

May 8, 1962

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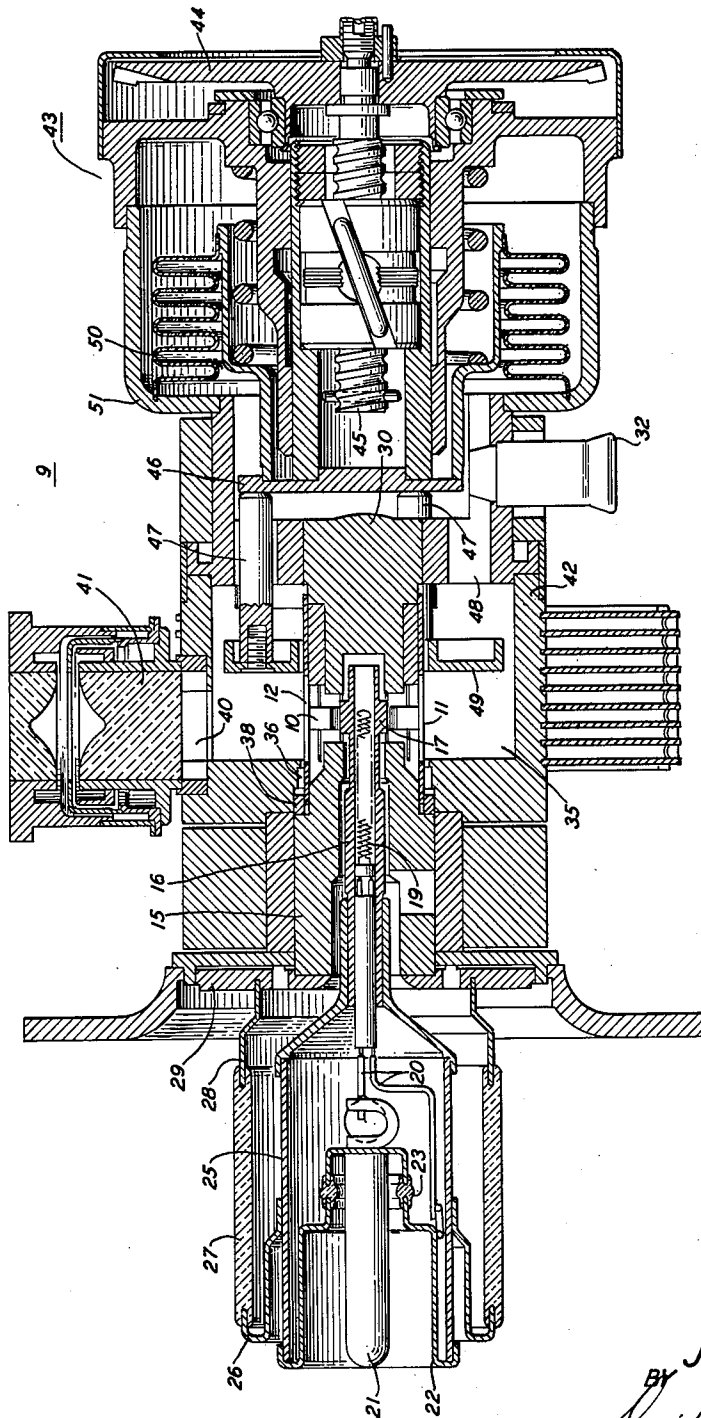
3,034,014

