Feb. 14, 1950

H. B. DE VORE

ELECTRON DISCHARGE DEVICE EMPLOYING CAVITY RESONATORS

Filed Aug. 22, 1945

2,497,831

Fig. 1.

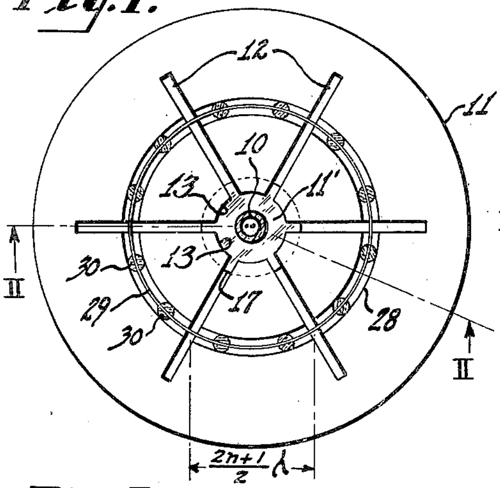


Fig. 2.

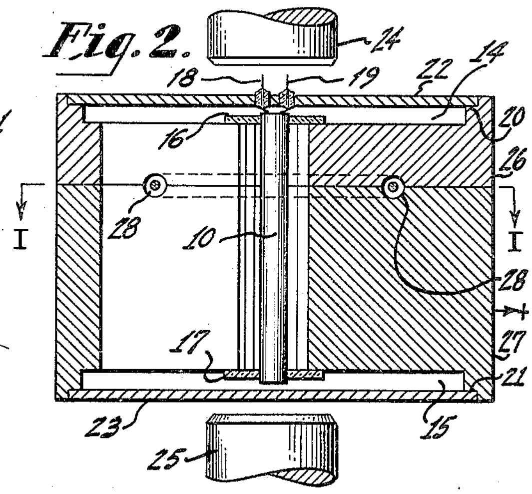


Fig. 3.

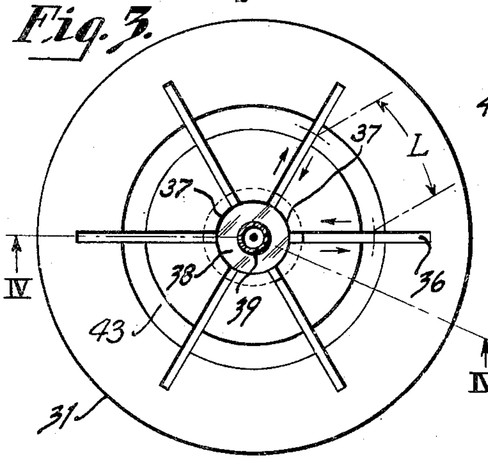


Fig. 4.

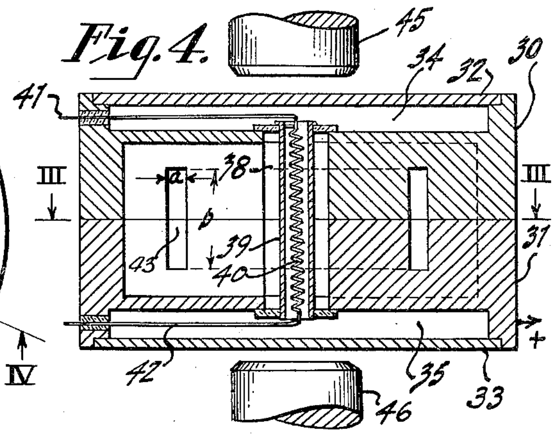


Fig. 5.

