Nov. 29, 1966 J. DREXLER 3,289,035

REVERSE MAGNETRON HAVING MEANS TO SUPPRESS UNDESIRED MODES

Filed Aug. 10, 1962 2 Sheets-Sheet 1

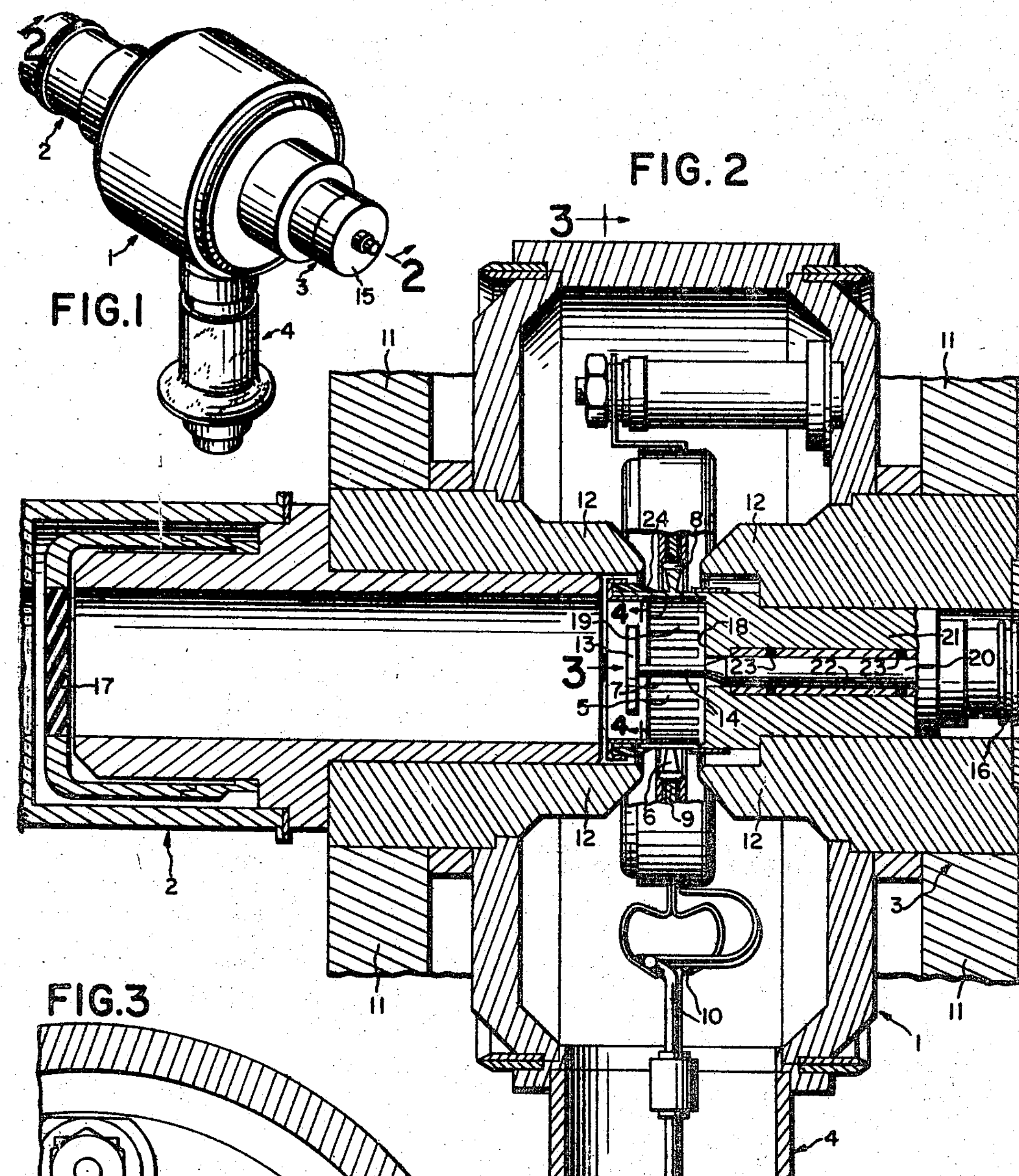

FIG. 1

FIG. 2

FIG. 3

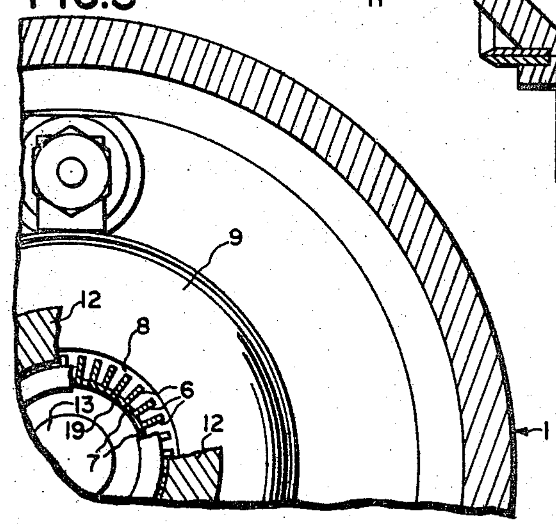

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FIG.4

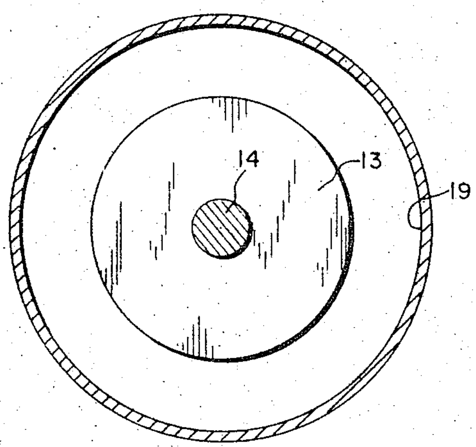
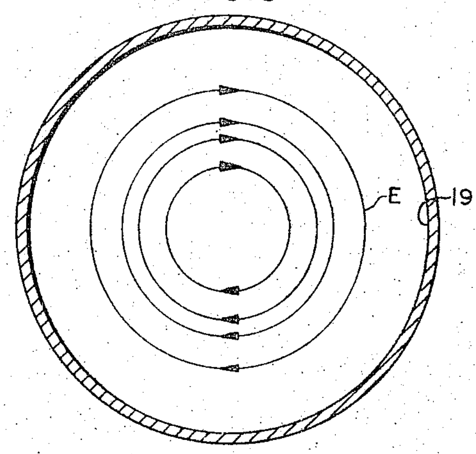


FIG.5



$TE_{0,1}$ MODE

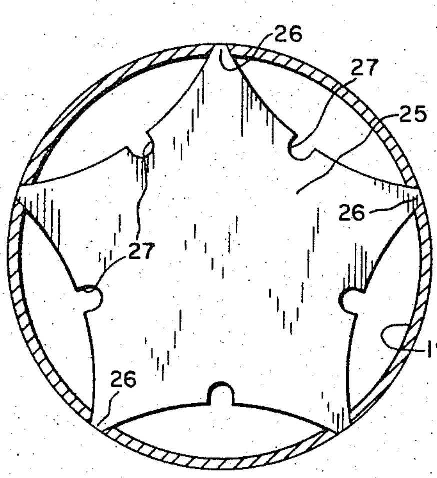


FIG.6

$TE_{2,1}$ MODE

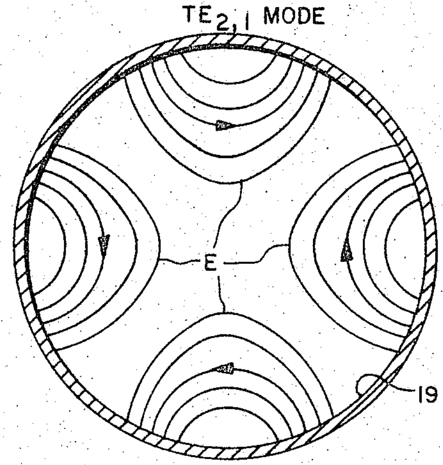


FIG.7

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REVERSE MAGNETRON HAVING MEANS TO SUPPRESS UNDESIRED MODES

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11 Claims. (Cl. 315—39.51)

The present invention relates in general to electron discharge devices of the crossed electric and magnetic field type and more specifically to a reverse magnetron useful for generating high power microwave energy at extremely high frequencies such as required in high power, high resolution radars.

