

April 15, 1947.

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2,419,172

ELECTRON DISCHARGE DEVICE HAVING COUPLED COAXIAL LINE RESONATORS

Filed Nov. 19, 1943

3 Sheets-Sheet 1

Fig. 2.

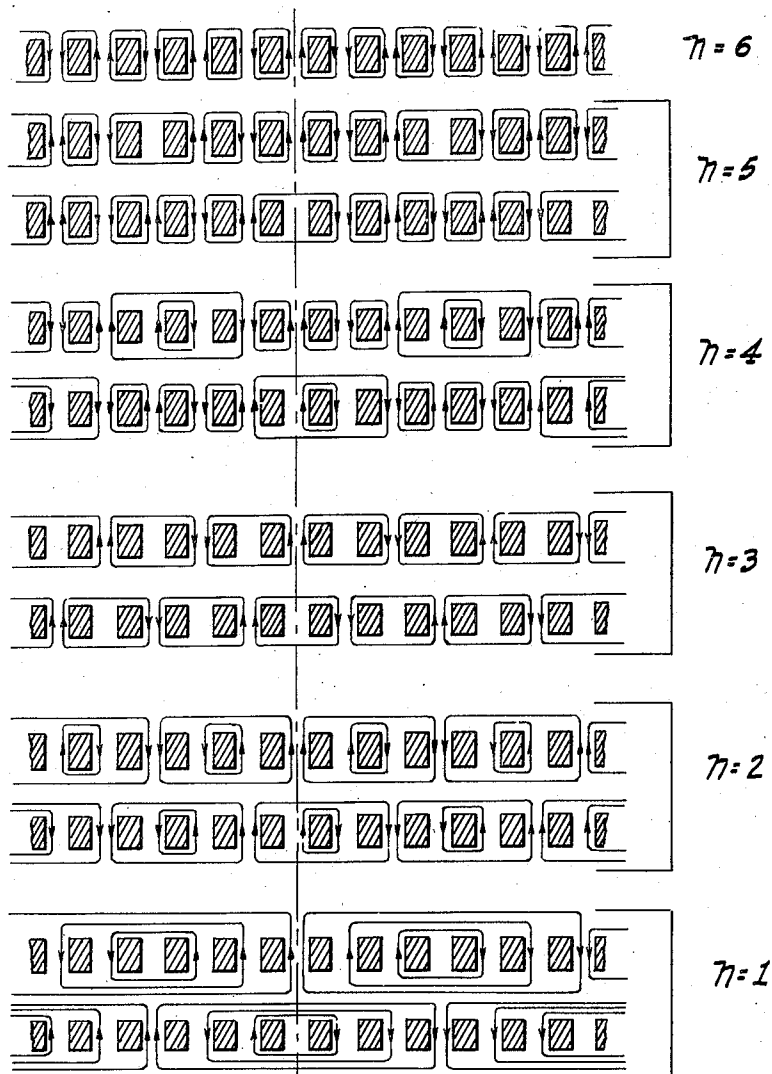
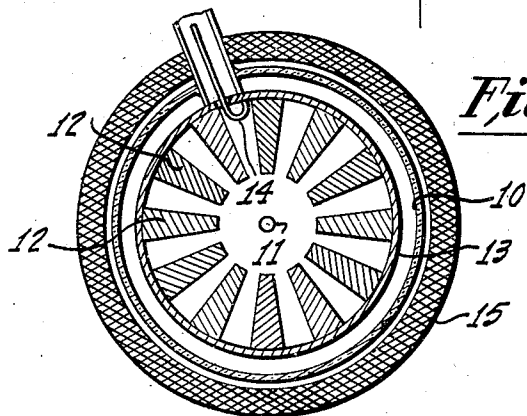


Fig. 1.



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Fig. 3.

