

Sept. 30, 1958

R. J. COLLIER ET AL
MAGNETRONS

2,854,603

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3 Sheets-Sheet 1

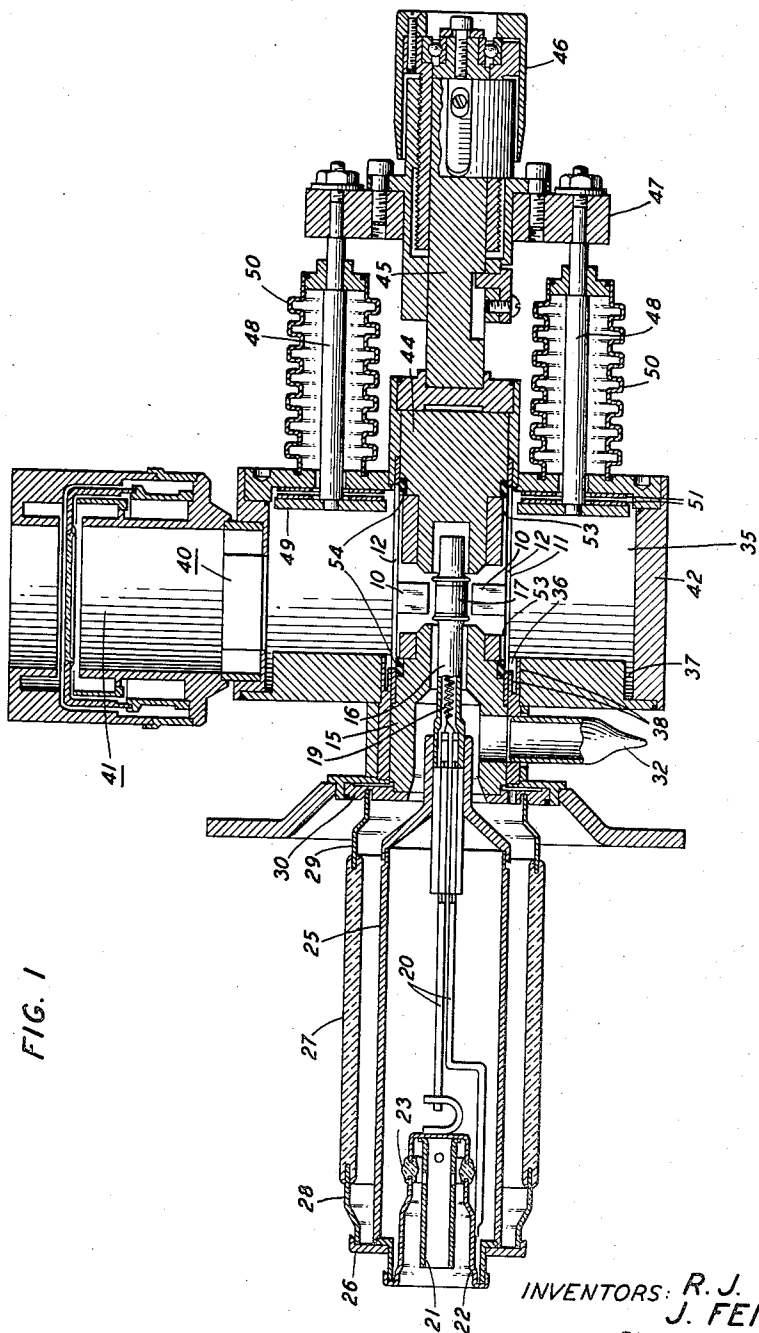


FIG. 1

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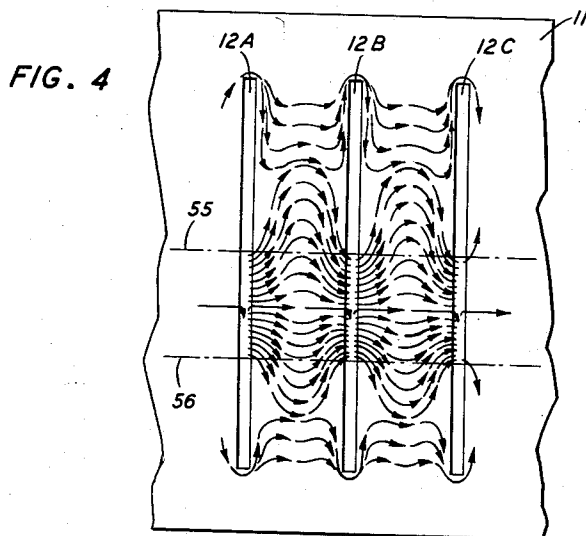
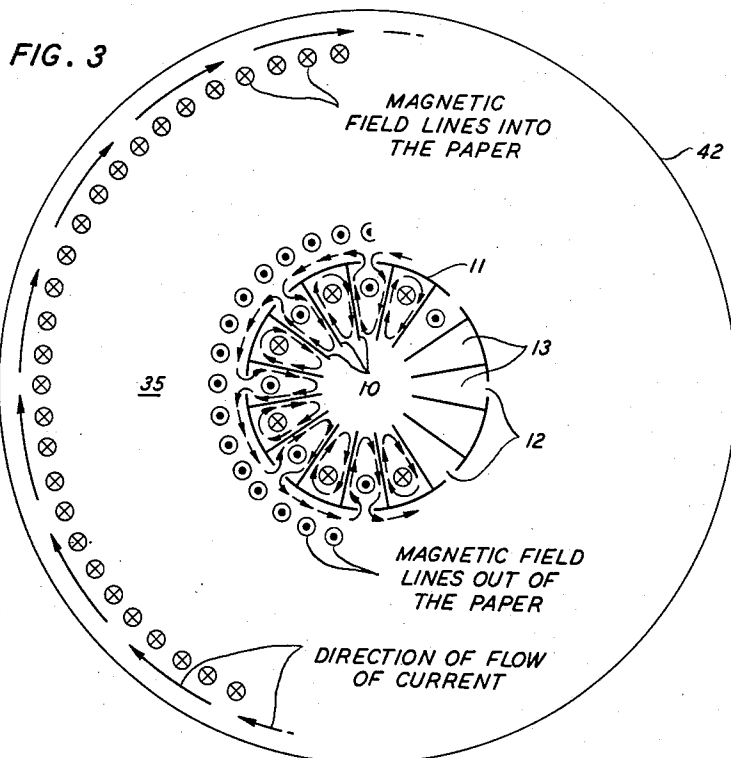
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3 Sheets-Sheet 2