A reverse magnetron tube typically comprises a circular electric mode cavity or circular electric mode wave propagating structure surrounded by a circumferential array of outwardly directed vane or cavity resonators coupled to the excited circular electric structure via a circular array of axial slots communicating with alternate anode resonators. The array of anode resonators is surrounded by a magnetron interaction region formed by an annular cathode emitter, emitting radially inwardly into the anode, in the presence of a strong axial magnetic field. Rotating spokes of electron space charge interact with the π mode fields of the anode resonators to excite the circular electric mode in the circular electric mode cavity. Since the energy stored in the circular electric mode cavity is much higher than that of the vane resonator circuit the anode vane resonator system is locked in the π mode to the circular electric cavity mode thereby stabilizing the magnetron. The reverse magnetron structure may be used as an oscillator or as an amplifier and microwave energy is extracted from the circular electric mode wave propagating structure or cavity and fed to a suitable load.

Heretofore a reverse magnetron of the above described type has been built operating at approximately 32 gigacycles and generating a peak power of approximately 15 kilowatts. When an attempt is made to push this prior art design to higher output levels of 300 kilowatts peak, 50 watts average, 30% efficiency and a tunable band of approximately 12% several severe problems are encountered which prevent attaining these late specifications.

Some of the problems associated with pushing the power output of the prior art reverse magnetron design to higher power levels are as follows:

In pulse operation, as of 1 microsecond, certain non-circular electric modes of the cavity are excited due to insufficient selective mode suppression, thereby causing the anode resonators to operate in an unstable non π mode resulting in pulse jitter and reduced efficiency; during tuning of the circular electric mode cavity, parasitic modes associated with the back cavity spaces behind the non-contacting movable wall tuner results in dips in the power versus frequency curve over the operating band of the tube.

The reverse magnetron tube of the present invention solves the aforementioned difficulties associated with the prior art tube and provides a 32–35 gigacycle magnetron having a peak power output in the order of 290 kilowatts with average power output of approximately 50 watts while yielding overall efficiencies of approximately 30% and a tunable bandwidth up to 12%. This tube represents more than an order of magnitude increase in peak power output with approximately double the previously obtained efficiency while having a long operating life in excess of 2,400 hours.

The principal object of the present invention is to provide an improved high power reverse magnetron tube yielding substantially enhanced peak power with increased efficiency and operating life.

One feature of the present invention is the provision of a novel output coupling method and apparatus for the circular electric mode cavity which more heavily and selectively couples the undesired non-circular electric modes of the cavity to the load thereby loading and suppressing the undesired non-circular electric modes, whereby when used in a reverse magnetron the result is stable operation of the tube and elimination of pulse jitter.

Another feature of the present invention is the provision of a novel tuner structure and method for the circular electric mode cavity wherein a structure is provided for tuning by producing axial translation of the output coupling structure, whereby dips in the power versus frequency curve over the band of the tube are eliminated, such dips being heretofore caused by parasitic resonance associated with spaces behind the prior art non-contacting movable end wall tuners.

Another feature of the present invention is the provision of an axial rod centrally disposed of the circular electric mode cavity, said rod carrying the output coupling structure for facilitating axial translation of the coupling structure and tuning of the circular electric mode cavity.

Other features and advantages of the present invention will become apparent upon a perusal of the specification taken in connection with the accompanying drawings wherein:

FIG. 1 is an outside perspective view of the reverse magnetron tube of the present invention,

FIG. 2 is an enlarged fragmentary view partly broken away and partly in section of the structure of FIG. 1 taken along the line **2—2** in the direction of the arrows,

FIG. 3 is a fragmentary view partly in cross-section and partly broken away of the portion of the structure of FIG. 2 taken along the line **3—3** in the direction of the arrows,

FIG. 4 is an enlarged fragmentary cross-sectional view of the portion of the structure of FIG. 2 taken along the line **4—4** in the direction of the arrows,

FIG. 5 is a cross-sectional mode diagram showing the TE_{01} circular electric mode of the cavity of FIG. 4,

FIG. 6 is an alternative structure of that depicted in FIG. 4, and

FIG. 7 is a mode diagram showing the electric field lines for the TE_{21} mode in the cavity of FIG. 4.

Referring now to FIGS. 1, 2 and 3, character **1** represents the hollow tubular supporting body of the reverse magnetron, as of copper, to which other parts are brazed or otherwise suitably fastened to form a structure capable of being evacuated. On opposite sides of the body **1** in axial alignment there are brazed to the body **1** a tubular output waveguide assembly **2** and tuner assembly **3**. Cathode lead-in insulator structure **4** extends outwardly from the main body section **1** in quadrature with the axially aligned output waveguide and tuner structures **2** and **3**, respectively.

