

March 21, 1961

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MAGNETRON

2,976,458

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2 Sheets-Sheet 1

FIG. 1

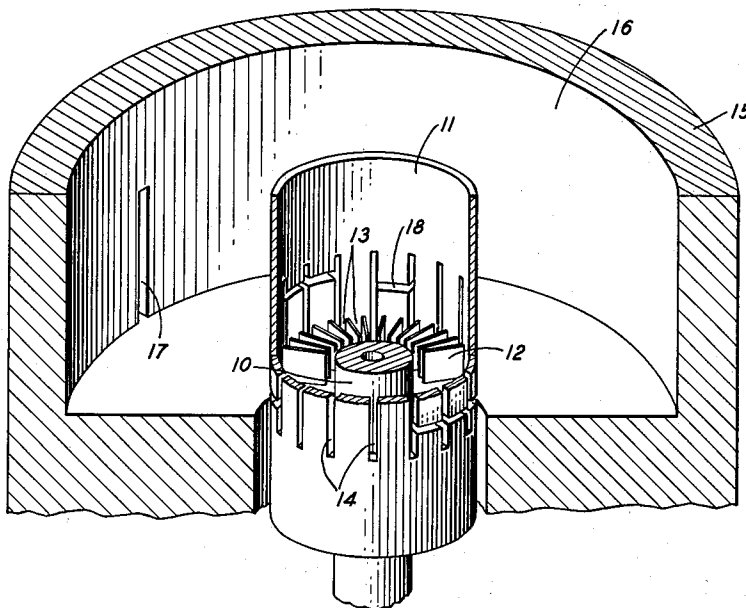
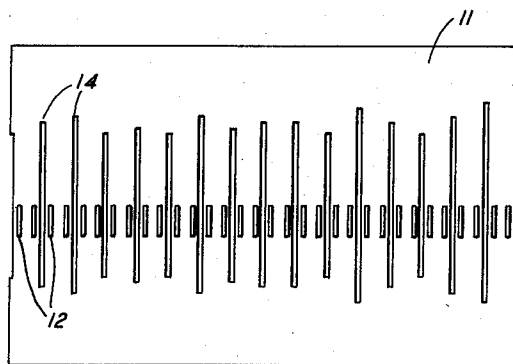


FIG. 4



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FIG. 2

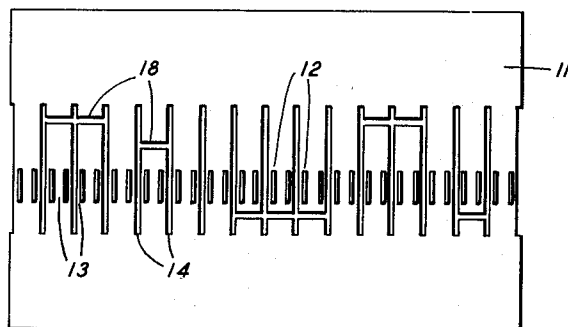


FIG. 3

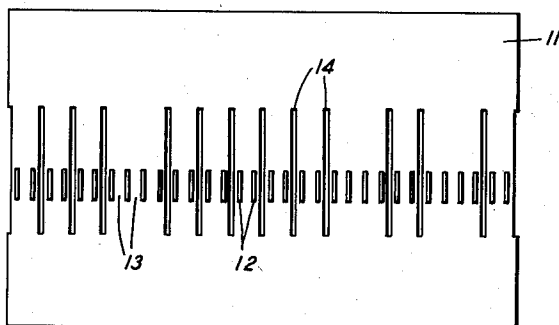
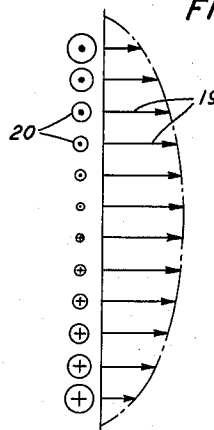


FIG. 5



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2,976,458

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12 Claims. (Cl. 315—39.77)

This invention relates to electron discharge devices and, more particularly, to magnetron type devices.

