Aug. 7, 1956 R. H. VARIAN 2,758,245

BEAM TYPE-ELECTRONIC TUBE

Filed Dec. 14, 1950

Fig. 1.

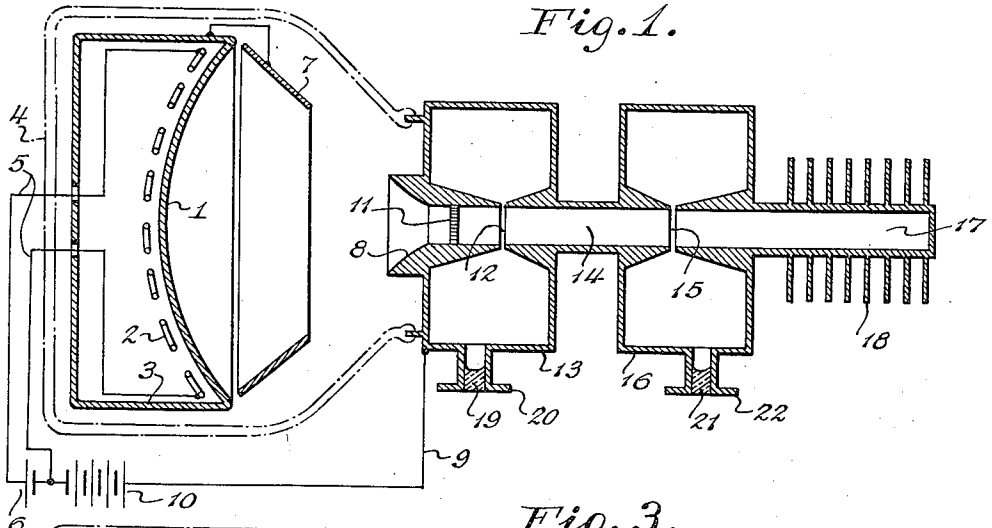


Fig. 3.

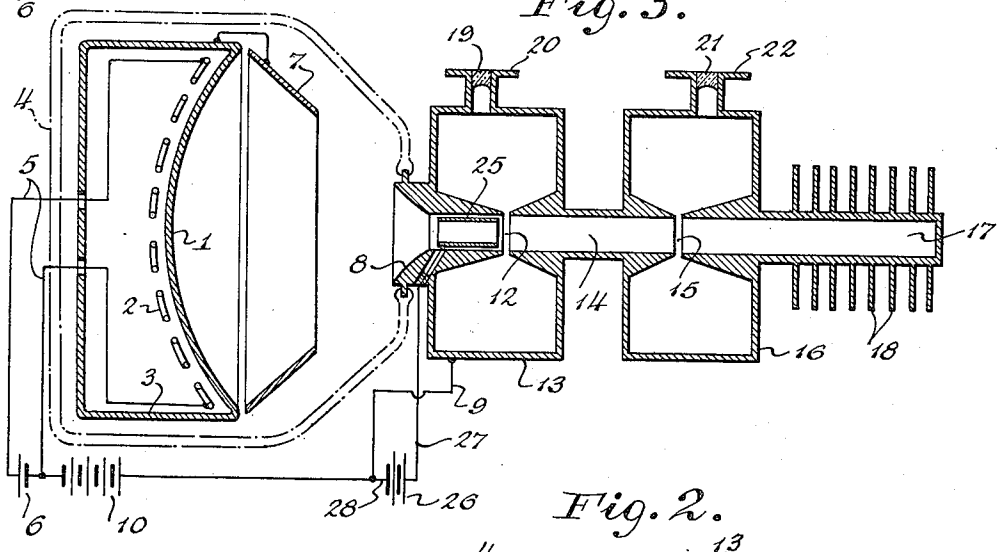
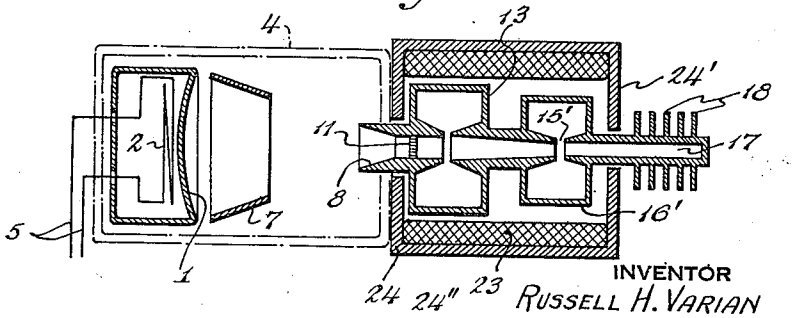


Fig. 2.