MAGNETRON

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2 Sheets-Sheet 1

FIG. 1



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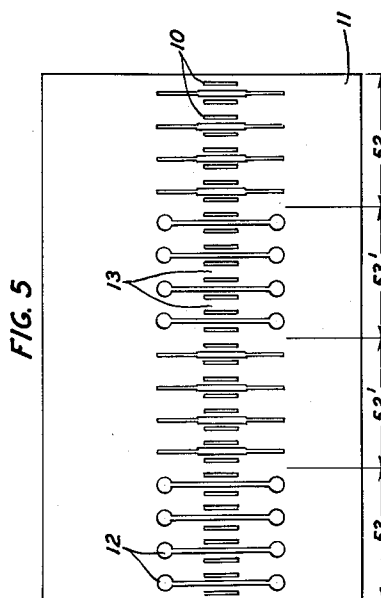
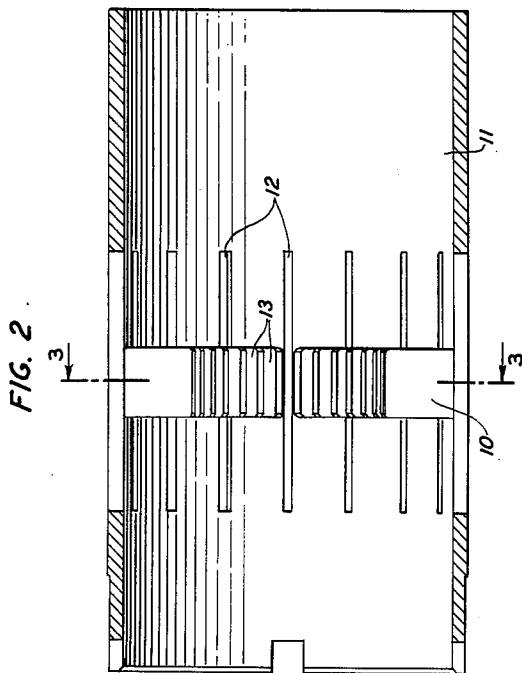
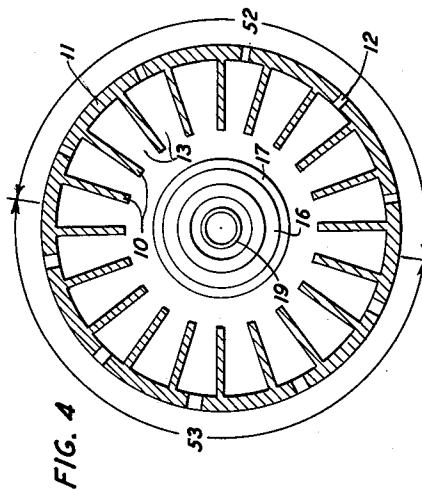
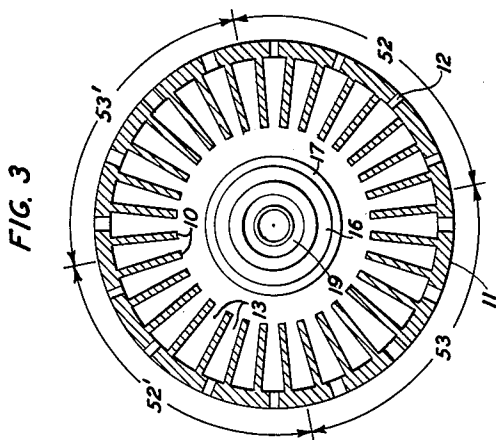
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MAGNETRON

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2 Sheets-Sheet 2



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MAGNETRON

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Filed Dec. 29, 1958, Ser. No. 783,600
10 Claims. (Cl. 315—39.77)

This invention relates to electron discharge devices of the magnetron type and more particularly to a coaxial cavity type of magnetron discharge device.

One of the most serious drawbacks of the conventional magnetron has been the inadequate compromise which has been necessary between efficiency and stability. By coupling the resonant system of a conventional magnetron heavily to the load, the radio frequency voltage across the anode gaps can be reduced, thereby increasing the electronic efficiency of the tube. Such heavy loading, however, necessitates closer coupling between the load and the magnetron which, in turn, increases the sensitivity of the magnetron to load changes and hence results in instability. At conditions of high efficiency, the conventional magnetron is so unstable that it may easily break into oscillation in an undesired mode, such operation generally being known as moding.