In R. J. Collier and J. Feinstein Patent 2,854,603, issued September 30, 1958, there is disclosed a unique coaxial magnetron structure which comprises an inner and outer resonant system. The inner resonant system includes a cylindrical anode together with a plurality of anode vanes radially extending inwardly therefrom. These vanes define a circumferential array of inner, or anode, cavity resonators. An outer cavity resonator is defined between an outer wall and the cylindrical anode. The two systems are coupled by a circumferential array of uniformly spaced slots through the cylindrical anode which connect the outer resonant system with alternate ones of the anode cavity resonators. Advantageously the slots are made to extend beyond the limits of the anode resonators and thereby permit suitable damping elements to be positioned in close proximity to the ends thereof for removing or suppressing any undesirable electric modes. The inner resonant system is designed to oscillate in the π mode, while the outer system is designed to oscillate in the TE_{011} mode, the two systems being effectively locked together by means of coupling slots previously described.

Such a structural arrangement overcomes many disadvantages inherent in magnetrons of prior conventional design. More particularly, the coaxial magnetron arrangement permits the realization of substantial high frequency stability and efficiency simultaneously under varying input and load conditions. Since these objectives are not consistent, an inadequate compromise between efficiency and stability, dependent upon the particular application required, has been necessitated heretofore with conventional magnetrons. Increasing the loading of a conventional magnetron usually increases its electronic efficiency. Heavy loading, however, means close coupling between the load and the magnetron, making the magnetron more sensitive to load changes or, in other words, reducing the frequency stability. Such reduced stability may cause the magnetron to break into oscillation in an undesired mode, such operation being referred to as moding.

The aforementioned coaxial cavity magnetron appreciably solves these problems through the use of the outer "output" cavity. Because the inner resonant system is isolated from the output coupling means, changes in load have very little effect thereon.

Similarly, a structural arrangement as disclosed in the aforementioned Collier et al. patent substantially overcomes the problem of interfering modes without requiring straps. This is accomplished in the coaxial cavity magnetron partly by the specific geometry of the inner and outer resonant systems and also by the manner in which the undesired modes of this type are effectively loaded. The elimination of straps is a distinct advantage in that in structures built to produce very high frequencies straps become quite small and mechanically difficult to incorporate into the magnetron anode structure. More-

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over, the small spacing results in excessive copper loss and therefore lower magnetron efficiency.

As recalled from the description of the aforementioned coaxial cavity magnetron, coupling between the two resonant systems therein is accomplished by slots communicating with only alternate ones of the inner cavity resonators. This type of coupling basically results in the inner system by itself being capable of acting as an unstrapped rising sun magnetron. This is due to energy storage in each individual slot, giving rise to an electric field and a corresponding magnetic field. By uniform periodic coupling action between successive slots around the anode periphery, due to their symmetrical arrangement, these fields are propagated to produce an interfering rising sun mode hereinafter referred to as a slot mode. The deleterious effect of interaction of such a slot mode with the electron beam of the magnetron may be so serious as to cause moding. The coaxial magnetron removes certain of these slot modes, however, through the use of damping elements at the ends of the coupling slots which absorb energy stored therein. These damping elements have been found to be effective in removing specific slot modes, but they have not proven completely satisfactory in removing all of the interfering slot modes, mainly because the respective frequencies of such modes vary over a considerably wide range.

It is, therefore, an object of this invention to suppress interaction of undesirable slot modes with the electron beam of a coaxial cavity magnetron.

It is another object of this invention to obviate the necessity of using attenuating elements in the oscillatory system of a coaxial cavity magnetron.

These and other objects of this invention are attained in one specific embodiment of the invention wherein a magnetron comprises an inner and an outer resonant system. The inner resonant system comprises a plurality of inner resonant cavities defined by a plurality of anode vanes extending inwardly from a cylindrical anode. The outer resonant system surrounds the cylindrical anode and is coupled to alternate ones of the inner resonant cavities through coupling slots in the cylindrical anode. As taught in the aforementioned patent, the anode vanes are arranged to be approximately one-quarter wavelength long at the frequency of the outer cavity resonator. This assures that the slots present a low impedance to the currents of the desired mode of the outer cavity resonator whether it be oscillating at the same or a different frequency from that of the inner resonant system.

In accordance with one aspect of this invention, non-uniformities are introduced into the slot system which couples the inner and outer resonant cavities. Such non-uniformities may be employed to disrupt the propagation of an electromagnetic slot mode about the periphery of the cylindrical anode by weakening the coupling between adjacent slots, by altering the phase shift between adjacent slots, by altering the self-resonant frequency of successive slots, or by a combination of any of the foregoing. By disrupting or "breaking up" the pattern of an undesired slot mode, interaction of the slot mode with the electron beam is suppressed and therefore interference of the slot mode with the desired operation of the magnetron is substantially prohibited.