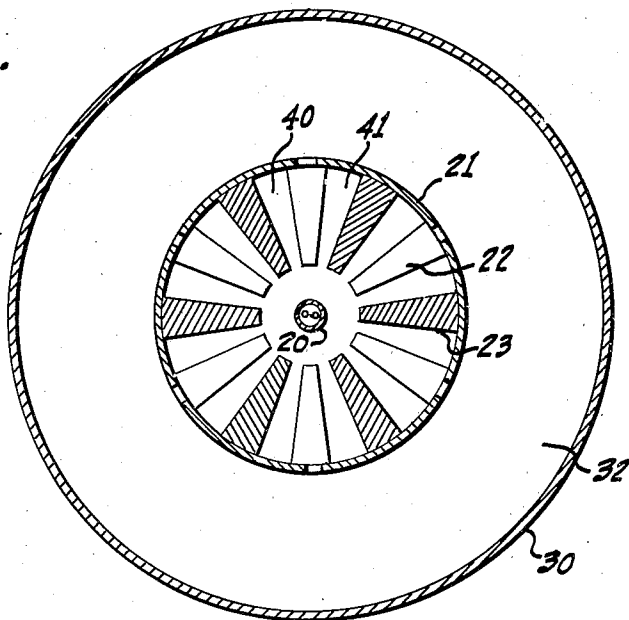
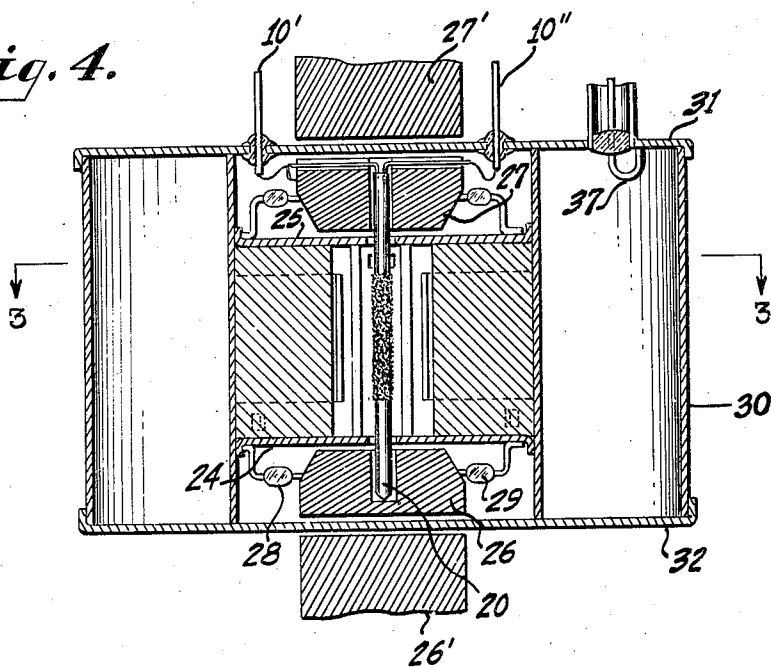


Fig. 4.



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3 Sheets-Sheet 3

Fig. 5.