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FIG. 5

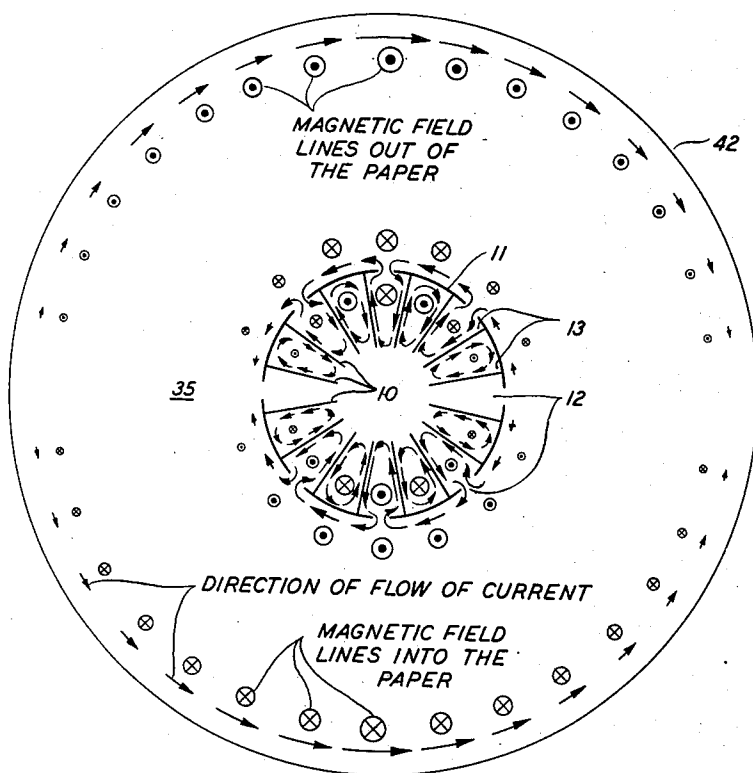
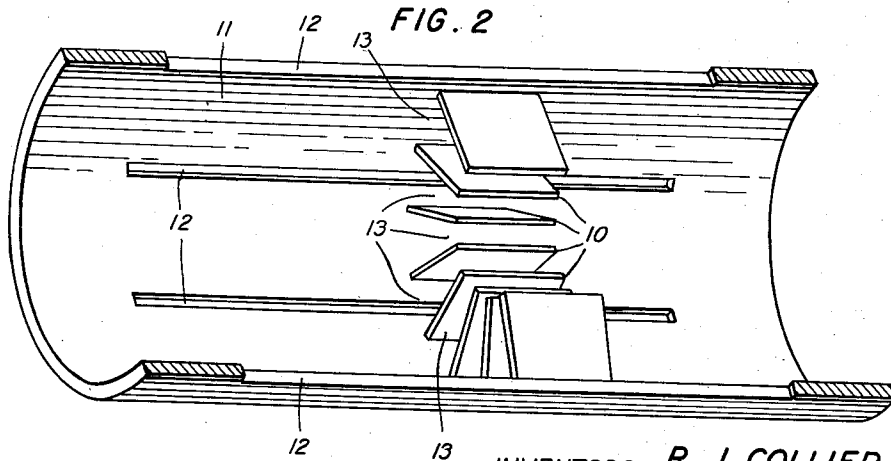


FIG. 2



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12 Claims. (Cl. 315—39.77)

This invention relates to electron discharge devices and more particularly to multicavity magnetrons.

At higher frequencies of operation, as in the microwave region, proper operation of magnetrons becomes increasingly difficult due to a number of possible occurrences to which magnetrons are susceptible. One problem is that of mode separation. As is known, magnetrons may oscillate in a number of modes, the frequencies of which may be quite close and in fact, over a tunable range, may coincide at various points. In order to obtain oscillation in only the desired mode, provision is generally made to separate the frequencies of the desired modes. In conventional magnetron designs this has been done most usually by strapping. At higher frequencies, however, strapping is not feasible or desirable.

