

March 30, 1965

D. A. WILBUR

3,176,188

MIXED LINES CROSSED FIELDS OSCILLATOR OR AMPLIFIER

Filed Oct. 28, 1960

3 Sheets-Sheet 1

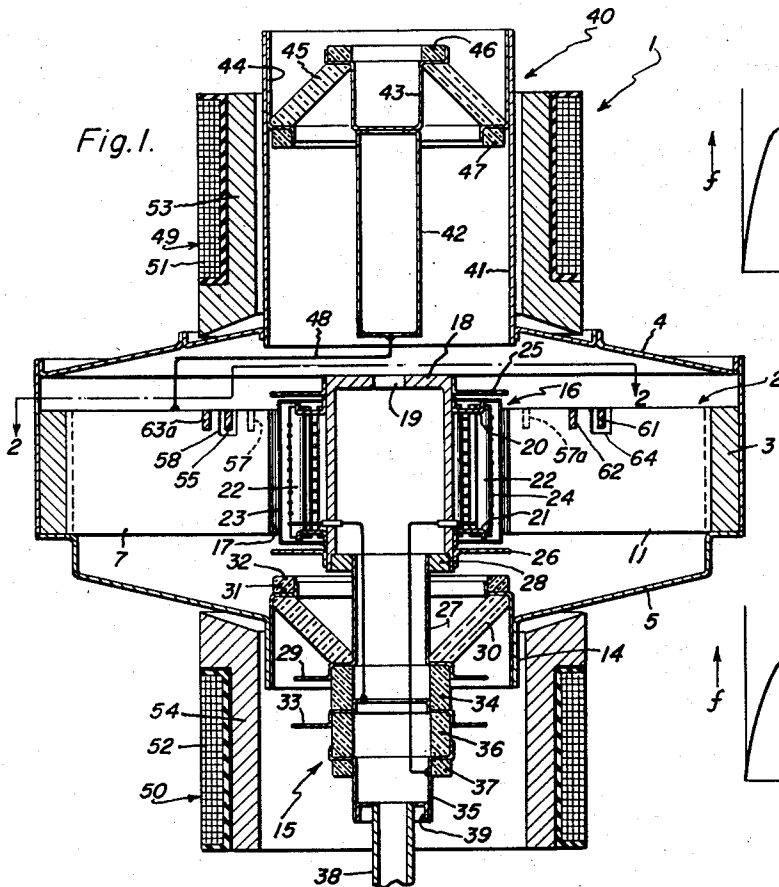


Fig. 1.

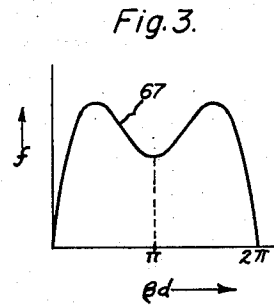


Fig. 3.

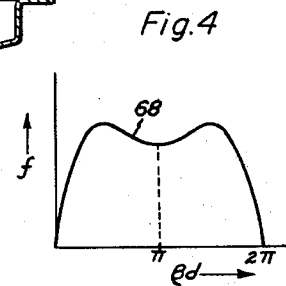


Fig. 4.

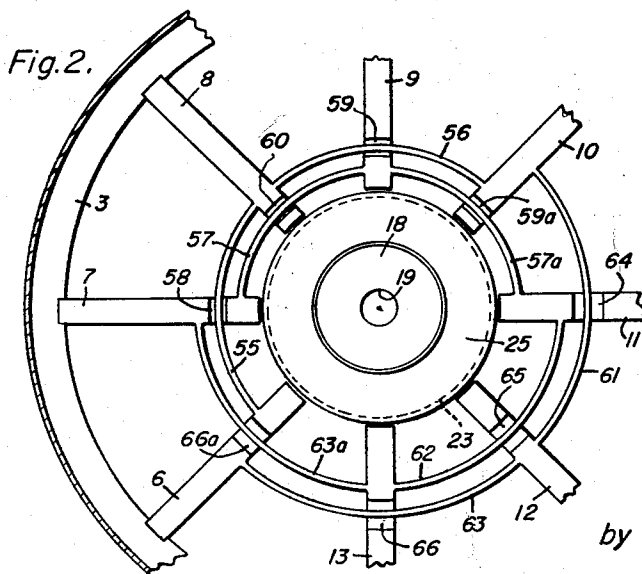


Fig. 2.

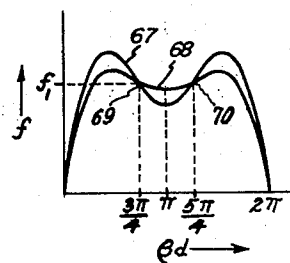


Fig. 5.

