

March 11, 1958

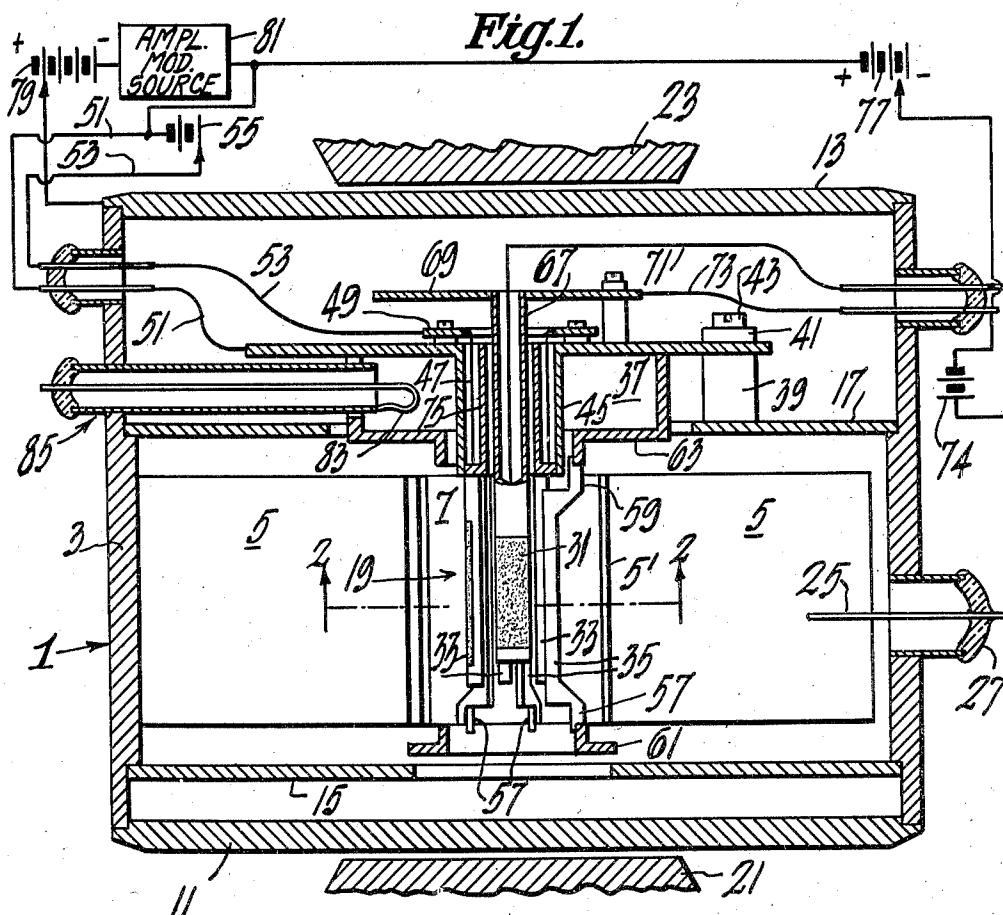
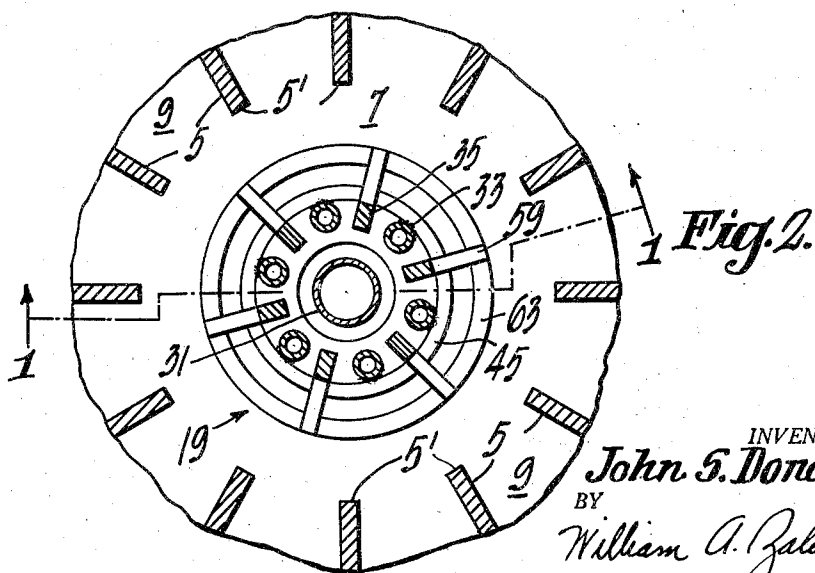
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2,826,719

MAGNETRON

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MAGNETRON

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Fig. 3.