Another difficulty that arises is to attain a high frequency stability under varying loads. Magnetrons may change their mode of oscillation under various load conditions. Similarly, due to the different loads present to different modes of oscillation, magnetrons may commence oscillation in an undesired mode, presenting a problem that is known as moding.

Further, at higher frequencies and smaller anode structures, tuning of the magnetrons becomes difficult. Tuning has generally been attained by varying the capacitance or the inductance of the resonant cavities of the anode structure, as by inserting tuning pins into the cavity bores to change the inductance of the circuit.

It is a general object of this invention to provide an improved magnetron tunable over a desired high frequency band.

It is another object of this invention to provide a tunable magnetron for use in the microwave region possessing a high degree of frequency stability and freedom from moding.

A further object of this invention is to facilitate the tuning of magnetrons.

These and other objects of this invention are attained in one specific illustrative embodiment wherein the magnetron comprises a pair of resonant systems, the first or inner system including a plurality of anode vanes mounted on a cylindrical wall member and around a cathode and the second or outer system including a cavity resonator having the cylindrical wall member as its inner wall. In accordance with one aspect of this invention, alternate ones of the inner cavity resonators defined by adjacent anode vanes are coupled to the outer or coaxial cavity resonator by slots extending through the boundary wall between the two resonant systems. The anode vanes are arranged to be approximately one-quarter wavelength long at the outer cavity resonator frequency so that the slots present at low impedance to the currents of the main mode of the outer cavity resonator.

In accordance with an aspect of this invention, the resonant frequency of the inner cavity resonators is not exactly the resonant frequency of the outer cavity resonator and specifically it is advantageous that the resonant

frequency of the inner cavity resonators be outside the tuning range of the magnetron output. Accordingly, the frequency of the magnetron is determined primarily by the coaxial cavity resonator and not by the primary anode resonators themselves.

In accordance with an aspect of this invention, the mode of oscillation in the outer cavity resonator is the TE_{011} mode, in which the magnetic field is axial and the electric field is circumferential; in this mode electric currents flow around the outer wall of the anode block. In this manner the correct currents are supplied to the back ends of the individual resonators to assure that the resonators oscillate in the π -mode.

Because of this coaxial cavity resonator coupling, the system is locked into the desired mode of operation, affording high mode stability, limiting and substantially eliminating the possibility of moding. Further, because large amounts of energy may be stored economically in the coaxial cavity resonator, the frequency stability is also high, without danger of moding. This in turn permits operation at lower impedance, yielding higher electronic and circuit efficiencies.

Because straps are not required, the power loss in the resonator system is reduced and the RF field distortion in the interaction space is also lessened.

Advantageously the magnetron may be tuned by inserting a piston or other movable element into the outer coaxial cavity resonator to vary its dimensions. This type of tuning is considerably simpler than the conventional multipin tuning of the resonator bores themselves, affords a wider frequency range, and does not require holes to be bored in the magnet pole pieces, thereby producing a much simpler structure. Further, in order to tune the desired TE_{011} mode of the outer cavity resonator no metal-to-metal contacts are required between the tuning ring and the inner and outer walls of the cavity resonator.

Because every degenerate mode of the inner resonant system, i. e., capable of existing at the anode vanes, must have compatible boundary conditions to a superior TE mode of the outer cavity resonator, it is possible in the outer cavity resonator to load both types of undesired modes. Any TM modes that might possibly interfere in the operation of the device may be removed in frequency from the output frequency range of the device by chokes placed at appropriate places.

It is a feature of this invention that a magnetron comprise a pair of resonant systems having a common wall boundary, the outer system being constructed to oscillate in the TE_{011} mode and the inner system being coupled to the outer system at alternate cavity resonators of the inner system, by slots extending through the common boundary wall, whereby the inner resonant system must oscillate in its π -mode and be locked into the TE_{011} mode of the outer resonant system.

It is another feature of this invention that the resonant frequency of the π -mode of the inner cavity resonators be outside the range of frequencies of the outer cavity resonator.

It is a further feature of this invention that the anode vanes be approximately a quarter-wave long in the frequency range of the TE_{011} oscillations of the outer cavity resonator so that the currents flowing along the outer surface of the boundary wall see a low impedance at the slot through the wall in the region of the anode vanes though a high impedance at the slot at those portions of the wall where the anode vanes are not located. Thus, in accordance with this feature of the invention, the high currents flowing into the slot at the base of the anode vanes cause appropriate high voltages to appear at the alternate anode tips adjacent the cathode, thus providing the proper conditions for oscillation in the π -mode,

It is still a further feature of this invention that the coupling be maintained constant and high by extending the slots considerably beyond the anode vanes, whereby a very large proportion of the current flowing along the outer surface of the boundary wall is forced into the slots adjacent the anode vanes.

It is still another feature of this invention that each degenerate mode of the inner resonant system is locked to a spurious TE mode of the outer resonant system and is loaded by appropriate damping of the spurious TE mode of the outer resonant system. Accordingly, it is a feature of this invention that separation and loading of the degenerate modes of the inner resonant system, which is electronically excited, be attained by damping of the modes of the outer resonant system to which they are coupled.