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Fig. 6

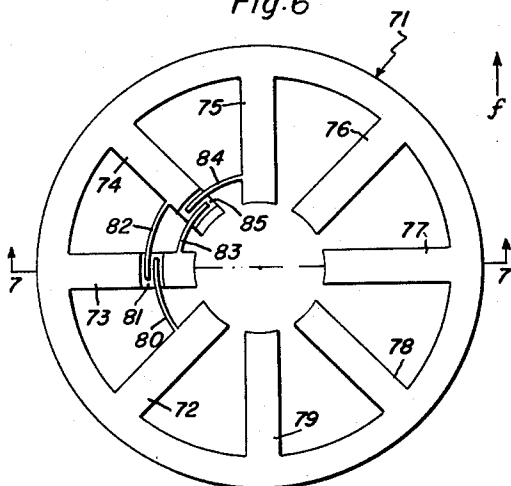


Fig. 7

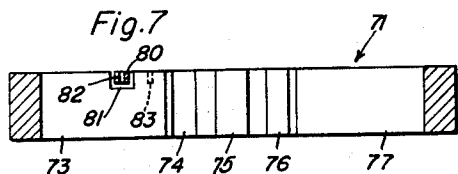


Fig. 11

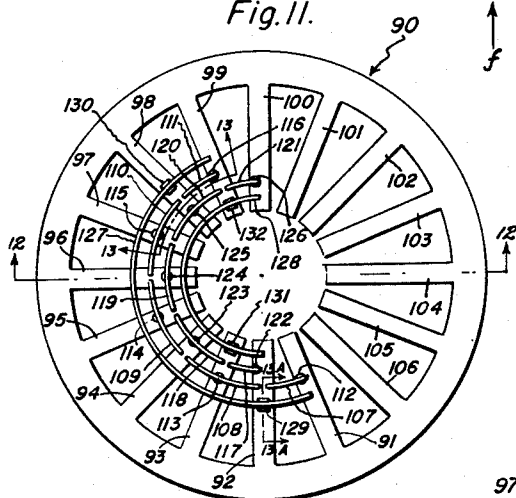


Fig. 12

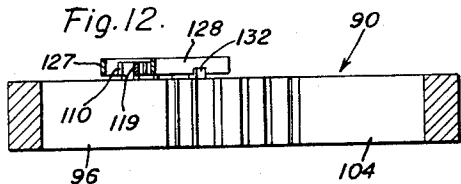


Fig. 9

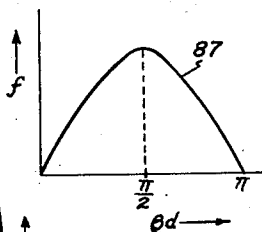


Fig. 8

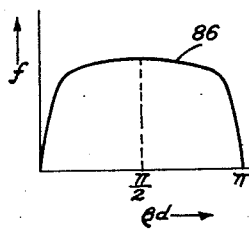


Fig. 10

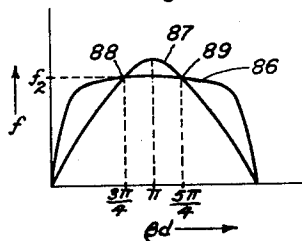


Fig. 15

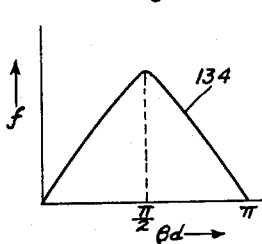


Fig. 14

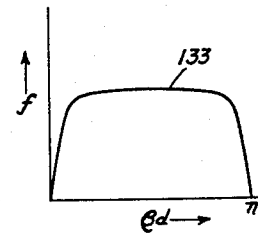


Fig. 13A

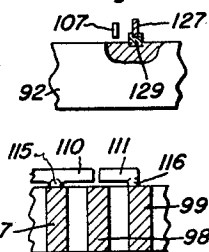
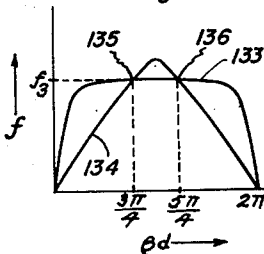


Fig. 13

Fig. 16



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Fig.17

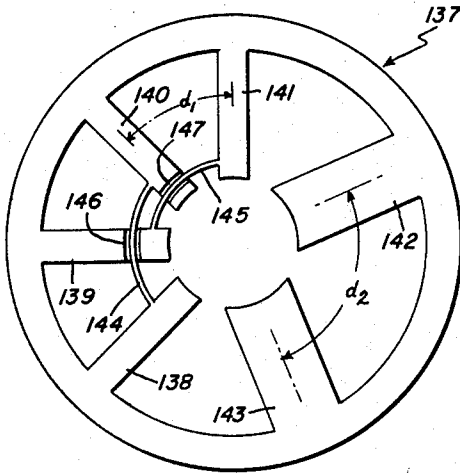


Fig.18.

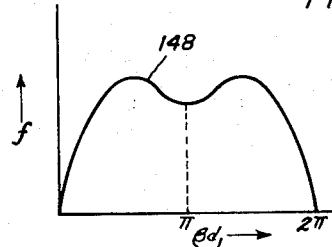


Fig.20.

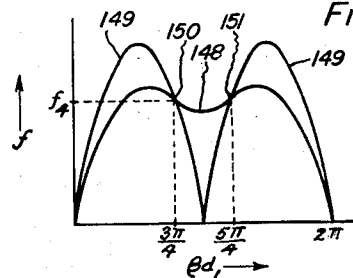


Fig.19.

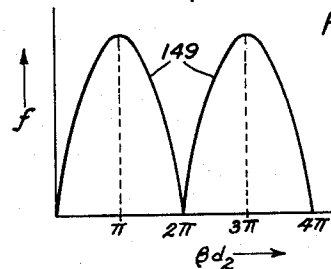


Fig.21.

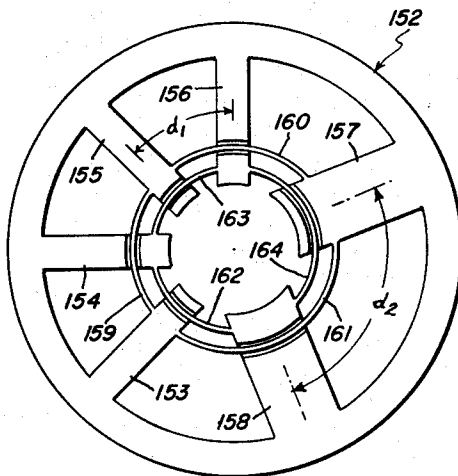


Fig.22.

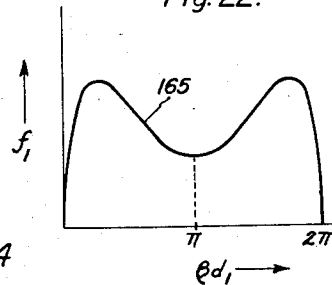


Fig.23.

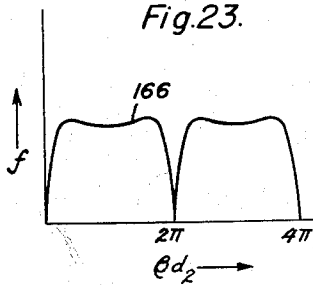
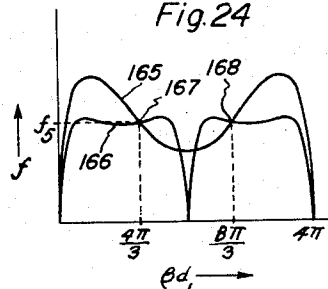


Fig.24



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3,176,188

MIXED LINES CROSSED FIELDS OSCILLATOR OR AMPLIFIER

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Filed Oct. 28, 1960, Ser. No. 65,716

12 Claims. (Cl. 315—39.69)

This invention relates to a magnetron tube apparatus and more particularly to innovations facilitating mode stabilization in the operation of magnetrons.

In general, magnetrons comprise an anode block in which a plurality of resonant cavities are formed in symmetrical arrangement about its circumference and which are separated by partitions called segments or vanes extending from the inner periphery of the anode to an inner radius to terminate in anode tips. A cathode is disposed longitudinally along the tube axis and is equally spaced from the anode tips to form an inter-electrode interaction region therebetween. A positive potential applied to the anode with respect to the cathode establishes a direct electric field between these electrodes and a direct magnetic field is established along the magnetron axis. Thus, crossed electric and magnetic fields exist in the interaction region between cathode and anode. In the operation of the magnetron, electrons are emitted from the cathode to form a beam which travels around the cathode in the interaction region and an electromagnetic wave is propagated along the magnetron anode as a slow wave structure. Under the influence of substantially constant electric and magnetic fields, the beam moves at substantially constant velocity. Effective transfer of energy from the beam to the electromagnetic wave is achieved wherein the wave is propagated uniformly about the magnetron and is in synchronism with the beam. That is, the two travel at the same angular velocity about the magnetron anode. If the two travel at different velocities, synchronism is lost and energy is not transferred from the beam to the wave.

