Feb. 18, 1964 D. A. WILBUR 3,121,820

SINGLE MODE AMPLIFIER OR OSCILLATOR

Filed Oct. 28, 1960 2 Sheets-Sheet 1

Fig. 1.

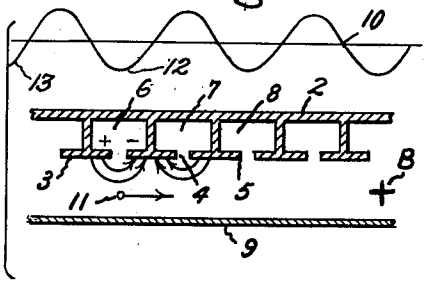


Fig. 2.

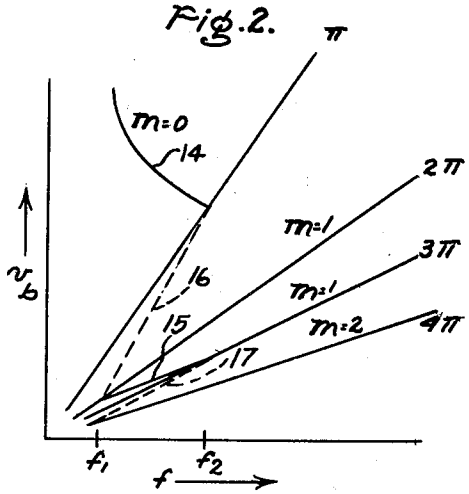


Fig. 3.

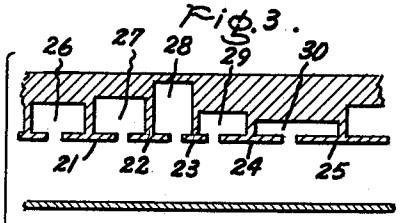
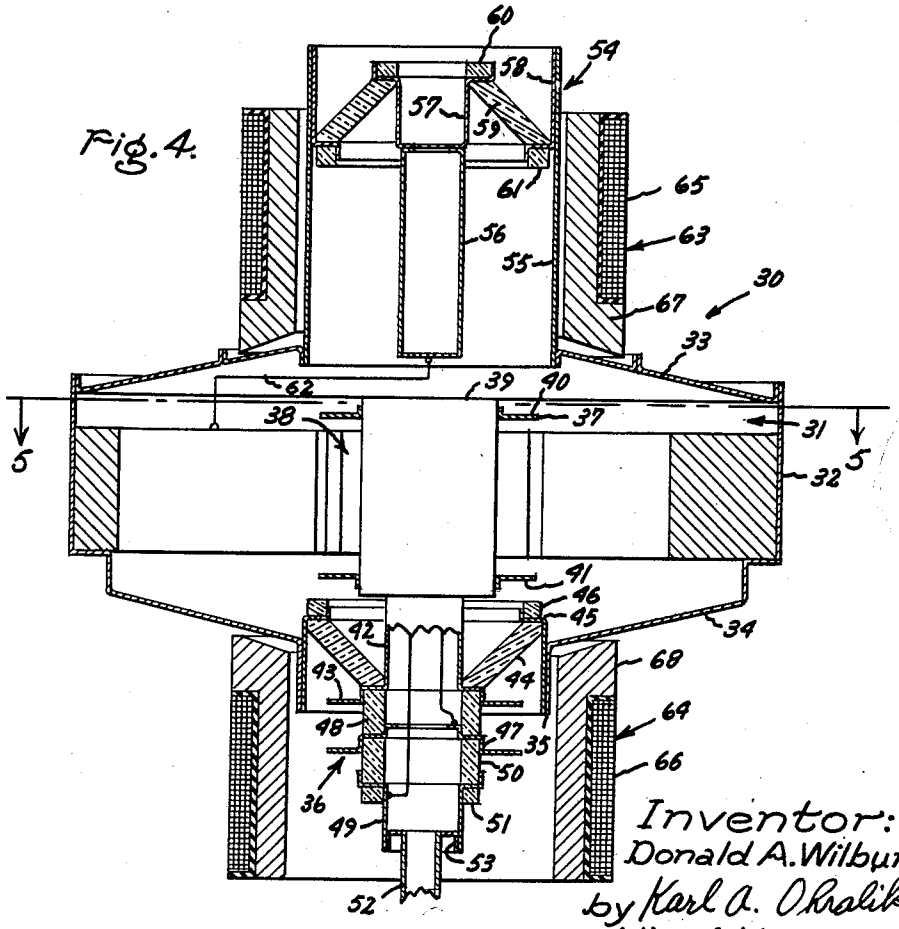


Fig. 4.