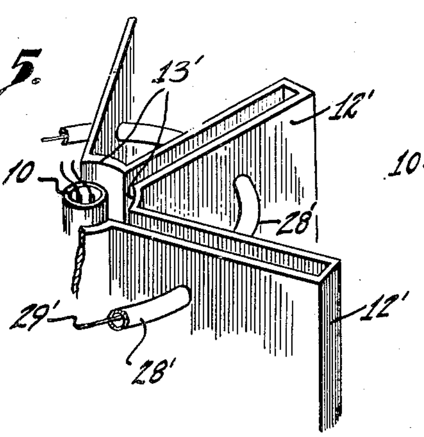
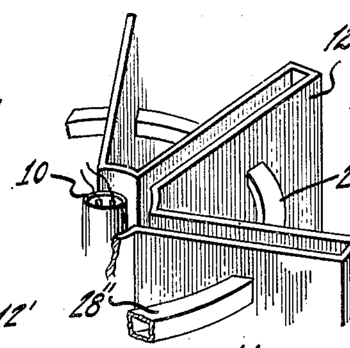


Fig. 6.



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ELECTRON DISCHARGE DEVICE EMPLOYING CAVITY RESONATORS

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19 Claims. (Cl. 315—39)

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My invention relates to electron discharge devices useful at ultra high frequencies and more particularly to such devices utilizing cavity resonators, for example, cavity resonator type magnetrons.

In one form of magnetron utilizing cavity resonators the anode segments or elements define a cylindrical chamber in which is coaxially mounted a cathode or into which chamber electrons are axially directed. Adjacent anode segments are coupled together by means of cavity resonators. In one form of magnetron, a cylindrical anode block has at its axis a cylindrical chamber extending therethrough. Radial slots which are closed at their outer ends and open at their sides communicate at their inner ends with this chamber and provide the cavity resonators, the walls of the cathode chamber between the slots providing the anode segments. The cathode is mounted coaxial of this chamber. The cavity resonators may also take the form of tubular chambers extending parallel to the axis of the anode block and communicating with the central cathode chamber by means of radially directed slots. In another form radially directed vanes may be mounted within a drum-shaped enclosure, the inner ends forming the anode elements and the spaces between the vanes forming the resonators. Again the cavity resonators may be formed simply by sheet metal structures coupling adjacent edges of the anode elements or segments surrounding the cathode space and defining the cathode chamber. The usual magnetic means are provided for directing a magnetic field parallel to the cathode or parallel to the cathode chamber into which the electrons may be directed. One theory is that in this type of magnetron the cavity resonators are coupled to one another presumably by linkage of magnetic flux from one slot to the next at the open sides thereof. The indefiniteness of this coupling is believed to be the cause of several possible modes of oscillation for the device with several possible frequencies of oscillation being generated. This multiplicity of modes of oscillation is observed in actual operation of these types of magnetrons and is regarded as undesirable.

It is, therefore, an object of my invention to provide an improved form of electron discharge device useful at ultra high frequencies and employing cavity resonators.

It is another object of my invention to provide such an improved device, particularly of the magnetron type, utilizing cavity resonators, and more particularly to insure the desired mode or modes of oscillation during operation of the device.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims, but the invention itself will best be understood by reference to the following description taken in connection with

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the accompanying drawing in which Figure 1 is a transverse section of an eletcron discharge device made according to my invention and taken along the line 1—1 of Figure 2, Figure 2 is a longitudinal section taken along the line 2—2 of Figure 1, Figure 3 is a transverse section taken along the line 3—3 of Figure 4 and showing a modification of the construction of Figures 1 and 2, Figure 4 is a transverse section taken along the line 4—4 of Figure 3, Figure 5 is a perspective of a further modification of the construction shown in Figures 1 and 2, and Figure 6 is a perspective showing a modification of the construction shown in Figures 3 and 4 of an electron discharge device made according to my invention.

Referring to Figures 1 and 2, the anode block of conducting material designated generally at 11 comprises two registering sections 26 and 27 at the longitudinal axis of which is provided the cathode chamber 11′ from which extend the radially directed slots 12. These slots 12 form the cavity resonators, the portions 12′ of the chamber wall between slots 13 providing the anode segments or elements defining the cathode chamber 11′. The ends of the anode block are provided with the recessed chambers 14 and 15 and the step portions 20 and 21 for receiving the cover members 22 and 23, the cover members and the sections 26 and 27 of the anode block being hermetically sealed, for example, by silver brazing, to provide a vacuum-tight interior.

