Feb. 18, 1964 M. R. BOYD 3,121,822

CIRCUITS FOR UNIMODING CROSSED FIELD DEVICES

Filed Oct. 28, 1960

Fig. 1.

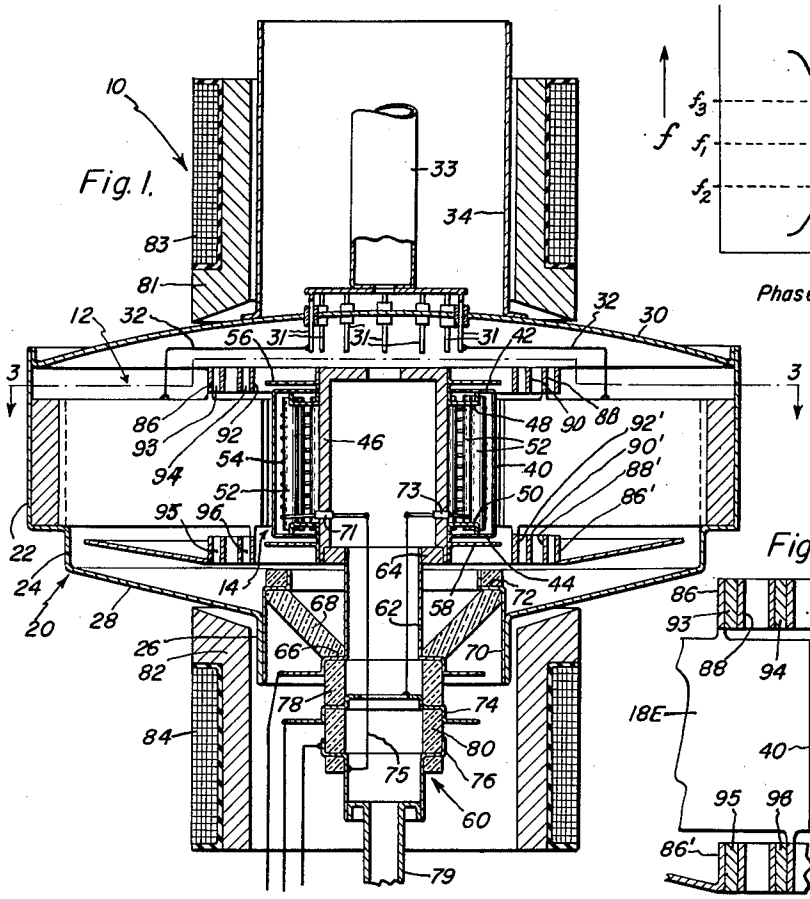
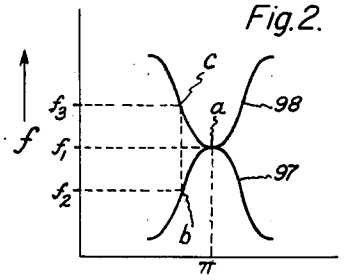


Fig. 2.



Phase Shift per Section

Fig. 7.

Fig 6.

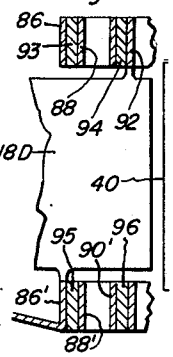


Fig. 3.

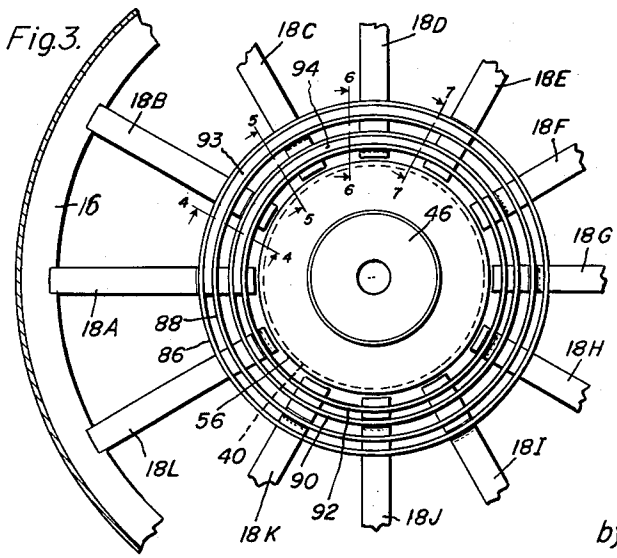


Fig. 5.