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SINGLE MODE AMPLIFIER OR OSCILLATOR

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Fig. 5

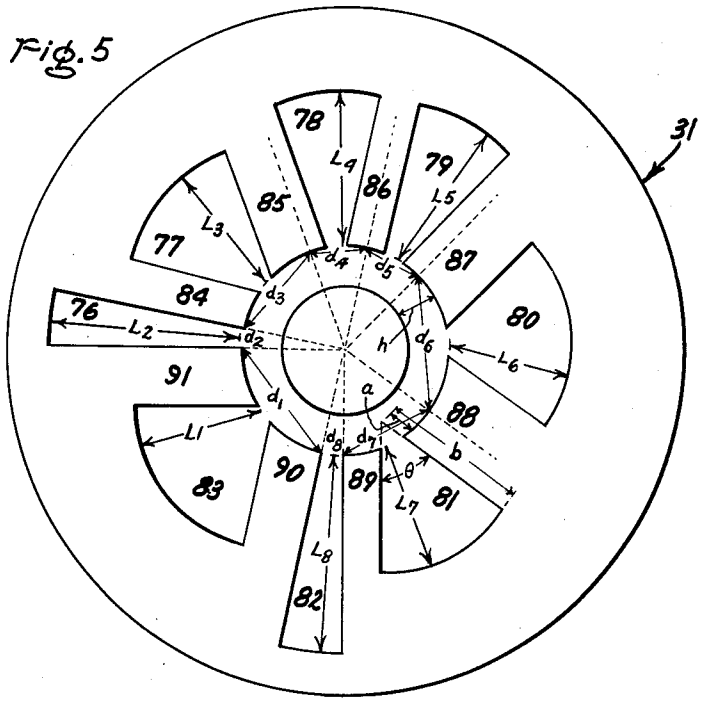


Fig. 6.

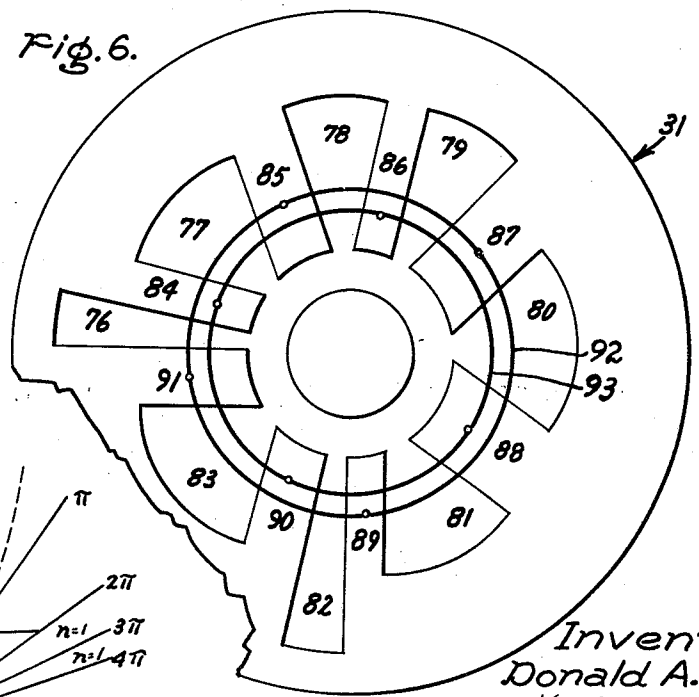
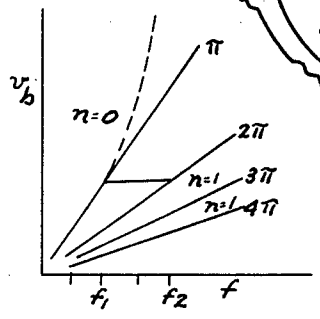


Fig. 7.



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United States Patent Office 3,121,820 Patented Feb. 18, 1964

3,121,820

SINGLE MODE AMPLIFIER OR OSCILLATOR

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Filed Oct. 28, 1960, Ser. No. 65,718
7 Claims. (Cl. 315—39.65)

My invention relates to electron discharge devices utilizing slow wave structures and more particularly to a novel construction of the slow wave structure for restricting the operation of the device to a single mode and frequency of operation.

In electronic oscillators or amplifiers, in general, the intensity of an electromagnetic wave is enhanced by transferring energy from an electron beam to the wave. In various electron discharge tube devices such as magnetrons and traveling wave tubes, an electromagnetic wave is propagated along a slow wave structure so as to have a phase velocity substantially equal to that of an established electron beam and in energy transferring relationship with it. The moving beam may be made to be in proper position with respect to the wave so as to impart energy to it.

Although these devices have in large measure been effective as amplifiers and oscillators etc., they suffer the drawback that during operation they are susceptible to shifts in mode and frequency so as to operate in undesired and unwanted modes. Various techniques such as strapping arrangements have been applied to magnetrons for purposes of mode stabilization. In many cases these have provided admirable results. In accordance with my present invention, another novel structure is provided for achieving mode stabilization in tubes utilizing slow wave structures, particularly in magnetrons.