The term circular electric mode cavity, waveguide, or wave supporting structure as used herein is defined to mean a cavity, waveguide, or wave supporting structure formed, dimensioned, and excited in such a manner as to support at its certain preselected operating frequency a certain circular electric mode, of the general form $TE_{O,m,n}$, to the exclusion of other modes. A circular electric mode cavity, waveguide, or wave supporting structure typically includes an outer cylindrical side wall and may or may not have an axially directed center conductor.

A hollow circular electric mode cavity resonator **5** is disposed centrally of the anode body **1** on the axis of the tube. In amplifier embodiments of the present invention, the circular electric mode cavity **5** is replaced by a circular electric wave supporting structure such as, for example, a hollow cylindrical pipe having an input port as well as an output port. A circumferential array of outwardly directed vanes **6** surround the circular electric mode cavity **5** and form an array of anode resonators by the spaces between adjacent vanes **6**. Alternate anode resonators are electromagnetically coupled to the circular electric mode cavity **5** via an array of axially directed slots **7** communicating through the common wall between the anode resonators and the circular electric mode cavity **5**. A magnetron interaction region **8** surrounds the outer tips of the vanes **6** and is defined by the space inbetween the vanes **6** and a surrounding cathode emitter ring **9**.

A strong axial magetic field as of 12,000 to 15,000 gauss for the magnetron interaction region **8** is provided by a bowl shaped magnet **11**, only partially shown in FIG. 2, enveloping the anode body portion **1** and having a re-entrant internal magnetic gap extending in the axial direction through the magnetron interaction region **8** between the magnetic pole pieces **12** disposed on opposite sides of the anode vanes **6**.

Tuning of the tube over its approximate 12% tuning band, centered at approximately 34 gigacycles, is obtained by means of axial translation of a combined cavity end wall and output coupling plate **13** carried upon the end of an axially directed and positioned rod **14** which is axially translatable via the intermediary of a captured nut **15** and bellows assembly **16**, partially shown.

The negative cathode potential of approximately 23 kv. is applied to the cathode emitter **9** via high voltage lead-in insulator assembly **4**. The cathode **9** uses a low voltage A.C. filament heater and therefore a dual wire cathode lead-in **10** is used.

In operation, the π mode of the anode resonator system adjacent the magnetron interaction region is locked to the circular electric mode resonator **5** via the intermediary of the coupling slots **7** serving to drive the resonator **5**. An annular slot mode absorber **24**, juxtapositioned the coupling plate end of the slots **7**, suppresses the undesired slot mode. The slot mode absorber **24** and its support structure form the subject matter of and are claimed in copending U.S. application 223,499, filed September 13, 1962, now issued as 3,231,781 on January 25, 1966, and assigned to the same assignee as the present invention. Output energy from the resonator **5** is extracted via the coupling plate **13** and transmitted to the load, not shown, via the intermediary of the circular electric mode output waveguide structure **2** and an output vacuum tight wave permeable window **17**.

The tube structure and mode of operation will now be described in greater detail as it specifically relates to each of the before mentioned features of the present invention.

The novel output coupling method and apparatus feature of the present invention can be seen by reference to FIGS. 2, 3 and 4. The circular electric mode cavity **5** is defined and bounded on one end by the fixed circular end wall **18** as of copper, and on the sides by the circular relatively thin anode wall **19**, as of copper, and on the other end by axially translatable combined tuner and coupling plate **13**, as of copper. The coupling plate **13** is carried upon the extremity of the axially directed centrally disposed rod **14** as of, for example, copper. The rod **14** is provided with an axially directed enlarged extension portion **20** as of molybdenum and is rectilinearly translatable axially of the tube for tuning of the circular electric cavity **5**. The rod extension **20** is sealed in a vacuum tight manner to the tube body **1** via the intermediary of the axially extensible bellows **16**. The rod extension portion **20** slides in an axial directed bore in an anode block **21** as of copper having an insert sleeve **22** as of molybdenum serving as a bearing support for the molybdenum extension **20**.

A pair of axially spaced apart sapphire rings **23** of slightly smaller inside diameter than the molybdenum sleeve insert **22** are carried in the sleeve **22** and serve as the sliding bearing contact between the enlarged portion of the tuning rod **20** and the fixed sleeve insert **22**. The rings **23** serve to facilitate axial movement of the tuning rod by minimizing sliding friction while at the same time providing a firm bearing support to minimize microphonics in use.