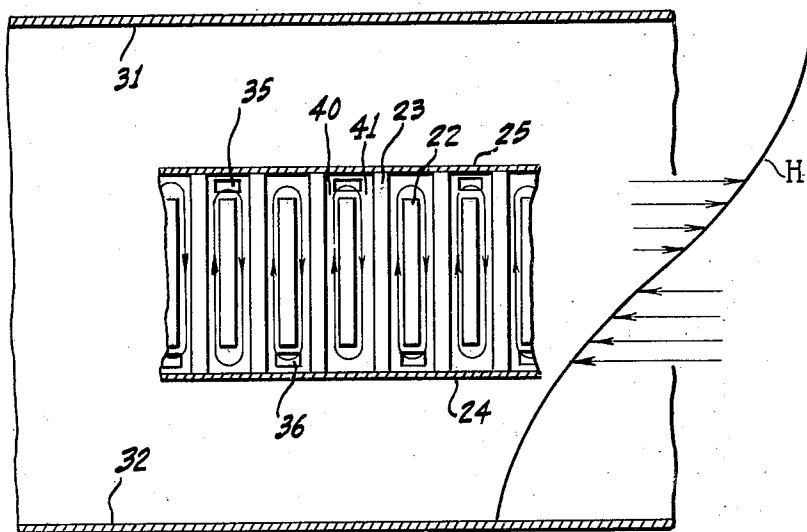
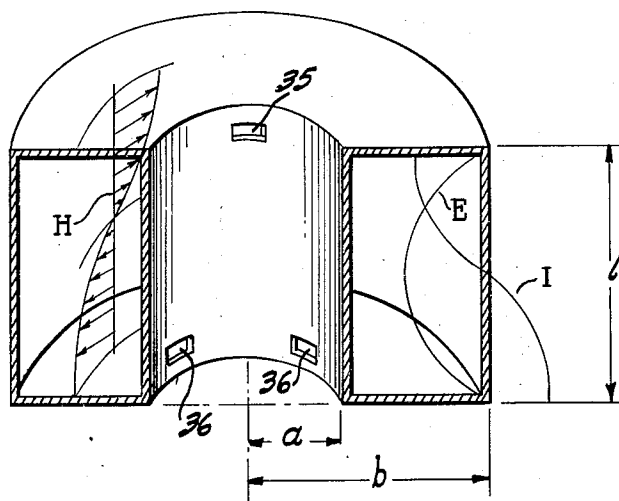


Fig. 6.



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ELECTRON DISCHARGE DEVICE HAVING
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17 Claims. (Cl. 250—27.5)

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My invention relates to electron discharge devices and associated circuits useful at ultra high frequencies, and more particularly to magnetrons utilizing cavity resonator circuits.

In certain types of magnetrons the anode segments are interconnected by means of cavity resonator circuits and form together the anode structure for the magnetron. One such construction comprises an elongated centrally positioned cathode having an anode member surrounding the cathode and provided with a plurality of cavity resonator circuits formed by cylindrical cavities in the anode member, radial slots extending between these cavities and the space between the cathode and the anode member, the anode segments being formed by the portions of the anode member positioned between adjacent slots, the slots lying parallel to the cathode.

In conventional multi-slot or multi-cavity magnetrons, there are two main difficulties which arise in their use. One difficulty is connected with the fact that a number of possible modes of operation exist, some of which are associated with different frequencies and some of which are degenerate and are associated with a single frequency. For example, in a twelve-slot anode magnetron structure it is possible to have eleven different modes in six distinct frequencies, the mode associated with one frequency being non-degenerate while all of the other modes are doubly degenerative. Since all six frequencies lie so near one another, frequency instability may develop under load. Because of the small differences between the frequencies, it is difficult to confine the generation of power to just one of the modes.

Another difficulty encountered in magnetron operation comes from the fact that in a perfectly symmetrical cylindrical arrangement of slots there is another type of degeneracy present, namely rotational degeneracy. This means that the field pattern may be rotated an arbitrary number of slots without changing the operation of the magnetron. In other words there is nothing to fix the field pattern so far as rotation is concerned. A small perturbation of the symmetry of the system will, however, remove this degeneracy and thereby fix the rotational position of the field pattern. In a practical magnetron, the coupling loop placed in or near one of the slots serves to fix the rotational position of the field pattern. However, it can be shown that the field pattern will assume that position for which the least magnetic flux associated with one of the degenerate modes will link the load coupling loop.

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Thus it is possible that the magnetron may operate in such a mode that no magnetic flux would exist in the slot containing the coupling loop. The magnetron could thus unload itself. The results are extremely important. For example, if one coupling loop were used a magnetron operating in one of the degenerate modes could appear to be a very inefficient generator of this mode. Actually the field intensity inside the magnetron for this mode could be very high and the energy be lost in circulating current losses in the walls. This in fact can lead to such high electric fields in the slots that sparking occurs.

