

Feb. 21, 1967

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3,305,693

INTERDIGITAL MAGNETRON INCLUDING MEANS FOR SUPPRESSING
UNDESIRE MODES OF OPERATION BY SEPARATING
THE FREQUENCY OF POSSIBLE UNDESIRE
OPERATING MODES

Filed Jan. 2, 1963

4 Sheets-Sheet 1

Fig. 1

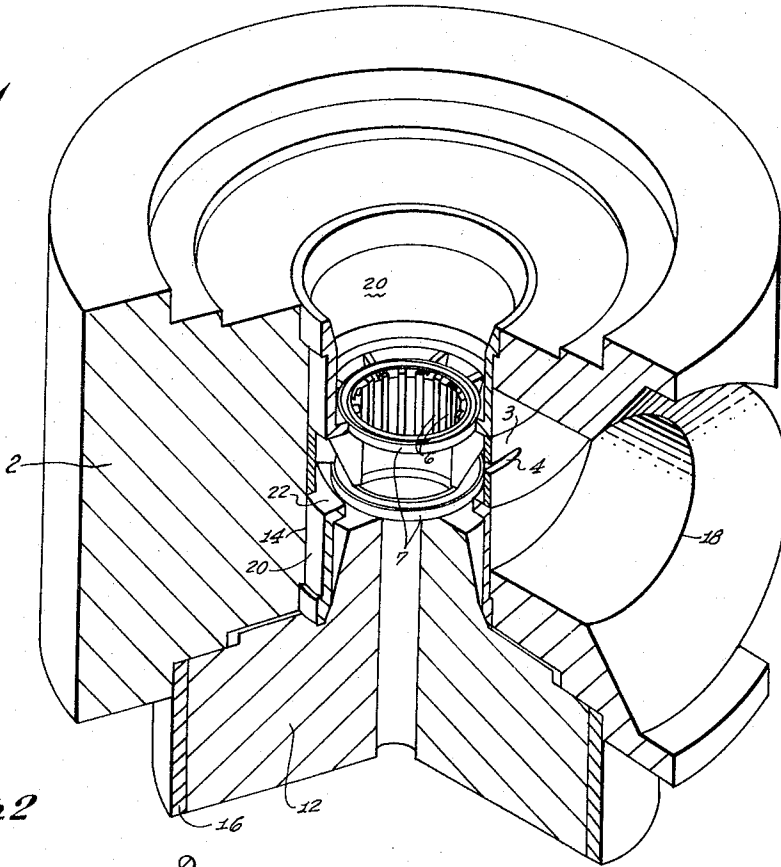
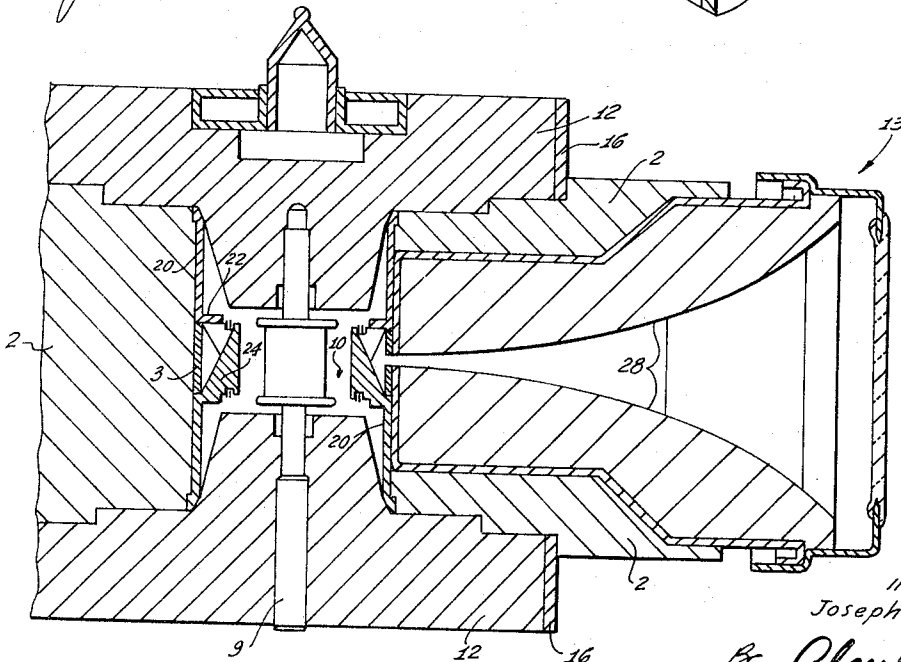


Fig. 2



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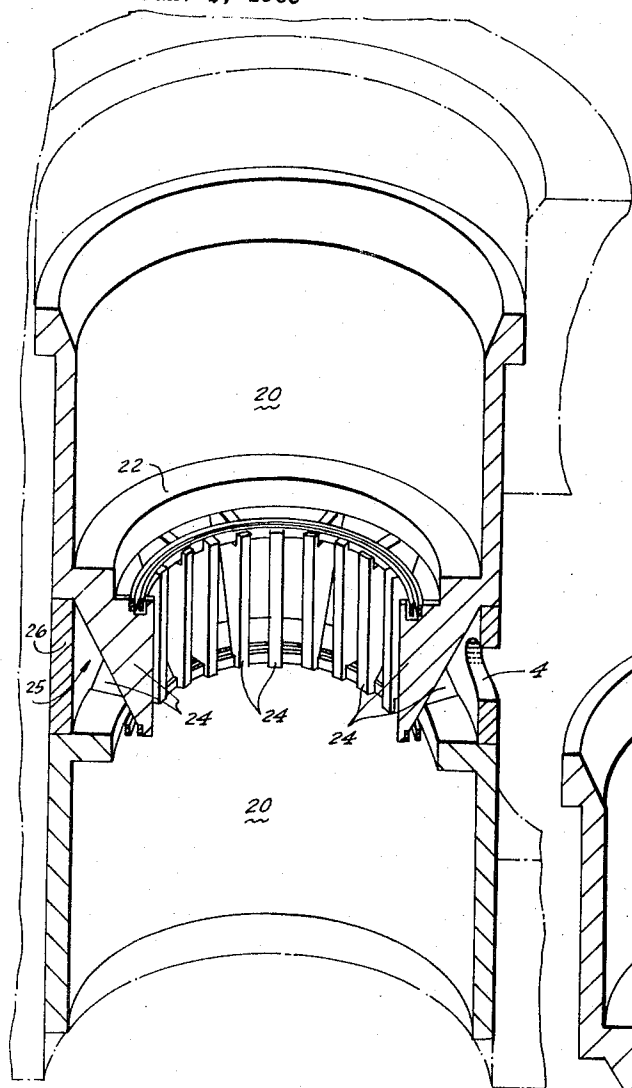
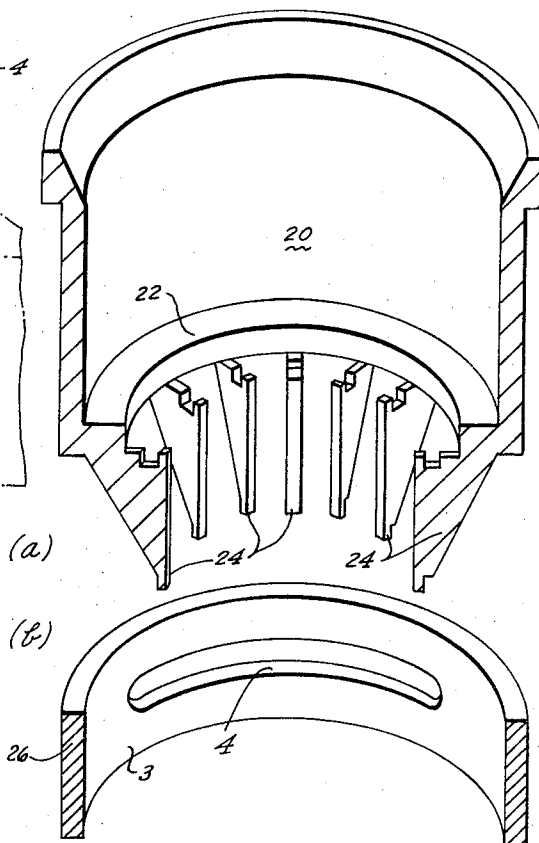