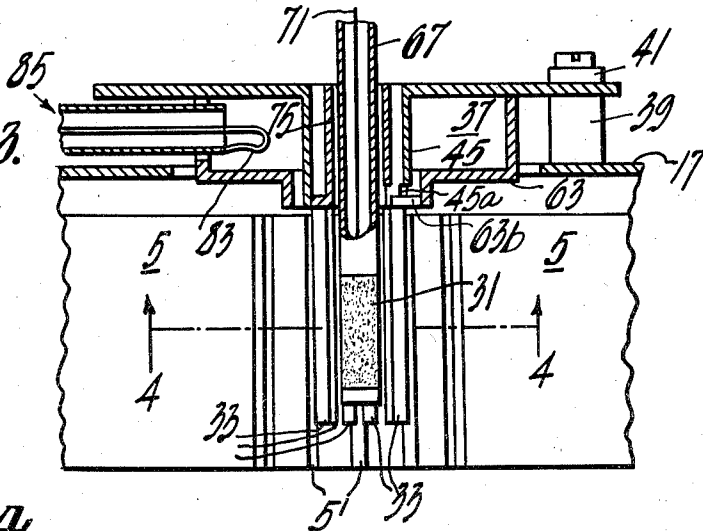


Fig. 4.

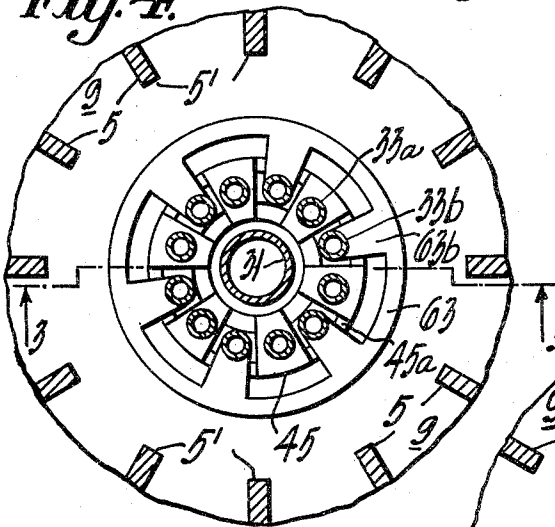
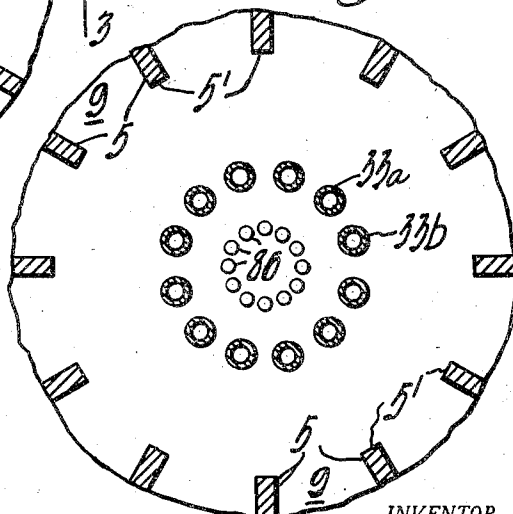


Fig. 5.



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MAGNETRON

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This invention relates to magnetrons, and particularly to amplitude-modulated magnetrons with means for locking in the oscillating frequency during variation in the power output. The invention is particularly useful in providing frequency control of ultra-high-frequency magnetrons, such as the multi-cavity and interdigital single-cavity types.