It is still a further feature of this invention that dissipative or damping elements be positioned at the ends of the slots to absorb energy stored in the slots when the inner resonant structure oscillates in a rising sun mode, the pole pieces and boundary wall defining transmission lines extending from the inner resonant system to the dissipative elements.

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 drawing, in which:

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

Fig. 2 is a perspective view of a portion of the anode vanes and boundary wall for the embodiment of Fig. 1;

Fig. 3 is a plot of current and magnetic fields for the dominant TE_{011} and π -modes in the embodiment of Fig. 1;

Fig. 4 is a developed view of a portion of the boundary wall cylinder showing current flow along the wall and into the slots in the embodiment of Fig. 1 for the dominant TE_{011} mode; and

Fig. 5 is a plot of current and magnetic fields for the TE_{121} and 7-modes in the embodiment of Fig. 1.

Turning now to the drawing, the specific illustrative embodiment of this invention depicted in Fig. 1 comprises a plurality of anode vanes 10 mounted on a cylindrical wall member 11, as best seen in Fig. 2. The vanes 10 extend only a small portion of the length of the wall member 11 to which they are attached as by brazing. In accordance with an aspect of this invention, slots 12 extend through the wall member 11 along a major portion of its length and parallel to its axis, the slots communicating with alternate ones of the primary cavity resonators 13 defined between the adjacent anode vanes 10. Positioned at one end of the 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 the 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 an end cap 26 which in turn is supported from the cathode pole piece 15 by a vitreous cylindrical section 27, a pair of metallic cylindrical sections 28 and 29, and an end pole piece member 30.

An exhaust tubulation 32 extends through the pole piece 15 into the region of the cathode sleeve 16 for exhausting the device, as is known in the art.

Encompassing the cylindrical wall member 11 is an outer coaxial cavity resonator 35 in which are positioned a pair of cylindrical groove choke portions 36 and 37. Choke portion 36, closely adjacent the wall 11 separating the inner resonators and the outer coaxial resonator may advantageously be provided with a soft iron lining 38 and

serves to absorb and thus damp out an interfering TE mode having maximum currents in that vicinity, as described further below. The choke portion 37, which is unlined, may be employed to aid in separating an undesired TM mode of operation from the desired mode by displacing its frequency slightly.

The outer or secondary resonator 35 is connected, as through a dumb-bell or basically H-shaped transformer section 40, as is known in the art, to an 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 to the other side of the anode vanes 10 than the cathode pole piece 15 is a tuning head pole piece 44 to which is secured a tuning yoke 45. Mounted by yoke 45 are a micrometer tuning mechanism 46, a cross-piece 47, and a pair of tuning shafts 48, the shafts 48 and cross-piece 47 being movable axially along the yoke 45 on rotation of the tuning mechanism 46. The shafts 48 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. Sylphon bellows 50 are attached between the pistons 48 and the top of the cavity 35 to maintain the vacuum within the magnetron. The back of the tuning ring 49 and the wall of the cavity 35 directly adjacent the tuning ring 49 are both advantageously lined with Kovar coatings 51 to damp out back cavity resonances on motion of the tuning ring 49 into the cavity resonator 35.

As can be seen in Fig. 1 of the drawing the pole pieces 15 and 44 are not directly adjacent the wall cylinder 11 but slightly removed therefrom, thereby forming narrow passageways 53 between the pole pieces and the wall cylinder. Positioned at the base of each of these narrow passageways is a ring 54 of a lossy material, such as a barium titanate ceramic, for damping out unwanted modes of oscillation as described in detail below. Further, in accordance with an aspect of this invention, the slots 12 which define the communication paths between the primary cavity resonators 13 and the secondary cavity resonator 35 are extended along the length of the narrow passageways 53 so that the damping rings 54 are positioned within the wall 11 and at a region where they do not communicate with the outer cavity resonator 35.

In order to understand best the operation of our invention and the advantages attainable thereby, let us first consider the various manners of operation of the resonant systems involved. There are in actuality four types of resonant systems in the structure depicted in Fig. 1 which we can and should consider. These are (1) the system comprising the resonant cavities 13 within the wall 11, considered as an unstrapped magnetron structure; (2) the system comprising the outer coaxial cavity resonator 35 alone; (3) the system comprised by the interaction of these two in accordance with this invention; and (4) the system comprising a rising sun type of magnetron structure when the resonant cavities 13 are considered as including, in alternate resonators, the slots 12 so that adjacent resonant cavities are different and alternate resonant cavities are similar, which basically defines a rising sun structure. This last system we shall not consider now but shall refer to again with reference to the employment of the dissipative or damaging elements 54 at the ends of the slots 12.

The outer cavity resonator 35 is capable of sustaining a number of different modes of oscillation. However, in accordance with this invention it is dimensioned, as is well known in the art, for maximum energy storage of the TE_{011} mode which is a symmetric mode in which the magnetic field lines are axial and along the upper and lower plates of the cavity and the electric field lines are entirely circumferential, electric currents flowing circumferentially along the outer surface of the wall 11 and along the inner surface of the outer wall 42 of the

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cavity resonator 35. Other TE modes will, of course, also be present to a greater or lesser degree and may be damped out in various ways, as discussed further below. Similarly, some TM modes, in which the electric field is radial and the magnetic field circumferential, may also be present; these modes may be strengthened by slight irregularities in the physical system, such as deviations in the positioning of the cavity end plate and tuning piston 49 from being exactly perpendicular to the cavity axis.