Because of the closeness of the frequencies of some of the modes, it is possible for a loaded magnetron to oscillate in two modes at once. In this case with one coupling loop used the field for the uncoupled mode can become very high, thus again bringing about poor efficiency.

It is, therefore, an object of my invention to provide an electron discharge device of the magnetron type having improved characteristics.

It is a further object of my invention to produce such a device of the multi-segment type in which undesired modes of operation are suppressed.

More specifically it is an object of my invention to provide such an electron discharge device utilizing cavity resonator circuits of improved design which insure operation only in the desired mode or modes.

A further object of my invention is to provide a magnetron using cavity resonator circuits including improved means for coupling the magnetron to a load.

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 the accompanying drawing in which Figure 1 shows a transverse section of a conventional multi-slot cavity resonator type magnetron, Figure 2 is a diagrammatic representation of the modes of operation of the device shown in Figure 1, Figure 3 is a transverse section of an electron discharge device and associated circuit made according to my invention, Figure 4 is a longitudinal section of the device shown in Figure 1, Figure 5 is a diagram representing the electromagnetic fields in a device made according to my invention, and Figure 6 is a longitudinal perspective view of the cavity resonator associated with an electron discharge device made according to my invention and the wall current, and

electric and magnetic field relationships diagrammatically represented.

In one form of magnetron of the so-called multi-cavity type or multi-slot type as shown in Figure 1 and provided with an envelope 10, an elongated indirectly heated cathode 11 has spaced around the cathode and extending radially therefrom a plurality of anode segments 12 surrounded in turn by a tubular wall 13 closing the ends of the anode segments so as to provide cavity resonators between adjacent anode segments. The anode assembly may be made in various ways, either by stacking punched-out plates or by forming from a solid block, or by the use of radial fin-like inserts in a tubular member. Energy may be coupled out of the magnetron by means of coupling loop 14 and the electromagnetic field provided by means of an electromagnetic coil 15.

As pointed out above, a tube of this kind may have a number of possible modes of operation, some of which are associated with different frequencies and some of which are degenerate and are associated with a single frequency. In the case of the tube such as shown in Figure 1 having twelve slots, eleven different modes and six distinct frequencies may be generated. The magnetic field patterns for all these modes are diagrammatically shown in Figure 2. In viewing these figures the anode block and cylinder may be viewed as cut along a longitudinal axis and the cylinder unrolled so that the open ends of the slots are viewed. The magnetic field pattern labeled $n=6$ is the only non-degenerate mode as indicated by the arrows representing a magnetic field line, it being noted that all of the adjacent arrows point in the same direction. This means there is only one field pattern which is associated with the frequency which may be referred to as the ω_6 frequency. The two magnetic field patterns labeled $n=5$ are the two linearly independent patterns associated with a slightly lower frequency ω_5 . Thus the mode $n=5$ is two fold degenerate. By independent patterns associated with the frequency ω_5 is meant those patterns chosen such that any and all possible field patterns associated with the frequency ω_5 may be formed by a superposition of the two fundamental or independent field patterns. Because of the small difference between the frequency ω_6 and ω_5 , it is difficult to confine the generation of power to just one of these modes. Other modes and the degenerative action in these modes are shown in figures $n=4$, $n=3$, $n=2$, $n=1$. The letter n designates the number of periods through which the magnetic field goes once around the anode structure; that is, $n=6$ means that the field goes through 6 complete periods or 12 reversals.