One attempted solution to this problem is the employment of wire straps which connect alternate anode segments to lock the resonant system in the desired π mode frequency. Although this arrangement is effective in preventing moding, it is impractical for short wavelength devices because of the construction problems inherent in such small structures; further, the strapped resonator system possesses a lower Q due to capacitive losses.

Another device in the evolution of a stable, efficient magnetron is the unstrapped rising sun magnetron. In this system, alternate resonators are made quite large with respect to the other resonators such that two groups of mode frequencies are developed in which corresponding modes of the same pattern periodicity add in phase or π radians out of phase. The excess energy storage in the large resonators, however, produces a coupling action which tends to propagate, around the anode periphery, a spurious electric mode called a "rising sun mode."

A better solution to the efficiency and stability problem is offered by the coaxial cavity magnetron. In this device, resonators for producing a conventional π mode are defined by a plurality of anode vanes extending radially inwardly from a cylindrical anode block. Instead of being coupled to an output, however, this resonant system is coupled to an outer annular resonant system which surrounds the cylindrical anode block. The two resonant systems are coupled by axially extending slots through the cylindrical anode which connect the outer resonator with alternate ones of the inner resonators. The slots extend beyond the vane region of the anode to suppress current flow around the ends thereof. The anode vanes are made to be approximately a quarter-wavelength long at the TE_{011} mode frequency range of the outer resonator so that the anode currents produced by the outer mode "see" a low impedance in the vane region and are further inhibited from flowing around the elongated slots. The high currents flowing at the base of the anode vanes cause appropriate high voltages to appear at alternate anode tips, thus providing proper conditions for oscillations in the desired π mode. Since the inner resonant system is isolated from the load and since it is also effectively locked in the desired π mode, high efficiency can be attained without producing instability.

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Because of energy storage in the coupling slots, however, other spurious modes are produced similar to those of the rising sun magnetron. To reduce this energy storage, damping elements and chokes are placed in close proximity to the ends of the slots. This, however, has not proven entirely satisfactory for removing such rising sun slot modes, hereafter referred to simply as slot modes.

One improvement on the coaxial cavity magnetron is described in the copending application of J. Feinstein, Serial No. 783,597, filed December 29, 1958, which is now U.S. Patent No. 2,976,458, granted March 21, 1961, wherein random non-uniformities are introduced into the slot array which tend to break up the slot mode pattern and thereby suppress slot mode interaction with the electron stream. One arrangement therein described is the use of slots of random length; another arrangement is the random omission of slots normally included along the anode periphery; a third arrangement is the connecting of various slots by transverse cuts through the anode wall. These arrangements have proven very effective in suppressing those first order effects which are the primary cause of spurious oscillations, but they do not prohibit certain second order effects which will be discussed hereinafter.

From circuit considerations, one may consider each slot to be a storage means of inductive and capacitive energy and, hence, a self-resonant circuit. This is clear when one considers the alternating potential difference of opposite sides of the slot which is more pronounced at the middle portion thereof because current tends to discharge around the ends to neutralize such difference. The middle portion, therefore, acts as a capacitance while the end portions act as inductances and the slot, as a whole, acts as a self-resonant tank circuit. Due to inductive coupling between adjacent slots, a slot mode is propagated around the periphery of the conventional coaxial cavity magnetron to form a slot mode pattern representative of the resonant frequency of the slots.

In the aforementioned application, random slot lengths tend to reduce coupling by virtue of the different resonant frequencies of adjacent slots. It has been found, however, that beyond a certain point the resonant frequency of a slot is changed very little by an increase in the length. This is due to the fact that the relatively large amount of capacitive storage near the center of the slot is augmented by the capacitive storage between the anode vanes which are also located near the slot centers. Further, if certain of the slots are made shorter than the normal slots, anode current induced by the desired π mode will flow around the slot ends, thereby seriously disrupting the desired π mode. Since a certain amount of π mode energy is stored in the slots, transverse cuts interconnecting certain slots also tend to affect deleteriously the desired π mode, since such direct coupling between the slots tends to alter the 180 degree phase shift between adjacent resonators which is essential to π mode operation. The omission of slots around the anode periphery does not permit optimum coupling of the inner and outer resonant systems and therefore also hampers desired operation.