The magnetron anode structure is effective in supporting the propagation of electromagnetic waves in different modes wherein adjacent vane tips assume different instantaneous potential phase relationships with respect to each other. Thus, a wave in one mode may be in synchronism with the beam while the waves in other modes are not. It is a characteristic of magnetrons that operation thereof in different singlet modes necessarily entails operation at different frequencies since the wave length of the energy produced is determined by the phase relationship between anode tips. In the case of doublet anode modes, the magnetron may operate at slightly different frequencies in the same electronic modes since the phase-shift-per-anode-vane is nearly the same in both cases.

Magnetron devices providing high output power at high frequencies have found widespread use for many purposes and in certain of such uses, the load conditions vary widely. In various functions of a magnetron under such varying load conditions, it is important that the magnetron have frequency stability and consequently, also mode stability. Since magnetrons during operation have a tendency to shift to unloaded modes, the problem of mode stabilization under widely varying load conditions is accentuated.

The problem of mode shifting may be considerably lessened by operation of magnetrons in the so-called pi-mode in which adjacent anode tips are in instantaneous 180° phase relationship with respect to each other and to aid in such stabilization, various strapping techniques have been proposed. This mode is a non-doublet mode or in other words, only one frequency satisfies operating conditions in this mode. Accordingly, stabilization of magnetron operation in this mode is somewhat simplified

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over that of other modes and operation of magnetrons in the pi-mode is, therefore, frequently preferred. However, even stabilization of magnetron operation in the pi-mode according to strapped structures heretofore known, presents considerable difficulty, particularly under high or varying load conditions.

Stability of magnetrons and suppression of undesirable modes have been even further accomplished by introducing an asymmetry for these undesirable modes into the strapping system. This may be achieved by strapping the magnetron over less than its entire anode circumference, thus leaving a portion or portions of it unstrapped. In this way, for a desirable pi-mode operation, the resonant frequency and phase-shift-per-anode-vane for the desired frequency are the same for both strapped and unstrapped portions of the anode while for all other modes, these parameters are different for strapped and unstrapped portions of the anode. The undesired modes may be greatly suppressed in accordance with this arrangement because a discontinuity exists for each such undesired mode. To maintain operation in a single undesired mode, the frequency would necessarily alternate between relatively widely separated values. However, even this technique is not fully effective under all conditions and improved stabilization is desirable or required for certain magnetron operations.

Accordingly, it is a principal object of my invention to achieve improved mode and frequency stabilization in magnetron operation, particularly in the pi-mode of operation.

In a magnetron structure wherein the anode is continuous, uniform and re-entrant, it will be resonant at frequencies for which it is an integral number of wavelengths long at the operating frequency. The phase velocity of the wave of electromagnetic energy will be constant and for each mode, the instantaneous phase difference in potential between adjacent vanes will be uniform around the anode although the phase-shift-per-anode-vane at different modes will be different. Power can be generated at each of the mode frequencies. However, the tendency of the magnetron to operate in a single desired mode and at a single frequency may be greatly increased in magnetron structures wherein the anode line comprises a series of effective lines having different frequency to phase-shift-per-anode-vane characteristics for all modes except the desired mode of operation of the magnetron. This is done by establishing a wide separation in frequencies of operation between different portions of the anode.

In accordance with one embodiment of my invention different portions of the anode are strapped and the straps along the different anode portions are positioned at different radii to control the strap lengths and the extent or, in other words, the effectiveness of strapping. The straps at lower radius are more effective in strapping the vanes than straps at a larger radius. The effect of such an arrangement is to establish different frequency versus phase-shift-per-anode-vane characteristics of the different anode portions. At a certain preselected, desired frequency, the phase shift of the electromagnetic wave per unit length of magnetron anode is the same over both portions of the anode and at other frequencies, the phase-shift-per-anode-vane characteristics over the different portions of the anode are different whereby the desired mode is uniformly propagated along all such portions while the undesired modes are propagated non-uniformly, are presented discontinuities and are impeded.

In accordance with another embodiment of my invention, an anode is strapped over only a portion of its circumference and each strap connection is modified by a construction effective to introduce a capacitance in the

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strapping connections which has the effect of producing a greater variation in frequency to phase-shift-per-anode-vane characteristics of the anode. By proper proportioning of elements, the anode line may again be uniform and continuous for the desired mode of operation and non-uniform and discontinuous for undesired modes, to strongly favor operation in the desired mode.

In accordance with another embodiment of my invention a magnetron anode is strapped along a portion of its periphery in a capacitive manner wherein alternate vanes are interconnected and additionally, a pair of conductive rings are mounted in proximity to the respective straps to establish a capacitive coupling between the rings and the closely disposed straps. The effect of such an arrangement is to establish a greater variation in frequency of operation at different values of frequency to phase-shift-per-anode-vane characteristics of the anode.

In accordance with another embodiment of my invention, strapping is provided along only a portion of the anode but along other portions thereof, the spacing between anode segments is increased and the segments themselves are made thicker or, in other words, of greater circumferential dimension. The effect of such an arrangement is again to control the phase velocity and frequency versus phase-shift-per-anode-vane characteristic along the different portions of the anode whereby desired modes are presented regions of uniform phase velocity and are uniformly propagated and undesired modes are presented regions of non-uniform phase velocity and are impeded in their propagation.

In accordance with still another embodiment of my invention, strapping is provided around the entire circumference of the magnetron anode but along a portion of the anode, the spacing between the anode segments is increased and the segments themselves are enlarged in circumferential dimension to alter the phase velocity and phase-shift-per-anode-vane of the wave along this portion of the anode. The phase velocity along the entire anode, however, is the same for a wave of the desired mode while this characteristic is different for unwanted modes whereby the desired mode of operation is strongly favored over unwanted modes.