However, when we consider the outer cavity resonator 35 alone as a resonant system, what we see is a system which is designed to store maximum energy in the TE_{011} mode but in which, to lesser degrees, other modes are also present.

When we consider the resonant system defined by the resonators 13 alone we have a usual untrapped magnetron system which will tend to oscillate in both the π and the various degenerate modes. As is known for these various modes the oscillations in the adjacent resonators and thus the fields appearing across adjacent anode slots bear a definite phase relationship. This is sometimes also thought of in terms of the potentials placed on the anode segments by the resonators, the variation of the potential from one segment to the next depending upon the mode of oscillation of the system as a whole.

In the specific embodiment depicted in Fig. 1 there are sixteen cavity resonators 13 so that the π -mode is the 8-mode. The mode closest in frequency to the π -mode would thus be the 7-mode whose frequency may actually be within one percent of the π -mode frequency of an untrapped structure such as depicted in Fig. 2.

Thus when we consider each part of the structure of Fig. 1 as a distinct resonant system we see that there are a number of modes of oscillation in which each can oscillate and store energy. However, in accordance with this invention, when the two systems are placed together and considered as a single composite system, the inner cavity resonators 13 are locked in the π -mode of oscillation, the degenerate modes, such as the 7-mode, of the inner resonators are removed in frequency and are damped out in the outer cavity resonator 35, and the overall frequency appearing at the output of the magnetron is substantially that of the TE_{011} mode of the outer resonator. This last is because the outer cavity resonator 35 is so much larger than the inner cavity resonators 13 and accordingly can store so much more energy that its characteristics are controlling.

These various advantages occur when the two systems are placed together and considered as a single composite system because for each mode of one system to exist it must find a mode of the other system whose boundary conditions, at the wall 11, are exactly identical. Accordingly, the wall 11 is of extreme importance in this invention as defining the boundary between the two systems but being, in certain respects, common thereto.

We have found that in structures in accordance with our invention the boundary conditions at the wall 11 are compatible for the TE_{011} mode in the outer cavity resonator 35 and the π -mode of oscillation in the inner cavity resonators 13. The various electric and magnetic fields for these two modes and the manner of operation of the structure depicted in Fig. 1 and illustrative of one embodiment of this invention can clearly be seen in the plot of Fig. 3 wherein the inner and outer resonant systems are depicted as separated by the wall 11 through which extend the slots 12 coupling alternate of the inner resonators 13 to the outer resonator 35. As can be seen in the figure and is known for a TE_{011} mode, the currents flow circumferentially around the outer wall 42 and the inner wall 11 of the resonator 35 and the magnetic field lines adjacent these walls are axial. These are depicted by the arrows, dots, and crosses, as explained in the legends on the figure.

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In structures in accordance with this invention current flows along the inner wall 11 and arrives at a slot 12 perpendicular to the direction of the slot. What the current sees at the slot can be considered to be a short transmission line terminated in an open end, the line comprising two adjacent anode vanes 10 terminated in the anode interaction gap adjacent the magnetron cathode. By making these vanes approximately a quarter wavelength long in the range of frequencies of the current flowing along the wall 11, the high impedance termination at the inner end of the anode vanes is thus reflected back to the slot 12 as a very low impedance and, accordingly, the current flows into the resonator and down the adjacent vane, as depicted. The current flows across the interaction space between that vane and the adjacent one, and specifically through the capacitance defined between these two vanes at that point, back along the other vane, and through the slot 12 to the outer surface of the wall 11. Thence it flows along the wall 11 until the next slot 12 where the process is repeated.

Because high currents are supplied, from the outer cavity resonator 35, to the ends of the anode vanes 10, high voltages appear at the inner ends of the anode vanes 10 due to the quarter wave transformation involved. Further, as only alternate inner cavity resonators 13 are coupled by slots 12 to the outer cavity resonator 35, high voltages appear across alternate of the anode vanes 10. Voltages at the other alternate anode vanes are provided by mutual inductance, these voltages at the other alternate vanes being 180 degrees out of phase with those at the adjacent vanes. This, however, is the proper condition for sustaining the π -mode of oscillation in the inner resonant system. Accordingly, the π -mode of oscillation of the smaller resonant system is locked into the TE_{011} mode of oscillation of the larger resonant system.

It should be pointed out that the mutual inductances between adjacent cavity resonators couple those cavity resonators 13 which are not directly coupled to the outer cavity resonator 35 through slots 12. This mutual inductance is indicated in Fig. 3 by the magnetic field lines shown within the cavity resonators 13, the field lines in the directly coupled resonators 13 coming out of the paper and those in the inductively coupled resonators being shown as going into the paper. Actually the magnetic fields in the directly coupled resonators 13 and in the outer cavity resonator 35 merge at the slots 12. And similarly, in accordance with this invention, the magnetic fields in the inductively coupled alternate resonators, which must be in the opposite direction to sustain the π -mode of oscillation in the inner resonant system, are prevented from interfering with the magnetic fields of the outer cavity resonator, which must be all in the same direction adjacent the inner wall for the TE_{011} mode of oscillation, by the wall 11.