Fig. 4

Fig. 3



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Fig. 6

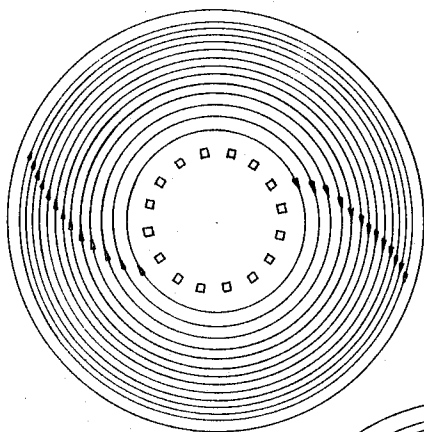


Fig. 5

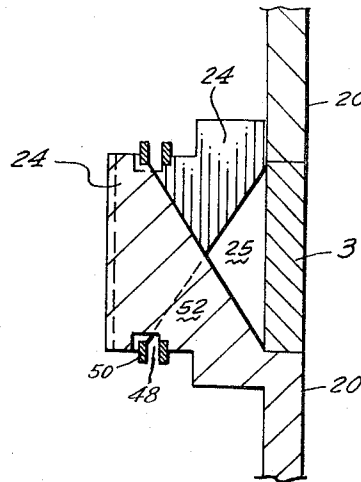


Fig. 7

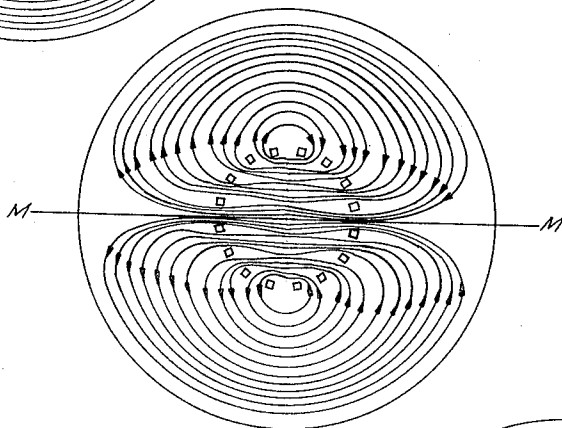
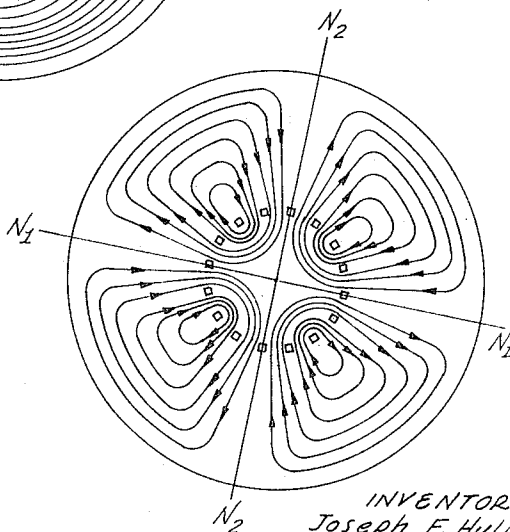


Fig. 8



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Fig. 12

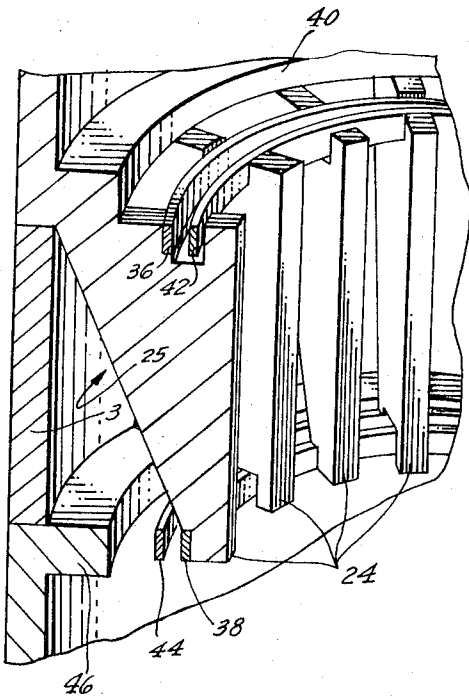


Fig. 9

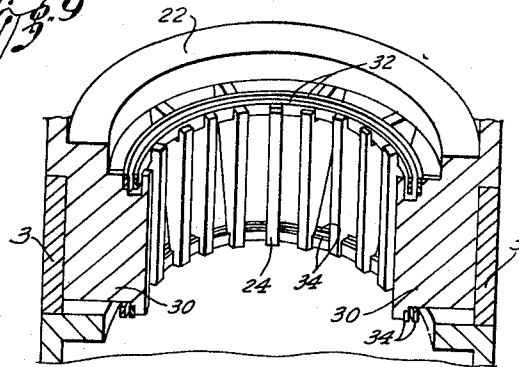


Fig. 10

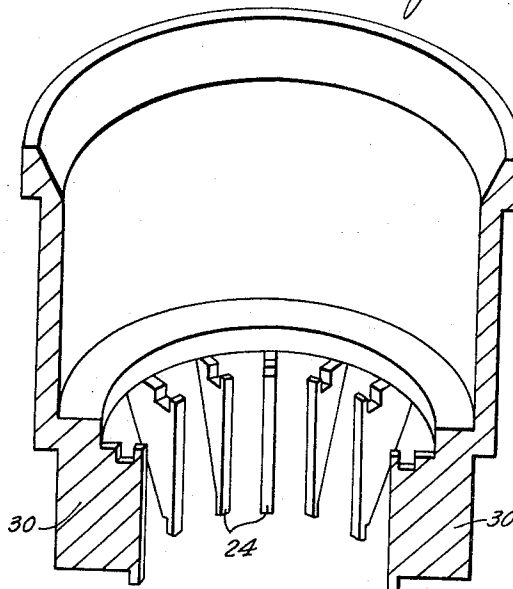
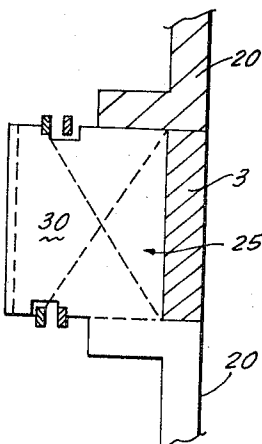