Although the arrangements of the aforementioned application have proven very effective in breaking most of those slot modes which may interact deleteriously with the magnetron electron stream, it has been found that certain slot mode patterns may be created in spite of such random non-uniformities. This is partly due to weak coupling between slots which are not adjacent and also to weak coupling between adjacent slots which present

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different characteristics. For example, when random slot lengths are used, this mode represents the mean self-resonant frequency of all of the slots.

Also from electronic considerations, the arrangements of the aforementioned application have presented certain shortcomings. Any electromagnetic mode in the inner resonant system will "bunch" the electrons of the electron beam which, of course, is the undesirable result of slot modes. Even if slot mode patterns around the anode periphery are broken up, this bunching, which has been produced by a particular slot mode, may persist through a region in which a different frequency slot mode is present if such a region is not long enough to "de-bunch" the electrons. Where random non-uniformities are used these undesired bunchings may well persist around the entire periphery of the interaction region and give up energy which produces spurious oscillations.

It is an object of the present invention to prevent undesirable oscillations in a coaxial cavity magnetron due to slot modes formed therein.

It is another object of this invention to prevent the production of any slot mode around the entire periphery of the cylindrical anode in a coaxial cavity magnetron.

It is still another object of this invention to prevent bunches of electrons which may be formed by one slot mode from persisting around a substantial part of the electron stream path in a coaxial cavity magnetron.

It is another object of this invention to prevent undesirable oscillations in a coaxial cavity magnetron due to slot modes formed therein without the use of damping means.

These and other objects of the invention are attained in one illustrative embodiment wherein the slots of a coaxial cavity magnetron are so constructed that various slot modes are formed along the periphery of the cylindrical anode. Each of these slot modes, however, represents a different frequency such that a uniform slot mode pattern is not allowed to build up around the entire anode periphery. These various slot modes each exist along certain predetermined discrete portions of the anode periphery such that electrons of the magnetron electron stream which are bunched by one slot mode interact with a successive slot mode and are "de-bunched" thereby.

It is one feature of this invention that the coupling slots of a coaxial cavity magnetron be arranged into groups, the slots of each group exhibiting a different self-resonant frequency from the slots of adjacent groups. By such an arrangement, a slot mode is formed by each group which has different characteristics from slot modes which exist adjacent thereto. These groups are made sufficiently large such that there will be no coupling between slots of different groups which exhibit the same, or nearly the same, self-resonant frequency. Further, these groups are made sufficiently large so that bunches of electrons which are formed by the slot mode of one group cannot persist through an adjacent area represented by the slot mode of a successive group.

It is another feature of this invention that the difference in resonant frequency of the various slots in a coaxial cavity magnetron be determined solely by differences in width thereof, whereby such differences will have a negligible effect on the desired π mode of the inner resonant system.

It is a feature of one of the embodiments of this invention that the slots of one group in a coaxial cavity magnetron be relatively wide on their end portions with respect to their middle portion, while the slots of groups adjacent thereto be relatively wide in their middle portion with respect to their end portion. An increase in the area of the end portions will provide for an increase of inductive energy storage, while an increase in the width of the slot in the middle portion will provide a decrease of capacitive energy storage. The self-resonant frequency of any self-resonant circuit is inversely proportional to the square root of the product of inductance and

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capacitance. Where the end portions of a slot are widened, this product is increased, while widening the middle portion of the slot decreases the product. Hence, the slots of one group will exhibit a substantially different resonant frequency than the slots of an adjacent group.

It is a feature of another embodiment of this invention that the slots of one group in a coaxial cavity magnetron be uniformly wider than the slots of adjacent groups. Because the capacitive storage of a slot is augmented so heavily by the capacitance between anode vanes, the net capacitance is not as greatly affected by changes in width as is the net inductance. Although this method of producing different resonant frequencies in slots of different groups is theoretically not as effective as the foregoing embodiment, it is often more practical because of ease of manufacture.