While the specification concludes with claims particularly pointing out and distinctly claiming the subject matter which I regard as my invention, it is believed that the invention will be better understood from the following description taken in connection with the accompanying drawings in which:

FIGURE 1 is a cross-sectional side view of a magnetron incorporating one embodiment of my invention,

FIGURE 2 represents a view taken along section 2—2 of FIGURE 1, showing an anode block strapped according to one embodiment of my invention,

FIGURE 3 is a graph showing a plot of the frequency of the high frequency wave versus its phase-shift-per-anode-vane along one strapped portion of the anode shown in FIGURES 1 and 2,

FIGURE 4 is a graph showing a plot of the frequency of a high frequency wave versus its phase-shift-per-anode-vane along another strapped portion of the magnetron anode shown in FIGURES 1 and 2,

FIGURE 5 is a graph showing the superposition of the curves of FIGURES 3 and 4,

FIGURE 6 is a top view of an alternative embodiment of magnetron anode according to my invention wherein capacitive strapping of anode vanes is established along a portion of the anode,

FIGURE 7 is a view taken along section 7—7 of FIGURE 6,

FIGURE 8 is a graph showing a plot of the frequency of a high frequency wave versus its phase-shift-per-anode-vane along the unstrapped portion of the anode shown in FIGURES 6 and 7,

FIGURE 9 is a graph showing a plot of the frequency

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of the high frequency wave versus its phase-shift-per-anode-vane along the strapped portion of the magnetron anode shown in FIGURES 6 and 7,

FIGURE 10 is a graph showing the superposition of the curves shown in FIGURES 8 and 9,

FIGURE 11 is a top view of a magnetron anode block according to another embodiment of my invention wherein straps are provided along a portion of the periphery of the anode and capacitive rings radially spaced from the straps introduce uniform capacitance between strapped segments,

FIGURE 12 is a view taken along section 12—12 of FIGURE 11,

FIGURE 13 is a view taken along section 13—13 of FIGURE 11,

FIGURE 13A is a partial view taken along section 13A—13A of FIGURE 11 showing insulating supporting member for a capacitive conductor,

FIGURE 14 is a graph showing a plot of the frequency of a high frequency wave versus its phase-shift-per-anode-vane along the unstrapped portion of the anode shown in FIGURES 11 and 12,

FIGURE 15 is a graph showing a plot of the frequency of the high frequency wave versus its phase-shift-per-anode-vane along the strapped portion of the magnetron anode shown in FIGURES 11 and 12,

FIGURE 16 is a graph showing the superposition of the curves of FIGURES 14 and 15,

FIGURE 17 is a top view of a magnetron anode according to another embodiment of my invention wherein strapping is provided along a fraction of the anode circumference and along another portion the intervane spacing and vane thicknesses are increased,

FIGURE 18 is a graph showing a plot of the frequency of the high frequency wave versus its phase-shift-per-anode-vane along the strapped portion of the anode shown in FIGURE 17,

FIGURE 19 is a graph showing a plot of the frequency of a high frequency wave versus its phase-shift-per-anode-vane along the unstrapped portion of the anode shown in FIGURE 17,

FIGURE 20 is a curve showing the superposition of the curves of FIGURES 18 and 19,

FIGURE 21 is a top view of an anode block according to another embodiment of my invention showing conductive strapping of the entire anode but wherein along one portion of the anode the intervane spacing and vane thicknesses are increased,

FIGURE 22 is a graph showing a plot of the frequency of a high frequency wave versus its phase-shift-per-anode-vane along the portion of the anode block having relatively small intervane spacings,

FIGURE 23 is a graph showing a plot of the frequency of a high frequency wave versus its phase-shift-per-anode-vane along the portion of the anode having relatively large intervane spacings, and

FIGURE 24 is a graph showing the superposition of the curves of FIGURES 22 and 23.

Referring now to FIGURE 1 of the drawings, 1 represents generally an entire magnetron structure embodying an anode 2 according to my invention, the details of which are shown better in FIGURE 2 of the drawings. The anode 2 comprises a block of conductive material such as copper and is enclosed in a chamber formed by a peripheral ring 3 and respective end plates 4 and 5 connected at their outer peripheries, to the ring 3. Anode block 2 is provided with a circular aperture centrally thereof and a plurality of cavities formed by a plurality of vanes at 6, 7, 8, 9, 10, 11, 12 and 13 extending radially inwardly from the ring 3 as shown more clearly in FIGURE 2 of the drawings. Plate 5 is centrally apertured and flanged at 14 to accommodate and support a post 15 on which is mounted a cathode represented in its entirety at 16, disposed in the central aperture of anode 2. The cathode is of a smaller radius than the anode aper-

ture to establish an annular interaction region 17 between the cathode and inner tips of the adjacent anode vanes.

Cathode 16 includes a hollow thimble shaped member 18 apertured at 19 to establish convection communication with the interior of the magnetron. A pair of outwardly projecting rings 20 and 21 are secured near respective ends of member 18 and are provided with axially aligned notches to accommodate insulating columns 22. A hollow cathode emissive member having its outer surface 23 facing the anode coated with a suitable electron emission enhancing material is also supported on the rings 20 and 21. For heating cathode surface 23 to a temperature of copious electron emission, a resistive wire 24 responsive to an electrical current for producing heat is wound spirally about the columns 22 as a group. The electrons emitted by surface 23 are axially confined in the interaction region 17 by end hats 25 and 26 extending radially from respective ends of member 18 to a radius just less than that of the anode aperture to allow for insertion and removal of the cathode.

Post 15 includes a tubular, conductive member 27 having one end connected through a conductive ring 28, to one end of member 18. The other end of member 27 terminates in a stepped flange 29 which provides an external electrical terminal for the cathode. For establishing mechanical and electrical insulating support for the member 27, a hollow, frusto-conical ceramic member 30 has one end secured in abutment with flange 29 and its other end in abutment with a radial, inward flange 31 of a tubular member secured to flange 14. For imparting rigidity and support to the flange 31, a ceramic ring 32 is secured to the flange on the side of it opposite to member 30. For establishing external electrical connections to the ends of heater wire 24, an annular flanged conductive member 33 forming one external terminal, is supported in insulated relationship to member 27 by an annular insulator 34 secured to members 27 and 33 and a flanged, tubular, conductive member 35 is supported in insulated relation to member 33 by an annular insulator 36. The ends of the heater wire are connected to these members as shown. The junction of member 35 to the insulator 36 is strengthened by an annular insulator 37 secured to the side of the flange remote from insulator 36. A tubulation 38 is secured to the exterior end of member 35 by connection between a folded-back flange 39 of the tubulation and the inner part of the member 35. Although shown broken away, the tubulation which facilitates evacuation of the interior of the magnetron is hermetically sealed after such evacuation.

For providing an output line for the magnetron, a co-axial line 40 is provided and includes an outer conductor 41 and an inner conductor 42. Outer conductor 41 is disposed in the aperture of plate 4 and is secured thereto. For mounting inner conductor 42 centrally along the interior of conductor 41, a flanged thimble shaped supporting member 43 and a flanged tubular member 44 with a rigid, hollow, frusto-conical insulator 45 in abutment with the flanges of these members are provided. Rigidity and strength is imparted to the structure by ceramic insulators 46 and 47 bonded on the sides of the flanges opposite to the ends of member 45. The inner conductor 42 is connected to a point on one end of vane 7 of the magnetron anode block through a line 48 to facilitate conduction of output power from the magnetron.

A direct magnetic field is established axially along the interaction region by opposed electromagnets 49 and 50 having respective coils 51 and 52 and respective cores 53 and 54 at opposite ends of the magnetron.