A conventional multi-cavity magnetron comprises an anode structure including an annular array of anode segments or elements connected by a resonant anode circuit made up of cavity resonators, a central cathode coaxially mounted within the anode block, a housing or envelope enclosing the cathode and anode, means for establishing a constant axial magnetic field, means for applying a direct-current voltage between the cathode and the anode, and means for coupling an output load to one of the cavity resonators. In operation, electrons from the cathode are caused by the direct-current electric and magnetic fields to follow curved paths past the gaps between anode elements and induce high frequency voltages between the anode elements, thus exciting oscillations in the anode cavity resonators. The cavity resonator circuit is capable of oscillating in a plurality of different modes each having a different resonant frequency. Usually it is desired that the circuit oscillate in the so-called " π -mode," wherein adjacent anode elements are π radians, or 180° , out of phase at every instant. Magnetrons usually have alternate elements "strapped" together to favor operation in the π -mode.

The cavity resonator magnetron is capable of supplying high power at ultra-high-frequencies with high efficiency. Its geometry and construction are simple and straightforward, making the tube very attractive for application in certain U. H. F. systems. However, the systems which have found a place for the cavity resonator magnetron are principally pulse and continuous-wave systems. It is a difficult tube to incorporate into an amplitude-modulation system because of its tendency to shift its operating frequency with changes in magnetron current or load impedance. The undesired variation of magnetron frequency as a function of magnetron current is called "pushing." The undesired variation in frequency as a result of variation in load impedance is called "pulling." The angular frequency of an operating cavity resonator magnetron can be written:

$$\omega = \omega_0 + \omega_e - \omega_L$$

where ω_0 = the angular resonant frequency of the unloaded, non-operating anode circuit

ω_e = the "pushing" angular frequency shift due to the presence of the electron space charge, and

ω_L = the "pulling" angular frequency shift, due to the coupling of the external load to the anode circuit

Several systems have been demonstrated for utilizing a cavity resonator magnetron in an amplitude-modulation transmitter using injection-locking apparatus associated with the output line or otherwise coupled to the cavity

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resonator anode circuit of the magnetron to eliminate frequency variation due to amplitude-modulation or variation in load impedance.

It has been suggested that a magnetron be provided with a series of radio frequency control electrodes around the usual central cathode for establishing radio frequency control electric fields in the part of the interaction space near the cathode to lock-in the oscillating frequency at a desired value during variation in power output. In this arrangement, the two sets of alternate control electrodes are connected to the two terminals of a low power radio frequency source of standard frequency. Experiments proved that a magnetron could be locked-in with this arrangement of control electrodes. However, a disadvantage of this arrangement is that, since the control electrodes are in the path of the electrons from the cathode to the anode, they cause a deteriorating influence on the performance of the tube in that they interfere somewhat with the setting up of the space-charge configuration near the cathode that is vitally necessary for effective control of the oscillating frequency. Therefore, it has also been suggested that, instead of providing radio frequency control electrodes between the cathode and the anode, the cathode itself be divided into an annular series of cathode elements and that the lock-in voltage source be connected to alternate elements to produce radio frequency control voltages between adjacent cathode elements. The present invention is an improvement over the two arrangements just described, and in some respects combines certain features thereof.

The principal object of the present invention is to provide more efficient means for stabilizing the oscillating frequency of magnetrons during variation in power output.

In accordance with the present invention, there is provided, in effect, a magnetron within a magnetron, or a high power magnetron stabilized in frequency by a low power magnetron built into the envelope of the larger magnetron. In one embodiment of the invention, a central cathode is surrounded by an annular series of control electrodes, which serve as the anode of the low power control magnetron, at least part of the control electrodes are electron-emissive and serve as the cathode for the surrounding main anode of the high power magnetron. The two sets of alternate control electrodes are connected to the terminals of a tuned circuit, which may be a cavity resonator within the tube envelope. The main magnetron may be stabilized in frequency by the action of the control magnetron and its tuned circuit alone, or the control magnetron and its circuit may be also stabilized by connection to an external radio frequency source of standard frequency. In a modification of the invention, the central cathode may be divided into an annular series of cathode elements connected to an external radio frequency source to serve as frequency control elements. This series of cathode elements may be provided with a central cathode, to form a still lower power magnetron to control the frequency of the low power magnetron.