The indirectly heated cathode 10 coated with the usual emitting material is insulatingly supported within the cathode chamber 11′ by means of insulating discs 16 and 17, the cathode and its associated heating element being provided with insulated leads 18 and 19 extending to the exterior of the envelope. The usual magnetic poles 24 and 25 provide a constant magnetic field parallel to the cathode and between the cathode and anode block.

In accordance with my invention the sections 26 and 27 are provided with annular depressions or channels of semi-circular cross section which register to provide the tubular duct or passageway 28 between the cavity resonators. Mounted centrally of this duct 28 is a conductor 29 in the form of a closed ring and insulatingly supported within the duct by means of insulating beads 30—30. Thus I provide in effect concentric transmission lines for coupling adjacent resonators.

The proper location for this concentric transmission line is such that the propagation time for a wave passing along the line from one cavity to the next is an odd number of half periods of oscillations generated. For the case of a concentric transmission line, for example, the speed of propagation of a wave is equal to the velocity of light, and the length of the concentric transmission lines between adjacent cavities should be an odd number of half wave-lengths. This line then should be located at such a distance from the center of the anode that its length is

$$\frac{2n+1}{2}\lambda N$$

where λ is the wavelength of the oscillations, N is the number of cavities and n is any integer.

In an anode block of the type shown in Figures 1 and 2, with the upper and lower ends of the cavity resonators open, the slots cannot be very deep, the radial dimensions being of the order of a quarter wavelength. If there are more than four cavity resonators in the anode, the distances between them are so small that the resonators must be operated in a higher mode to utilize the concentric transmission line. It is, therefore, desirable when many cavities are used that the cavities have large radial dimensions. It might also be desirable to utilize a wave transmission means in the form of a wave guide instead of the concentric transmission line shown in Figures 1 and 2.

An electron discharge device in which the cavity resonators have a long radial length, and in which a waveguide is used, is shown in Figures 3 and 4. The anode block comprises the two annular sections **30** and **31** in which the cavity resonators **36** are broached or otherwise formed such that the upper and lower ends are closed as shown. The portions **37** between the slot resonators **36** provide the anode segments. Thus in this form the cavity resonators are shaped as rectangular cavities completely enclosed except for the opening into the cathode space **38**. Each cavity would thus be in the form of a hollow rectangular box with the end facing the cathode open. These boxes are so proportioned as to resonate with the oscillating electric field direction circumferential with respect to the anode cylinder or block. Under these conditions the axial dimension of the box is less than one wavelength and more than one-half wavelength of the radiation to be generated. The dimension in the direction of the electric field may be any convenient value, preferably smaller than a half wavelength. The radial dimension may be any value, preferably greater than a half wavelength. The possibility of making this radial dimension large adds to the convenience of manufacture in the case of the device designated to produce oscillations of the order of ten thousand megacycles and greater.

In the arrangement shown, the indirectly heated cathode **39** is provided with heater **40**, and the leads **41** and **42** are taken out radially and sealed through the members **30** and **31** passing through the spaces **34** and **35** between the ends of the resonators and the cover members **32** and **33** hermetically sealed to the anode block. In this case the wave transmission means for coupling the adjacent resonators is a tubular waveguide having dimensions a and b, the waveguide being formed by an annular depressions or grooves in the facing surfaces of the two portions **30** and **31** of the anode block which when assembled provide a peripherally closed tubular passageway **43**. The magnets **45** and **46** provide the usual magnetic field parallel to the cathode and filling the cathode-anode space. In this case the speed of propagation is not equal to the speed of light and must be calculated for the mode of propagation in the guide, the cross sectional dimension of the guide and the frequency of oscillation. From the calculated speed of propagation the proper

length of the waveguide may be chosen to give the propagation time of a wave from one cavity wall to the next equal to an integral number of periods. The method whereby a waveguide couples to a resonant cavity is somewhat different from that for a coaxial line. In either case, the object is to have the oscillations in adjacent cavities in opposite phase. This entails an opposite direction of current flow along the corresponding walls of adjacent cavities, such as might be represented at some instant by the small arrows shown in Figure 3. The field in the connecting waveguide **43** may be considered as caused by interruption in the wall current flow, and will have the same direction as the wall current. Thus, it is apparent that the field direction at the ends of a connecting waveguide must have the same direction at every instant, and hence the proper length of the waveguides must be an integral number of wavelengths, measured in the guides.