In accordance with my invention the anode 2 is provided with conductive straps interconnecting alternate vanes of the anode. These straps are shown more clearly in FIGURE 2 of the drawings wherein 55 represents a conductive strap interconnecting vanes 6 and 8, 56 is a conductive strap interconnecting vanes 8 and 10, 57 is

a conductive strap interconnecting vanes 7 and 9, 57a is a conductive strap interconnecting vanes 9 and 11. Each of the straps 55, 56, 57 and 57a is capacitively coupled to the vane which is intermediate to the vanes to which it is connected. Thus, strap 55 passes through a groove 58 in vane 7 in relative close proximity thereto, strap 56 passes through groove 59 in vane 9 in similar manner, strap 57 passes through groove 60 in vane 8, and strap 57a passes through groove 59a in vane 10. These straps establish strapping over one-half of the magnetron anode circumference and along the other half of the magnetron circumference, a group of 4 straps, 61, 62, 63 and 63a interconnect respective pairs of vanes 10 and 12, 11 and 13, 12 and 6 and 13 and 7. These respective straps are accommodated by grooves 64 in vane 11, 65 in vane 12, 66 in vane 13 and 66a in vane 6. In each of these cases the strap is in relative close proximity to the vane having the groove for accommodating the strap so as to establish a capacitive coupling between this vane and the two vanes to which the strap is directly connected.

In accordance with a feature of my invention, the straps 61, 62, 63 and 63a are disposed at a greater radius from the magnetron axis than the corresponding straps 55, 56, 57 and 57a. Also the grooves 64, 65, 66 and 66a are wider than grooves 58, 59, 60 and 59a so that the capacitive coupling between these and the vanes through which they pass is decreased. In accordance with known magnetron principles, the effect of strapping a magnetron along a greater radius is to lessen the effectiveness of such strapping. That is, the greater the radius at which the straps are positioned, the lower the coupling between the vanes to which they are attached and the lower the coupling between adjacent cavities. Accordingly, the characteristics of frequency versus phase-shift-per-anode-vane are different along the respective halves of the magnetron anode. This is represented by the curves 67 and 68 in FIGURES 3 and 4 respectively, of the drawing.

In FIGURES 3 and 4 the ordinates represent the frequency of a wave propagated along the magnetron anode and the abscissas represent the phase-shift-per-anode-vane along the anode of the electromagnetic wave. The curves 67 and 68 thus represent the variation of frequency with respect to phase-shift-per-anode-vane of the electromagnetic wave along the respective halves of the magnetron anode and the effect of the position of the straps is indicated by the greater dip in curve 67 at a phase-shift-per-anode-vane of pi-radians than that of curve 68. In FIGURE 5 the curves 67 and 68 are superimposed and it is to be observed that the curves have points of intersection 69 and 70. Accordingly, an electromagnetic wave of frequency f_1 , and a phase-shift-per-anode-vane of $3\pi/4$ corresponding to the point 69 is propagated with equal velocity along the two halves of the magnetron anode. The point 70 is a space harmonic of this wave and has a phase-shift-per-anode-vane of $5\pi/4$. At each other value of phase-shift-per-anode-vane, the frequency of operation along the magnetron halves is different as observed by the spacing of the waves 69 and 70. Thus, electromagnetic waves at these frequencies and values of phase-shift-per-anode-vane are impeded and not propagated uniformly about the anode.

It is to be noted that in accordance with my invention the magnetron may be made to operate with stability at a number of different frequencies which are determinable by the points of intersection of curves such as 67 and 68. Also, it should be observed that the shape of curves 67 and 68 is affected by the vane strapping and in particular by the radial position of the straps along the magnetron anode. Thus, in accordance with this feature of my invention, the frequency of stable operation of a magnetron may be readily controlled and curves 67 and 68 may be made to coincide at several different values of phase-shift-per-anode-vane at which a wave may be propagated about the magnetron anode.

Referring now to FIGURE 6 of the drawing illustrat-

ing another embodiment of my invention, 71 represents an entire magnetron anode similar to the anode 2 shown in FIGURES 1 and 2 and having vanes 72 through 79. A portion of the anode circumference is capacitively strapped and in accordance with a particular feature of this embodiment of my invention, comprises bi-partite straps between two pairs of alternate vanes. Specifically, a conductive strap member 80 extends from conductive contact with vane 72 circumferentially to a point within a groove 81 in vane 73 and another strap member 82 extends from conductive contact with vane 74 circumferentially to another point within groove 81. The members 80 and 82 are in overlapping relation and spaced from each other so as to establish a capacitive coupling therebetween. Also each of these straps is in spaced, but proximate relation to the vane 73 to also establish capacitive coupling between each of the vanes 72 and 74 and the vane 73. In a similar manner a pair of strap members 83 and 84 extend respectively from vanes 73 and 75 to points within groove 85 in vane 74 and are in overlapping relation with respect to each other so as to establish capacitive coupling between vanes 73 and 74, 73 and 75, and 74 and 75. The portion of the magnetron extending circumferentially from vane 75 clockwise to vane 72 is unstrapped.

The propagation characteristics of the respective unstrapped and strapped portions of the magnetron anode 71 are shown in FIGURES 8 and 9, respectively. In FIGURES 8 and 9 the ordinates represent the frequency of an electromagnetic wave propagated along the anode and the abscissas represent the phase-shift-per-anode-vane of the wave about the magnetron anode. The curve 86 in FIGURE 8 represents the propagation characteristics along the unstrapped portions of anode 71 and the curve 87 in FIGURE 9 represents the propagation characteristics along the strapped portion. It is to be observed from curve 87 that in this embodiment of my invention, the effect of the capacitive strapping is to make the curve of propagation characteristics peaked. As shown in FIGURE 10 of the drawings, illustrating the superposition of curves 86 and 87, points of coincidence 88 and 89 of the curves establish values of frequency and phase-shift-per-anode-vane at which the magnetron would be stable in operation. That is to say, that for frequency f_2 and a phase shift of $3\pi/4$ an electromagnetic wave will propagate uniformly about the magnetron anode. A space harmonic at this same frequency would be propagated at a phase-shift-per-anode-vane of $5\pi/4$. At all other frequencies the magnetron anode 71 presents discontinuities and these frequencies are not uniformly propagated so as to interact favorably with the beam. Accordingly, this embodiment of my invention comprises an alternate arrangement for providing mode stabilization of the magnetron anode.