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BEAM TYPE ELECTRONIC TUBE

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5 Claims. (Cl. 315—5)

This invention relates generally to an improved electron tube possessing enhanced performance characteristics, and the invention has reference, more particularly, to a novel electron tube as of the klystron or traveling wave type employing a narrow electron beam.

Heretofore, electron tubes of the klystron type have been classified into three general types; firstly, the most usual type is a klystron having a resonator or resonators having relatively large re-entrant hollow poles, the ends of which are closed by grids. This type has a number of good and bad features. The good features are that the cross section through which the beam is projected is relatively large. This allows for wide tolerances in the electron optical system which projects electrons through the resonator, no magnetic focusing is required, and it is possible to design electron guns which operate at relatively low voltage and high current, thus making possible the design of klystrons operating at relatively low voltage.

The objectionable features of this type of klystron are firstly, a multiplicity of grids result in the loss of a considerable fraction of the electrons by impact thereon before they can become useful in generating power, secondly, the grids being relatively large in diameter and closely spaced produce a large amount of capacity loading, thus reducing the shunt impedance, and the gain bandwidth product, and thirdly, what is usually more serious is that the grids being subject to bombardment by the electron beam give off secondary electrons which absorb a large amount of the power delivered to the resonator or resonators by the bunches in the beam, or by the input signal. This effect may in typical cases reduce the efficiency of tubes by a very large factor. The three factors combined may reduce the efficiency by a factor of ten or more. In spite of the very low efficiency of this type of tube, it is nevertheless used in large numbers because of the good features mentioned above.

The second type of klystron tube is currently increasing in use because it is capable of much greater efficiency, although it is deficient in most of the good features of the first type of tube. This type of tube is generally a relatively high voltage tube which is entirely devoid of grids. The apertures through which the electrons pass must be small enough so that reasonably good electron coupling to the field in the cavity exists throughout the beam. Since the tube is without grids, the positive ions are fairly completely drained out of the beam, and so the beam would rapidly expand as a result of its own space charge were it not prevented from doing so by the use of a strong magnetic field along the axis of the beam. These tubes usually operate at high voltage and high power, and actually approach the efficiency that theory would predict; however, the necessity for the magnetic field and high voltage makes this type undesirable for low and medium power tubes.

A third type of tube is useful only as reflex tubes, and consists of a beam focused through a gridless aperture in a resonator after which it expands rapidly in diameter

because there is no magnetic field used, but is refocused through the hole of the resonator by a concave negative reflecting electrode. This type of tube is not in very general use, and need not concern us here.

It is a primary object of the present invention to combine the good features of the first and second classes of tubes mentioned, and to omit most of their faults.

Another object of the invention is to provide a novel tube structure having an electron beam of high density and low divergence over a considerable distance.

Another object of the invention is to provide a klystron type tube of greatly increased power efficiency.

Another object of the invention is to provide a klystron type tube having a much improved gain band width product.

Another object of the invention is to provide a klystron type tube having reduced microphonics.

Still another object of the invention is to provide a klystron type tube of high efficiency without use of magnetic focusing fields.

A further object of the invention is to provide a klystron type tube that, with the addition of a magnetic field, obtains a very dense and sharp focus of electrons.

A further object is to provide an electron tube which does not require magnetic focusing.

A still further object is to provide an electron tube having an electron beam interaction space or passage that is devoid of field coupling grids, the said tube having means for preventing the drainage of positive ions from said interaction space.

Fig. 1 is a longitudinal cross-sectional view of a novel tube embodying the subject invention.

Figs. 2 and 3 are similar views of somewhat modified structures.

Referring now to Fig. 1, the reference numeral 1 designates a focusing type cathode surface, 2 is a heater for heating the surface, 3 is the heater sleeve which is mounted on a base 4 and provided with electrical connections 5, which connect the heater 2 to a power source 6. A focusing shield 7 is shown electrically connected to cathode 1. Cathode 1 is connected to a frusto-conically recessed electron beam accelerating electrode or anode 8 through a wire 9, and power source 10.

The apparatus so far described constitutes a cathode gun structure of known design. The requirement of the gun is that it deliver a sharply focused beam having a cross section at its smallest point which is small compared to the area of the cathode, and also that the electrons when passing through the plane of minimum cross section are all traveling parallel to each other. This condition is particularly well met in cathodes of the Heil type.