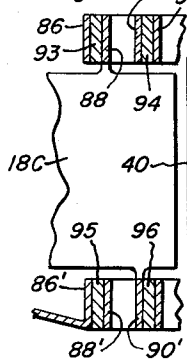
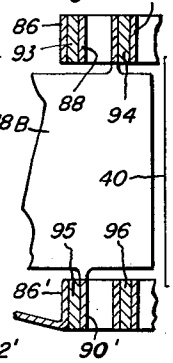


Fig. 4.



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CIRCUITS FOR UNIMODING CROSSED FIELD DEVICES

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10 Claims. (Cl. 315—39.69)

This invention relates to an electron discharge apparatus of the type commonly called a magnetron, for producing electromagnetic waves of high frequency.

Magnetron oscillators are well known and generally include a cathode centrally disposed in a hollow anode which has a plurality of anode segments or vanes protruding radially inwardly toward the cathode. The spaces between pole faces are resonant slots or resonant cavities. The anode is made electrically positive with respect to the cathode to attract electrons emitted by the cathode and a constant magnetic field perpendicular to the electric field so produced and substantially parallel to the cathode, is established to further influence the trajectories of electrons emitted from the cathode. Under proper conditions of electric and magnetic field intensity, electron flow in the space between the cathode and anode sections establishes a high frequency alternating potentials or oscillations at the inner anode sections. The potentials at adjacent anode sections at any instant of time may be in exact phase opposition or in other words, 180° out of phase with each other, in which case the magnetron is said to be operating at pi mode, or the potentials at adjacent pole faces may be less than 180° out of phase with each other wherein the magnetron is said to be operating at a mode other than pi mode.

It is an inherent characteristic of magnetrons that operation thereof in different modes entails oscillation at different frequencies. That is, operation of any specific magnetron in any particular mode produces a particular frequency and the frequencies of oscillation of that magnetron in different modes are also different. It frequently occurs that in magnetron oscillators without special provisions for establishing a contrary characteristic, the frequencies of operation in adjacent modes are narrowly spaced and the magnetron is readily susceptible to shifts in operation between adjacent modes. This is particularly true when the magnetron is loaded at a frequency of a specific mode wherein the magnetron shifts to operation at another mode and therefore, at another frequency that is not so heavily loaded.

The satisfactory operation of electronic apparatus often depends upon an accurate, and stable source of high frequency electromagnetic energy. Accordingly, the mode shifting characteristic of magnetrons as hereinabove described renders the same objectionable in situations requiring such a source of relatively precise and stable electromagnetic energy.

It is known to lessen the tendency for mode shifting in magnetrons from pi mode by the provision of "strapping" wherein a pair of spaced, adjacent conductive straps are each connected to different alternate anode sections or vanes. With this arrangement, each strap connects poles of like polarity and as a consequence the potentials of the straps are 180° out of phase with each other. Because of the symmetry and phasing of alternate poles, no current flows in the straps at the frequency of pi mode. Thus, the capacity between the straps is added to the capacity between anode sections or in other words, to the capacity of the resonant cavities. The result of such added capacity is to lower somewhat, the frequency of operation of the magnetron in the pi mode. Simultaneously, since the phase shift between anode sections at modes other than pi mode is other than 180°, potential difference across these sections occur for these other

modes and currents at frequencies of these other modes will flow in the straps to introduce an effective inductance in parallel with the inductance of the cavities, raising the frequency of oscillation at adjacent modes. Thus, the difference in operating frequencies between adjacent modes is increased and the shift in operation from one mode to the other is rendered less likely and stability of operation is increased.

It is noted, however, that the aforedescribed technique of improving the operational stability of a magnetron is not completely effective and that in many circumstances, in magnetrons strapped according to known practice, a shift in mode and frequency of operation results from loading thereof.