In accordance with another embodiment of my invention shown in FIGURE 11 of the drawings, enhanced capacitive coupling between vanes may be achieved to produce an even sharper peak of the curve of frequency versus phase-shift-per-anode-vane characteristic. In FIGURE 11, the anode 90 is provided with sixteen vanes numbered consecutively from 91 through 106. In accordance with a feature of this embodiment of my invention, the portion of the anode from vane 91 clockwise to vane 99 is provided with a plurality of arcuate strap elements 107, 108, 109, 110 and 111 extending along arcs of the same circle. The strap elements are circumferentially spaced from each other and successive ones are connected to alternate vanes as represented by the solid enlarged dots 112, 113, 114, 115 and 116 connecting strap elements 107, 108, 109, 110 and 111 to respective vanes 91, 93, 95, 97 and 99. The respective strap elements terminate above the vane located between the vanes connected to the different strap elements along this portion of the anode.

In a manner similar to that described, capacitive strap-

ping is provided between the alternate vanes along the portion of the anode from vane 92 clockwise to vane 100 by a plurality of strapped segments numbered 117, 118, 119, 120 and 121 extending along arcuate portions of the same circle and being spaced circumferentially from each other. These segments are connected respectively to vanes 92, 94, 96, 98 and 100 as represented by the enlarged dots shown at 122, 123, 124, 125 and 126. The interconnection between strap elements and vanes and the relationship between strapped segments is shown more clearly in FIGURE 13 of the drawings representing a view taken along section 13-13 of FIGURE 11. In this figure, it is observed that the strap elements are axially spaced but in relatively close proximity to the vanes of the magnetron to which they are not connected to establish a significant capacitance therebetween.

In accordance with another feature of this embodiment of my invention, the capacitance between any one strap element and other strap elements along the circle of the same radius is increased by a conductive arcuate member extending in close proximity to each of the strapped elements and preferably along the arc of a circle concentric with that of the strapped elements. Thus, the conductive member 127 extends from a point above vane 91 arcuately to a point above vane 99 so as to be circumferentially coextensive with the strapped arrangement including straps 107 through 111. The close spacing between member 127 and each of these strapped segments establishes a capacitive coupling between the member and each of these segments and therefor also between any one of these segments and any one other of these segments. Similarly, conductive member 128 extends from a point above vane 92 to a point above vane 100 so as to be in proximity to and circumferentially coextensive with the strap elements 117 through 121. The conductive members 127 and 128 may be supported in axially spaced relation to the vanes by insulating members as shown at 129 and 130 between member 127 and respective vanes 92 and 98 and insulating members 131 and 132 disposed between member 128 and vanes 93 and 99, respectively. These insulating members are shown in FIGURE 11 and insulator 129 is shown in detail in FIGURE 13A.

In accordance with the invention shown in FIGURE 11 of the drawing the portion of the anode which is unstrapped has a frequency versus phase-shift-per-anode-vane propagating characteristic as shown at 133 in FIGURE 14 of the drawings and the propagating characteristic along the strapped portion of the anode is as shown at 134 in FIGURE 15 of the drawings. In each of these figures the ordinate represents the frequency of the propagated wave while the abscissa represents the phase-shift-per-anode-vane. It should be observed that by reason of the increased capacitance between strapped elements established by the conductive members 127 and 128, the curve 134 is more peaked than curve 87 shown in FIGURE 9 of the drawings and thus, the strapping arrangement of FIGURE 11 is advantageous in providing increased capacitive strapping in situations wherein it is desirable.

In FIGURE 16 is shown the superposition of curves 133 and 134. At point 135 these curves intersect to designate a frequency f_3 and phase-shift-per-anode-vane of $3\pi/4$ at which the respective strapped and unstrapped portions of the magnetron anode propagate with equal facility. That is to say, the electromagnetic wave having the frequency f_3 and being propagated in the mode of $3\pi/4$ radians per vane is propagated uninhibited around the magnetron anode while all other frequencies are presented discontinuities and therefore are greatly inhibited. A space harmonic is also readily propagated at frequency f_3 indicated by the intersection of these curves at 136 but which has a phase-shift-per-anode-vane of $5\pi/4$ radians.

In accordance with still another embodiment of my invention as shown in FIGURE 17 of the drawings, a magnetron anode represented generally at 137 is provided

with a plurality of vanes such as shown at 138, 139, 140 and 141 which are of substantially the same dimensions and spaced uniform distances d_1 over a portion of the circumference of the anode and a pair of further vanes 142 and 143 are provided along the remaining portion of the anode circumference. In accordance with a feature of my invention the vanes 142 and 143 are circumferentially spaced from each other at a distance d_2 , substantially twice the spacing of the vanes 138 and 139 from each other. Also, the thickness of each of the vanes 142 and 143 is substantially twice the thickness of any of the vanes 138 through 141. Along the portion of the anode having the narrow vanes 138 through 141, a conventional strapping arrangement is provided by a pair of straps 144 and 145 interconnecting respective pairs of vanes 138 and 140, 139 and 141. Appropriate grooves 146 and 147 in respective vanes 139 and 140 are provided to accommodate the respective straps 144 and 145.

In accordance with this embodiment of my invention, the propagation characteristics of an electromagnetic wave traveling along the portion of the anode having the strapped vanes is represented by the curve 148 in FIGURE 18 of the drawings wherein the ordinate represents the frequency of the wave and the abscissa represents the phase-shift-per-anode-vane along this portion. It is observed from this curve that it represents a conventional condition of strapping wherein the curve is depressed at a phase-shift-per-anode-vane of π radians and is peaked at phase shift values between zero and π radians and between π and 2π radians.

As shown in FIGURE 19 of the drawings, the propagation characteristics of an electromagnetic wave along the portion of the anode having enlarged vanes subtending angles twice as large as the angles subtended by vanes along the strapped portion and the spacings is as represented by the curve 149 and wherein the ordinate represents the frequency of the wave and the abscissa represents the phase-shift-per-anode-vane along this second portion. It is observed that in this figure of the drawings the curve is peaked at a value of π and 3π radians phase-shift-per-anode-vane.

In FIGURE 20 of the drawings the curves 148 and 149 have been superimposed using the βd_1 scale for the abscissa at the points 150 and 151. Since the phase shift of the electromagnetic wave per unit length around the strapped portion of the magnetron is the same as that along the unstrapped portion, the phase shift of the wave is twice as great along the unstrapped portion as it is along the strapped portion. Thus, in the superimposed positions in FIGURE 20 curve 149 is shown for 4π radians on the βd_2 scale while the curve 148 is shown for merely 2π radians on the βd_1 scale. At point 150, an electromagnetic wave of frequency f_4 and having a phase-shift-per-anode-vane along the strapped portion of the anode equal to $3\pi/4$ radians and a phase-shift-per-anode-vane of $6\pi/4$ radians along the unstrapped portion of the anode is propagated uninhibited. That is, this wave is presented no discontinuity and travels with equal facility along each section of the anode. Also, a space harmonic of this wave at the same frequency and having a phase shift per vane of $5\pi/4$ radians represented by the point 151 may also be propagated uninhibited along the magnetron anode. At all other frequencies which are space harmonics of frequency f_4 the electromagnetic waves are presented discontinuities about the magnetron anode and therefore are not propagated.