It is not intended here to imply that this invention requires a cathode of the highly convergent type described to be operative. As long as cathode materials are used which cannot emit more than a few tenths of an ampere per sq. cm. in continuous operation, this is a good type of cathode to employ, but if cathodes such as those recently made public by North American Philips Co. which emit hundreds of amperes per sq. cm. are used, a very small substantially non-convergent cathode may be used.

If all the electrons are traveling parallel at a point along their path, they will continue to travel parallel unless acted upon by some force. As such a cathode is ordinarily used, a strong force exists tending to spread the beam apart again, and therefore the beam expands rapidly after passing the point of minimum cross section. The force causing the spreading of the electrons is the mutual repulsive force existing between the electrons in transit. This force may, however, be canceled by the trapping of positive ions by the negative space charge of the beam.

Positive ions are continuously being produced in any electron beam in a vacuum because no vacuum is perfect, and there will always be some collisions between the electrons of the beam and gas molecules in the beam. However, it may be readily shown that, although a colliding electron may have many thousands of times the energy associated with thermal motion, it cannot transfer energy to the positive ion greater than the order of magnitude of the energy of thermal motion. This energy at room temperature is about $\frac{1}{30}$ electron volt. This is because a positive ion is many thousands of times as heavy as an electron, and an encounter between an electron and an atom is like an encounter between a golf ball and a locomotive. Hence, a positive ion produced in a beam cannot escape from the beam to the surrounding metal walls as long as there is any appreciable negative space charge in the beam.

The electron beam may therefore serve as a trap for all the positive ions formed unless and until the negative charge of the electron beam becomes completely neutralized by positive ions. However, an electron beam will not become so neutralized as long as there is an unobstructed avenue of escape for positive ions along the length of the electron beam to the cathode. The cathode which is emitting a beam of electrons is always more negative than any point in the beam, and as long as there is a continuous and reasonably large potential gradient along the beam to the cathode, the positive ions will be drained out to the cathode at such a rate that there are never enough ions present in the beam to neutralize the space charge produced by the electrons. This situation exists in all gridless klystron type tubes and also in traveling wave tubes unless special means are used to reverse the potential gradient along the beam at some point which can act as a dam to stop positive ions from passing the point of reversal, or if not to reverse it, to reduce it to such a low level that ions are not removed at a rapid enough rate to deplete the supply of ions in the beam.

It has been known for some time that an electrode made somewhat positive with respect to the rest of the drift tube will accomplish this result. This, however, complicates the tube construction considerably because it requires a voltage more positive than the main supply voltage, extra electrodes, and insulators within the tube, and complication of the electron optics by the lens action of the added electrode.

I have found that it is possible to make a partial or nearly complete dam to the positive ions by interposing a grid type electrode in a tube surrounding a beam, the grid subdividing the beam into a number of parts. The potential of the beam in the middle of one of the tubules of a hexagonal grid can be formed by assigning an effective radius to the charge in a single tubule of the grid, and by use of the well-known formula for the capacity of a condenser consisting of concentric cylinders. The formula is

$$C=K\frac{.2416L}{\log 10\frac{r_1}{r_2}}$$

K=dielectric constant
L=length
r_1=radius of outer cylinder
r_2=radius of inner cylinder

Examination of this formula shows that the capacity depends only on the variables

$$\frac{r_1}{r_2}$$

and L. If the current is uniformly distributed over the cross section of the grid tubule, the effective capacity per

unit length of the tubule is independent of its diameter, but the charge within the tubule

$$q\alpha r_1^2$$

Then the potential at center,

$$p\alpha\frac{1}{r_1^2}\alpha\frac{1}{N}$$

where N is the total number of holes in the grid. Then, if a grid having for example, 100 holes is placed along the path of beam having uniform density and just filling a drift tube, and the grid is moderately deep compared to the diameter of the holes, the negative potential in the center of the beam will suddenly drop to $\frac{1}{100}$ of its value existing at the time of entering the grid. Initially timewise, on passing beyond the ion flow-restricting grid **11**, the potential at the center of the beam will be more negative than at the novel grid **11**. As the beam continues to pass through the device ionization of residual gas molecules continues thereby creating positive ions which dam up beyond the novel ion flow-restricting grid **11**. These dammed up positive ions serve to neutralize the negative space charge in the beam after passing the grid **11** and thereby cause the beam expanding forces (electron mutual repulsion forces) to be diminished thereby aiding in confining the beam diameter. When the positive ion reservoir is full, that is, when a sufficient number of positive ions have formed and have been restricted beyond the novel grid **11** to neutralize the negative space charge within the beam, to essentially the potential of the beam at the novel grid, the excess ions that are produced will begin to drain through the grid **11** toward the cathode **1**. The grid therefore acts as an incomplete ion trap, but any desired degree of completeness may be achieved by making the holes in the grid smaller and more numerous.