The rectangular waveguides should be dimensioned such that the radical dimension a is less than one-half of the free space wavelength while the dimension b parallel to the axis of the anode is greater than one-half and preferably less than one free space wavelength. The guide wavelength will then be determined by this axial dimension. The guide wavelength λ_g is given by:

$$\lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{\lambda}{2b}\right)^2}}$$

where λ is the free space wavelength. Then the radial position of the guide should be such that its length L, measured along the center of the guide and between the ends thereof, is an integral multiple of λ_g

$$L = n\lambda_g = \frac{n\lambda}{\sqrt{1-\left(\frac{\lambda}{2b}\right)^2}}$$

where $n=1, 2, 3$, etc.

In the case of a concentric transmission line as shown in Figures 1 and 2, however, the coupling is to the electromagnetic field between the cavity walls. Since this is exactly opposite in phase in adjacent cavities, the connecting concentric transmission line should be an odd number of half wavelengths in length, measured to the cavity centers.

In Figures 5 and 6 I show a still further modification of the invention. Figure 5 is of the form shown in Figures 1 and 2, except that each of the cavity resonators **12'** is formed by sheet metal which is connected to the adjacent edges of two adjacent anode segments or elements **13'**. Here conventional coaxial lines **28'**, **29'** couple adjacent cavity resonators.

In Figure 6 a somewhat similar construction is shown, except that instead of utilizing coaxial lines **28'** and **29'**, I use a rectangular shaped waveguide **28''** for coupling adjacent cavities. Dimensions are the same as above described.

In all of the forms described, energy may be coupled out of the device in the usual ways, such as for example by coupling loops extending into a coaxial transmission line or through windows into waveguides.

While I have indicated the preferred embodiments of my invention of which I am now aware and have also indicated only one specific application for which my invention may be employed, it will be apparent that my invention is by no means limited to the exact forms illustrated or the use indicated, but that many variations may be made in the particular structure used and the purpose for which it is employed without departing from the scope of my invention as set forth in the appended claims.

What I claim as new is:

1. An electron discharge device having a plurality of anode elements defining a chamber, a cathode for supplying electrons within said chamber, cavity resonators coupled between adjacent anode elements and wave transmission means coupling said resonators together, said coupling means including a peripherally-closed tubular conducting wall extending between and opening into adjacent resonators intermediate the ends thereof.

2. An electron discharge device having a plurality of anode elements defining a chamber, a cathode for supplying electrons within said chamber, cavity resonators coupled between adjacent anode elements and wave transmission means coupling said resonators together, said coupling means including a peripherally-closed tubular conducting wall extending between and opening into adjacent resonators intermediate the ends thereof, said tubular conducting wall having an axial length substantially equal to an odd number of half wavelengths of the fundamental frequency of said resonators.

3. An electron discharge device having an anode block of solid conducting material, said block having an axially directed central chamber, and cathode means for supplying electrons within said chamber, said anode block having radially directed slots extending from said chamber and forming therebetween anode elements defining said chamber and cavity resonators connecting adjacent anode elements, said block having a tubular passageway connecting adjacent cavity resonators intermediate the inner and outer ends thereof and a conductor positioned axially of said tubular passageway and insulated from the walls thereof and providing with said tubular passageway a concentric transmission line connecting adjacent resonators.

4. An electron discharge device having an anode block of solid conducting material and having an axially directed central chamber, and cathode means for supplying electrons within said chamber, said anode block having radially directed slots extending from said chamber and forming anode elements between the inner ends of adjacent slots, said slots providing cavity resonators connecting adjacent anode elements, said block having resonator coupling means comprising a peripherally-closed tubular passageway connecting adjacent cavity resonators intermediate the inner and outer ends thereof.