In accordance with my present invention as applied to magnetrons, the magnetron anode which serves as the slow wave structure, is made to present variations or discontinuities in wave propagation characteristics to unwanted modes and frequencies of electromagnetic waves and is continuous for a wanted mode. This is achieved by forming the resonant cavities of the magnetron, which may be of any regular form such as holes, cavities between vanes, or slots, of different size with respect to each other along the anode periphery. To support the propagation of desired electromagnetic waves the spacings between vanes are correspondingly made of different values to compensate for the different size cavities. That is to say, by interrelating each intervane spacing to the size of the cavity between such vanes, the phase velocity of the wave of desired frequency may be made constant around the entire magnetron anode while all other waves are made to have a phase velocity which is different for each cavity and intervane spacing. The effect of such a construction is to cause the electromagnetic wave of desired frequency to be presented with a continuous slow wave structure around which it has a constant phase velocity and each other wave at another frequency is presented a discontinuous structure. Under these circumstances, in a magnetron wherein the average beam velocity is substantially constant, the beam and desired wave are in good energy transferring relationship with respect to each other and all other waves are not. The desired wave is increased in magnitude and undesired waves are subdued.

In a more general sense, the intervane spacing and cavity size between each pair of vanes may be interrelated with each other so as to cause the wave of desired frequency to have a phase velocity equal to the beam velocity even if this is not a constant value. Thus, in a magnetron wherein the beam velocity may be different along different portions of the anode, the cavity size and intervane spacing may establish for the wave of desired frequency, a phase velocity which differs as does the beam velocity.

In my copending application Serial No. 65,716, filed October 28, 1960, entitled "Mixed Lines Crossed Fields Oscillator or Amplifier" and assigned to the assignee of the present application, I have disclosed and broadly claimed apparatus embodying a slow wave structure having two or more portions with frequency versus phase shift per section characteristics which intersect for only one frequency. I do not intend to claim herein the broad invention of that application but only a species of the broad invention embodying cavities having volumes or depths varying in correspondence to the variation of section spacing.

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, together with further objects and advantages thereof, may best be understood with reference to the drawing in which:

FIGURE 1 illustrates schematically a simplified, conventional linear magnetron anode and cathode arrangement together with a wave representing the instantaneous values of potential of a space harmonic propagated along the anode which facilitates an explanation of the present invention,

FIGURES 2 and 7 are graphs illustrating the variation of frequency with beam velocity in structures according to FIGURES 1 and 6, respectively,

FIGURE 3 represents schematically a linear magnetron having an anode with different sized cavities and different distances between adjacent vanes according to my present invention,

FIGURE 4 is a cross-sectional elevation of a complete magnetron incorporating an anode according to my invention,

FIGURE 5 is a view taken along section 5—5 of FIG. 4 and illustrating a magnetron anode construction according to my invention, and

FIGURE 6 is a plan view of an alternative embodiment of magnetron anode according to my invention.

A better understanding of the principles underlying my invention may be had by reference to FIGURE 1 of the drawing, which illustrates schematically, the partial construction of a conventional linear magnetron 1 having an anode designated 2 with a plurality of evenly spaced vanes such as 3, 4 and 5, to provide a plurality of cavities such as shown at 6, 7 and 8, of uniform size. A cathode 9 spaced equidistantly from each of the anode vanes is provided as a source of electrons. For establishing an electron beam the anode may be made positive with respect to the cathode and a magnetic field as represented by the cross designated, B, is provided with lines of force perpendicular to the electric field. In this structure, a traveling electromagnetic wave is propagated along the anode as a slow wave structure. The values and polarity of the potential of this electromagnetic wave at one instant of time is represented by the wave 10. By

propagating an electromagnetic wave along the magnetron anode such as represented by this curve an electric field is established between adjacent vanes at the gaps therebetween. As shown in FIGURE 1, the instantaneous electric fields produced by a wave represented by curve **10** are as shown, for example, by the lines extending from vane 3 to vane 4 and terminating in arrows and by the lines extending from vane 5 to vane 4 and terminating in arrows. For transferring energy from the electron beam to the electromagnetic wave, electrons necessarily travel so as to be retarded by the electric fields between adjacent vanes. This is represented by an electron **11** having a direction of motion as represented by the arrow and being in a position so as to be retarded by the electric field between vanes **3** and **4**. It is to be noted that for proper magnetron operation, the velocity of the electrons in the beam and the phase velocity of the wave as represented by the wave **10** are coordinated so that they are substantially equal. Under this set of circumstances, by the time that electron **11** reaches the gap between vanes 4 and 5 the electric field between these vanes has become reversed from that shown in this figure of the drawing and thus, imposes a retarding force on the electron. In one mode of operation this would require that the trough **12** of the electromagnetic wave **10** progress from the gap between vanes **3** and 4 to the gap between vanes 4 and 5. As the electron travels on further along the tube in the interelectrode region, it encounters successive retarding fields across adjacent vanes produced by the moving trough **12** until it has lost so much energy that it becomes collected at one of the anode vanes. In this operation of the magnetron, both the electron beam and the wave travel the distance between vanes, represented by the letter, *d*, in the same period of time, represented by the letter, *t*.