Fig. 11



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INTERDIGITAL MAGNETRON INCLUDING MEANS FOR SUPPRESSING UNDESIRE MODES OF OPERATION BY SEPARATING THE FREQUENCY OF POSSIBLE UNDESIRE OPERATING MODES

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Filed Jan. 2, 1963, Ser. No. 248,910
9 Claims. (Cl. 315—39.69)

This invention relates to electronic discharge devices useful at microwave frequencies and, more particularly, to interdigital type magnetrons.

A magnetron is a type of tube which can convert direct current electronic energy into microwave radio frequency energy by oscillations developed in its anode cavity or cavities, and is known as a cavity resonator. There are two basic types of magnetrons in common use and well known to the art: interdigital and vane types. The standard embodiment of both types employs a cathode assembly surrounded by a concentric interaction space; a concentric anode assembly containing a cavity or a plurality of cavities; and some type of coupling device which taps the energy within the cavity or cavities. Both types may be used at high microwave frequencies including X-band, i.e. 5,200 to 10,900 megacycles, and higher frequencies. Unfortunately, an output power circuit efficiency of approximately 60 percent at X-band frequencies is the maximum obtainable for either of these magnetron types.

The vane type magnetron is characterized by an anode comprised of a plurality of radially-spaced cavities separated by elements called vanes, each of which delivers energy of oscillation to the sum total of energy. This configuration limits the circuit efficiency of this type magnetron because of the difficulty in extracting energy from a plurality of cavities.

On the other hand, the interdigital type magnetron is characterized by an anode with a single cavity containing a plurality of elements called fingers. Although the interdigital type would seem to present high efficiency because of the ease of coupling to its single cavity, as a practical matter its utility is limited by other factors, such as cavity size and instability at high current loadings.

The size of the cavity of an interdigital type magnetron limits the utility of this type magnetron at X-band and higher frequencies. The cavity size is a function of the wavelength at the fundamental frequency and decreases with an increase in the fundamental frequency of the tube. At X-band and higher frequencies the cavity size becomes extremely small. This small cavity size creates several problems.

The most important problem is created by the difficulty of dissipating high heat when it is generated in a small cavity. A high power tube will generate a tremendous amount of heat in the cavity structure and if this heat cannot be properly dissipated, then the tube will be destroyed. The second problem involves the difficult manufacturing problems involved in producing very tiny assemblies with critical tolerances. At X-band and higher frequencies the cavity and the associated anode assembly are required to be so small that it is economically impractical to manufacture such assemblies. In fact, there is some doubt as to whether such assemblies can be built to the required tolerances at the present time.

The present invention greatly mitigates the problems of uneconomical manufacture and inadequate heat dissipation in interdigital magnetrons by increasing the cavity size for a given frequency. This is done by causing the cavity to oscillate at a frequency different from its fundamental frequency. A given cavity is capable of operation

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at several different frequencies even though the tube has strong tendencies to operate in its fundamental frequency which is associated with the so-called " π mode." The number of oscillation frequencies for a tube is related to the number of elements in the anode assembly, where each frequency is determined by the electric and magnetic field pattern, called a mode, existing within the anode assembly. For each mode of operation there is a different electric and magnetic field pattern and a different frequency of oscillation. The π mode is characterized by concentric circular magnetic field lines surrounding the cathode and by an axial potential gradient which varies outwardly from the cathode.

One possible way of increasing the cavity size for a given frequency, so that practical manufacture of the anode assembly is possible, is to cause a larger tube to operate in a mode other than the fundamental mode. This will allow a larger cavity size and anode assembly for a given frequency than is possible for a tube operating in the π mode. The prior art has encountered difficulties with this approach because of the instability caused by the tube's tendency to shift back to the fundamental or π mode.

Accordingly, it is an object of this invention to develop an interdigital type magnetron for operation at X-band frequencies and above with an anode cavity assembly large enough to allow practical manufacture and adequate heat dissipation at high power levels.

The foregoing objects are realized in accordance with an embodiment of the present invention by the use of a unique baffle arrangement which effectively suppresses the π or fundamental mode by displacing it to another frequency far above the frequency of the normal operating modes of the tube. Such an arrangement may be an extension of two oppositely disposed conductive fingers to the back wall of the interdigital cavity to block the cavity and electrically short-circuit the top and bottom crowns at two points.

These conductive baffles affect both the electrical and the magnetic fields associated with the various modes of operation of the tube. Since the baffle is conductive, magnetic lines varying at microwave frequencies will not be able to pass through them; and since the baffle shorts-out the top and bottom crown, it is at zero electrical potential and forms a potential clamp. The mode adjacent the π mode has a magnetic field distribution composed of two half-circular groupings of lines which tend to divide the cavity in half. This higher order mode also has an electric field potential distribution which includes a zero potential line along the division between the two groupings of magnetic field lines. On the other hand, the magnetic field lines associated with the π mode are in the form of concentric circles filling the cavity, and the electric field lines are formed by a potential gradient which varies radially from the inward edge of the fingers to the back wall of the cavity. By placing two copper baffles opposite each other, the magnetic field line distribution and the natural potential distribution of the electric field of the mode adjacent the π mode will be aided. However, the magnetic field lines and the potential distribution of the π mode will be greatly hindered. The practical effect of the baffles is to suppress the π mode and make the adjacent mode the favored mode of the tube.

Since the frequency of the mode adjacent to the π mode is considerably higher than the frequency of the π mode, this allows the cavity size to be substantially increased when the magnetron is operated in this higher mode. Adding more baffles will favor various other modes. Each baffle configuration will cause a different mode to replace the π mode as the favored mode.

It is, therefore, possible to triple or quadruple the cavity size of the magnetron for any given frequency. Since

the addition of these baffles makes it practical to manufacture interdigital magnetrons for much higher frequencies than has heretofore been possible, they represent a great advance over the prior art.