In the accompanying drawing:

Fig. 1 is an axial sectional view, taken on line 1—1 of Fig. 2, of a vane-type multi-cavity magnetron embodying the present invention;

Fig. 2 is an enlarged fragmentary transverse sectional view taken on line 2—2 of Fig. 1;

Fig. 3 is a fragmentary axial sectional view, taken on line 3—3 of Fig. 4, of a modification of Fig. 1;

Fig. 4 is an enlarged fragmentary transverse sectional view taken on line 4—4 of Fig. 3; and

Fig. 5 is a view similar to Fig. 4 of a further modification.

Referring now to the drawing, in detail, Figs. 1 and 2 show an embodiment of the invention incorporated in a vane-type multi-cavity magnetron designed for about 1

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kw. output at a frequency of about 1000 mc. The tube structure shown comprises a main anode structure 1 including an outer cylindrical wall 3 which serves also as part of the vacuum envelope of the tube, within which are mounted in an annular array a plurality of radially extending anode vanes 5 which terminate at their inner ends or edges 5' on the surface of a cylindrical electron interaction space 7. The vanes 5 and the portions of the wall 3 between the vanes provide twelve cavity resonators 9 coupled between the inner ends 5' of the vanes 5, which inner end 5' serve as anode elements of a high power magnetron. The ends of the wall 3 are hermetically closed by plates 11 and 13 which complete the vacuum envelope of the tube. The anode may be provided with conventional strapping means for favoring π -mode operation and/or tuning means for changing the resonant frequency of the resonator system (not shown). Apertured end plates 15 and 17 are mounted on the wall 3 adjacent to the vanes 5 to serve as end-plates for the resonators 9. A main cathode for the main anode 1, generally indicated by the reference numeral 19, is axially mounted in the interaction space 7. An axial magnetic field is provided within the interaction space 7 by suitable means, such as the magnet poles 21 and 23. Radio frequency oscillations, generated on the anode 1 in a manner well known in the art, may be extracted from the tube by means of a coupling loop 25 and output line 27 coupled to one of the resonators 9. The structure described thus far is conventional. In normal use to generate amplitude modulated radio frequency energy, the power output of the tube would be varied by varying the anode-cathode voltage in accordance with a modulating wave. However, this would produce changes in oscillating frequency due to the phenomenon of "pushing," as described above. If the output load impedance is varied, changes in frequency due to "pulling" occur.

In accordance with the invention, the main cathode 19 is divided into an annular series of electrode elements, one for each anode element 5', which not only provide electron emission for the main auxiliary anode elements 5' but also serve as auxiliary anode elements for a central auxiliary cathode 31. In Figs. 1 and 2, only the alternate electrode elements are electron-emissive cathode elements 33, the intermediate electrode elements being non-emissive control elements 35. The main cathode 19 is shown mounted on a coaxial cavity resonator 37, which in turn is mounted by insulators 39 and 41 and screws 43 on the plate 17. The cathode elements 33, which may be coated only on the side facing the nearest anode elements 5' as shown, are mounted at one end on the inner conductor 45 of resonator 37. Each cathode element 33 may be indirectly heated by a conventional heater element (not shown) within the element, connected at one end to the element and at the other end by a heater lead 47 to a heater terminal ring 49 insulatedly mounted on the resonator 37. Heater current may be fed to the heater means of cathode lead 51 and heater lead 53 extending through the envelope and connected to a heater source 55. The non-emissive control elements 35 are provided at the ends with offset portions 57 and 59 connected, respectively, to a ring 61 and the outer conductor 63 of the resonator 37. The auxiliary cathode 31 is axially mounted in the space defined by the electrode elements 33 and 35, as by means of a tubular extension 67 and a support plate 69 mounted in insulated relation on the resonator 37. The cathode 31 is provided with an internal heater (not shown) and leads 71 and 73 extending through the envelope for connection to a heater voltage source 74. Preferably, the inner conductor 45 is provided with a tubular re-entrant extension 75 for shielding the heater leads 47 from the cathode extension 67, as shown.