5. An electron discharge device having an anode block of solid conducting material, said block having an axially directed central chamber, cathode means for supplying electrons within said chamber, said anode block having radially directed slots extending from said chamber and forming anode elements between the inner ends of the slots, said slots providing cavity resonators connecting adjacent anode elements, said block having an annular tubular passageway connecting adjacent cavity resonators intermediate the inner and outer ends thereof, and a ring-like conductor positioned centrally of said passageway and insulated from the walls thereof and providing a concentric transmission line connecting adjacent resonators, said ring-like electrode and passageway having a length between adjacent resonators of an odd number of half wavelengths of the resonant frequency of said resonators.

6. An electron discharge device having an anode block comprising two registering parts, each of said parts having an axially directed central chamber and a plurality of radially directed slots extending from said chamber and forming anode elements between the inner ends of the slots, said slots providing cavity resonators connecting adjacent anode elements, each of said parts having an annular channel in the contacting face thereof, said channels registering for providing an annular tubular passageway, said annular tubular passageway coupling adjacent resonators together.

7. An electron discharge device having an anode block comprising two registering parts, each of said parts having an axially directed central chamber and a plurality of radially directed slots extending from said chamber and forming anode elements between the inner ends of the slots, said slots providing cavity resonators connecting adjacent anode elements, each of said parts having an annular semi-cylindrical channel in the contacting face thereof, said channels registering for providing an annular tubular passageway, said annular tubular passageway coupling adjacent resonators together, and a ring-like conductor positioned within said annular tubular passageway but insulated from the walls thereof whereby a concentric transmission line is provided for coupling adjacent resonators together.

8. An electron discharge device having a plurality of arcuate shaped elongated conducting anode elements lying in the surface of a cylinder and defining a central chamber, and spaced along their longitudinal edges to provide gaps therebetween, a plurality of elongated sheet-like U-shaped members having their legs connected to adjacent edges of adjacent arcuate shaped elements to provide cavity resonators connected between adjacent anode elements, cathode means for supplying electrons within said central chamber, and tubular conducting members extending between adjacent resonators for coupling adjacent resonators intermediate the ends thereof.

9. An electron discharge device having a plurality of arcuate shaped elongated conducting anode elements lying in the surface of a cylinder and defining a central chamber and spaced along their longitudinal edges to provide gaps therebetween, a plurality of elongated sheet-like U-shaped members having their legs connected to adjacent edges of adjacent arcuate shaped elements to provide cavity resonators connected between adjacent anode elements, cathode means for supplying electrons within said central chamber and tubular conducting members extending between adjacent resonators intermediate the ends thereof, and a conductor within said tubular members insulated therefrom for providing a transmission line coupling adjacent resonators.

10. An electron discharge device having a plurality or arcuate shaped elongated conducting anode elements lying in the surface of a cylinder and defining a central chamber and spaced along their longitudinal edges to provide gaps, a plurality of elongated sheet-like U-shaped members having their legs connected to adjacent edges of adjacent arcuate shaped elements to provide cavity resonators connected between adjacent anode elements, cathode means for supplying electrons within said central chamber, and tubular wave guide sections extending between ad-

jacent resonators, said sections being arcuate shaped and having a radius of curvature such that the length of each section is substantially equal to an integral number of wavelengths in the wave guide section of the resonant frequency of the cavity resonators.

11. An electron discharge device having a plurality of arcuate shaped elongated conducting anode elements lying in the surface of a cylinder and defining a central chamber and spaced along their longitudinal edges to provide gaps, a plurality of elongated sheet-like U-shaped members having their legs connected to adjacent edges of adjacent arcuate shaped elements to provide cavity resonators connected between adjacent anode elements, cathode means for supplying electrons within said central chamber, tubular conducting members extending between adjacent resonators, and a conductor within said tubular members and insulated therefrom for providing a transmission line coupling adjacent resonators, said tubular members being arcuate shaped and having such a radius of curvature that the length of said tubular members is substantially equal to an odd number of half wavelengths of the resonant frequency of the cavity resonators.