An advantage of such a baffle arrangement is that a much larger size interdigital magnetron can be used for X-band operations than the normal size interdigital magnetron operating in the π mode. Since the cavity size of an interdigital magnetron operating in the π mode at upper X-band frequencies is so small that the manufacturing difficulties become prohibitive, the larger size magnetron is a great advance over prior art.

Another advantage of the baffle is that the π mode is effectively suppressed by being removed to a frequency so high that for practical purposes it is impossible for the tube to move into this mode of operation.

A feature of this invention is an interdigital type magnetron utilizing baffles to suppress the π mode of operation.

High frequency operation requires small cavity size. As was mentioned above, causing the tube to operate in a mode adjacent to the π mode so that a larger cavity may be used only partially solves the heat dissipation problem attendant upon high power operation in the X-band and above frequency range. Even with a larger size cavity, heat dissipation in an interdigital magnetron using standard fingers is still a problem. In the standard interdigital magnetron the fingers are slender, narrow protrusions only able to transfer heat axially through a narrow cross section to an annular ring connecting one end of the fingers which, in turn, transfers the heat to the back wall of the cavity and the heat dissipating anode block.

Accordingly, it is an object of this invention to improve the heat dissipation of the fingers in an interdigital type magnetron.

In accordance with a specific embodiment of this invention this is accomplished by the use of generally triangularly shaped fingers extending to the back wall of the cavity which is connected to the heat dissipating anode block. Such fingers allow lateral as well as axial heat flow to the anode block and are much more efficient in dissipating heat than the standard interdigital fingers.

As previously mentioned, a magnetron has its strongest tendencies toward operation in the fundamental or π mode. If an attempt is made to cause an interdigital magnetron to operate in a mode other than the π mode, however, various factors can cause an uncontrolled shift from one mode of operation to another, especially a shift to the π mode. This mode shift makes the tube unstable in that the output frequency undergoes jumps or sudden shifts.

One of the things which increases the tendency to shift modes is a lack of sufficient frequency separation between the modes. Another factor is high loading currents resulting from an attempt to more efficiently couple the output load of the tube to the cavity to extract more microwave energy. High loading currents are believed to disturb the electric field pattern of the cavity near the coupling device and thus cause mode shift.

However, it is extremely desirable in many applications to get a very high circuit efficiency from operation of the tube. The 60 percent efficiencies obtainable from standard vane and interdigital type tubes at X-band frequencies and higher are not sufficient. A circuit efficiency of 80 to 95 percent is desired. The difficulties in coupling to the multiple cavity configuration of the vane type tube have heretofore prevented increasing the circuit efficiency to such high values; however, the configuration of the interdigital type magnetron offers highly efficient output coupling when the tube is made stable under the high loading currents associated with high efficiency.

Accordingly, it is a further object of this invention to increase the mode stability of interdigital type magnetrons to utilize the inherently high output of efficiency characteristics of interdigital type cavity coupling.

In accordance with the present invention this object is achieved through the use of strapping between alternate fingers of the interdigital anode structure. The effect of the strapping techniques is to accomplish mode separation by pushing the fundamental mode down to a lower frequency, pushing the adjacent mode to a higher frequency, and, more generally, increasing the frequency separation of all modes. With this increased frequency separation, there is little tendency to jump modes, and high loading currents are possible. Thus, it is possible to couple closely enough to achieve circuit efficiency in the range of 80 to 90 percent. This is much higher than the 60 percent efficiency previously obtainable.

To the best of my knowledge strapping has never been used before for stabilizing interdigital type magnetrons. The technique is well known in the vane type magnetron art to promote stability in the π mode. In an interdigital type magnetron there is no need of such means to keep the interdigital magnetron operating in the π mode, so strapping was never necessary. In the present invention the opposite effect is desired; rather than promoting stability in the π mode, it is desired to suppress the π mode and increase the frequency separation between the other modes. In the vane type magnetron the strapping achieves stability by coupling different cavities so that they operate at the same frequency independent of variations in cavity size. In the present invention it is desired to cause frequency separation between the modes other than the π mode in order to prevent the tube from jumping from one mode of operation to another.

An advantage of this invention is that it allows utilization of the inherent efficiency of coupling to the single cavity of an interdigital type magnetron without the mode instability which is a characteristic of interdigital magnetrons at high loading.

Another advantage of this invention is that it increases the mode stability of an interdigital type magnetron. This increase in mode stability is accomplished by the use of strapping between alternate fingers of an interdigital type magnetron.

Accordingly, a feature of this invention is an interdigital type structure with means for providing mode stability under high loading conditions.

For certain applications it has become desirable to have an interdigital magnetron capable of delivering an efficiency of 80 percent or more at upper X-band frequencies. Prior art magnetrons are not capable of doing this.

When the triangular interdigital fingers, baffle structure, and the interdigital strapping structure of the present invention are combined, an interdigital tube can be practically manufactured which will operate at upper X-band frequencies with an efficiency of 80 percent or more.

In accordance with an important feature of this invention, an interdigital magnetron is provided with an anode assembly having baffles for π mode suppression, and with strapping joining alternate fingers for mode stability at high current loadings. The anode assembly may also be provided with substantially triangular fingers for increased heat dissipation.

The novel features which are believed to be characteristic of the invention both as to its organization and method of construction and operation, together with further objects and advantages thereof, will be better understood from the following description, considered in connection with the accompanying drawings in which illustrative embodiments of the invention are disclosed by way of example. It is to be expressly understood that the drawings are for the purposes of illustration and description only and do not constitute limitations of the invention.

In the drawings:

FIG. 1 is an isometric drawing, partly cutaway, of a portion of a magnetron comprising an anode block, an anode section, and a pole piece;

FIG. 2 is an elevational view, in section, of a portion of a magnetron comprising an anode assembly, a cathode assembly, an interaction space, pole pieces, and a broadband output device;

FIG. 3a is an elevational view, in section, of one of two cylindrical crowns which provide the interdigitating fingers of the anode assembly;

FIG. 3b is an elevational view, in section, of the back wall of the cylindrical anode assembly showing the output coupling aperture;

FIG. 4 is an elevational view, partly in section, of the anode assembly of the magnetron of FIG. 1;

FIG. 5 schematically illustrates a cross section of the triangular cavity formed by the back edges of the interdigital fingers and the cavity back wall;

FIG. 6 illustrates the magnetic field lines in an interdigital magnetron cavity operating in the π mode;

FIG. 7 illustrates the magnetic field lines in an interdigital magnetron cavity operating in the $N/2-1$ mode;

FIG. 8 illustrates the magnetic field lines in an interdigital magnetron cavity operating in the $N/2-2$ mode;

FIG. 9 illustrates a portion of the anode assembly of FIG. 2 with baffle elements substituted for two of the fingers;

FIG. 10 illustrates a crown with two of the fingers replaced by baffles;

FIG. 11 illustrates the blocking effect of the baffle elements on the triangular cavity; and

FIG. 12 is an enlarged portion of the anode structure as shown in FIG. 2 which illustrates the strapping arrangement.