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

FIG. 1 is a sectional view of a magnetron illustrative of one specific embodiment of this invention;

FIG. 2 is a sectional view of the anode vanes and anode wall of the embodiment of FIG. 1;

FIG. 3 is a view, taken along lines 3—3 of FIG. 2, showing, in addition, the cathode assembly of the embodiment of FIG. 1;

FIG. 4 is a view, similar to that of FIG. 3, of a magnetron anode and cathode assembly illustrative of another embodiment of this invention, and

FIG. 5 is a development of a magnetron anode wall illustrative of still another embodiment of this invention.

Referring now to the drawings, the specific illustrative embodiment of this invention depicted in FIG. 1 comprises a magnetron 9 having a plurality of anode vanes 10 mounted on a cylindrical anode wall member 11 as best seen in FIGS. 2 and 3. The vanes 10 extend along only a small portion of the length of the anode wall member 11 to which they are attached as by brazing. These vanes define an array of inner cavity resonators 13. Slots 12 extend through the anode wall member 11 along a major portion of its length and parallel to its axis, the slots communicating with alternate ones of the inner cavity resonators 13. Positioned at one end of the anode wall member 11 is a cathode pole piece 15 through a central aperture of which a cathode sleeve 16 extends, the sleeve having an emissive coating 17 thereon in the vicinity of the anode vanes 10. A heater element 19 extends within cathode sleeve 16 and is connected to a pair of leads 20. One lead 20 is connected to an inner cylindrical terminal conductor 21 and the other to an outer cylindrical terminal conductor 22, the two terminals 21 and 22 being separated from each other by a vitreous bead 23. The cathode sleeve 16 is mounted by a supporting cylinder 25 secured to a metallic cylindrical section 26 which, in turn, is supported from the cathode pole piece 15 by a vitreous cylindrical section 27, a metallic cylindrical section 28, and an end to pole piece member 29.

Opposite cathode pole piece 15 is a tuning head pole piece 30. An exhaust tubulation 32 extends into the region of tuning pole piece 30 for exhausting the device, as is well known in the art.

Encompassing the cylindrical wall member 11 is an outer coaxial cavity resonator 35 in which is positioned a cylindrical groove choke 36. Choke portion 36, closely adjacent the anode wall 11 separating the inner resonators and the outer coaxial resonator, may advantageously be provided with a soft iron lining 38 which serves to absorb and thus damp out interfering TE modes having maximum currents in that vicinity.

The outer resonator 35 is connected, as through a basically H-shaped transformer section 40, as is well known in the art, to a glass filled output wave guide section 41 through which the energy of the magnetron is

transmitted to external circuitry. The transformer section 40 is inserted in the outer wall 42 of the cavity resonator 35. Positioned adjacent the tuning end pole piece 30 is tuning mechanism 43. Mounted thereon is a tuning disc 44 which is connected to a tuning screw 45 which, in turn, controls the axial movement of yoke 46. Extending through tuning pole piece 30 are tuning shafts 47 which are connected to yoke 46 and are movable therewith. The shafts 47 extend into the outer resonant cavity 35 and support a tuning ring 49 for motion within the cavity 35 to tune the magnetron, as discussed further below. Syphon bellows 50 are attached to wall 51 and, by virtue of exhaust holes 48, maintain the vacuum within the magnetron as is well known in the art.