It is, accordingly, a primary object of my invention to improve the operational stability of strapped magnetron oscillators.

It is another object of my invention to facilitate operation of a magnetron oscillator in a predetermined mode and suppressing any tendency to operate in any other mode.

Pursuant to the foregoing objects and in accordance with a feature of my invention, operation of a magnetron at pi mode may be established and maintained notwithstanding heavy loading or other influences on the magnetron, by the provision of two pairs of continuous ring straps, each being short circuited to the other of the pair over a fraction of its length and each being connected to a different, every fourth vane or section of the anode. The short circuiting between straps may be continuous or discontinuous about the circumference thereof. Under these circumstances, the portion of the magnetron having the shorted straps has conductive connections between vanes and operates as a conventionally strapped magnetron for mode stabilization and along the unshorted portions, a capacitive coupling exists between vanes which are desired to be operated in phase. The effect of these different strapping arrangements is to produce two different frequency versus phase-shift-prev-vane characteristics the curves of which are convex to each other and which are coincident at a single point at pi mode. The frequency separation between curves differ increasingly at modes away from pi mode. The effect of the capacitive strapping arrangement is to increase the slope of one curve over that which would be obtained with an unstrapped arrangement and, therefore, to enhance the separation of frequency of operation between different portions of the magnetron at modes removed from pi mode.

In copending Donald A. Wilbur 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, there is 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. The invention of the said Wilbur application was made prior to my invention and is to be regarded as prior art with respect to the invention of this application.

Other and further objects and advantages will appear by referring to the following detailed description of the invention considered with the accompanying drawings in which:

FIGURE 1 is a cross-sectional elevation of a magnetron oscillator according to the invention,

FIGURE 2 is a graph representing the characteristics of conventionally strapped and capacitively strapped magnetrons,

FIGURE 3 is a partial plan view taken along section 3—3 in FIGURE 1 showing the connections between straps and vanes of the magnetron, and

FIGURES 4, 5, 6 and 7 are partial, elevational views taken along sections 4—4, 5—5, 6—6 and 7—7, respectively, in FIGURE 3 showing the respective connections between straps and vanes in the magnetron oscillator.

Referring now to the drawings, **10** represents generally an entire magnetron structure embodying my invention and includes an anode represented generally at **12** and a cathode represented generally at **14**. As shown more clearly in FIGURE 3, the anode includes a ring **16** being interiorly notched to receive the respective ends of a plurality of vanes **18A** through **18L** and the ring **16** is maintained in position by an outer housing **20** which along a portion **22** of its length encloses the anode and extends axially therefrom along portions **24** and **26** joined by tapered portion **28**. An end closure member **30** is joined at its outer periphery to housing **20** about the free edge of portion **22**. For abstracting energy from the magnetron, a "spider" having a plurality of arms **31** each of which is connected to one of the vanes through leads as shown at **32** is connected to an inner conductor **33** of a coaxial output line having an outer conductor **34**.

For establishing an interaction region, the inner ends of the vanes terminate along a circumference of a circle and the sectorial portions between pairs of vanes comprise cavities resonant at a frequency of the order of the desired operating frequency of the magnetron. Cathode **14** is disposed within the region formed by the vane tips, and includes a hollow cylindrical emitting surface **40** having planar ends **42** and **44** secured to a conductive cup **46** shown inverted in FIGURE 1. A pair of circular brackets **48** and **50** are secured to respective ends of cup **46** and engage the inner surfaces of ends **42** and **44** to mount the cathode **40**. Aligned notches in the brackets accommodate a plurality of ceramic columns **52** about the cup **46** for facilitating the mounting of a heater wire **54** which is spirally wound about the ceramic columns collectively. Heat may be produced by wire **54** by an electric current passed through the same and such heat raises the temperature of cathode **14** to a point of electron emissivity. To intercept stray electrons emitted from cathode **14**, a pair of end hats **56** and **58** are mounted at the ends of cup **46** and extended therefrom to the radius of cathode **14**.