As no other possible modes of oscillation of the inner resonant system will present at the boundary between the two systems, i. e., at the wall 11, the electric field and magnetic field conditions which are compatible with the dominant TE_{011} mode for which the outer cavity resonator 35 has been designed, only the π -mode oscillation can be locked to the TE_{011} mode in energy transfer relationship.

In order to optimize the coupling between the two resonant systems it is desirable that a maximum of the current flowing along the wall 11 in the outer cavity resonator 35 be coupled through the slots 12 and flow down the vanes 10 of the inner resonant system. The feature of this invention whereby this is attained is depicted in Fig. 4 which is a developed view of the outer surface of a portion of the boundary wall 11, three slots 12A, 12B, 12C being depicted. The slots 12 are essentially open circuits and therefore high impedances in the path of currents flowing circumferentially around the wall 12. However, at that length of slot 12 along which,

on the inner surface of the wall 11, the vanes 10 are positioned, there appears a very low impedance, due to the impedance transformation caused by the vanes themselves, as explained above; this length of slot is indicated between the lines 55 and 56 in Fig. 4, which lines depict the height of the vanes 10.

Current flowing along the wall 12 will therefore flow along a low impedance path until it comes to a slot, such as slot 12B. The current, in seeking the lowest impedance path, will then converge down to that portion of the slot between the lines 55 and 56 where there is a low impedance; this current is thus forced into the inner resonators 13 and flows along the vanes 10. However, at a certain distance from each of the lines 55 and 56 there is a point at which the total impedance of the path offered to the current flowing into the slots is just equal to the total impedance of a path wherein the current flows around the end of the slot. In order to reduce this end current flow to a minimum, the slots 12 should be extended considerably beyond the height of just the anode vanes themselves, i. e., in Fig. 4 considerably beyond the lines 55 and 56. Actually the upper ends of the slots will be outside the cavity resonator due to the presence of the tuning piston or ring 49 and, in accordance with an aspect of certain embodiments of this invention, as described further below, the ends of the slots may advantageously be placed outside the outer cavity resonator to enable the positioning of dissipative or damping elements therein solely for the purpose of effecting a selective damping in the inner cavity resonator when considered as a rising sun structure. Accordingly the currents flowing along the outer wall which take paths around the end of the slots 12 are considerably reduced.

The currents flowing into the slots 12 and therefore into the inner resonators 13 thus lock the π -mode of oscillation of the inner structure to the dominant TE_{011} mode of the outer cavity resonator 35. There are still to be considered the other possible modes of operation of these two systems, considered alone. These are the various degenerate modes of the inner system, the TE modes of the outer system and the possible TM modes of the outer systems. For any degenerate mode of the inner system to exist it must find a TE mode of the outer system with which it has compatible boundary conditions at the boundary wall 12. Let us consider the 7-mode of the inner cavity resonators 13 of the illustrative embodiment depicted in Fig. 1. As mentioned above, in an unstrapped magnetron with sixteen resonant cavities this mode is very close in frequency to the desired π -mode. It is therefore desirable to alter its frequency and to damp or load it. This is attained, in this invention, because the 7-mode must be locked to a TE mode in the outer cavity resonator. Whereas there is very little physical space within the inner resonant system for the positioning of selective damping elements which could reduce the effect of the 7-mode on the inner resonant system, there is a lot of room in the large outer resonant cavity 35 for the positioning of damping elements which reduce the effect of the TE mode to which the inner 7-mode is coupled; and, because of this coupling, the effect of the 7-mode itself is also reduced.

In Fig. 5 there is depicted the current vectors and magnetic field for the 7-mode within the wall 11 and thus within the inner resonant system and the TE_{121} mode outside the boundary wall 11 and thus within the outer resonant system, radial TE_{121} currents, however, not being depicted as these do not couple to the inner cavity resonators. In both these modes there is a sinusoidal variation of current and magnetic field strength with two nodes of substantially zero points and two maxima, the current direction reversing at the nodal points. In Fig. 5 the length of the arrows and the relative size of the dots and crosses give a qualitative approximation of current and field strength at the boundary between the resonant systems. Accordingly, the 7-mode is pulled, in fre-

quency, away from the π -mode by the TE_{121} mode of the outer cavity resonator 35.

Further, the TE_{011} mode is the only mode that is entirely symmetrical with no radial current flow at all. In all the other TE modes there is some radial current flow, i. e., current flow along the end plates of the outer cavity resonator 35. For the TE_{121} mode it was found that there is a current maximum at the inner conductor of the coaxial outer cavity resonator, i. e., adjacent the wall 11 for radial currents. Accordingly the quarter-wave circular end plate choke 36 is advantageously positioned adjacent to and coaxial with the wall cylinder 11, and the walls of the choke lined with soft iron, as indicated at 38 in Fig. 1. The use of the choke 36 alone does not destroy the mode, as the current has the choice of an alternate low impedance path running circumferentially along the choke walls; however, by placing soft iron in that path, magnetic losses attain the desired damping.

Due to the coupling at the boundary wall 11, this damping is loaded onto the 7-mode itself in the inner cavity resonators 13. Thus the degenerate modes of the inner resonators, which are coupled to the outer cavity resonator 35, may be loaded within the large outer cavity resonator 35, the loading being effective within the smaller cavity resonators 13.