The outer cavity resonator 35 is capable of sustaining a number of different modes of operation. In accordance with this invention, however, it is dimensioned, as is well known in the art, for maximum storage of the TE_{011} mode in which the magnetic field lines are axial along the upper and lower plates of the cavity and the electric field lines are entirely circumferential. Electric currents induced thereby flow circumferentially along the outer surface of anode wall 11 and along the inner surface of the outer wall 42 of the outer cavity resonator 35. Currents induced by other modes will have an axial component which will be damped by choke portion 36 thereby, in effect, damping the mode. The inner resonant system defined by the resonators 13, when considered alone, is a usual unstrapped magnetron system which will tend to oscillate in both the π and various degenerate modes. Thus, outer cavity resonator 35 and the inner resonators 13 can be considered as two distinct resonant systems; however, when the two systems are placed together they can be considered to be a single composite system, as will be explained hereinafter.

Current produced by the outer cavity mode flows along anode wall 11 in a direction perpendicular to slots 12. Anode vanes 10 are made approximately a quarter-wavelength long in the range of frequencies of the current flowing along wall 11, such that the high impedance termination at the free end of the anode vanes is reflected back to slot 12 as a low impedance, and, accordingly, the said current flows into the resonator and down the adjacent vane. Because such currents are quite high, a high voltage is produced on the vane. These high voltages appear only across alternate anode vanes 10 at a given time because only alternate inner cavity resonators 13 are coupled by slots 12 to the outer cavity resonator 35. Voltages at the other alternate anode vanes are provided by mutual inductance, resulting in such voltage being 180 degrees out of phase with adjacent vanes. This, of course, is the proper condition for maintenance of the π mode of oscillation within the inner resonant system. Hence, the two systems are effectively locked together.

As is evident from the drawing, energy is delivered from the outer cavity through wave guide 41, and the TE_{011} mode frequency is therefore the frequency which is utilized. The manner of energy transfer from the inner resonant system to the outer cavity can be appreciated from a consideration of the structure of the inner resonant system. As is well known in the art, the electron beam of the inner resonant system induces voltages in the tips of anode vanes 10. These voltages, in turn, produce currents which flow out through the slots into the outer cavity resonator. Since the TE_{011} mode tends to sustain itself, these currents flowing along the boundary wall 11 are balanced by currents flowing along outer wall 42. Power is tapped out of the outer cavity resonator 35 at the outer wall 42. Actually, it is, of course, correct to consider both currents, those which flow into the slots from the outer cavity resonator and those which flow out of the slots due to electronically induced voltages, since what is involved here is a matching of the boundary conditions of the two systems.

It is not to be thought that in coupling the π mode

of the inner system to the TE_{011} mode of the outer system, both modes must oscillate at the same frequency. In fact, it is intended that the resonators 13 be so constructed as to support a frequency outside the frequency range of the outer cavity. By so doing, the frequencies are made substantially independent so that the frequency of the outer mode can be varied by movement of tuning ring 49, while minimally affecting the π mode of oscillation. Such minimal effects produce no overall deleterious effect unless certain spurious modes which are inherent in the rising sun type of structure of the inner resonant system become prominent. These spurious rising sun modes are produced by energy stored in slots 12 and will hereafter be referred to as slot modes.

Due to potential difference which occurs across a slot in the middle, or vane region, that portion of the slot may be considered to be a capacitive storage means, or a capacitor. Such potential tends to produce a current around the end of the slot, which creates a self-induction thereat, such that the slot ends may likewise be considered to be inductors. Hence, the slot acts as a self-resonant circuit, the characteristic frequency of which is dependent upon its inherent capacity and inductance.

The magnetic fields which are produced in each slot tend to link with those of other slots, particularly those which are adjacent. If the slot modes created between individual slots have the same, or nearly the same configuration, a uniform slot mode pattern may be propagated around the entire periphery of anode wall 11. Such a uniform slot mode pattern tends to interact with the electron stream which flows in the gap between cathode 17 and the anode vanes 10, thereby causing spurious oscillations in the inner resonant system.