For mounting and supplying electrical connections to cathode **14** a mounting post represented generally at **60**, is provided which includes a nested arrangement of several components bonded or secured together in a suitable manner. A hollow conductive member **62** is conductively coupled with the cathode through a metal ring **64** which is interposed between and secured to the member **62** and bracket **50** and a flange **66** near the end of member **62** provides an abutment support for a frustoconical insulator **68**. A sleeve **70** with an inwardly directed flange **72** is in abutment and attachment with the other end of insulator **68** and this sleeve may be secured to axial portion **26** of housing **20**. Connections to heater wire **54** are facilitated through leads from ends of wire **54** extending through the wall of cup **46** and being insulated therefrom at **71** and **73**, to generally annular terminal members **74** and **76** separated from other parts and each other by annular insulators **78** and **80**. Electrical connections to cathode **40** are made through a line **75** connected to a conductive tube **77** serving as a terminal member. Each of the terminal members is connected exteriorly to lines leading to other circuitry. A tubulation **79** for evacuation purposes is provided as the lowermost portion of post **60** and communicates with the interior of the magnetron through the hollow of post **60**.

The interaction region of the magnetron is immersed in a magnetic field produced by a pair of electromagnets having respective pole pieces **81** and **82** and respective coils **83** and **84** energizable by a direct current of substantially constant value.

In accordance with an important feature of my invention a first pair of conductive straps **86** and **88** and a second pair of conductive straps **90** and **92**, each strap being circularly continuous, are mounted at one side of the magnetron vanes for contact with selected vanes and similar pairs of straps **86′** and **88′** and **90′** and **92′** are mounted at the other side of the vanes also for contact with selected vanes. Each strap is conductively connected to every fourth vane and each vane is connected to only one strap. Thus, in a twelve vane magnetron as shown in FIGURE 3 each strap is connected to three vanes symmetrically spaced about the circumference of the anode. In the specific embodiment shown, strap **86** is connected to vanes **18A**, **18E** and **18I**, strap **88** is connected to vanes **18C**, **18G** and **18K** and strap **90** is connected to vanes **18B**, **18F** and **18I** and strap **92** is connected to vanes **18D**, **18H** and **18L**. The vanes are also connected to different straps of the four at the other side of the vanes. Vanes **18A**, **18E** and **18I** are connected to strap **92′**, vanes **18B**, **18F** and **18J** are connected to strap **88′**, vanes **18C**, **18G** and **18K** are connected to strap **90′** and vanes **18D**, **18H** and **18L** are connected to strap **86′**. As illustrated in representative detail FIGURES 4, 5, 6 and 7, each vane such as vanes **18B**, **18C**, **18D** and **18E** are connected to a strap of a pair disposed at different radii at different sides of the vane to effect a balance in the structure.

Further, in accordance with this feature of my invention, the pairs of straps **86** and **88** are connected together over a portion or portions of their lengths less than the total length and each of the other pairs of straps **90** and **92**, **86′** and **88′** and **90′** and **92′** are also connected together over a portion or portions of their lengths as shown with respect to **86** and **88** and **90** and **92** in FIGURE 3. Thus, conductive members **93** and **94** interconnect segments of pairs of straps **86** and **88** and **90** and **92**. Similarly, conductive members **95** and **96** interconnect corresponding portions of pairs of straps **86′** and **88′** and **90′** and **92′**.

The particular extent of interconnection of pairs of straps or the particular location or locations of interconnections may be varied over wide limits, it being essential only to leave a portion thereof not interconnected so as to impose a discontinuity to unwanted modes tending to propagate in the magnetron. With this construction, along the short circuited portions of the straps the magnetron appears and operates as a conventionally, conductively strapped magnetron for pi mode operation while along non-short circuited portions it appears as a capacitively strapped magnetron. Thus, for example, pairs of straps may be interconnected continuously over one-half of their lengths and be disconnected over the remaining one-half of their lengths whereby the magnetron appears as a conventionally, conductively strapped structure over one half of its circumference and as a capacitively strapped structure over the other one-half. As further examples, the straps of each pair may be interconnected intermittently over several portions of their lengths, it being necessary only to provide an unconnected or connected portion long enough to render the magnetron a conventionally, conductively strapped or capacitively strapped structure over such lengths rather than merely present a slight disturbance. As a still further example, the pairs of straps may be short-circuited over different arcuate portions and over different circumferential lengths.