In the operation of the magnetron according to FIGURE 1, energy may also be transferred from the electron beam to the traveling electromagnetic wave, wherein, after the conditions that prevail as shown in this figure of drawing, the electron **11** moves from the position between vanes **3** and **4** to that between vanes **4** and **5** as before but the trough **13** rather than the trough **12** of the wave **10** moves to a position between vanes **4** and **5** so as to establish the mentioned retarding electric field in the gap between these vanes to receive energy from the electron **11**. Under these circumstances it is observed that the electromagnetic wave travels considerably faster than the electron beam and that for the same period of time, *t*, the electron moves a distance, *d*, between adjacent vanes and the electromagnetic wave travels a distance equal to one wave length of the wave represented by the letter λ plus the distance, *d*, or in terms of symbols, $(\lambda+d)$. It is also to be understood that the magnetron tube may be effectively operated by the wave traveling any integral number of wave lengths plus the distance between vanes, *d*. This would require troughs subsequent to trough **13** of wave **10** to move to the space between vanes **4** and **5** in the period of time, *t*, after the condition that exists in FIGURE 1. This is represented by the expression $(m\lambda+d)$ wherein *m* represents the number of trough subsequent to trough **12**. Also, it is to be noted that effective transfer of energy from the beam to the electromagnetic wave may be accomplished under conditions wherein the electromagnetic wave travels any integral number of wave lengths, less the distance between vanes, since this condition also brings successive troughs of wave **10**, for example, to positions so as to establish an electric field between gaps which retard the electron beam. This condition may be represented by the expression $(m\lambda-d)$ wherein m again represents the number of troughs subsequent to trough **12**. Thus, in general, energy is transferred from the beam to the wave whenever the wave travels the distance, $(m\lambda\pm d)$. Also, since the period of time required for the wave to travel this distance is the same as the period of time, *t*, required for

the electron beam to travel the distance, *d*, between vanes,

$$t=\frac{d}{v_b}=\frac{m\lambda\pm d}{v_w} \tag{1}$$

wherein v_b and v_w represent, respectively, the electron beam velocity and the phase velocity of the wave. Solving this equation for v_b, the expression,

$$v_b=\frac{v_w d}{m\lambda\pm d} \tag{2}$$

is obtained. However, v_w is equal to the frequency, *f*, of the propagated wave multiplied by the wave length, λ. Accordingly,

$$v_b=\frac{f\lambda}{\frac{m\lambda}{d}\pm 1}=\frac{f}{\frac{m}{d}\pm\frac{1}{\lambda}} \tag{3}$$

Since it is frequently desirable to operate at a single frequency and since in the simplified form of anode, the electron beam velocity is substantially constant, the expression

$$\frac{f}{v_b}$$

would be constant and equal to

$$\left(\frac{m}{d}\pm\frac{1}{\lambda}\right)$$

Again, since

$$\lambda=\frac{2\pi}{\beta}$$

wherein β represents the phase shift of the electromagnetic wave per unit length around the magnetron anode,

$$\frac{f}{v_b}=\frac{m}{d}\pm\frac{\beta}{2\pi} \tag{4}$$

Equation 4 thus expresses the necessary inter-relationship between the space harmonic, *m*, the spacing between any pair of vanes, *d*, and the phase shift per vane, β, for obtaining energy transfer between the electron beam and the electromagnetic wave. It is seen that to maintain the constant relationship set forth by this equation, as the spacing between vanes is increased or decreased, the value of β may be adjusted accordingly to compensate for this variation in vane spacing. Also, in some circumstances, the space harmonic as expressed by the value *m* may be changed to compensate appropriately for the change in spacing between vanes in order to maintain this constant relationship.

Under the conditions represented by the structure and wave **10** in FIGURE 1 of the drawings, the phase shift of the electromagnetic wave **10** is π radians per vane. Under these circumstances the successive troughs and crests of the wave are spaced apart a distance, *d*, equal to the spacing between adjacent vanes. Under conditions wherein the phase shift of the wave **10** per vane of the magnetron anode is less than π radians, an interaction is still obtained between the electron beam and the electromagnetic wave on the anode line. For these values of phase shift per vane the space harmonic characterized by the value of $m=0$ is propagated in a forward direction, that is, in the same direction as that of the electron beam. Under circumstances wherein the anode line is constructed so that the electromagnetic wave has a phase shift per vane of the magnetron between π and 2π radians, the wave on the anode line travels in a backward direction or, in other words, in a direction opposite that of the electron beam and *m* has a value of 1. Similarly, for phase shifts of the electromagnetic wave between 2π and 3π radians, the wave is a forward wave characterized by the value $m=1$ and between 3π and 4π radians, the wave is a backward one characterized by the value $m=2$. These characteristics are shown clearly in the graph of FIGURE 2 of the drawings wherein the ordinate represents the velocity of the electron beam which is directly