In order to prevent such interaction, it is desirable to prevent the build-up of a slot mode pattern around the anode periphery. This can be done by changing the self-resonant frequency of certain of the slots, thereby reducing the coupling thereof with other adjacent slots of different frequency and hence disrupting the propagation of a slot mode. Random differences in the self-resonant frequency of certain slots with respect to other slot, however, are not totally effective in preventing the propagation of a slot mode because coupling can exist between slots which are not adjacent. This coupling, of course, decreases with increased distance between the slots. Further, coupling can exist between slots if the difference of the self-resonant frequencies is not large. For thorough disrupting of a propagating slot mode then, it is necessary to introduce, along the anode periphery, a group of slots whose characteristics are considerably different from those of adjacent groups of slots and also provide such differences along a relatively long distance.

Another purpose of the grouping of slots is to prevent a particular "bunching" of electrons due to a particular slot mode from persisting around the entire electron stream path. Any electromagnetic field caused by a slot or group of slots will tend to "bunch" the electrons of the electron stream in a particular pattern. As these bunches move along with the electron stream, they give up energy or undesirably interact to produce spurious oscillations. If bunches formed by one particular slot mode move into a region of a different slot mode, the bunches may persist in spite of the different field to which they are exposed if such exposure is of relatively short duration.

If, on the other hand, the successive slot mode region is made relatively long, the electrons of the stream will be forced into redistribution, or "de-bunched." This debunching, of course, prevents the undesirable interaction pointed out above. The grouping of slots according to their different self-resonant frequencies is therefore advantageous for two reasons: Such grouping prevents the build-up of a uniform slot mode around the entire periphery of the anode wall; such grouping prevents undesirable bunches of electrons from persisting throughout their path around the cathode.

Consider next the modifications necessary to produce changes in the self-resonant frequency of a slot. As pointed out above, the middle, or vane portion, of a slot acts as a capacitor, while the end portions act as inductors. In a parallel plate capacitor, the capacity is inversely proportional to the distance between plates. In an inductive winding, the inductance is directly proportional to the area enclosed thereby. Hence, the area enclosed by the ends of a slot is indicative of the inductive storage thereof, while the width of the middle of the slot is indicative of the capacitive storage.

The resonant frequency of any self-resonant circuit is inversely proportional to the square root of the product of its inductance and capacitance. Widening the ends of a particular slot will increase the inductive energy stored therein, thereby increasing the LC product and hence will decrease the self-resonant frequency of the slot. Widening the middle of a slot will decrease the capacitive energy stored therein, thereby decreasing the LC product and hence will increase the self-resonant frequency of the slot.

FIG. 5 is a development of the cylindrical anode 11 illustrating one embodiment of the present invention. The slots 12 of groups 52 and 52' are wide in center with respect to the end portions and thereby exhibit relatively high self-resonant frequencies. The slots of groups 53 and 53' are wide on the ends with respect to the middle portions and thereby exhibit relatively low self-resonant frequencies.

The embodiment of FIGS. 2 and 3 show a similar grouping of slots of different self-resonant frequencies. Here, however, the slots are rectangular in shape, the slots of groups 52 and 52' being relatively narrow, and the slots of groups 53 and 53' being relatively wide.

At first glance, it may appear that this modification would not produce the necessary large frequency difference because the widening of a slot decreases its capacity as it increases its inductance. Due to large potential differences between adjacent vanes 10, however, a large capacitance is produced across the vane region of the slot thereby augmenting that slot capacitance which we have already discussed. Because of such vane loading, the change in capacitance due to change in slot width is small in comparison to the change in inductance. The slots 12 of groups 52 and 52' are relatively narrow such that the quantity of inductive energy stored therein is relatively small and hence the slots exhibit relatively high self-resonant frequencies. The slots of groups 53 and 53', on the other hand, are relatively wide such that the inductive energy stored therein is relatively large and hence the slots exhibit relatively low self-resonant frequencies. Although this embodiment is theoretically not as effective in producing a large frequency difference as the foregoing embodiment, it obviously presents fewer problems of manufacture.