The effect of the discontinuous interconnection of straps may be better understood by reference to FIGURE 2 of the drawing wherein curves **97** and **98** represent frequency variation of magnetron **10** versus the phase difference per section between adjacent vanes for the capacitively strapped and conventionally, conductively strapped arrangements, respectively. With respect to curve **97** for a capacitively strapped structure, it is observed that at pi mode wherein the phase shift between vanes is pi radians or 180°, operation is at a point "*a*" on the curve where the frequency is represented by f_1 and that for the same

magnetron with conventional strapping, according to curve 98, operation at pi mode results in the operation at the same frequency f_1 and the same point "*a*." In other words, point "*a*" is common to curves 97 and 98 and operation of a magnetron at pi mode either capacitively strapped or conventionally, conductively strapped results in the same operating frequency. Thus, when it is desired to operate at pi mode, it is immaterial whether the pairs of straps are conductively connected or capacitively connected.

For operation of the magnetron at a mode other than pi mode, however, as represented at mode "*m*" in FIGURE 2, for example, for a capacitively strapped magnetron anode portion, operation is at point "*b*" and thus, at frequency f_2 and for a conductively strapped magnetron anode portion operation is at point "*c*" and thus, at frequency f_3. It is readily observed that the frequency separation between points "*c*" and "*b*" is considerable. The relatively large slope of the sides of curve 97 results from the capacitive strapping of a portion of the anode. Accordingly, the magnetron to operate at mode "*m*" would be required to repeatedly shift between these frequencies of operation which it is not so inclined to do. That is, with the respective pairs of straps intermittently short circuited, the magnetron appears intermittently as a conductively strapped and as a capacitively strapped structure at modes other than pi mode. Thus, propagation of modes other than pi mode would entail the continuous shift between widely spaced frequencies. Since these frequencies are rather widely separated, the magnetron is strongly influenced to operate only at the pi mode.

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. An apparatus for producing high frequency electromagnetic oscillations comprising a plurality of symmetrically positioned, convergent, conductive vanes, a cathode equidistantly spaced from each of said vanes and means producing a magnetic field in the region between said vanes and cathode and perpendicular to a line between said cathode and any of said vanes, means applying a potential to said vanes positive with respect to said cathode, means for conductively connecting each of said vanes to the fourth vane therefrom and means intermittently conductively connecting said conductively connecting means together over a substantial length thereof whereby propagation of modes other than pi mode in said apparatus is minimized.

2. A magnetron comprising a plurality of vanes symmetrically positioned with respect to each other, a cathode spaced from each of said vanes and means for applying a potential to said vanes positive with respect to said cathode, means for establishing a magnetic field in the region between said vanes and said cathode and being perpendicular to a line between any one of said vanes and said cathode, two pairs of straps, each strap being connected to a different every fourth vane of said plurality and means intermittently conductively connecting the straps of each of said pairs together over a substantial length thereof, whereby propagation of modes other than pi mode in said magnetron is minimized.

3. A magnetron apparatus for producing high frequency electromagnetic oscillations comprising a plurality of symmetrically positioned convergent, conductive vanes, a cathode equidistantly spaced from each of said vanes and means establishing a magnetic field within the region of said vanes and cathode and being perpendicular to a line between said cathode and any one of said vanes, means applying a potential to said vanes positive with respect to said cathode, two adjacent pairs of straps, each vane being conductively connected to only one strap of said adjacent pairs of straps, means for connecting each strap to the other strap of said pair over a length less than the entire length of the strap whereby oscillations at modes other than pi mode are minimized in said magnetron.

4. A magnetron apparatus for producing high frequency electromagnetic oscillations comprising a plurality of symmetrically positioned, convergent, conductive vanes, a cathode equidistantly spaced from each of said vanes and means producing a magnetic field between the region of said vanes and cathode and being perpendicular to a line between said cathode and any one of said vanes, means applying a potential to said vanes positive with respect to said cathode, two pairs of straps, each of said straps being connected to sets of different vanes with each set including every fourth vane of said plurality of vanes and means conductively connecting each strap to the other strap of that pair of straps over a fraction of its length.