In accordance with still another embodiment of my invention shown in FIGURE 21 of the drawings, the magnetron anode as represented at 152 may be constructed as is the anode 137 in FIGURE 17 of the drawings with the addition of straps along the portion of the anode which is unstrapped in FIGURE 17. Thus, the anode 152 is provided with vanes 153, 154, 155 and 156 of predetermined thickness and adjacent spacing d_1 and with additional vanes 157 and 158 which are spaced from each

other a distance d_2 , substantially twice the intervane spacing of vanes 153 and 154, for example, and each of the vanes 157 and 158 is substantially twice as thick in a circumferential direction as any one of the vanes 153 through 156. The entire anode block is strapped by straps 159, 160 and 161 disposed along one radius and interconnecting respective pairs of vanes 153 and 155, 155 and 157, and 157 and 163. Also, straps 162, 163 and 164 disposed at another radius are provided to interconnect respective pairs of vanes 158 and 154, 154 and 156, and 156 and 158, respectively.

FIGURES 22 and 23 represent the propagation characteristics of electromagnetic waves along the respective portions of anode 152 from vane 153 to vane 156 and from vane 157 to vane 158, both taken in a clockwise direction in FIGURE 21. In these figures the ordinate represents the frequency of an electromagnetic wave and the abscissa represents the phase-shift-per-anode-vane. In FIGURE 22 the curve 165 shows that the propagation characteristics along the narrow vane portion of the anode is very peaked at values between zero and π radians and between π and 2π radians and in FIGURE 23 the curve 166 shows that the propagation characteristics along the wide vane portion of the anode is considerably less peaked between zero and π and between π and 2π radians. In FIGURE 24, the curves 165 and 166 are superimposed on the same scale and intersect at the points 167 and 168 at each of which the propagation characteristics along the respective portions of the anode are the same. Thus, at a frequency f_5 corresponding to these points waves having phase-shifts-per-anode-vane of approximately $4\pi/3$ or $8\pi/3$ radians per vane distance d_1 , are propagated with equal facility and uninhibited about the entire magnetron anode. At other frequencies which are not space harmonics of this frequency the electromagnetic waves are not propagated uniformly.

It is also within the purview of my invention to provide a magnetron anode as shown in either of FIGURES 17 or 21 of the drawings but without any straps between any of the vanes. In such an embodiment, the intervane spacings and vane widths would be uniform along one portion of the anode to establish a first propagating characteristic of frequency versus phase-shift-per-anode-vane and along the other portion of the anode a second propagating characteristic of frequency versus phase-shift-per-anode-vane is established. The characteristics may be so interrelated as to have a pair of values of frequency and phase-shift-per-anode-vane which are the same for each portion to support propagation of a wave around the entire anode at these values and to inhibit propagation of waves at all other values except space harmonics. Thus, mode stabilization may again be achieved in accordance with this technique.

While the present invention has been described by reference to particular embodiment thereof, it will be understood that numerous modifications may be made by those skilled in the art without actually departing from the invention. I, therefore, aim in the appended claims to cover all such equivalent variations as come within the true spirit and scope of the foregoing disclosure.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A magnetron anode comprising a hollow conductive structure having a plurality of spaced conductive segments extending inwardly from the inner wall of said structure defining an anode circuit between each adjacent pair of segments, means providing an electron beam adjacent the ends of said conducting segments including means subjecting said beam to crossed electric and magnetic fields to establish motion of said electron beam to provide high frequency excitation of said anode structure, means including conductive members establishing a predetermined capacitive coupling between alternate segments along a portion of said anode to provide a predetermined frequency versus phase shift per anode seg-

ment characteristic for said portion of said anode and means including conductive members establishing an electrical coupling different from said predetermined coupling between alternate segments along another portion of said anode to provide a different frequency versus phase shift per anode segment characteristic which intersects said first characteristic so that stable operation is attained for a frequency corresponding to the intersection of said frequency versus phase shift per anode segment characteristics, each of said anode portions including at least two adjacent anode circuits.

2. A magnetron anode comprising a hollow conductive structure having a plurality of convergent conductive segments extending inwardly from the inner wall of said structure defining an anode circuit between each adjacent pair of segments, means providing an electron beam adjacent the ends of said conducting segments including means subjecting said beam to crossed electric and magnetic fields to establish motion of said electron beam to provide high frequency excitation of said anode structure, means including conductive members establishing a predetermined capacitive coupling between alternate segments along a portion of said anode to provide a predetermined frequency versus phase shift per anode segment characteristic for said portion of said anode and means including conductive members establishing an electrical coupling different from said predetermined coupling between alternate segments along another portion of said anode to provide a different frequency versus phase shift per anode segment characteristic which intersects said first characteristic so that stable operation is attained for a frequency corresponding to the intersection of said frequency versus phase shift per anode segment characteristics, each of said anode portions including at least two adjacent anode circuits.

3. A magnetron anode comprising a hollow conductive structure having a plurality of spaced conductive segments extending inwardly from the inner wall of said structure, means establishing a predetermined electrical coupling between alternate segments along a portion of said anode and including a pair of conductive members associated with three successive ones of said segments, the first of said pair of conductive members being directly connected only to the first of said successive segments, the second of said pair of conductive members being directly connected only to the third of said successive segments, said pair of conductive members extending across the spaces between said successive segments into spaced capacitive relation with each other and with the second of said successive segments to provide a capacitive coupling between said members and the segments therebetween.

4. A magnetron anode comprising a hollow cylindrical conductive structure having a plurality of convergent, conductive segments extending inwardly from the inner wall of said structure, conductive members interconnecting alternate segments along a portion less than the total anode circumference having interruptions in each of said conductive members between said interconnected alternate segments for introducing a capacitance in said conductive connections.

5. A magnetron anode comprising a hollow circular, conductive structure having a plurality of convergent, conductive segments extending inwardly from the inner wall of said structure defining an anode circuit between each adjacent pair of segments, means providing an electron beam adjacent the ends of said conducting segments including means subjecting said beam to crossed electric and magnetic fields to establish motion of said electron beam to provide high frequency excitation of said anode structure, means establishing a predetermined capacitive coupling between alternate segments along a portion of said anode and between each of said alternate segments and the segments therebetween and cooperating therewith to provide a predetermined frequency versus phase shift

per anode segment characteristic for said portion of said anode, said means including conductive members connected to respective ones of said alternate segments and being in spaced proximate overlapping relation with each other and further being in spaced proximate relation to the segment between said alternate segments along a portion of said anode the remaining portion of said anode having a different coupling between said anode segments to provide a different frequency versus phase shift for anode segment characteristic which intersects said first characteristic so that stable operation is attained for a frequency corresponding to the intersection of said frequency versus phase shift per anode segment characteristics, each of said anode portions including at least two adjacent anode circuits.