proportional to the beam potential if the magnetic field is constant and the abscissa represents the frequency of operation of the magnetron. The respective solid lines 14 and 15 represent the conditions of operation of the magnetron with forward waves and the dotted lines 16 and 17 represent conditions of operation of the magnetron with backward waves and the solid straight lines through the origin represent operating conditions of the magnetron at values of phase-shift-per-vane equal to π, 2π, 3π and 4π radians respectively.

In accordance with the foregoing and in accordance with a feature of my invention, a magnetron anode is constructed so as to have different values of spacing between pairs of adjacent vanes. In accordance with Equation 4, the anode is also constructed so as to provide a value of phase-shift-per-vane, βd, so that the relationship,

$$\frac{f}{v_b}$$

for the entire magnetron anode remains a constant value. This is shown schematically in FIGURE 3 of the drawings and in greater detail in FIGURES 4 and 5 of the drawings showing a realistic embodiment of a magnetron incorporating this feature of invention.

In the construction of a magnetron anode so as to have a constant value of

$$\frac{f}{v_b}$$

with different values of vane spacing, it is seen from Equation 4 that in accordance with a feature of my invention, for any space harmonic of electromagnetic wave, the difference in spacing is compensated for by a change in value of the phase-shift-per-unit-length, presented to a wave propagated along the magnetron anode, by the respective anode cavities. The cavities are thus constructed so as to present an appropriate value of β between each pair of adjacent vanes. In a vaned type of anode structure having cavities as shown schematically in FIGURE 3 and in detail in FIGURES 4 and 5 of the drawings, the radial depth of the cavity may be varied to appropriately vary β. In FIGURE 3, the magnetron represented generally at 18 is provided with a cathode 19 and an anode 20 with vanes shown schematically at 21, 22, 23, 24 and 25 forming cavities 26, 27, 28 and 29. As shown in this figure, the cavities vary in depth as the intervane spacing varies. The greater the intervane spacing the smaller the depth of the cavity between these vanes to provide the proper value of β for satisfying Equation 4.

A more detailed and complete embodiment of anode structure according to my invention as incorporated in a magnetron is shown in FIGURES 4 and 5 of the drawing. Referring now to FIGURE 4 of the drawings, 30 represents generally an entire magnetron structure embodying an anode 31 according to my invention, the details of which are shown better in FIGURE 5 of the drawings. The anode 31 comprises a block of conductive material such as copper and is enclosed in a chamber formed by a peripheral ring 32 and respective end plates 33 and 34 connected at their outer peripheries, to the ring 32. Anode block 31 is provided with a circular aperture centrally thereof and a plurality of cavities extending radially from the aperture as shown more clearly in FIGURE 5 of the drawings. Plate 34 is centrally apertured and flanged at 35 to accommodate and support a post 36 on which is mounted a cathode represented in its entirety at 37, disposed in the central aperture of anode 31. The cathode is of a smaller radius than the anode aperture to establish an annular interaction region 38 between the cathode and inner tips of the adjacent anode vanes.

Cathode 37 includes a hollow member 39 having its outer surface coated with a suitable electron emission enhancing material and is apertured at its upper end as shown in FIGURE 4 of the drawing, to establish convection communication with the interior of the magnetron.

Within the member 39 is disposed a suitable resistance heating element, not shown, responsive to energization thereof to raise the temperature of cathode 39 to copious electron emission. The electrons emitted by the surface are prevented from traveling axially away from the interaction region 38 by end hats 40 and 41 extending radially from respective ends of member 39 to a radius just less than that of the anode aperture to allow for insertion and removal of the cathode.