It is a feature of one embodiment of this invention that transverse slots be introduced into the cylindrical anode of a coaxial cavity magnetron to connect certain coupling slots therein. In accordance with this feature of the invention, the electrical energy stored in the connected slots is also effectively connected such that the phase shift between each coupling slot of the group is substantially zero. As pointed out above, a slot mode is propagated by magnetic coupling between adjacent coupling slots, a given slot mode being defined by the

phase shift between adjacent slots of its field pattern. Hence a slot mode which is propagating along the periphery of the cylindrical anode with some certain discrete phase shift between each coupling slot is disrupted when it encounters a group of slots which represents a substantially zero phase shift.

It is a feature of another embodiment of this invention that the coupling slots of a coaxial cavity magnetron be of varying length. In accordance with this feature of the invention, the quantity of energy stored in various slots can be varied in accordance with the length of the slots, as will be more fully discussed hereinafter.

This produces a different resonant frequency in the various slots, thereby minimizing the coupling therebetween and, hence, disrupting the propagation of any spurious slot mode.

It is a feature of still another embodiment of this invention that certain coupling slots normally present in a coaxial cavity magnetron be omitted. In accordance with this feature of the invention, if a sufficient distance is provided between certain successive slots, magnetic coupling therebetween will be so weak as to impede greatly the propagation of a slot mode around the periphery of the cylindrical anode.

It is a feature of all of the embodiments of the present invention that the aforementioned non-uniformities re-occur along the entire periphery of a cylindrical anode in a coaxial cavity magnetron such that the disruptive effects on a propagating slot mode, as herein before described, be so multiplied as to prevent substantially the production of a uniform slot mode pattern around the periphery of the anode and hence prevent undesirable interfering interaction with the electron beam of the magnetron.

A complete understanding of this invention and of the foregoing and other features thereof may be gained from a consideration of the following detailed description and the accompanying drawings, in which:

Fig. 1 is a perspective sectional view of a magnetron illustrative of one embodiment of this invention;

Fig. 2 is a development of the cylindrical anode of Fig. 1;

Fig. 3 is a development of a cylindrical anode of a coaxial cavity magnetron illustrative of another embodiment of this invention;

Fig. 4 is a development of a cylindrical anode of a coaxial cavity magnetron illustrative of still another embodiment of this invention; and

Fig. 5 is a diagram of the electric and magnetic fields which are produced within a slot due to an alternating voltage across the sides thereof.

Referring now more particularly to the drawings, the specific illustrative embodiment of this invention depicted in Fig. 1 comprises a coaxial cavity magnetron having a cylindrical cathode 10. Surrounding the cathode 10 is a cylindrical anode 11 having a plurality of vanes 12 which extend radially inwardly therefrom. The planes of anode vanes 12 are parallel with the axis of cylindrical anode 11 and define an array of inner cavity resonators 13. Coupling slots 14 extend through cylindrical anode 11 and are centered between adjacent anode vanes 12. These slots communicate with alternate ones of the cavity resonators 13.

Surrounding the cylindrical anode 11 is an outer wall member 15 which, together with the cylindrical anode 11, defines an outer cavity resonator 16. Extending through wall member 15 such as to communicate with cavity resonator 16 is an output coupling slot 17. For purposes of simplicity, the envelope, output wave guide means, tuning means, input means, and various other elements of the coaxial cavity magnetron have not been shown. Such elements and their functions are described in the aforementioned patent and are known in the art.

In a device of this type, the outer cavity resonator

16 is designed to support the TE_{011} mode, while the inner cavity resonators 13 are designed to support the π mode of oscillation. Anode vanes 12 are advantageously one-quarter wavelength long at the TE_{011} mode frequency range of oscillation such that the high impedance at the inner ends thereof is reflected at the base as a low impedance, thus causing TE_{011} mode currents to flow through coupling slots 14 and lock the two resonant systems together, as described in the aforementioned patent. Coupling slots 14 extend considerably beyond the limits of anode vanes 12 so as to prevent the anode currents in the region of vanes 12 from flowing around the slots.