The TM modes do not couple into the inner resonators 13, as they do not have circumferential currents along the boundary wall 11. Accordingly, they cannot be electronically excited by the inner resonators. Therefore in general they need not be considered. However, it is possible that one of the TM modes may lie at or within the frequency range of the desired TE_{011} ; specifically in the embodiment depicted in Fig. 1 it was found that the TM_{11} mode frequency was substantially the same as the TE_{011} mode and would have energy coupled to it in the outer cavity resonator 35 if there were any slight physical irregularities in the dimensions of the outer cavity resonator, as by misalignment of the tuning ring 49 or deviation of the inner wall 11 from being entirely perpendicular to the cavity resonator axis. The TM_{11} mode was removed from the frequency range of operation of the device by being shifted to lower frequencies; in this specific embodiment this was attained by placing the quarterwave choke 37 on the end plate adjacent the outer cylinder 42 of the cavity resonator 35 where the TM_{11} currents are large.

In this manner the inner resonant system is locked into its desired π -mode of oscillation, the degenerate modes of the inner system are locked to spurious modes of the outer system, and both the degenerate and spurious modes are either suppressed or removed in frequency so as to be outside the operating range of the magnetron. This operating range is determined by the dimensions of the outer cavity resonator, and specifically by its inner and outer diameters and its length.

In accordance with another aspect of our invention, the resonant frequency of the π -mode of the inner resonant system is placed outside of the output range of the magnetron, i. e., outside the range over which the TE_{011} mode of the outer cavity resonator 35 is tuned. Thus 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, there must be the same resonant frequencies. Instead it is specifically a feature of our invention that the frequency of the inner system be outside the range over which the outer system is tuned. The π -mode frequency of the inner system is actually determined by the resonant frequencies of adjacent cavity resonators 13. Exactly at resonance when the frequency of the outer cavity resonator is the resonant frequency of the inner resonators, the resonators that are coupled put a very large resistive impedance across the slots 12 so that the outer cavity resonator would not deliver energy at that specific single frequency, the energy being supplied instead to these resistive impedance. Accordingly, to prevent this dis-

continuity in the output spectrum as the magnetron is tuned, it is desirable that the resonant frequency of the inner cavity resonators 13 be outside the range of frequencies of the outer cavity resonator.

To understand how energy is delivered from the inner cavity resonators 13 to the output of the magnetron we can consider the operation, not from the viewpoint of the currents from the outer cavity resonator coming into the inner cavity resonators, but from the viewpoint of the electrons within the inner resonant system. These electrons induce voltages at the tips of the anode vanes 10, as is known in this art. The voltages in turn produce currents which flow out through the slots into the outer cavity resonator. These currents flow along the boundary wall 11 but must, as is known, be balanced by currents flowing along the 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, as what is involved here, as pointed out above, is a matching of the boundary conditions of the two systems.

We have left for last the consideration of the fourth type of resonant structure that may appear in the embodiment of Fig. 1, namely the rising sun type of structure. This must be considered because the adjacent cavity resonators 13 are physically different while alternate cavity resonators are alike; such an arrangement gives rise to a rising sun type of structure though in this case the difference involved is the presence or absence of the slots 12. Actually we have found in the specific embodiment depicted in Fig. 1 that there are rising sun oscillations at frequencies considerably outside the range of oscillation of either the π -mode of the inner resonant system or the TE_{011} mode of the outer system. Further, this resonant system is independent of the outer cavity resonator. Accordingly, for C. W. operation it need not be of importance as being outside the operating range of the magnetron. However, for pulsed operation it is of importance as it was found to oscillate at both lower frequency and lower voltage. Thus in pulsing the magnetron it is necessary to go through the conditions at which the rising sun structure would oscillate.

In this rising sun structure there is a large amount of energy stored in the slots 12. Therefore, in accordance with an aspect of this invention, operation of the magnetron, when pulsed, in a rising sun mode of oscillation is prevented by placing dissipative rings 54 at the ends of the slots 12 where they can absorb the energy of these rising sun oscillations and thus damp them out. We have found such materials as carbonized alumina, barium titanate and ferrites to be advantageous for the rings 54, but other materials may be employed. By extending the slots 12 beyond the limits of the outer cavity resonator 35 none of the energy present in the outer cavity resonator is dissipated by the rings 54. As pointed out above, it is desirable, in order to force a maximum amount of the current onto the vanes 10, to extend the length of the slots 12 so that these two requirements work together. The rings 54 are coupled to the slots 12 and to the inner resonant system by the long narrow passage ways 53 formed between the pole pieces 15 and 44 and the wall cylinder 11.

The slots 12 may be of any of a large number of shapes. In the embodiment depicted, the slots are relatively thin; they may, however, be as wide as the spacing between adjacent vanes at the wall 11. They may also be of different sizes adjacent the vanes then removed from the vanes in order to assist in forcing the maximum amount of current onto the vanes. Additionally, they may be of different size adjacent the dissipative rings 54 to attain the best impedance matching between the rings and the transmission line defined by the slots 53 between the wall cylinder 11 and the pole pieces.

Thus it is to be understood that various shapes may be devised by those skilled in the art within the scope of this invention to optimize particular characteristics for the particular conditions and frequencies of any embodiment.