A magnetron generates microwave energy by employing the interaction between the electrons emitted from a cathode and a crossed electric and magnetic field. The general configuration of the magnetron includes an evacuated envelope containing a cathode assembly, a concentric interaction space and an anode assembly positioned concentrically around said cathode to define the interaction space.

The appropriate axial magnetic field is provided by suitable magnet arrangements, and suitable coupling devices are provided for extracting the energy generated within the tube.

With reference now to FIG. 1, there is shown in this figure a sectional view of a preferred embodiment of a magnetron anode assembly according to the invention which includes: an anode block 2, partially shown; a cavity wall 3 with an output coupling slot 4; annular end rings 22 connected to the ends of said cavity; and interdigital finger assembly 6 connected to the end pieces; and straps 7 interconnecting the fingers.

FIG. 2 is an elevational view, in section, of a portion of an interdigital magnetron containing such an anode assembly to illustrate the relationship of a cathode assembly 9, the anode block 2, an interaction space 10, interdigital fingers 24 forming part of the anode assembly, magnetic pole pieces 12, and a broadband output device 13.

The anode block 2 is formed upon a solid length of copper or circular cross section containing an axial hole 14 slightly larger than the diameter of the magnetron cavity. It is shaped at each end to receive magnetron pole pieces 12 of magnetic material and portions of a standard vacuum envelope 16 surrounding the magnetron. Another hole 18 perpendicular to the axial hole 14 and communicating with it extends through the side of the block. The mouth of this hole 18 is fashioned so as to receive an output coupling device 13 and the vacuum elements enclosing such elements.

FIG. 3a illustrates one of two oppositely opposed cylindrical copper crowns 20, each terminating in annular rings 22 with axially extending fingers 24. These crowns 20 are inserted in spaced relationship to each other within the anode block. The extending fingers of each crown interdigitate.

As shown in FIG. 3b, a cylinder 26 of the same circular cross section as the crowns and of axial length substantially equal to the axial length of the crown fingers is disposed within the annular rings of the crowns so as to preserve the spaced relationship of the crowns. This cylinder also serves as the back wall of the magnetron cavity and is partially capped by the annular rings 22 of the crowns 20.

FIG. 4 illustrates the anode assembly ready for insertion in the anode block 2 after the two crowns 20 and the cavity back wall 26, which acts as a spacer, are assembled so that the fingers 24 are interfitting.

As shown in FIG. 3a, the fingers 24 are radially disposed flat vanes of right triangular shape and may be milled into the ends of the crown. The fingers of each crown are so disposed that a surface joining their outer edges would have a conical shape and a surface joining their inner edges would form a concentric cylinder which intersects the conical surface. The base diameter of this conical surface may be about equal to the inside diameter of the cylindrical portion of the crown 20; and this base surface may abut the annular ring portion 22 of the crown.

The cylindrical spacer element 26, the annular rings 22 of the crowns, and the edges of the interdigital fingers 24 form an interdigital type ring-shaped cavity 25 of substantially triangular cross section as schematically illustrated in FIG. 5.

Interdigital type cavities are well known in the art but are usually comprised of fingers of substantially rectangular cross section. In the present case the fingers 24 are of triangular shape so as to provide efficient heat transfer from the inward edges of the fingers to the spacer cylinder forming the back wall of the cavity and from there to the anode block which has dimensions large enough to form an effective heat sink. These triangular fingers are a structural difference which completely differentiates the anode assembly of this interdigital magnetron from the standard interdigital magnetron. In the normal interdigital magnetron the fingers extend downward and upward from top and bottom end plates. The use of triangular fingers allows the substitution of narrow annular rings 22 which only cover a small part of the cavity in place of end plates. These rings 22 leave both the top and bottom ends of the fingers 24 free. This, of course, makes strapping and other modifications of the fingers possible. Other finger configurations may be substituted as long as they allow lateral as well as axial heat flow.

A circumferential slot 4 may be cut in the wall of the cylindrical spacer. This slot may be of a length up to $\frac{1}{2}$ the circumference of the spacer wall and provides output coupling between the cavity and suitable output transmission elements.

A standard tapered ramp, broadband output device 13 may be used for coupling purposes. The tapered elements 28 would extend through the anode block to connect the slot 4 in the cavity wall 3 with an output iris and flange, all of which would form part of the vacuum envelope for the tube.

In relation to the present invention, it is important to understand something about the modes of operation of a magnetron for two reasons. First, either a change in the mode of operation of a magnetron or a change in the size of the cavity will cause a change in the tube's frequency of operation. Second, interdigital magnetrons not operating in the π mode tend to shift modes and, consequently, frequency of operation under conditions of high output loading. High loading makes the tube frequency unstable, which is very undesirable for most applications.

It can be shown theoretically, and mathematically, that a cavity of a given size can oscillate at several frequencies. The oscillation at each frequency produces a different electromagnetic and electrical field pattern within the magnetron. Each pattern is referred to as a mode of operation.

It has been found experimentally that the number of different patterns or modes which can be formed in a magnetron is equal to half the number of segments in the anode block. In the vane type magnetron, these segments are called vanes. In an interdigital type, such as we are concerned with here, the segments are called fingers. This number is designated as n and is used as a handy reference to the mode in which the tube is operating. The possible modes in a magnetron are $n=0, 1, 2, 3, \dots N/2$ where N equals the total number of segments in the magnetron. For an interdigital magnetron having 8 fingers, the following values would obtain:

$$N=8$$

$$n_{\text{maximum}} = \frac{N}{2} = 4$$

For 8 fingers n would have values of 0, 1, 2, 3, 4.

$$n=3 = \frac{8}{2} - 1 = \frac{N}{2} - 1 \quad (2)$$

$$n=2 = \frac{8}{2} - 2 = \frac{N}{2} - 2 \quad (3)$$

In the art it is common to refer to the $n=N/2$ mode as the π or fundamental mode. As can be seen from Equations 1 and 2 the mode adjacent to the π mode is the $N/2-1$ mode and the mode adjacent to this mode is the $N/2-2$ mode.

In an interdigital type magnetron, the most common mode of operation is the π mode or $N/2$ mode. The magnetic field for this mode encompasses the entire cavity as is illustrated in FIG. 6. FIG. 6 and all of the figures illustrating magnetic fields for a particular mode are illustrative of field lines in a standard interdigital magnetron not containing triangular fingers. FIG. 7 represents the magnetic field of the $N/2-1$ mode and FIG. 8 represents the magnetic field of the $N/2-2$ mode.