Post 36 includes a tubular, conductive member 42 having one end connected to cathode member 39 and the other member terminating in a stepped flange 43 which provides an external electrical terminal for the cathode. For establishing mechanical and electrical insulating support for the member 42 a hollow, frusto-conical ceramic member 44 has one end secured in abutment with one portion of flange 43 and its other end in abutment with a radial inward flange 45 of a tubular member secured to flange 35. Rigidity and strength are imparted to the flange 45 by a ceramic ring 46 secured to the flange 45 on the side of it opposite to member 44. For establishing external electrical connections to the ends of the heater wire, an annular conductive flange member 47 forming one external terminal, is supported in insulated relationship with respect to member 42 by an annular insulator 48 secured to member 42 and 47 and a flanged, tubular, conductive member 49 is supported in insulated relationship with respect to member 47 by an annular insulator 50. The junction of member 49 with the insulator 50 is strengthened by an annular insulator 51 secured to the side of the flange remote from insulator 50. A tubulation 52 is secured to the exterior end of member 49 by connection between a folded-back flange 53 of the tubulation and the inner part of the member 49. 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 coaxial line 54 is provided and includes an outer conductor 55 and an inner conductor 56. Outer conductor 55 is disposed in the aperture of plate 33 and is secured thereto. For mounting inner conductor 56 centrally along the interior of conductor 55 a flanged, thimble shaped supporting member 57 and a flanged tubular member 58 with a rigid, hollow, frusto-conical insulator 59 in abutment with the flanges of these members, are provided. Rigidity and strength is imparted to the structure by ceramic insulators 60 and 61 bonded on the sides of the flanges opposite to the ends of member 59. The inner conductor 56 is connected to a point on one end of the magnetron anode block through a line 62 to facilitate conduction of output power from the magnetron.

A direct magnetic field is established axially along the interaction region by opposed electromagnets 63 and 64 having respective coils 65 and 66 and respective cores 67 and 68, at opposite ends of the magnetron.

As shown in FIGURE 5 of the drawing, the anode block 31 comprises a plurality of eight cavities, 76, 77, 78, 79, 80, 81, 82 and 83. Between pairs of these cavities are respective vanes 84, 85, 86, 87, 88, 89, 90 and 91, the inner surfaces of which are arcuate and equidistant from the axis of the anode. In accordanle with a feature of my invention, the spacing between vanes and the depths of the cavities between pairs of vanes in anode 31 are interrelated so as to satisfy the requirements of Equation 4 above. In this case, for a particular mode of operation, the phase velocity of a wave propagated along the anode is substantially the same as the velocity of an electron beam for energy interchange from the beam to the wave.

In the anode 31, the spacings between vanes 90 and 91, 91 and 84, 84 and 85, 85 and 86, are designated in FIGURE 5 as d_1, d_2, d_3 and d_4, respectively, and the radial depths of cavities between these pairs of vanes

are designated L_1, L_2, L_3 and L_4, respectively. For the present purposes, the intervane spacing is taken to be the arcuate distance between the intersection of a radial line parallel to a vane wall with the vane tip and a similar intersection at the next adjacent vane tip, measured at vane tip radius. Since opposite walls of the vane are parallel, these distances are clearly defined. The respective intervane distances are shown in FIGURE 5 of the drawing wherein the dotted lines are radial and parallel to the walls of the vanes through which they pass. The cavity depths are the respective distances measured radially from a vane tip to the back wall of the cavity which is arcuate having a center of curvature at the intersection of the projection of the cavity walls.

A specific embodiment of magnetron anode according to my invention and being capable of operating at a frequency of 3 kilo-megacycles per second may be as shown at **31** in FIGURE 5 of the drawings wherein the proportions of anode and cathode as shown in this figure are substantially twice actual size. More specifically, the cathode radius may be substantially .236 inch, the distance from the magnetron axis to the anode vane tips being substantially .394 inch and the cavity depths (L) and angles (θ) between opposite walls of the cavity are set forth in the following table:

L_1=.796 inch	θ_1=11.25 degrees
L_2=.618 inch	θ_2=33.75 degrees
L_3=.504 inch	θ_3=56.25 degrees
L_4=.493 inch	θ_4=78.85 degrees

With these values being known, the other proportions of the anode may be determined. The spacings between the described pairs of vanes are different, each from the others and consequently, the depths of cavities between these pairs of vanes are different each from the others. Along the remaining portion of the anode, each intervane spacing coincides with one of the intervane spacings previously described and consequently, the cavities between these pairs of vanes coincide with cavities already described. Thus, $d_5=d_4$ and $L_5=L_4$, also $d_6=d_1$, $L_6=L_1$, $d_7=d_2$, $L_7=L_3$, $d_8=d_2$ and $L_8=L_2$. It is to be understood, however, that in accordance with my invention, each intervane spacing may be different from all of the others of the anode whereby each cavity is different in depth from each other cavity. However, as shown in FIGURE 5, a nonperiodicity may be satisfactorily established in most cases by providing four different sizes of cavity around the anode particularly wherein the order of the respective cavities is non-repetitive.