It now can be seen that if the electrons of the beam are all traveling parallel as they pass through an ion flow restricting grid electrode **11** located, for example, in the cylindrical throat of the accelerating electrode or anode **8**, they will continue to travel substantially parallel after passing the grid **11**.

The beam then passes through a gridless gap **12** provided in a resonator **13** where the beam is velocity modulated by the alternating electromagnetic field within the resonator in use and becomes density modulated or bunched while passing through a drift tube **14** interconnecting resonator **13** and a second resonator **16**, the drift space within the tube **14** being substantially free of alternating fields. The beam then passes through a second gridless gap **15** provided in a second resonator **16** wherein the beam coacts with the field of this resonator to drive the same and then on into catcher bucket **17** where the energy remaining in the electron beam is dissipated as heat as by use of fins **18**. These cooling fins **18** may be provided on catcher bucket **17** if the amount of power dissipation requires their use.

The input signal may be supplied to the resonator **13** as through a coupling window **19** in coupling flange **20** provided on this resonator, and the amplified signal may be coupled out of cavity **16** through a window **21** in coupling flange **22**. It is understood that flanges **20** and **22** will be coupled to input and output wave guides, respectively, when the tube is operating. For the sake of simplicity no tuning means is shown, but it should be understood that any of the tuning means customarily used to tune the cavities of kystrons may be used.

In operation, the apparatus shown in Fig. 1 combines the advantages of high efficiency, large gain bandwidth product, low microphonics, and low voltage operation without the necessity of using a magnetic focusing field. The first three features are characteristic of magnetically focused gridless klystrons. The later two are characteristic of klystrons with grids; thus, it is seen that the combination of elements in Fig. 1 achieves a result never before achieved in a klystron type tube and that the result

of the combination of elements is much more than would be expected by one skilled in the art.

It should be pointed out that the diameter of drift tube **14** is of the order of that of a single aperture in a corresponding grided tube, i. e., the type shown, for example, in my Patent No. 2,449,569, and that the ion flow restricting or trapping grid **11** which is placed within that diameter must have many apertures to perform its ion trapping function. It must therefore be of a much finer mesh than is required or present in either resonator or smoother grids, i. e. the apertures of grid **11** are much smaller than is required for coupling the resonator field to the beam which latter is the function of ordinary grids. Typically, the radius of an aperture in a field-coupling grid as taught in the prior art would have a practical minimum value of approximately 0.5 radian of the applied R. F. at the beam voltage (see page 1035, Journal of Applied Physics, vol. 17, December 1946). In other words, the radius of an aperture in a field-coupling grid is normally larger than

$$\frac{v\lambda}{4\pi c}$$

where v is the velocity of the electrons in the beam in the absence of R. F. applied, λ is a wavelength of the applied radio frequency energy, c is the velocity of light. If a suitable cathode design is chosen, grid **11** will be far enough into the throat of anode **8** so that its presence will have no appreciable effect on the electron optics between cathode **1** and anode **8**. It should be pointed out however, that if for any reason a cathode is chosen in which the parallel part of the beam is exposed to the field of the cathode, the cathode will have to be especially designed to take account of the disturbing effect of the grid.

In the structure of Fig. 2, the cathode gun may be the same as illustrated in Fig. 1 and bears the same reference numbers. Grid **11** is employed as in Fig. 1. The beam enters a magnetic field supplied by coil or coils **23** and iron pole pieces **24**, **24'**, of a hollow cylinder **24''**. In entering the field the beam passes through a radial magnetic field in the hole in the pole piece **24**, and receives a velocity at right angles to its own direction of motion and the direction of the radial field. Every electron therefore acquires a tangential motion in passing into the field. In the absence of space charge in the beam, it can be shown that each electron will follow a helical path which crosses the axis of the beam, and all the electrons will cross the axis at the same point. Thus, a beam which is already small and dense at grid **11** can be made very much smaller where the cross-over occurs.