However, a magnetron made in accordance with my invention and as illustrated in Figures 3 and 4 suppresses substantially all the undesired modes. A device made according to my invention includes a preferably indirectly heated cathode 20 surrounded by a hollow tubular member or cylinder 21 having radially extending therefrom a plurality of plate-like anode segments or elements 22 and 23, the anode segments 23 being longer longitudinally than the anode segments 22 and being closed at their ends by means of closure members 24 and 25. The cathode is supported by the magnetic inserts 26 and 27 supported from the closure members 24 and 25 by means of the glass bead supporting arrangement 28 and 29. Surrounding the magnetron assembly

is a drum-like cavity resonator comprising the outside cylindrical member 30 closed by means of closure end members 31 and 32, which are sealed vacuum-tight to the member 30. The cathode heater leads 10' and 10'' extend through the closure member. A coupling loop for the outside resonator is shown at 37.

In effect the alternate long and short anode segments 22—23 produce quarterwave concentric line cavity resonators open adjacent the anode-cathode space and closed at the ends remote from this space.

In Figure 5 is shown an unfolded portion of the anode segment arrangement and the magnetic fields established in the coaxial line resonators. In this structure the magnetic flux through a slot is not permitted to divide at the upper and lower ends of the slot and pass through the slot on either side. In the present arrangement nearly all the flux, for example, through the slot 40 is required to pass through the slot 41. This is accomplished by making every other metal vane, for example 23, long enough to make good electrical contact with the top and bottom cover-plates 24 and 25. The vane or fin 22 is made short enough to permit flux lines to pass around the ends as shown in Figure 5. Thus the fin or vane 22 behaves like the inner conductor of the quarterwave transmission line. Although the magnetic flux is not permitted to pass into further adjoining slots, there is still electric coupling between similar elements of the structure and the electric field alternates when the inner circumference is traversed as it is in the conventional mode $n=6$. This improves the coupling since a simultaneous electric and magnetic coupling can reduce the electric coupling between the adjoining slots. The fact that the magnetic flux is not permitted out of adjoining slots means that the undesired modes $n=5$, $n=4$, etc., will not take place.

As pointed out above, another difficulty encountered in magnetron operation comes from the fact that in a perfectly symmetrical cylindrical arrangement of slots as shown in Figure 1 there is another type of degeneracy present, namely rotational degeneracy; that is, the field pattern can be rotated an arbitrary number of slots without changing the operation of the magnetron. In a practical magnetron where the coupling loop is placed in or near any one of the slots and fixes the rotational position of the field pattern, the field pattern will assume that position for which the least magnetic flux associated with one of the degenerate loads will link the load coupling loop. For example, if the magnetron were operated in the $n=5$ mode and the coupling loop were in a slot, then the field pattern would assume a position such that one of the slots containing no magnetic flux would coincide with the slot containing the coupling loop. Thus the magnetron could unload itself. If one coupling loop were used in a magnetron operating, for example, in the $n=5$ mode it would appear to be a very inefficient generator of this mode, but as pointed out a field intensity inside the magnetron for this mode could be very high and the energy would be lost in circulating current losses in the walls of the device. Since the frequencies ω_6 and ω_5 are so close together it is possible for a loaded magnetron to oscillate in the two modes at once and when this is the case and one coupling loop is used only the $n=6$ mode is coupled to the load while the field for the $n=5$ mode is not and can become very high. Again the magnetron would show poor efficiency.

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In accordance with my invention I provide means for reducing the likelihood of the operation in the undesired modes and at the same time not allow the magnetron to readily uncouple itself from the load.