In the particular embodiment of magnetron anode as shown at **31**, the radial length, L, of any cavity is determined by the relation:

$$\frac{1}{a\theta}\left[\frac{J_0(ka)N_1(kb)-J_1(kb)N_0(ka)}{J_1(ka)N_1(kb)-J_1(kb)N_1(ka)}\right]=\frac{k}{d}\sum_P\frac{1}{\beta}\left[\frac{\sin\alpha s}{\alpha s}\right]^2\coth\beta h \tag{5}$$

wherein:
$k=w./c.$
$w=2\pi f$
f=frequency of a propagated wave
c=velocity of light
$P=n+mN$
$n=0, 1, 2, \ldots N/2$
$m=\pm 0, 1, 2, 3, 4, \ldots$
N=number of vanes

$$\alpha=\frac{2\pi P}{Nd}$$

$\beta^2=\alpha^2-k^2$
d=average distance between cavities
h=distance between cathode and anode vane tips
$s=a\theta$

a=distance measured from a vane tip to the intersection of projections of opposite walls of a cavity.
b=distance measured from the radial extremity of a cavity to the intersection of the projections of opposite walls of a cavity.
θ=angle between walls of a cavity.
J's and N's are Bessel functions of first and second kinds and their orders are designated by subscripts.

For further clarification, the values of a, b, d, h and θ are shown in FIGURE 5 of the drawing.

In Equation 5, by a substitution of known and preselected values, the values of a and b are determined so that the sizes of the respective cavities of the anode may readily be determined.

The relationship expressed in Equation 5 applies to a magnetron having generally sectorial cavities as shown in FIGURE 5. However, the principles of my invention apply equally well to magnetron anodes having hole and slot cavities, merely slotted cavities or other configurations. In each case, however, the relationship between parameters, such as, cavity depth or size, intervane spacing, size of interaction region, etc., is different and may be determined by one skilled in the art so as to satisfy Equation 4.

Although the foregoing Equation 5 expresses an exact interrelationship between cavity depth and intervane spacing, it may be observed that, in general, to compensate for an increased spacing between vanes, the depth of the cavity therebetween is reduced. This is shown clearly in FIGURES 3 and 5 of the drawings.

In accordance with my invention, it is noted that spacings between pairs of magnetron anode vanes may be different from each other and yet the anode be constructed to support the propagation of an electromagnetic wave energy of selected mode and frequency. Alternatively, some of the intervane spacings may be equal to others, however, it is preferable to have relatively few such pairs in sequence or to have such pairs separated by intervane spacings that are different so as to avoid periodicity of any portion of the anode structure.

The principles of my invention as hereinabove described are also applicable to a magnetron anode structure similar to that shown in FIGURE 5 of the drawings which is provided with strapping between alternate vanes. A device so constructed is effectively an interdigital one wherein alternate vanes are connected to respective shorting bars **92** and **93**. This embodiment of my invention is shown in FIGURE 6 of the drawings. In a manner similar to that described in detail hereinabove for deriving Equation 4, an equation establishing the conditions which must be satisfied for operating a magnetron having an anode such as shown in FIGURE 6 of the drawing may be shown to be:

$$\frac{f}{v_b}=\frac{m+\frac{1}{2}}{d_m}\pm\frac{\beta}{2\pi} \tag{6}$$

where f, v_b, m and β are the parameters described hereinabove with respect to the embodiment of invention shown in FIGURE 5, and d_m is the spacing between adjacent vanes of the magnetron anode which are connected to different straps. It is to be observed that Equation 6 is very similar to Equation 4 with the difference being that the numerator of the first fraction on the right side of the equation is greater by the term one-half. This arises by reason of the fact that the electromagnetic wave propagated along the magnetron anode is required to travel an additional half wave length over the distance traveled in a magnetron anode as shown in FIGURE 5 so as to be in proper energy transferring relationship with the electron beam. For this embodiment of invention, the propagating characteristics of different modes of electromagnetic waves are represented by the graph shown in FIGURE 7 of the drawings. In this figure the ordinate represents the electron beam velocity and the abscissa rep-

resents the frequency of the propagated electromagnetic wave. The straight lines labeled π, 2π, 3π and 4π, represent the operating characteristics of the magnetrons in their respective modes in which the phase shift between anode vanes is equal to these respective values. The operation of the magnetron at a phase-shift-per-vane less than π radians is represented by the dotted line labeled $m=0$ to indicate a backward wave mode, the operation between π and 2π radians phase-shift-per-vane is characterized by the value $m=0$ and represented by the solid line extending between the two straight lines indicating a forward wave mode of operation, the operation between the value 2π and 3π radians phase-shift-per-vane the dotted line represents the backward wave mode of operation characterized by a value $m=1$ and finally between 3π and 4π radians phase-shift-per-vane, the solid line characterized by the value $m=1$ represents a forward wave mode of operation of the device. Although the graph of this figure illustrates the operation of the magnetron with phase-shifts-per-vane up to 4π radians, it should be understood that it is capable of being operated at many higher space harmonics wherein the phase-shift-per-anode-vane is considerably greater than 4π radians.

The present invention has generally applicability to slow wave structures and as pointed out hereinabove may be incorporated in magnetrons of various construction including those having hole and slot arrangements, merely slotted arrangements or cavities between vanes. Accordingly, as set forth in the present disclosure and in the claims following, the term "vane" should be considered in the generic sense to include any partition or separating wall rather than in the restricted sense as being purely a separating partition having planar and generally radial walls in a magnetron anode and the term "cavity" should also be taken to indicate the region between these vanes, irrespective of the form which this region may assume.