Fig. 2 illustrates a superior type of multiplier using gridless resonators as in Fig. 1. In fact, all the parts of these resonators are similar with the exception, however, that the second resonator **16'** is physically smaller than resonator **13** and tuned to a harmonic of this first resonator. The very small diameter of the beam at the second resonator **16'** enables the beam to pass through this very high frequency resonator. To represent the second resonator in its actual proportion to the cathode and the first resonator would interfere with clarity in the drawing, and would only represent one of a number of possible sizes, and so the second resonator is represented as only slightly smaller than the first. In operation this structure is a klystron multiplier of superior efficiency.

Fig. 3 represents a klystron type tube which is shown as using an ion trap, which is a positively biased ring surrounding the drift tube instead of a grid. This design is inconvenient for low power tubes, but is useful for high power tubes having beam current capacities beyond the upper limit of power that a grid can stand. The essential change in structure between Fig. 3 and Fig. 1 is the substitution of a positively biased ring **25** in lieu of an ion trap grid. The ring **25** should not be placed at the plane of the grid as shown in Fig. 1, but at a somewhat greater distance from the cathode, as shown. This is because the positive ring form of ion trap is inherently a convergent

electron lens, and the beam should have passed its point of minimum diameter and be diverging when it passes the positive ring. The positive ring will then turn the divergent beam into a parallel one.

In Fig. 3, ring **25** is positively biased and is attached to the positive side of a battery **26** by means of lead **27**. The circuit is completed by a lead **28** from the negative side of this battery and connected to lead **9** in turn connected to battery **10**.

It is apparent that many changes could be made in the construction of the devices of Figs. 1 to 3 and that many apparently different embodiments of the invention could be made without departing from the scope thereof. For instance, the invention may be embodied in traveling wave tubes, and accordingly, 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:

1. In an electron tube, a cathode, an accelerating electrode member spaced from said cathode and cooperating with said cathode to produce an electron beam passable through said accelerating electrode, a multi-apertured ion flow-restricting electrode spaced from the accelerating portion of said accelerating electrode on the side thereof remote from said cathode, said ion flow-restricting electrode being in electrical contact with and operating at the same potential as said accelerating electrode, a tubular passageway beyond said ion flow-restricting electrode, said tubular passageway containing in use a source of positive ions caused by the bombardment of molecules in the gaseous state by electrons making up the beam, said ion flow-restricting electrode coacting with the beam of electrons for limiting the flow of positive ions present in the electron beam back towards said cathode, and means arranged along said tubular passageway for exchanging energy with a beam of charged particles passable therethrough.

2. In an electron tube, a cathode, an elongated accelerating electrode member having a cylindrical throat portion, said electrode member being spaced from said cathode and cooperating with the latter to produce a concentrated electron beam, a multi-aperture electrode fitting snugly within the throat of said accelerating electrode member in electrical contact therewith and near the end thereof removed from said cathode, said apertured electrode operating at the potential of said accelerating electrode and coacting with the beam for limiting the flow of positive ions in the beam back toward said cathode, and means providing a gridless passage beyond said apertured electrode, said passage cooperating with said electron beam to couple the latter with electromagnetic waves within said electron tube for exchanging energy therebetween.

3. An electron tube as defined in claim 2 wherein said apertured electrode comprises a grid having many small apertures through which the beam passes after being accelerated by said accelerating electrode member, the over-all size of said grid and said passage being of the order of the size of a single aperture of a field coupling grid of a grided tube.

4. In an electron tube as claimed in claim 2 wherein said multi-apertured electrode member comprises a plurality of tubular cell elements, and the radius of a typical tubular cell element is less than

$$\frac{v\lambda}{4\pi c}$$

where v is the velocity of the electrons in the beam in the absence of R. F. applied, λ is the wave length of the applied radio frequency energy, and c is the velocity of light, whereby a less negative potential barrier is formed in said beam to aid in retaining positive ions in the beam.

5. In an electron tube, a cathode, an elongated accelerating electrode member cooperating with said cathode to produce an electron beam, said electrode member hav-

ing a hollow tubular portion accommodating the beam, a cavity resonator having opposed apertured re-entrant portions defining a circular gridless gap therebetween and positioned so that said beam passes through said apertured re-entrant portions for coacting with an electromagnetic field within said resonator at said gap, and a multi-apertured grid positively biased with respect to said cathode to the same potential as said accelerating electrode member by snugly contacting the latter and positioned in the tubular portion thereof in slightly spaced relation with respect to said gap to be passed through by said beam before reaching said gridless gap to thereby limit the flow of positive ions toward said cathode and prevent the spreading of said beam due to mutual repulsion of the electrons of the beam.

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