6. A magnetron anode comprising a hollow conductive structure having first and second pluralities of convergent, conductive segments of uniform length extending inwardly from the inner wall of said structure defining an anode circuit between each adjacent pair of segments, means providing an electron beam adjacent the ends of said conducting segments including means subjecting said beam to crossed electric and magnetic fields to establish motion of said electron beam to provide high frequency excitation of said anode structure, the thickness of the first plurality of segments along one portion of said anode each being of a first predetermined value and the spacing between each pair of adjacent segments along said portion being of a second predetermined value, the thickness of each of the segments along another portion of said anode being different from said first predetermined value and the spacing between segments along said other portion being of a value different from said second predetermined value, and conductive means interconnecting alternate segments along said one portion and establishing a capacitive coupling therebetween and cooperating therewith to provide a predetermined frequency versus phase shift per anode segment characteristic for said one portion of said anode, said other portion of said anode having a different coupling between said anode segments to provide a different frequency versus phase shift per anode segment characteristic which intersects said first characteristic so that stable operation is attained for a frequency corresponding to the intersection of said frequency versus phase shift per anode segment characteristics, each of said anode portions including at least two adjacent anode circuits.

7. A magnetron anode comprising a hollow conductive structure having a plurality of convergent conductive segments of uniform length extending inwardly from the inner wall of said structure, defining an anode circuit between each adjacent pair of segments, means providing an electron beam adjacent the ends of said conducting segments including means subjecting said beam to crossed electric and magnetic fields to establish motion of said electron beam to provide high frequency excitation of said anode structure, the segments along a portion of said anode being of a substantially uniform predetermined thickness and adjacent segments along said portion being of a predetermined spacing, the segments along another portion of said anode having a thickness substantially twice said predetermined thickness and the spacing between adjacent segments along said other portion being substantially twice said predetermined spacing, and means establishing a capacitive coupling between alternate segments along said one portion of said anode and cooperating therewith to provide a predetermined frequency versus phase shift per anode segment characteristic for said portion of said anode, said other portion of said anode having a different frequency versus phase shift per anode segment characteristic which intersects said first characteristic so that stable operation is attained for a frequency corresponding to the intersection of said frequency versus phase shift per anode segment charac-

teristics, each of said anode portions including at least two adjacent anode circuits.

8. A magnetron anode comprising a hollow conductive member having a plurality of convergent conductive segments of substantially uniform length extending inwardly from the inner wall of said structure, defining an anode circuit between each adjacent pair of segments, means providing an electron beam adjacent the ends of said conducting segments including means subjecting said beam to crossed electric and magnetic fields to establish motion of said electron beam to provide high frequency excitation of said anode structure, the segments along a portion of said anode being of a substantially uniform predetermined thickness and adjacent segments along said portion being of a predetermined spacing, the segments along another portion of said anode having a thickness substantially twice said predetermined thickness and the spacing between adjacent segments along said other portion being substantially twice said predetermined spacing, and means establishing a capacitive coupling between alternate segments of said anode said different portions of said anode having different frequency versus phase shift per anode segment characteristics which intersect so that stable operation is attained for a frequency corresponding to the intersection of said frequency versus phase shift per anode segment characteristics, each of said anode portions including at least two adjacent anode circuits.

9. A magnetron anode comprising a hollow conductive member having a plurality of spaced, conductive segments extending inwardly from the inner wall of said structure, means establishing an electrical coupling between alternate segments along a portion of said anode and including a plurality of coplanar conductive members, one of said members being connected to each of said segments and terminating in spaced proximity to each of the segments adjacent thereto, the plane of said members being transverse to the axis of said anode, further conductive means coplanar with said members and disposed in spaced proximity to each of said first mentioned conductive means for establishing a capacitive coupling between alternate segments along said portion of said anode.

10. A magnetron anode comprising a hollow conductive member having a plurality of convergent, conductive segments extending inwardly from the inner wall of said structure, means establishing an electrical coupling between alternate segments along a portion of said anode and including a first plurality of coplanar conductive members connected to alternate segments along said portion and terminating in spaced proximity to adjacent segments, the plane of said members being transverse to the axis of said anode, a second plurality of conductive members coplanar with said first plurality and conductively connected to different alternate segments along said portion and extending into spaced proximity to adjacent segments, a first conductor coplanar with said members and disposed in spaced relationship with each of said first plurality of conductive members for establishing a capacitive coupling between each of said first plurality of conductive members and each other thereof, a second conductor coplanar with said members and extending in spaced proximity to said second plurality of conductive members

for establishing a capacitive coupling between each of said second plurality of conductive members and each other thereof.

11. A magnetron device comprising an anode structure including a plurality of spaced conductive anode segments joined at one end to a conducting structure defining an anode circuit between each adjacent pair of segments, means providing an electron beam adjacent the opposite ends of said conducting segments including means subjecting said beam to crossed electric and magnetic fields to establish motion of said electron beam to provide high frequency excitation of said anode structure, conductive means connected to alternate anode segments establishing capacitive coupling over one portion of said anode and cooperating therewith to provide a predetermined frequency versus phase shift per anode segment characteristic for said portion of said anode, the remaining portion of said anode having a different coupling between said anode segments to provide a different frequency versus phase shift per anode segment characteristic which intersects said first characteristic so that stable operation is attained for a frequency corresponding to the intersection of said frequency versus phase shift per anode segment characteristics, each of said anode portions including at least two adjacent anode circuits.

12. A magnetron device comprising an anode structure including a plurality of spaced radially conductive anode segments joined at one end to a surrounding conducting structure defining a central opening at the opposite ends thereof, said anode structure further defining an anode circuit between each adjacent pair of segments, means providing an electron beam adjacent the inner ends of said conducting segments including means subjecting said beam to crossed electric and magnetic fields to establish motion of said electron beam to provide high frequency excitation of said anode structure, conductive means connected to alternate anode segments establishing capacitive coupling over one portion of said anode and cooperating therewith to provide a predetermined frequency versus phase shift per anode segment characteristic for said portion of said anode, a second portion of said anode having a different coupling between said anode segments to provide a different frequency versus phase shift per anode segment characteristic which intersects said first characteristic at equally spaced points on opposite sides of π radians phase shift per anode segment so that stable operation is attained for a frequency corresponding to the intersections of said frequency versus phase shift per anode segment characteristics.

References Cited by the Examiner

UNITED STATES PATENTS

2,408,235	9/46	Spencer	315—39.69	X
2,444,418	7/48	Bondley	315—39.69	X
2,504,329	4/50	Heising	315—39.69	
2,582,185	1/52	Willshaw	315—39.69	X
2,607,019	8/52	Dodds	315—39.69	
2,721,295	10/55	Posthumus	315—39.69	X
2,808,538	10/57	Cutler	315—39.69	X

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