In operation, the main anode 1 and main cathode 19 constitute a first or main magnetron for generating and delivering relatively high power radio frequency energy to a load. The cathode elements 33 and control elements

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35 constitute the anode of a low power second or auxiliary magnetron having auxiliary cathode 31 as the cathode for controlling or stabilizing the oscillating frequency of the first or high power magnetron. In operation of the magnetron as an amplitude-modulated oscillator, a direct-current voltage source 79 is connected between the resonator 37 and the anode 1, to establish the cathode-anode voltage on the high power magnetron. A direct-current voltage source 77 is connected between the lead 73 for the auxiliary cathode 31 and the lead 51 for the resonator 37, to establish the cathode-anode voltage on the control magnetron. The magnetron may be amplitude-modulated by connecting an amplitude modulated source 81 in series with the source 79 to vary the cathode-anode voltage of the power magnetron. Instead, the cathode elements 33 and control elements 35 may be insulated from each other and the amplitude-modulating signal be applied thereto as a low frequency voltage therebetween.

The resonator 37 is so connected to the electrode elements 33 and 35 as to cause π -mode operation of the control magnetron in which adjacent elements are 180° out of phase at any instant. The control magnetron generates radio frequency oscillations on the main cathode 19, by establishing control voltages of desired frequency between adjacent electrode elements 33 and 35, which in turn stabilize the oscillating frequency of the main or power magnetron at that frequency, or some harmonic frequency. By use of this arrangement the frequency of a relatively large magnetron delivering power to a load can be stabilized to a great extent during variation in power output without the necessity of an external radio frequency source. If desired, means can be provided for tuning the resonator 37 to different frequencies.

In some cases, the amount of "pushing" or "pulling" may be so great that the frequency cannot be stabilized sufficiently by the operation of the independent control magnetron by itself. In such cases, the control magnetron may itself be stabilized, as by coupling the resonator 37, by means of a coupling loop 83 and transmission line 85, to an external radio frequency source (not shown).

Figs. 3 and 4 show a modification of Figs. 1 and 2 in which all of the control elements of the magnetron are electron emissive cathode elements 33a and 33b constituting the main cathode. Alternate cathode elements 33a are mounted on the inner conductor 45 of resonator 37 as in Figs. 1 and 2. The intermediate cathode elements 33b are mounted on arms 63b which extend inwardly from the outer conductor 63 through slots 45a in the inner conductor 45. Thus, the two sets of alternate elements 33 are connected to the two terminals of the resonators, so that adjacent elements will operate 180° out of phase. The remaining structure and the method of operation of Figs. 3 and 4 are the same as in Figs. 1 and 2, except that it would not be practical to amplitude modulate the magnetron of Figs. 3 and 4 by applying the amplitude modulating signal between adjacent cathode elements.

Fig. 5 shows a modification of Figs. 3 and 4 in which the auxiliary inner cathode is also divided into an annular series of cathode elements 86, which may be similar to but smaller than the elements 33 of Figs. 1-4. The cathode elements 33a and 33b constituting the main cathode of the power magnetron may be mounted at one end (not shown) in the same manner as in Figs. 3 and 4. The inner cathode elements 86 may be mounted by means (not shown) similar to the mounting means for cathode elements 33a and 33b, which may include a second control resonator resonant at a frequency that is a harmonic of the operating frequency. In operation of Fig. 5, radio-frequency control voltages are applied by suitable means (not shown) between adjacent cathode elements 86 to stabilize the oscillating frequency of the control magnetron, which in turn stabilizes the oscillat-

ing frequency of the high power magnetron. In this arrangement the resonator 37 would not be separately excited.

It will be understood that the cathode elements 86 of Fig. 5 could also be used in place of the auxiliary cathode 31 in the embodiment shown in Figs. 1 and 2. Moreover, the elements 86 could be alternately emitting and non-emitting, like the elements 33 and 35 of Figs. 1 and 2.

What is claimed is:

1. A magnetron structure including: a main magnetron comprising a main anode, and means including a main cathode adjacent to said main anode for generating radio frequency oscillations on said anode; and an auxiliary magnetron comprising said main cathode as an auxiliary anode, and means including an auxiliary cathode adjacent to said main cathode on the side thereof opposite to said main anode for generating radio frequency oscillations on said main cathode, to control said oscillations on said main anode.