In order to couple out the power from the magnetron I provide at the top and bottom alternately adjacent the short vanes, apertures communicating with the resonator surrounding the magnetron as shown in Figures 3 to 6, inclusive. As shown in Figure 6, I provide a resonator having inner and outer radii a and b respectively and length l . The dimensions of this resonator are so chosen that it will operate in the mode in which the electric field is radial and the magnetic flux lines are circles as shown by arrows H in Figure 6 with centers on the axis of the coaxial cylinders. The wall current and electric field relationships are shown by the lines I and E. The direction of the magnetic flux in the upper half of the resonator is opposed to that in the lower half as shown in the left of Figure 6, as lines H. In selecting the dimensions which make frequencies of this mode coincide with the resonant frequency of this slot, it is advantageous to make the ratio b to a greater than two and thereafter bring the frequencies to the right value by selecting the length l . If this is not done the difference in frequency of the mode under consideration and the next higher frequency may become too small so that this undesirable mode might also be excited. The appropriate dimensions can be readily calculated. The coupling between slots and cylindrical cavity is accomplished by apertures 35 and 36 in the backs of the slots located at opposite ends adjacent the slots. At these places the magnetic field in the slot is largest and is for the most part horizontal as shown in the figure. In the upper part of alternate slots this field will be in the same direction as, and is made to match with, the field in the cylindrical resonator which is also large near the inner wall. In the slots of the lower ends, for example, slots 35, the magnetic field is opposite but matches the field in the lower part of the cylindrical resonator. In this way there is coupling between all slots and the main resonator and the tendency to uncouple, present where coupling loop is in one slot, is materially reduced. The modes $n=5, 4$, etc., are discouraged. The fields are thus made more uniform throughout, thereby facilitating transfer of electric energy to one mode of the high frequency field. The coupling holes are placed so as not to interfere with the large circulating currents at the back of the slots. The coupling of the load to the large cylindrical resonator can be done in a conventional way either by means of a loop, such as 37, or a wave guide.

A magnetron with a considerable number of slots constructed in a manner described above will have very much greater frequency stability and very high efficiency. The possibility of obtaining good efficiency in magnetrons with many slots makes it feasible to use lower anode voltages.

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 depart-

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ing from the scope of my invention as set forth in the appended claims.

What I claim as new is:

1. A device for use at ultra high frequencies and comprising a plurality of adjacent coaxial line resonators, a cavity resonator having a wall closing one end of each of said coaxial line resonators, said cavity resonator having apertures in the closed ends of said coaxial line resonators and communicating with said cavity resonator, and means adjacent the open ends of said coaxial line resonators for energizing said coaxial line resonators.

2. A device for use at ultra high frequencies and comprising a plurality of adjacent coaxial line resonators each closed at one end and open at the other end, a cavity resonator adjacent the closed ends of said coaxial line resonators, the closed ends of said coaxial line resonators having apertures communicating with the interior of said hollow resonator, means adjacent the open ends of said coaxial line resonators for energizing said coaxial line resonators.

3. A device for use at ultra high frequencies and including a cavity resonator and a plurality of coaxial line resonators extending from said cavity resonator and each closed at one end by said cavity resonator, said coaxial line resonators having elongated rectangular-shaped transverse sections, said cavity resonator having apertures communicating with the closed end of said coaxial line resonators, alternate apertures being disposed at opposite sides of the closed ends of said coaxial line resonators, and means including an electron source for supplying electrons adjacent the open ends of said coaxial line resonators for energizing said coaxial line resonators.

4. A device for use at ultra high frequencies and including a cavity resonator and a plurality of coaxial line resonators extending from said cavity resonator and each closed at one end by said cavity resonator, said cavity resonator having apertures communicating with the closed end of said coaxial line resonators, and means including an electron source adjacent said coaxial line resonators for supplying electrons adjacent the open ends of said coaxial line resonators for energizing said coaxial line resonators.

5. A device for use at ultra high frequencies and including a cavity resonator having a shape formed by a surface of revolution, coaxial line resonators extending inwardly from said cavity resonator and radially thereof toward the axis of said resonator, and means positioned axially of said coaxial line resonators for energizing said resonators, said cavity resonator being provided with a plurality of apertures providing communicating passageways between the interior of the cavity resonator and the ends of said coaxial line resonators adjacent said cavity resonator.

6. A device useful at ultra high frequencies and comprising a plurality of quarterwave coaxial line resonators having inner and outer ends, inner ends of said resonators surrounding a space and a cavity resonator surrounding the coaxial line resonators and contacting the outer ends of said coaxial resonators closing the said outer ends of said coaxial line resonators, said cavity resonator having a plurality of apertures providing communicating passageways between said cavity resonator and said coaxial line resonators, and means within the space surrounded by the ends of said coaxial line resonators for energizing said coaxial line resonators.