According to one aspect of this invention, certain coupling slots 14 are connected by transverse slots 18 as best seen in Fig. 2. These transverse slots effectively provide a short circuit between the coupling slots so connected insofar as energy stored therein is concerned. Such direct coupling results in a substantially zero phase shift between slots 14 so connected, rather than a certain discrete phase shift between slots that are coupled solely by induction.

It may be appreciated that any electromagnetic mode is defined by a certain periodic phase shift. When random non-uniformities are introduced into the coupling system of a coaxial cavity magnetron, as described above, which alter the periodicity of this phase shift, a uniform slot mode is prevented from propagating around the anode periphery. When one considers the slot modes as standing waves, they can be considered to have been "broken up" into a series, each existing along only a small portion of the anode periphery and therefore being prohibited from effectively interacting with the electron beam.

Fig. 3 illustrates another embodiment of this invention wherein certain coupling slots 14 of a conventional coaxial cavity magnetron are omitted. In this embodiment the distance between certain adjacent coupling slots in the array is relatively great. Since the propagation of a slot mode depends upon magnetic coupling between adjacent slots, such propagation may be eliminated by the absence of a slot. Even if coupling between displaced slots does exist, it will be so weak that that periodicity of the slot mode propagated thereby will be seriously disrupted. With several slots randomly omitted as shown, any slot mode pattern around the anode 11 will be effectively broken up.

Fig. 4 is illustrative of another embodiment of the invention wherein the slots 14 are of randomly varying length. The effect of such asymmetries in the coupling system of a coaxial cavity magnetron can be appreciated from a consideration of the energy stored in each slot.

If an alternating voltage is placed across the middle of any slot in a conductor, the middle portion of the slot may be considered to be a capacitor. Such voltage, of course, tends to produce a current flowing around the ends of the slot, giving rise to inductive energy storage at the slot ends. A maximum capacitive storage, therefore, occurs at the center of the slot, with such storage uniformly tapering to zero at the ends thereof, while a maximum inductive storage occurs at the slot ends and uniformly tapers to zero at the center. The capacitive energy storage produces an electric field proportional thereto as designated by arrows 19 of Fig. 5. The length of these arrows indicates the strength of the electric field at various distances along the length of a slot. The magnetic field which is produced by the inductive energy storage is perpendicular to the electric field and is represented by circles 20. Dotted circles represent flux lines leaving the paper, while crossed circles represent flux lines entering the paper. The size of the circles indicates the strength of the magnetic field at various distances along the length of a slot. Due to capacitive and inductive storage, the slot considered is essentially a resonator. It is clear from a study of Fig.

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5 that the length of the slot represents half a wavelength at its self-resonant frequency.

In the coaxial cavity magnetron of the aforementioned patent, all of the slots exhibited are of the same self-resonant frequency and, therefore, strong coupling exists between adjacent slots which permits the formation of a slot mode around the anode periphery. In view of the preceding discussion, it is clear that by changing the length of a slot 14 one may produce a different self-resonant frequency therein. Because of the different self-resonant frequencies of adjacent slots in the embodiment shown in Fig. 4, coupling therebetween is very weak, and the propagation of any spurious slot mode is thereby seriously disrupted.

As can be understood from the above-described arrangements, the introduction of any of the disclosed non-uniformities into the coupling slot system of a coaxial cavity magnetron tends to disrupt the propagation of electromagnetic slot modes around the cylindrical anode thereof. By introducing such non-uniformities in a random fashion about the entire periphery of a cylindrical anode this disruptive effect is multiplied, thereby so suppressing the production of a uniform peripheral slot mode as to effectively prohibit deleterious interaction with the electron beam.

In the aforementioned patent dissipative rings were positioned near the ends of the slots for slot mode suppression. The instant invention may be used without such dissipative rings in many cases since the non-uniformities in the coupling system may provide sufficient slot mode suppression, or it may be used in conjunction therewith, when desired, to provide even more effective suppression.

It is to be understood that the above-described arrangements are merely illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A magnetron comprising a wall member, a plurality of anode vanes positioned on said wall member and defining anode cavity resonators, a cathode positioned adjacent said vanes, means including said wall member defining an output cavity resonator, means comprising an array of slots extending through said wall member for coupling certain ones of said anode cavity resonators to said output cavity resonator, said slots giving rise to spurious slot modes, and means for suppressing said spurious slot modes comprising array non-uniformities in said array of slots.