2. A magnetron structure including: a main magnetron comprising a hollow cylindrical main anode including at least one cavity resonator, and means including a hollow cylindrical array of electrode elements, at least part of which are electron-emissive, coaxially mounted within said main anode; and an auxiliary magnetron comprising said array of electrode elements as an auxiliary anode, and means including an auxiliary cathode coaxially mounted within said array of electrode elements.

3. A magnetron structure as in claim 2, wherein said auxiliary cathode comprises a hollow cylindrical array of electrode elements, at least part of which are electron-emissive.

4. A magnetron comprising: a main anode, a main cathode adjacent to said anode, means for establishing a magnetic field normal to the paths of electrons from said cathode to said anode, means for establishing a first direct-current potential difference between said cathode and said anode, for generating radio frequency oscillations on said main anode, and means for varying the amplitude of said oscillations; and an auxiliary cathode adjacent to said main cathode and means for establishing a second direct-current potential difference between said auxiliary cathode and said main cathode, for generating radio frequency oscillations on said main cathode to stabilize the frequency of said oscillations on said main anode during said amplitude variation; said main cathode being located between said auxiliary cathode and said main anode.

5. A magnetron comprising: a hollow main anode, a hollow main cathode mounted within said anode, means for establishing an axial magnetic field within said anode, and means for establishing a first direct-current potential difference between said cathode and said anode, for generating radio frequency oscillations on said anode; and an auxiliary cathode mounted within said main cathode and means for establishing a second direct-current potential difference between said auxiliary cathode and said main cathode, for generating radio frequency oscillations on said main cathode to control said oscillations on said main anode.

6. A magnetron including a hollow main anode comprising an annular array of spaced main anode elements defining an interaction space, a resonant anode circuit coupled between adjacent anode elements, means for establishing an axial magnetic field within said space, an auxiliary cathode coaxially mounted in said space, and an anode for said auxiliary cathode comprising an annular array of spaced auxiliary anode elements interposed between said auxiliary cathode and said main anode ele-

ments, at least part of said auxiliary anode elements being electron-emissive and adapted to serve as the cathode for said main anode.

7. A magnetron as in claim 6, wherein said anode circuit comprises at least one cavity resonator connected between adjacent main anode elements.

8. A magnetron as in claim 6, wherein the number of said auxiliary anode elements is the same as the number of main anode elements.

9. A magnetron as in claim 8, wherein each of said auxiliary anode elements is located opposite the midpoint of the gap between two adjacent main anode elements to minimize electrostatic coupling therebetween.

10. A magnetron including a hollow anode comprising an annular array of spaced anode elements defining an interaction space, a resonant anode circuit coupled between adjacent anode elements, means for establishing an axial magnetic field within said space, a cathode coaxially mounted in said space, an electrode structure comprising an annular array of spaced control elements interposed between said cathode and said anode elements, at least part of said control elements being electron-emissive, and a resonant circuit coupled between adjacent control elements.

11. A magnetron as in claim 10, wherein said resonant circuit comprises a cavity resonator located within the vacuum envelope of the magnetron.

12. A magnetron as in claim 11, including means for coupling said cavity resonator to an external source of radio frequency control voltage.

13. A magnetron including a hollow anode comprising an annular array of spaced anode elements defining an interaction space, a resonant anode circuit coupled between adjacent anode elements, means for establishing an axial magnetic field within said space, a cathode coaxially mounted in said space, and an electrode structure comprising an annular array of spaced control elements spaced interposed between said cathode and said anode elements, alternate ones of said control elements being electron-emissive and the other control elements being non-emissive.

14. A magnetron including a hollow main anode comprising an annular array of spaced anode elements defining an interaction space, a resonant anode circuit coupled between said adjacent anode elements, means for establishing an axial magnetic field within said space, an auxiliary cathode coaxially mounted in said space, and an electrode structure comprising an annular array of spaced electron-emissive control elements interposed between said auxiliary cathode and said anode elements and adapted to serve as the cathode for said main anode and also as the anode for said auxiliary cathode.

15. A magnetron as in claim 6, wherein said auxiliary cathode is a single cylindrical electron-emissive element.

16. A magnetron as in claim 6, wherein said auxiliary cathode comprises an annular array of elements, at least part of which are electron-emissive, adapted to be excited to establish radio frequency control voltages between adjacent cathode elements for locking-in the frequency of said magnetron.

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