It is clear from an examination of FIGS. 2 and 5 that the only differences in the structure of the various slots are differences in width. As has been pointed out above, the currents induced by the desired TE_{011} and π modes flow in a direction perpendicular to the slots. It is therefore evident that changes in width of the slots have little or no effect on these currents. Since each slot forms part of a resonant cavity 13, some π mode energy is stored therein. Examination of FIG. 3 will show, however, that this energy is small as compared to that stored in the rest of a given resonant cavity 13, and changes in the width of a slot will have no determinative effect on the stored π mode energy.

The embodiments of FIGS. 2, 3 and 5 illustrate slot grouping along an anode having 32 vanes and 16 slots. As pointed out above, a grouping such as 52 must be long enough to prevent coupling between the slots of groups 53 and 53' and also to cause redistribution of electrons bunched by the modes produced by the slots of either adjacent group. For example, if the electron stream were moving clockwise around cathode 17 of FIG. 3, the elec-

trons thereof would be bunched by the slot mode existing along group 53'. The slot mode of the next successive slot group, group 52, would exhibit an entirely different field configuration due to the different self-resonant frequencies of the slots therein. As the electrons moved into this region, they would accordingly be redistributed or de-bunched, and their energy would not be given up to produce spurious oscillations.

If, of course, a slot group such as group 53' is made extremely long, undesired interaction will take place before the electrons are de-bunched. On the other hand, if a slot group is made extremely short, including, say, only two slots, it will be ineffective in redistributing the electrons bunched by a preceding slot mode. The desired optimum is arrived at by experiment. While the optimum number of groupings for a 16 slot anode is four, as shown by FIG. 3, the optimum number for a 10 slot anode is two, as shown by FIG. 4.

It is intended that the specific embodiments described be merely illustrative of the general principles of the invention. Various other arrangements may be devised by one skilled in the art without departing from the spirit and scope of this invention.

What is claimed is:

1. A magnetron comprising a cathode, a plurality of anode resonators adjacent said cathode, and an output cavity resonator adjacent said anode resonators, said anode resonators and said output cavity resonator having a common wall portion, and means for coupling certain ones of said anode resonators to said output cavity resonator comprising a plurality of groups of adjacent slots in said wall portion, the slots of each group exhibiting a substantially uniform self-resonant frequency which is different from the self-resonant frequency of the slots of adjacent groups.
2. The combination of elements of claim 1 in which all of the said slots are of uniform length.
3. The combination of elements of claim 1 in which the slots in at least one of the said groups are narrower than the slots in at least one other of said groups.
4. The combination of elements of claim 1 in which the slots in alternate groups are narrow with respect to the slots in the remaining groups.
5. The combination of elements of claim 1 in which each of said groups is composed of the same number of slots.
6. The combination of elements of claim 1 in which said wall portion contains a total of four groups of slots, each of said groups containing a total of four slots.
7. A magnetron comprising a cylindrical cathode for forming and projecting a stream of electrons, a cylindrical anode wall surrounding said cathode and coaxial therewith, an array of anode vanes extending radially inwardly from said anode wall and defining a plurality of anode resonators, means including said anode wall defining an outer cavity resonator, and means for coupling certain ones of said anode resonators with said outer resonator, said last mentioned means comprising groups of adjacent slots extending through said cylindrical anode wall, a first group of slots being characterized by a first slot mode which modulates said electron beam to form bunches of electrons therein, a second group of slots, adjacent said first group, being characterized by a second slot mode and which extends along a sufficiently long portion of the periphery of said cylindrical anode wall to demodulate substantially said electron beam with respect to said bunches produced by said first slot mode.
8. The combination of elements of claim 7 wherein the slots of all of said groups are substantially rectangular and wherein the slots of said first group are wider than the slots of said second group.
9. The combination of elements of claim 7 in which the slots of said first group are wider on the end portions thereof than in the middle portion and the slots of said

second group are wider on the middle portion thereof than on the end portions.

10. The combination of elements of claim 7 in which each of the slots of said first group exhibits a first self-resonant frequency and each of the slots of said second group exhibits a second self-resonant frequency which is different from said first self-resonant frequency.

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