While the present invention has been described by reference to particular embodiments 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 structure comprising a conductive member having a plurality of vanes along a portion thereof, the distance between each pair of adjacent vanes along said portion being different from that of any other pair of adjacent vanes therealong, a cavity between each pair of adjacent vanes, the volume of each cavity along said portion being different to compensate for the differences in said spacings and present a characteristic to an electromagnetic wave of predetermined frequency propagated about said anode causing said electromagnetic wave to have a constant phase velocity whereby an electron beam having a velocity substantially equal to said phase velocity is effective to interact with an electromagnetic wave propagated along said anode.

2. An apparatus comprising a magnetron anode having a plurality of spaced vanes along a portion thereof establishing a plurality of cavities between said vanes, the spacing between each pair of adjacent vanes being different from the spacing between other pairs of vanes, the depth of each cavity varying in accordance with the spacing between adjacent vanes on respective sides of said cavity, the depth of any cavity between a pair of adjacent vanes of a predetermined spacing being greater than the depth of another cavity between a pair of adjacent vanes having a spacing greater than said predetermined spacing.

3. A magnetron anode comprising a circular member having a plurality of vanes protruding radially inwardly to a predetermined radius, the spacing between each pair of adjacent vanes being different from the spacing between

any other pair of adjacent vanes, the radial depth of a cavity between any pair of adjacent vanes being determined by the relationship:

$$\frac{1}{a\theta}\left[\frac{J_0(ka)N_1(kb)-J_1(kb)N_0(ka)}{J_1(ka)N_1(kb)-J_1(kb)N_1(ka)}\right]=\frac{k}{d}\sum_P\frac{1}{\beta}\left[\frac{\sin\alpha s}{\alpha s}\right]^2\coth\beta h$$

wherein:

$k=w/c$

$w=2\pi f$

f=frequency of a propagated wave

c=velocity of light

$P=n+mN$

$n=0, 1, 2, \ldots N/2$

$m=\pm 0, 1, 2, 3, 4, \ldots$

N=number of vanes

$$\alpha=\frac{2\pi P}{Nd}$$

$\beta^2=\alpha^2-k^2$

d=average distance between cavities

h=distance between cathode and anode vane tips

$s=a\theta$

a=distance measured from a vane tip to the intersection of projections of opposite walls of a cavity

b=distance measured from the radial extremity of a cavity to the intersection of the projections of opposite wall of a cavity

θ=angle between walls of a cavity

J's and N's are Bessel functions of first and second kinds and their orders are designated by subscripts.

4. An apparatus comprising a slow wave structure including a plurality of spaced vanes forming cavities between respective pairs of vanes along a portion thereof, the spacing between any pair of adjacent vanes along said section being different from the spacing between any other pair of adjacent vanes therealong, the depth of any one of said cavities between any pair of adjacent vanes of a predetermined spacing being greater than the depth of a cavity between another pair of adjacent vanes of a greater spacing than said predetermined spacing.

5. An apparatus comprising a slow wave structure for reducing the phase velocity of an electromagnetic wave capable of being propagated therealong, a portion of said slow wave structure including a plurality of discrete sections defining recesses therebetween, the spacing between each adjacent pair of said sections being different from the spacings between any other pair of said sections, each of said recesses having a different depth so that the electrical characteristics of each section is controlled to provide substantially the same constant phase velocity to an electromagnetic wave of a predetermined frequency propagated therealong and phase velocities different from said constant phase velocity along each section at frequencies other than said predetermined frequency.

6. A magnetron anode comprising a conductive member having a plurality of conductive segments projecting therefrom along a portion thereof forming cavities between adjacent pairs, the spacing between any adjacent pair of segments along said portion being different from the spacing between any other adjacent pair of segments therealong, the volume of each cavity along said portion being different from the volume of other cavities to compensate for the difference in spacing between adjacent pairs of said segments and establish parameters producing the same, constant phase velocity between all pairs of segments along said portion for an electromagnetic wave of a single frequency propagated along said portion and different phase velocities between said pairs of segments at other frequencies.

7. An apparatus comprising a conductive member having a plurality of spaced vanes along a portion thereof

forming a plurality of cavities between pairs of said vanes, the spacing between any pair of adjacent vanes along said portion being different from the spacing between any other pair of adjacent vanes therealong, the depth of any one of said cavities being different from the depth of any of the other of said cavities so that the inductance of any one of said cavities being different from the inductance of any other one of said cavities to compensate for said different spacings and to establish the same phase velocity of an electromagnetic wave of a predetermined frequency between each pair of adjacent vanes along said portion and different phase velocities between adjacent pairs of vanes along said portions for electromagnetic waves having frequencies different from said predetermined frequencies.

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