When it is desired to operate the magnetron at X-band frequencies and, more particularly, at above X-band frequencies, the cavity size for π mode operation becomes so small that it is very impractical to get adequate heat dissipation and to build an anode structure. The parts have to be machined to very small dimensions. Since the total dimensions of the cavity are small, machining tolerances become very critical because the tolerance becomes large in relation to the size of the parts. Assembly becomes very difficult because of the difficulty in accurately working with very tiny parts. The assemblers find it very difficult to work on very small cavity assemblies, because the human eye needs magnification to work with such small parts. Also, the assembler's fingers and hand tools are clumsy in relation to the size of the parts. When the tube is operated at high power levels the magnetron fingers are subjected to a tremendous amount of heat because the inherently low electronic efficiency of a magnetron converts much of the electrical energy delivered to the cathode and to the field into tremendous heat at the fingers which must be dissipated. The cavity size necessary for π mode operation at X-band frequencies requires an anode assembly with fingers and other elements too tiny for dissipation of the heat generated at high power levels before the tube burns up.

The present invention obviates these difficulties by a unique structure which causes an interdigital magnetron to operate in the $N/2-1$ mode instead of the π mode. This has the effect of electrically dividing the cavity in half, which approximately doubles the frequency of operation for a given cavity size. Thus, a tube operating in the $N/2-1$ mode at a given frequency can be almost twice as large as a tube operating in the π mode and is much easier to manufacture and assemble. Forcing $N/2-1$ operation makes the interdigital type magnetron practical from a manufacturing standpoint for use at X-band and higher than X-band frequencies.

Prior to the present invention, forcing an interdigital magnetron to operate stably in the $N/2-1$ mode was a problem because of the tendency of a tube to operate in the π mode whenever it could. This is normally the favorite mode of the tube. The present invention is unique in that the structure described in this patent allows the favorite mode of the tube to be changed at will. Insertion of a pair of structural elements will cause the $N/2-1$ mode to replace the π mode as the favored mode of operation of the tube.

In the preferred embodiment of the present invention, the favored mode of the tube is changed to the $N/2-1$ mode by inserting opposing copper baffles 30 clamped to a preset potential in the cavity so as to interfere with the normal magnetic field lines and electrical field line potential distribution within the cavity. The baffles are designed to favor the magnetic and electrical field configuration of the $N/2-1$ mode and to act in opposition to the corresponding configurations of the π mode.

In order to describe the action of the baffles it is necessary to return to our discussion of the magnetic and electric field patterns associated with each mode.

Each mode has a characteristic magnetic and electric field pattern. The magnetic field pattern indicates the strength of the magnetic field by the proximity to each other of the grouped field lines within the cavity. The electric field indicates a potential distribution within the cavity. In general, the electric field is zero where the magnetic field is a maximum, and vice versa. Both fields have intermediate values in the range in between.

Metal elements set to a zero electric field potential will affect the magnetic field lines within the cavity as well as electric field potential distribution within the cavity. Magnetic field lines fluctuating at microwave frequencies are unable to pass through metal, and an electrical field is reduced to zero when it comes in contact with metal elements set at zero potential. Magnetic lines are unable to pass through the metal elements, but magnetic lines tangential to the element are unaffected. If metal elements are inserted within a cavity and clamped to a zero electrical potential, then a mode which has a magnetic field configuration with lines tangential to the baffles and an electric field configuration with the electrical field potential equal to zero along the baffles becomes favored. Other modes, including the π or fundamental mode, may be disfavored because their normal mode configuration includes magnetic lines normal to the baffles and an electrical field potential distribution other than zero along the baffles.

In the preferred embodiment of the present invention, the π mode is suppressed by the use of copper baffle elements 30 as shown in FIGS. 9 and 10. These baffle elements are formed by modifying two oppositely disposed fingers within the cavity into rectangular form, instead of triangular, so as to effectively block the cavity. These fingers extend radially outward from their inner edge so as to intersect the cavity back wall 26 and contact that wall for the axial length of the wall. The effect of the baffles is to divide the cavity into two half-ring portions. Although the preferred embodiment utilizes solid rectangular copper elements, other elements which will block the magnetic field lines and short-out the crowns may be used. For example, a rectangular screen with holes of a diameter less than $1/10$ of a wavelength may be used.

These baffles 30 connect the top and bottom crowns 20 and are thus at zero electrical potential so as to pull the electrical field potential down to zero at the two places where they block the cavity. Thus, shorting bars may be used in place of the rectangular vanes employed as baffles in the preferred embodiment of the invention. By pulling the electric field potential down to zero at the baffle surfaces and by blocking the magnetic field lines at two places, these copper baffles or shorting members have the effect of electrically dividing the cavity into two portions

This results in a realignment of the magnetic and electrical field distribution within the cavity.

It will be seen from FIG. 7 that the magnetic field in the N/2-1 mode is a maximum along a line M—M dividing the cavity in half. The electric field is zero where the magnetic field is at a maximum; therefore the electric field will be zero along this line. Baffles at zero potential can be inserted along this line without upsetting the potential distribution of the N/2-1 mode. Furthermore, such baffles will not upset the magnetic field pattern of the N/2-1 mode, since, as can be seen from FIG. 7, the magnetic field of the N/2-1 mode consists of lines which are tangential to any baffles inserted along the line M—M. On the other hand, as FIG. 6 illustrates, the magnetic field distribution of the π mode increases to a maximum at the cavity back wall from a minimum at the center of the cavity. The magnetic field lines consist of concentric circles filling the cavity, which are normal to the baffle elements and prevented from passing through them. The electric field of the π mode will have a potential gradient increasing in the reverse direction to that of the magnetic field distribution and will, thus, conflict with a zero potential element with no potential gradient. The effect of adding zero potential baffles so as to block the cavity at two points is to completely suppress the π mode for practical purposes, although it will still be possible at frequencies very much higher than the operating range of the tube. The baffles, of course, also aid the mode adjacent to the N/2-1 mode which is the N/2-2 mode. As seen in FIG. 8 this mode also possesses a zero potential line N_1 — N_1 dividing the cavity in half and another zero potential line N_2 — N_2 transverse to the first to divide the cavity into quarter portions. This N/2-2 mode can be favored by the addition of another pair of baffle elements along the second zero potential line. This enables an interdigital magnetron of relatively large cavity size to operate at very high frequencies. Other modes can be similarly favored.

Even with the baffle structure for suppressing the π mode of operation, the interdigital magnetron described above would still have the limitations of other interdigital magnetrons known in the art with respect to mode instability at high loading. High loading currents result from the close coupling between the output load and the tube cavity which is necessary for high efficiency operation. Interdigital type magnetrons not operating in the π mode are known to be unstable when subjected to the high loading currents associated with high efficiency and high power operation. It is believed that the close coupling necessary for high loading currents disturbs the mode pattern so as to cause mode instability. This causes a frequency change in the output and is highly undesirable. Prior to this time, it had not been possible to get higher loading currents than those equivalent to 60 percent circuit efficiency without getting mode instability.