7. An electron discharge device having a hol-

low drum-like member and an elongated cathode positioned axially of and within said drum-like member, and radially extending plate-like members contacting the wall of said drum-like member and extending radially toward said cathode, alternate plate-like members of shorter axial length than the other plate-like members and spaced at their ends from the ends of the drum-like member whereby a plurality of coaxial line resonators are provided having one end closed and their open ends adjacent said cathode, a tubular member surrounding said drum-like member and coaxial with said drum-like member, and members closing the ends of said drum-like member and said coaxial tubular member providing a cavity resonator, the walls of said drum-like member having apertures providing communicating passageways between the closed ends of said coaxial line resonators and said cavity resonator.

8. An electron discharge device including a pair of concentric coaxial tubular members and flat closure members closing the ends of said tubular members and providing a central hollow chamber surrounded by a second hollow chamber, radially directed plate-like elements extending from the inner wall of the inner tubular member, and a second closure means closing the ends of said radially extending plate-like members, alternate plate-like members being of shorter axial length than the other plate-like members and having spaces between the ends of the shorter plate-like members and said second closure means providing a plurality of radially directed coaxial line resonators having open ends adjacent a central space, and a cathode mounted within said central space, the wall of said inner tubular member having apertures communicating with the closed ends of said coaxial line resonators, and magnetic inserts positioned at opposite ends of the cathode and between the closure members.

9. An electron discharge device including a pair of concentric coaxial tubular members and flat closure members closing the ends of said tubular members and providing a central hollow chamber surrounded by a second hollow chamber, radially directed plate-like elements extending from the inner wall of the inner tubular member, and a second closure means closing the ends of said radially extending plate-like members, alternate plate-like members being of shorter axial length than the other plate-like members and having spaces between the ends of the shorter plate-like members and said second closure means providing a plurality of radially directed coaxial line resonators having open ends adjacent a central space, and a cathode mounted within said central space, the wall of said inner tubular member having apertures providing communicating passageways between the closed ends of said coaxial line resonators and the interior of said cavity resonator, and magnetic inserts positioned at opposite ends of the cathode and between the closure members, a coupling loop extending into said second hollow chamber, and magnetic means linked with said magnetic inserts.

10. An electron discharge device having an elongated cathode, a cylindrically shaped anode member surrounding and coaxial with said cathode and including a plurality of plate-like elements extending radially toward and parallel to said cathode, alternate plate-like elements being of shorter axial length than the other plate-like

elements, conducting means contacting the ends of the longer plate-like elements and enclosing the shorter plate-like elements and the space between said plate-like elements and the cathode, whereby a plurality of coaxial line resonators are formed, one end of each of said resonators being adjacent said cathode, and means providing a magnetic field parallel to said cathode and between said cathode and said plate-like elements.

11. An electron discharge device having an elongated cathode, a cylindrically shaped anode member surrounding and coaxial with said cathode and including a plurality of plate-like elements extending radially toward and parallel to said cathode, alternate plate-like elements being of shorter axial length than the other plate-like elements, flat conducting means contacting the ends of the longer plate-like elements extending above and below the shorter plate-like elements and enclosing the space between said plate-like elements and the cathode, and a conducting member surrounding and enclosing said plate-like elements and contacting the outer edges of said plate-like elements whereby a plurality of coaxial line resonators are formed, the open ends of which are adjacent said cathode, and means adjacent said device for providing a magnetic field parallel to said cathode and between said cathode and said plate-like elements.