2. A magnetron comprising a wall member, a plurality of anode vanes positioned on said wall member and defining anode cavity resonators, a cathode positioned adjacent said vanes, means including said wall member defining an output cavity resonator, and means comprising an array of slots extending through said wall member for coupling certain ones of said anode cavity resonators to said output cavity resonator, the spacing between certain successive ones of said slots being greater than the spacing between certain other successive ones of said slots.

3. A magnetron comprising a wall member, a plurality of anode vanes positioned on said wall member and defining anode cavity resonators, a cathode positioned adjacent said vanes, means including said wall member defining an output cavity resonator, and means comprising an array of slots extending through said wall member for coupling certain ones of said anode cavity resonators to said output cavity resonator, certain ones of said slots being interconnected by other slots transverse thereto.

4. A magnetron comprising a cylindrical wall member, a plurality of anode vanes positioned on said member and defining anode cavity resonators, a cathode positioned adjacent said vanes, means including said

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cylindrical wall member defining an output cavity resonator, means comprising an array of elongated slots extending through said cylindrical wall member and parallel with the axis thereof for coupling certain ones of said anode cavity resonators to said output cavity resonator, said slots giving rise to spurious slot modes, and means for suppressing the propagation of spurious slot modes along the periphery of said cylindrical wall member comprising other elongated slots extending through said cylindrical wall, said other elongated slots each interconnecting a plurality of said elongated coupling slots.

5. A magnetron comprising a cylindrical cathode, a cylindrical anode surrounding said cathode and coaxial therewith, an outer wall member surrounding said cylindrical anode and defining therewith an output cavity resonator, a plurality of vanes extending radially inwardly from said cylindrical anode and defining a circular array of anode cavity resonators, the planes of each of said vanes being parallel with the axis of said cylindrical anode, a coupling system comprising an array of slots extending through said cylindrical anode and parallel with the axis thereof for coupling certain ones of said anode cavity resonators to said output cavity resonator, said slots giving rise to spurious slot modes, and means for suppressing the propagation of spurious slot modes around the entire periphery of said anode comprising non-uniformities in said coupling system.

6. A magnetron comprising a cylindrical cathode, a cylindrical anode surrounding said cathode and coaxial therewith, an outer wall member surrounding said cylindrical anode and defining therewith an output cavity resonator, a plurality of vanes extending radially inwardly from said cylindrical anode and defining a circular array of anode cavity resonators, the planes of each of said vanes being parallel with the axis of said cylindrical anode, and a coupling system comprising an array of slots extending through said cylindrical anode and parallel with the axis thereof for coupling certain ones of said anode cavity resonators to said output cavity resonator, a majority of pairs of successive ones of said slots having therebetween two of said vanes, and a minority of pairs of successive ones of said slots having therebetween four of said vanes.

7. In combination an inner resonant system comprising a cylindrical wall plate having a plurality of vanes equally spaced thereon and defining individual cavity resonators, an outer resonant system directly adjacent said inner resonant system and comprising a single resonant cavity including said wall plate, means for coupling said inner and outer resonant systems comprising a plurality of slots extending through said wall plate intermediate said vanes, and means for suppressing spurious modes resulting from energy storage in said slots comprising circumferentially distributed non-uniformities in the resonant characteristics of said slots.

8. The combination is set forth in claim 7 wherein said means for suppressing spurious modes comprises transverse slot interconnecting certain of said coupling slots, said transverse slots being removed from the location of said vanes.

9. The combination as set forth in claim 7 wherein said means for suppression spurious modes comprises non-uniform dimensioning of said coupling slots.

10. The combination as set forth in claim 9 wherein certain of said slots are larger than other of said slots.

11. A magnetron comprising a wall member, a plurality of anode vanes positioned on said wall member and defining anode cavity resonators, a cathode positioned adjacent said vanes, means including said wall member defining an output cavity resonator, and means comprising an array of slots extending through said wall member for coupling certain of said anode cavity resonators with said output cavity, adjacent slots having different resonant characteristics in at least part of said array for suppressing spurious slot modes.

12. A magnetron comprising a cylindrical wall member, a plurality of anode vanes positioned on said wall member and defining anode cavity resonators, a cathode positioned adjacent said vanes, means including said wall member defining an output cavity resonator, and means comprising a circumferential array of slots extending through said wall member for coupling certain ones of said anode cavity resonators with said output cavity, said array of slots having different resonant characteristics dis-

tributed non-uniformly about the circumference of said wall member for suppressing spurious slot modes.

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