If the baffles described above are used, then the mode instability would not be between the π mode and the N/2-1 and other adjacent modes, but instead would be between the N/2-1 and N/2-2 and other adjacent modes. This is because a two-baffle arrangement would suppress the π mode and substitute the N/2-1 mode as the favored mode.

One way of getting mode stability is to increase the frequency separation of the adjacent modes from the favored mode. In a magnetron where the π mode is suppressed by baffles, the N/2-1 mode is the favored mode. The frequency of this mode should be widely separated from the frequency of the N/2-2 mode and other adjacent modes, if frequency stability is to be achieved.

In order to accomplish the desired frequency separation, strapping is provided between alternate fingers of the interdigital structure.

In the present invention, the strapping consists of two concentric annular rings 32 at the top of the interdigital

fingers 24 and two concentric annular rings 34 at the bottom of the interdigital fingers as shown in FIG. 9. Each annular ring is connected to alternate fingers. The outer ring 36 at the top of the fingers and the inner ring 38 at the bottom of the fingers are electrically and mechanically connected to the fingers of the upper crown 40. Conversely, the inner ring 42 at the top of the fingers and the outer ring 44 at the bottom of the fingers are electrically and mechanically connected to the fingers of the bottom crown 46. As shown in FIG. 5 each finger 24 has a slot 48 on its edge nearest its crown 20 through which the ring 50 which is not connected to it passes without touching so as to be air insulated from the finger. The annular rings 32 and 34 connecting the fingers are made of copper or some other low impedance material.

The effect of these straps is to cause frequency separation between the modes. The π mode, if it has not already been suppressed by use of a baffle, is lowered in frequency, and the N/2-1, the N/2-2 and other higher modes are raised in frequency. The frequency increase in the modes is not uniform, and the frequency increase of the modes further away in frequency from the π mode is much greater than the frequency increase of the modes immediately adjacent the π mode. Thus, the increase in frequency of the N/2-1 mode may be very slight compared to the increase in frequency of the N/2-3 mode. The effect of this difference in frequency increase between the modes is to increase the frequency separation between the modes. For example, the frequency separation between the N/2-1 mode and the N/2-2 mode will be much greater when strapping is employed than it will be when the fingers are unstrapped. When strapping is used it becomes very difficult for the magnetron to shift modes of operation between adjacent modes, since in many cases the frequency shift has to be almost twice as great as in a magnetron not using such strapping.

The strapping operates by varying the inductance and capacitance of the cavity so as to change its resonant frequency for each mode of operation. The strapping will add a capacitive effect at all frequencies and for all modes of operation; and for modes of operation other than the π mode the strapping will add an inductive effect because for these modes current will flow between fingers connected by the strapping and this current will be inductive current. All the ends of the fingers on one crown at any given instant of time are at potentials of the same sign, either "+" or "-". The fingers on opposite crowns are at opposite potentials. Thus, at a given instant of time, fingers on one crown are at a "+" potential and the fingers on the other crown are at a "-" potential. When the tube is operating in the π mode, all of the fingers on the "+" potential crown are at the same amplitude of "+" potential and all of the fingers on the "-" potential crown are at the same amplitude of "-" potential; therefore, in the absence of a potential difference between fingers on the "+" crown, no current will flow in a low impedance strapping element connecting the fingers. The effect of current flow between fingers at microwave frequencies is to add a shunt inductance. Since there is no shunt inductive effect where there is no current flow, no shunt inductance is added when the tube is operated in the π mode because no current flows between the strapped fingers.

On the other hand, the addition of strapping will add a capacitive effect even when the tube is operating in the π mode. Capacity is added to the resonant circuit formed by the fingers, the crowns and the cavity back wall. The effect of this increased capacitance is to lower the resonant frequency of the π mode. This is because

$$2\pi f = \omega = \frac{1}{LC} \quad (4)$$

where f equals frequency, L equals inductance and C equals capacitance in appropriate units.

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At modes other than the π mode, the ends of the fingers on one crown are still at a "+" potential at any given instant of time and the fingers on the opposite crown are at a "-" potential at any given instant of time; however, the amplitude of these potentials varies from finger to finger. Thus, for example, three adjacent fingers on the same crown can have potentials of +, ++, ++++. Thus low impedance strapping connecting the fingers on one crown will have current flow which is caused by the difference in potential amplitude between fingers. This current flow adds a shunt inductance to the resonant circuit formed by the fingers, crowns and back wall which lowers the total circuit inductance under Formula 4 given above. This causes the frequency of operation of any mode other than the π mode to increase.

Modes widely separated from the π mode are affected more than modes immediately adjacent the π mode and are subjected to a more marked increase in frequency than those immediately adjacent the π mode. However, all modes are boosted in frequency by the strapping. Since all modes are boosted in frequency but the boost is not uniform, the effect of the strapping is to cause wider frequency separation between the adjacent modes and especially to cause a large frequency separation between the π mode which is decreased in frequency and the adjacent mode which is increased in frequency.

The strapping which has been described consists of low impedance electrically conductive rings interconnecting the fingers of one crown. While this form of "inductive" strapping is very effective, other types of strapping may be used. For example, "capacitive" strapping between fingers of the same crown may be employed. The triangular configuration of the fingers shown in the preferred embodiment lend themselves to "capacitive" strapping. As can readily be seen from FIG. 5, there is a substantially triangular area 52 on the fingers of one crown that is not overlapped by the fingers of the opposite crown and which thus presents flat surfaces of adjacent fingers on the same crown in an unobstructed parallel relationship to each other. The capacitive effect is relatively minor in the preferred embodiment because of the separation between adjacent fingers. However, by adding projections of various configurations to these parallel surfaces, the capacitive effect can be enhanced so that true "capacitive" strapping exists.

In vane type magnetrons, it has been common in the art to use strapping between the vanes to force the vane type magnetron to operate stably in the π mode. However, because of the difference in theory and operation between the vane type and interdigital type magnetrons and because the normal construction of interdigital tubes requires upper and lower end plates, such strapping elements have not been successfully employed to eliminate non- π mode instability in interdigital magnetrons.

In accordance with this invention, tubes using both the baffles and the interdigital strapping have been successfully operated at X-band frequencies and higher and have operated at circuit efficiencies better than 80 percent. These tubes have operated in the N/2-1 mode and have provided sufficient heat dissipation to prevent the tube from burning out. By the use of unique triangularly shaped fingers 24 which allow efficient heat transfer from the edges of the fingers to the back wall 26 of the cavity, a large copper anode block 2 then acts as a heat sink to draw the heat from the back wall of the cavity for dissipation to the ambient. The triangularly shaped fingers allow lateral as well as axial heat flow to the anode block and are much more efficient in dissipating heat than the standard slender interdigital fingers which allow only axial heat transfer.