12. A device useful at ultra high frequencies and comprising a plurality of quarterwave coaxial line resonators each closed at one end and open at the other end, the open ends of said coaxial line resonators surrounding a space, a hollow cavity resonator surrounding said coaxial line resonators and contacting the closed ends of said coaxial line resonators, each of said coaxial line resonators having an aperture providing a communicating passageway between said hollow cavity resonator and the interior of said coaxial line resonators, and means within the space enclosed by the open ends of said coaxial line resonators for energizing said coaxial line resonators.

13. A device useful at ultra high frequencies and comprising a plurality of quarterwave coaxial line resonators each closed at one end and open at the other end, the open ends of said coaxial line resonators surrounding a space, each of said coaxial line resonators having an elongated rectangular transverse section, a hollow cavity resonator surrounding said coaxial line resonators and contacting the closed ends of said coaxial line resonators, each of said coaxial line resonators having an aperture providing a communicating passageway between said hollow cavity resonator and the interior of said coaxial resonators, apertures in alternate coaxial line resonators being oppositely disposed, and means within the space enclosed by the open ends of said coaxial line resonators for energizing said coaxial line resonators.

14. An electron discharge device having an elongated cathode, a plurality of radially directed rectangularly shaped plate-like members extending radially toward said cathode the ends adjacent said cathode being spaced therefrom, a conducting member coaxial with said cathode and contacting the ends of said plate-like members remote from said cathode, and closure means closing the ends of said conducting member surrounding said plate-like members and enclosing said cathode and said plate-like members, the ends of alternate plate-like members being spaced from said closure means and providing with the

other plate-like members a plurality of radially directed coaxial line resonators having open ends adjacent said cathode, and means adjacent said device for producing a fixed magnetic field parallel to said cathode and between said cathode and said plate-like members.

15. An electron discharge device having an elongated cathode, a plurality of radially directed rectangularly shaped plate-like members extending radially toward said cathode, the ends adjacent said cathode being spaced therefrom, a conducting member coaxial with said cathode and contacting the ends of said plate-like members remote from said cathode, flat disc-like members coaxial with said cathode and closing the ends of said member surrounding said plate like members and enclosing said cathode and said plate-like members, the ends of alternate plate-like members contacting said flat disc-like members and providing with the other plate-like members a plurality of radially directed coaxial line resonators having open ends adjacent said cathode, and means adjacent said device for producing a fixed magnetic field parallel to said cathode and between said cathode and said plate-like members, and a cylindrical cavity resonator surrounding said plate-like members and communicating with said coaxial line resonators.

16. An electron discharge device having an elongated cathode, a plurality of radially directed rectangularly shaped plate-like members extending toward said cathode, the ends adjacent said cathode being spaced therefrom, alternate members being of shorter axial length than the other members, flat disc members at the ends of said plate-like members and contacting the ends of the longer plate-like members and providing with the shorter plate-like members a plurality of radially directed coaxial line resonators having open ends adjacent said cathode, a cylindrical cavity resonator surrounding said cathode and plate-like members and coaxial with said cathode and closing the outer ends of said coaxial line resonators, said cavity resonator having aper-

tures in the wall adjacent said coaxial line resonators whereby the interior of said cavity resonator communicates with the interior of said coaxial line resonators, and means adjacent said device for producing a magnetic field parallel to said cathode and between said cathode and said plate-like members.

17. An electron discharge device including an elongated cathode, a hollow cylindrical member coaxial with and surrounding said cathode, a plurality of radially directed elongated elements extending from said cylindrical member toward said cathode but spaced therefrom, alternate elements being shorter than the other elements in the direction of the axial length of said cathode closure members closing the ends of said hollow cylindrical member and contacting the ends of alternate elements providing a plurality of radially directed coaxial line resonators having open ends adjacent said cathode and closed at the ends remote from said cathode, a second hollow cylindrical member surrounding said first cylindrical member and providing a hollow resonator surrounding said cathode and said radially directed elements, said first cylindrical member having a plurality of apertures providing communicating passageways between the interior of said last resonator and said coaxial line resonators, and means adjacent said device producing a magnetic field between said cathode and said radially directed elements.

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