12. An electron discharge device having a plurality of spaced anode elements defining a chamber, a cathode for supplying electrons within said chamber, cavity resonators coupled between adjacent anode elements and opening into said chamber, said resonators being substantially closed except for the opening into said chamber, and wave transmission means for coupling said resonators together, said coupling means including a tubular conducting wall extending between and opening into adjacent resonators intermediate the ends thereof.

13. An electron discharge device having a plurality of spaced anode elements defining a chamber, a cathode for supplying electrons within said chamber, cavity resonators coupled between adjacent anode elements and opening into said chamber, said cavity resonators being substantially closed except for the opening into said chamber, and wave transmission means coupling adjacent resonators together, said coupling means including a tubular wave guide extending between and opening into adjacent resonators intermediate the ends thereof, the length of said wave guide being substantially equal to an integral number of wavelengths in the wave guide of the fundamental frequency of said resonators.

14. An electron discharge device having an anode block of solid conducting material, said block having an axially directed central chamber, and cathode means for supplying electrons within said chamber, said anode block having radially directed slots extending from said chamber and forming therebetween anode elements defining said chamber and cavity resonators connecting adjacent anode elements, said cavity resonators being substantially closed on all sides and at the outer end and open to the central chamber, said block having a tubular passageway connecting adjacent cavity resonators intermediate the inner and outer ends thereof.

15. An electron discharge device having an anode block of solid conducting material, said block having an axially directed central chamber, and cathode means for supplying electrons within said chamber, said anode block having radially directed slots extending from said chamber and forming therebetween anode elements defining said chamber and cavity resonators connecting adjacent anode elements, said block having resonator coupling means comprising a tubular passageway connecting adjacent cavity resonators intermediate the inner and outer ends thereof, the axial length of each of said cavity resonators slots being less than one wavelength of the generated frequency but greater than one-half wavelength, and the radial dimension thereof being greater than one-half wavelength.

16. An electron discharge device having a plurality of anode elements defining a chamber, a cathode for supplying electrons within said chamber, cavity resonators coupled between adjacent anode elements, and wave transmission means coupling said resonators together and including a peripherally-closed tubular wave guide section extending between and opening into each pair of adjacent resonators intermediate the ends thereof.

17. An electron discharge device of the magnetron type comprising an annular series of spaced parallel elongated anode elements defining a cylindrical cathode space, an elongated cathode coaxially mounted in said space, a radially directed rectangular cavity resonator connected between each pair of adjacent anode elements, means for establishing a constant magnetic field axially of said cathode space, and wave transmission means coupling said resonators together and including an arcuate peripherally-closed tubular conducting wall concentric with said cathode space and extending between and opening into each pair of adjacent resonators intermediate the inner and outer ends thereof, whereby the desired mode of operation of said device is favored.

18. An electron discharge device according to claim 16, wherein the length of the wave guide section between adjacent resonators is substantially equal to an integral number of wavelengths in the guide of the fundamental frequency of said resonators.

19. An electron discharge device having a plurality of anode elements defining a chamber, a cathode for supplying electrons within said chamber, cavity resonators coupled between adjacent anode elements, and wave transmission means coupling said resonators together and including a tubular wave guide section connecting adjacent resonators together and having a length between resonators substantially equal to an integral number of wavelengths in the wave guide of the fundamental frequency of said resonators.

HENRY B. DE VORE.

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Certificate of Correction

Patent No. 2,497,831 February 14, 1950

HENRY B. DE VORE

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows:

Column 2, line 22, for "portions 12'" read *portions 13*; line 23, for "slots 13" read *slots 12*; column 3, line 51, for the word "designated" read *designed*; line 64, strike out "an"; column 4, line 22, for "radical" read *radial*; column 6, line 65, for "or arcuate" read *of arcuate*;

and that the said Letters Patent should be read as corrected above, so that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 10th day of October, A. D. 1950.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.