from drift spaces. There is shown just that much of a two-cavity resonator klystron which suffices to explain the present invention, it being understood that the apparatus shown, or at least the beam path, is enclosed within a vacuum type envelope and may include other structural features not shown. An annular cathode **31** having a slightly concave emitter surface produces an annular beam of electrons when heated by a heater **32** extending under the cathode. This stream of electrons is focused by a circular focusing member **33** having a substantially W-shaped cross section, the upwardly extending cylindrical central portion **34** of this focusing member extending within the central opening of the annular cathode **31** and in axial alignment with the klystron. An annular accelerating grid **35** is positioned in the path of the electron beam for accelerating the electrons therein to a constant velocity within the drift space formed by wall **36** of the tube. The beam passes through the gap formed by the resonator grids **37** and **38** of the first or buncher cavity resonator **39** where radio frequency energy acts on the beam for velocity modulating the electrons therein, the electrons then passing through the drift space **64** where they become density modulated and then passing across the second resonator gap formed by the output resonator grids **41** and **42** where the bunched electrons give up energy to the output cavity resonator **43**. The electrons in the beam then collect on the collector electrode **44**. Since in customary operation of beam discharge tubes of this type the focus electrode **33** is at a negative potential with respect to the walls of the drift tube space and the cavity resonators and since in this particular embodiment the central upwardly extending portion **34** of the focusing electrode **33** extends slightly above the cathode **31** and is aligned with the central opening in the annular accelerating grid **35**, ions will be drained out from the drift tube space formed by wall **36** by the negative potential on the focus electrode through the central opening in the annular accelerator grid to thus prevent formation of ion traps in the drift tube space.

FIG. 7 discloses another embodiment of the present invention wherein the ion draining feature disclosed in FIG. 4 is applied to a multicavity gridless klystron tube which may be, for example, of the high power amplifier class such as disclosed in the U.S. patent application, Serial No. 370,568, of Wayne G. Abraham and Sigurd F. Varian entitled "High Frequency Tube," filed on July 27, 1953, now Pat. No. 2,879,440. The electron beam emitted from the cathode **51** is transmitted down the series of drift tubes **52**, **53**, **54** and **55**, the ends of which define resonator gaps in the three cavity resonators **56**, **57** and **58**. The inner diameter of each succeeding drift tube along the beam path is slightly smaller than the inner diameter of the preceding drift tube, the drift tube inner diameters of each drift tube being constant. The electrons in the beam are expended in the collector end of the tube. In heretofore employed velocity modulation tubes of this type the drift tubes had equal and constant inner diameters throughout the length of the tube as shown in the above cited patent application. In these heretofore employed multicavity resonator tubes a potential depression is produced at each of the resonator gaps, these depressions producing ion traps at each gap. This is better illustrated in FIG. 7(*a*) which is a plot of the potential along the beam axis versus the distance along the beam path. The potential curve labeled **61** is typical of the heretofore employed multicavity klystrons while the curve **62** which is vertically transposed on the graph with respect to curve **61** is that of the novel tube structure shown in FIG. 7. As seen in curve **61**, the potential depressions at the reasonator gaps produce ion traps **63** which are designated by the cross-hatched area. As indicated by the curve **62** representing the novel structure shown in FIG. 7, these ion traps are eliminated due to the fact that as the curve is traced from left to right there occur no potential depressions where ion traps may be formed. In addition to preventing the formation of ion traps at the resonator gaps, this novel configuration also permits the rapid draining of ions formed throughout the entire length of the beam path due to the fact that the beam potential curve **62** decreases in its positive value from right to left, whereas the beam potential curve **61** is a flat or unchanging curve. This illustrates another embodiment where an increased portion of the drift space is occupied by the electron beam as it passes through the tube.

Although the klystron disclosed in FIG. 7 has each succeeding drift tube of a smaller inner diameter than the preceding drift tube, the greatest benefit in tube operation is derived from the elimination of the ion trap at the first resonator gap and a lesser benefit by eliminating the ion trap at the second resonator gap. This is due to the fact that any ambiguities in operation that appear early in the stage of this amplifier tube are amplified to a great extent as the beam proceeds down the tube. If such a high degree of perfection in operation is not necessary, the drift tube **55** may have the same sized inner diameter as the drift tube **54** or, to carry it a step further, the inner diameters of drift tubes **53**, **54** and **55** may be of the same value or drift tubes **54** **55** may be made with larger inner diameters than drift tube **53** in certain cases, for example, to accommodate spreading of the beam. In these latter examples, ion traps would occur at the resonator gaps in resonators **57** and **58** but not at the resonator gap in resonator **56**. These latter examples were given to illustrate the flexibility of this particular embodiment of the invention.

As an example of the application of this invention, the inner diameters of the drift tubes of a power amplifier tube of the type disclosed in the above cited patent are each 1.2". To achieve the improvement described herein this power amplifier tube would be modified such as, for example, changing the inner diameter of the first drift tube to 1.5", the inner diameter of the second drift tube to 1.3" and the inner diameter of the third and fourth drift tubes to 1.1".

Since many changes could be made in the above construction of the novel invention and many apparently widely different embodiments of this invention could be

made without departing from the scope thereof as, for example, its utilization in other types of klystrons, in traveling wave tubes and in other electron beam devices, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

In an electron discharge device comprising an annular cathode for emitting a beam of electrons, a focusing electrode for focusing the beam of electrons comprising a central portion axially aligned with the central opening in the annular cathode, a beam-field interaction structure in the path of said electron beam, an annular accelerator grid axially aligned with the cathode and positioned between said cathode and said interaction structure for accelerating the beam of electrons, the central portion of the focusing electrode being in axial alignment with the central opening in the annular grid, a source of electrical potential and means coupling the source to the discharge device such that the focusing electrode is at a negative potential with respect to the accelerator grid to thereby cause positive ions formed in the region between the accelerating grid and the interaction structure to be drained through the central opening in the grid to the central portion of the focusing electrode.

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