Accordingly 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 cylindrical wall member, a plurality of vanes extending inwardly from said wall member and defining inner cavity resonators, a cathode positioned within said vanes, means including said wall member defining an outer cavity resonator encompassing said inner cavity resonators, means for coupling alternate ones of said inner cavity resonators to said outer cavity resonator, said coupling means including axial slots extending through said wall member beyond the ends of said vanes, and means positioned at the ends of said slots for selectively damping unwanted oscillations which cause energy storage in said slots, each of said vanes being approximately a quarter wavelength long at the frequency of said outer cavity resonator.

2. A magnetron in accordance with claim 1 further comprising means for varying the dimensions of said outer cavity to tune said magnetron, the resonant frequency of said inner resonant cavities being outside of the range of frequencies of said outer cavity.

3. A magnetron comprising a cylindrical wall member, a plurality of anode vanes extending inwardly from said wall member and defining cavity resonators, a cathode positioned adjacent said anode vanes, means including said wall member defining an outer cavity resonator encompassing said inner cavity resonators, means for locking a mode of oscillation of said outer cavity resonator to the π mode of oscillation of said inner cavity resonators, said means including axial slots extending through said wall member for coupling alternate ones of said inner cavity resonators to said outer cavity resonator, said slots extending beyond the ends of said vanes and each of said vanes being approximately a quarter wavelength long at the frequency of said outer resonant cavity, and damping elements positioned at the ends of said slots for damping the energy stored in said slots by rising sun modes of oscillation in said inner cavity resonators, said slots extending beyond said outer cavity resonator whereby modes of oscillation of said outer cavity resonator are not affected by said damping elements.

4. A magnetron in accordance with claim 3 further comprising means for loading a degenerate mode of said inner resonant cavities, said means comprising dissipative means positioned in said outer cavity at a current maximum location for the TE mode of said outer cavity to which said degenerate mode is coupled at said wall member.

5. A magnetron in accordance with claim 3 wherein said dissipative means comprises a cylindrical choke section positioned adjacent said wall member at one end of said outer cavity and a dissipative lining for said choke section.

6. A magnetron in accordance with claim 3 further comprising pole pieces positioned within said wall member adjacent said anode vanes, said pole pieces being spaced from said wall member so as to define transmission lines with said wall member between said anode vanes and said damping elements.

7. An electrical circuit comprising an outer cavity resonator sustaining a TE_{011} mode of oscillation and having a cylindrical inner wall, a plurality of cavity resonators within said inner wall, means for locking the

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π mode of oscillation of said plurality of cavity resonators to said TE_{011} mode of said outer cavity resonator, said means including axial slots extending through said outer wall member at alternate ones of said inner cavity resonators, and vanes defining said inner cavity resonators, each of said vanes being approximately a quarter wavelength long at the frequency of said outer cavity resonator, and rings of lossy material adjacent the ends of said slots for loading of unwanted modes of oscillation of said inner cavity resonators only, said unwanted modes being characterized by storage of energy in said slots.

8. An electrical circuit in accordance with claim 7 wherein said slots extend along said wall member beyond said outer resonant cavity, whereby the major portion of the TE_{011} currents flowing circumferentially around said inner wall member are forced into said slots adjacent said vanes.

9. A magnetron comprising a wall member, a plurality of anodes 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 for coupling alternate ones of said anode cavity resonators to said output cavity resonator, said coupling means including slots extending through said wall member, said slots being positioned between said vanes and extending beyond the ends of said vanes and each of said vanes being approximately a quarter wavelength long at the frequency of said output cavity resonator, and dissipative means positioned at the ends of said slots for selectively damping unwanted oscillations which cause energy storage in said slots.

10. A magnetron comprising a wall member, a plurality of vanes extending from 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 for coupling certain of said anode cavity resonators to said output cavity resonator, said coupling means including slots ex-

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tending through said wall member beyond the ends of said vanes, damping means positioned at the ends of said slots for selectively damping unwanted oscillations which cause energy storage in said slots, and means for varying the dimensions of said output cavity resonator to tune said magnetron.

11. An electrical circuit comprising an outer cavity resonator sustaining a TE_{011} mode of oscillation and having an inner wall, means including said inner wall and vanes positioned thereon defining a plurality of inner cavity resonators, means for locking the π mode of oscillation of said plurality of inner cavity resonators to said TE_{011} mode of said outer cavity resonator, said means including slots extending through said outer wall member at alternate ones of said inner cavity resonators, and rings of lossy material adjacent the ends of said slots for loading of unwanted modes of oscillation of said inner cavity resonators only, said unwanted modes being characterized by storage of energy in said slots.

12. A magnetron comprising an inner wall member, a plurality of anodes vanes extending inwardly from said wall member and defining inner cavity resonators, a cathode positioned adjacent said anode vanes, means including said wall member defining an outer cavity resonator, means for locking a mode of oscillation of said outer cavity resonator to the π mode of oscillation of said inner cavity resonators, said means including slots extending through said wall member for coupling alternate one of said inner cavity resonators to said outer cavity resonator, said slots extending beyond the ends of said vanes, damping elements positioned at the ends of said slots for damping the energy stored in said slots by rising sun modes of oscillation in said cavity resonators, and means for varying the dimensions of said outer cavity resonator to tune said magnetron.

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