To restate the advantages of the invention, the novel baffle arrangement eliminates the π mode of operation of a magnetron for all practical purposes and replaces it with another mode of higher frequency. This allows a

higher frequency output at anode cavity assembly sizes large enough for practical manufacture.

The novel strapping of interdigital fingers in an anode assembly provides mode stability in an interdigital magnetron at the high loading currents associated with high circuit efficiencies of 80 percent or more.

The combination of the baffles and the strappings allow the practical manufacture of an interdigital type magnetron which will operate at X-band frequencies and higher and will have sufficient mode stability to allow a circuit efficiency of 80 percent or more.

The triangularly shaped fingers allow the efficient dissipation of cavity heat from the fingers of the interdigital magnetron which would cause a magnetron using standard interdigital fingers to burn up.

It is to be understood that the above described arrangements are illustrative of the application of the principles of invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention. Thus, by way of example and not by limitation, the fingers and the baffles described in the preferred embodiment may be changed in shape or arrangement and the number of arrangement of the strapping rings may be changed as desired.

Accordingly, from the foregoing remarks, it is to be understood that the present invention is to be limited only by the spirit and scope of the appended claims.

What is claimed is:

1. An interdigital magnetron comprising:

a cathode assembly;

an anode assembly including an interdigital cavity enclosing said cathode assembly to form an interaction space between the two assemblies, said cavity being capable of oscillation in different modes, wherein the high frequency magnetic field lines are arranged in groupings with a maximum magnetic field in predetermined radial zones separating the groups;

means for applying a steady magnetic field to said interaction space substantially parallel to said cathode; baffle elements of conductive material disposed within the interdigital cavity along the radial zones as separations between the groupings of high frequency magnetic field lines peculiar to a desired mode of operation; and

means for maintaining said baffles at a fixed predetermined potential.

2. The magnetron of claim 1 wherein the interdigital cavity includes:

two sets of axially disposed interdigitated fingers; means for conductively strapping said first set of fingers to provide mode stability; and

separate means for conductively strapping said second set of fingers to provide mode stability.

3. In an interdigital magnetron where the interaction between electrons emitted from a cathode and a crossed magnetic field is employed for generating microwave energy, an interdigital anode assembly positioned concentrically around said cathode, said anode comprising:

an interdigital cavity, said cavity being capable of oscillation in different modes;

electrically conductive baffle elements disposed within the interdigital cavity, said baffle elements being disposed within said cavity in conflicting relationship to the electric field potential distribution peculiar to the π mode of operation; and

means for maintaining said baffle elements at zero electric field potential.

4. In an interdigital magnetron where the interaction between electrons emitted from a cathode and a crossed magnetic field is employed for generating microwave energy, an interdigital anode assembly positioned concentrically around said cathode, said anode comprising:

an interdigital cavity, said cavity being capable of oscillation in different modes; and

electrically conductive baffle elements disposed within the interdigital cavity, said baffle elements being disposed within said cavity in conflicting relationship to the electric field potential distribution of some modes of operation different from the desired mode of operation.

5. In an interdigital magnetron where the interaction between electrons emitted from a cathode and a crossed magnetic field is employed for generating microwave energy, an interdigital anode assembly positioned concentrically around said cathode, said anode comprising: 10
an interdigital cavity, said cavity being capable of oscillation in different modes;

electrically conductive baffle elements disposed within the interdigital cavity, wherein said baffle elements are disposed within said cavity along the lines of minimum electric field potential peculiar to a desired mode of operation; and 15
means for maintaining said baffle at zero electric field potential.

6. In the anode assembly of an interdigital magnetron: 20
a cavity structure;

first and second sets of interfitting fingers, each of said fingers including a base connected to said cavity structure and a tip extending away from the point of connection of said finger to said cavity;

the tips of said first set of fingers extending in one direction;

the tips of said second set of fingers extending in the opposite direction;

conductive strapping means connecting the tips of said first set of fingers and in insulated relationship to said second set of fingers; and 30

conductive strapping means connecting the tips of said second set of fingers and in insulated relationship to said first set of fingers. 35

7. In an interdigital magnetron where the interaction between electrons emitted from a cathode and a crossed magnetic field is employed for generating microwave energy, an interdigital anode assembly positioned concentrically around said cathode, said anode comprising: 40
an interdigital cavity structure;

first and second sets of interfitting fingers connected to such structure;

said first set of fingers extending in one direction; 45
said second set of fingers extending in the other direction;

low impedance strapping rings connecting said first set of fingers and in insulated relationship to said second set of fingers;

low impedance strapping rings connecting said second set of fingers and in insulated relationship to said first set of fingers;

said cavity being capable of oscillation in different modes, wherein the high frequency magnetic field lines are arranged in groupings with maximum magnetic field lines in predetermined radial zones separating the groups; and

electrically conductive baffle elements disposed within the interdigital cavity as separations between group-

ings of high frequency magnetic field lines peculiar to a desired mode of operation.

8. In an interdigital magnetron where the interaction between electrons emitted from a cathode and a crossed magnetic field is employed for generating microwave energy, an interdigital anode assembly positioned concentrically around said cathode, said anode comprising: 5
two sets of axially disposed interdigitated fingers;

a resonant cavity including a conductive cylindrical wall and conductive top and bottom walls encircling said fingers;

means for connecting said first set of fingers to the top wall of said cavity and said second set of fingers to the bottom wall of said cavity;

means for conductively strapping said first set of fingers to provide mode stability;

separate means for conductively strapping said second set of fingers to provide mode stability; and

two of said fingers in oppositely opposed relationship shaped in substantially rectangular form extending back to said cylindrical wall of said cavity so as to divide said cavity, whereby the π mode of operation is suppressed. 20

9. In an interdigital magnetron where the interaction between electrons emitted from a cathode and a crossed magnetic field is employed for generating microwave energy, an interdigital anode assembly positioned concentrically around said cathode, said anode comprising: 25
two sets of axially disposed interdigitated fingers;

a resonant cavity including a conductive cylindrical wall and conductive top and bottom walls encircling said fingers;

means for providing heat transfer to the cylindrical wall from the edge of said fingers adjacent the cathode;

means for connecting said first set of fingers to the top wall of said cavity, and said second set of fingers to the bottom wall of said cavity;

means for conductively strapping said first set of fingers to provide mode stability;

separate means for conductively strapping said second set of fingers to provide mode stability; and

one or more pairs of said fingers in oppositely disposed relationship shaped in substantially rectangular form extending back to said cylindrical wall of said cavity so as to divide said cavity. 30

References Cited by the Examiner

UNITED STATES PATENTS

2,463,524	3/1949	Derby	315—5
2,759,123	8/1956	Jenny	315—39.57
2,922,075	1/1960	LaRue	315—39.63

OTHER REFERENCES

55 Okress: "Crossed-Field Microwave Devices," vol. II, 1961, Academic Press, New York and London (pp. 36—37, 67 and 293 relied on).

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