5. A magnetron apparatus for producing high frequency electromagnetic oscillations comprising a plurality of symmetrically positioned, convergent, conductive vanes, a cathode centrally disposed with respect to said vanes and being spaced therefrom, means producing a magnetic field in the region between said vanes and cathode and being perpendicular to a line between said cathode and any one of said vanes, means applying a potential to said vanes positive with respect to said cathode, two pairs of straps each of said straps being conductively connected to sets of different vanes with each set including every fourth vane of said plurality and each vane being connected to only a single strap, means establishing a continuous portion of conductive interconnection between the straps of each pair, whereby propagation of modes other than pi mode in said magnetron is minimized.

6. An apparatus for producing high frequency electromagnetic oscillations comprising a plurality of symmetrically positioned, convergent, conductive vanes, a cathode centrally disposed with respect to said vanes and being spaced from each of said vanes and means producing a magnetic field in the region between said vanes and cathode and being perpendicular to a line between said cathode and any of said vanes, means applying a potential to said vanes positive with respect to said cathode, two pairs of straps, each of said straps being conductively connected to every fourth vane of said plurality and each vane being connected to only a single strap, means establishing conductive interconnection between the straps of each of said pairs over a plurality of spaced portions of said straps whereby propagation of electromagnetic modes other than pi mode in said magnetron is minimized.

7. An apparatus for producing high frequency electromagnetic oscillations comprising a plurality of symmetrically poistioned, convergent, conductive vanes, a cathode centrally disposed with respect to said vanes and being spaced from each of said vanes and means producing a magnetic field in the region between said vanes and cathode and being perpendicular to a line between said cathode and any of said vanes, means applying a potential to said vanes positive with respect to said cathode, two pairs of straps on one side of said vanes, each of said straps being conductively connected to every fourth vane of said plurality and each vane being connected to only a single strap of said further pairs, means establishing an interconnection between the straps of each of said pairs over a plurality of spaced portions of said straps whereby propagation of electromagnetic modes other than pi mode in said magnetron is minimized.

8. A magnetron apparatus for producing high electromagnetic oscillation comprising a plurality of symmagnetic oscillations comprising a plurality of symcathode equidistantly spaced from each of said vanes and means producing a magnetic field between the region of said vanes and cathode and being perpendicular to a line

between said cathode and any one of said vanes, means applying a potential to said vanes positive with respect to said cathode, two pairs of straps, that of said straps being connected to every fourth vane of said plurality and each strap being connected to different vanes than the other of said straps and means connecting each of said straps to the other strap of each pair over a fraction of its length and each short circuiting connection being over a different arcuate portion of said straps.

9. An apparatus for producing high frequency electromagnetic oscillations comprising a plurality of symmetrically positioned, convergent, conductive vanes, a cathode equidistantly spaced from each of said vanes and means producing a magnetic field in the region between said vanes and said cathode, said field being perpendicular to a line between said cathode and any of said vanes, means applying a potential to said vanes positive with respect to said cathode, means conductively interconnecting all alternate vanes along a fraction of the circumference of said apparatus and means providing a capacitive coupling between all alternate vanes along another fraction of the circumference of said apparatus.

10. Magnetron apparatus for producing high frequency electromagnetic oscillations comprising an anode structure including a plurality of circumferentially spaced conducting portions extending radially inwardly and defining a generally circular array of high frequency circuits, said conducting portions terminating short of the center to provide an opening and means for supplying electrons in proximity to the ends of said conducting portions including means defining an annular space charge region in said opening and subjecting the electrons therein to mutually perpendicular electric and magnetic fields and a conductive structure for strapping said radially extending portions including means conductively connecting all alternate portions together near the inner ends thereof over a portion of said anode structure defining several adjacent circuits and conductively connecting every fourth anode portion over a second portion of said anode defining several circuits and capacitively coupling together the alternate anode sections of said second portion.

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