The circular electric mode cavity **5** is capable of supporting certain interfering non-circular electric modes such as, for example, the $TE_{2,1,1}$, $TE_{1,1,1}$, the $TE_{3,1,1}$, . . . etc. modes. These non-circular electric modes all have associated therewith certain radially directed currents in the end walls **13** and **18** of the circular electric mode cavity **5**. The radial currents are exemplified by the $TE_{2,1}$ electric field mode distribution as shown in FIG. 7.

The novel coupling plate **13** approximates a cavity end wall having an elongated peripherally directed coupling slot therethrough. Such a coupling slot heavily couples to those modes having radial currents in the end walls while much less heavily coupling to the circular electric mode currents. It is believed that the circular electric mode currents are perturbed slightly by the coupling plate **13** causing them to move radially inwardly toward the center of the cavity. This inward movement of the desired circular electric mode field, see FIG. 5, is desirable since it tends to thereby move currents associated with the desired circular electric mode further away from the slot mode absorber **24** surrounding the coupling plate end of the axially directed coupling slots **7**. The annular slot mode absorber **24** is used for suppressing certain undesired slot modes.

The elongated circumferentially directed coupling slot, formed by the annular space between the disc shaped coupling plate **13** and the inner side wall **19** of the circular electric mode cavity **5**, performs the function of coupling out wave energy from the desired circular electric mode and also more heavily coupling the load, not shown, to the undesired non-circular electric modes thereby resulting in suppression of these undesired modes. This selective mode suppression stabilizes operation of the circular electric mode cavity **5** in the circular electric mode and locks the coupled system of anode resonators on the desired π mode in the magnetron interaction region **8**.

Typical dimension for a circular electric mode cavity **5**, designed for operation at 34 gigacycles on the dominant $TE_{0,1,1}$ mode are: the inside diameter of the cavity **5** is approximately 0.570″, the height of the cavity is approximately ½ a wavelength, the axial thickness of the disc shaped coupling plate **13** is approximately 0.030″, the disc **13** has a diameter of approximately 0.341″, and the diameter of the tuning rod **14** is approximately $\frac{1}{10}$ the diameter of the cavity **5**.

In a fixed tuned alternative output coupling embodiment of the present invention, the coupling disc **13** of FIGS. 2, 3 and 4 is replaced by a snowflake shaped plate **25** as shown in FIG. 6. The elongated peripherally directed openings in the plate **25** between the radially directed members or points **26** of the snow-flake shaped plate serve to couple the circular waveguide structure, and consequently the load, more heavily to the non-circular electric modes within the cavity, characterized by radially directed currents in the cavity end walls **18** and **25**.

This selective heavy coupling of the non-circular electric modes to the load serves to suppress these modes and prevent their sustained oscillation in the circular electric mode cavity 5. The inwardly directed peripherally spaced apart notches 27 in the snowflake plate 25 serve to enhance coupling between the desired circular electric mode and the load for coupling output wave energy from the cavity 5 to the load. As in the previous embodiment, the snowflake 25 may be carried upon the extremity of the rod 14 for tuning or may be fixedly secured to the side walls 19 of the circular electric mode cavity 5 at the tips 26 of the snowflake plate 25, as by brazing.

In a preferred embodiment the snowflake shaped coupling plate 25 has an odd number of connecting points 26. If the plate 25 has an even number of points 26, as for example six, then the undesired $TE_{3,1,1}$ mode could align itself to minimize its coupling to the load.

In operation, the combined tuning and coupling plate embodiments, as described above, readily permit tuning of the reverse magnetron oscillator over a 12% band centered at 34 gigacycles without encountering substantial dips in the power versus frequency curve as previously encountered due to back cavity resonances associated with prior art non-contacting movable wall tuners. In addition, the selective mode suppressing coupling plate readily permits enhanced efficiencies of 30% while eliminating pulse jitter at power levels of 290 kw. peak power.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A coupling device for wave energy communication between a hollow cavity resonator operating in a circular electric mode and a load including, a circular electric mode cavity resonator having an end wall, said end wall having an elongated coupling hole therethrough, a hollow circular electric mode wave supporting structure axially aligned with said coupling hole for wave communication between said cavity and the load, said elongated coupling hole being elongated in the circumferential direction of said cavity end wall to provide coupling to the desired circular electric mode while more heavily coupling the load to the undesired non-circular electric modes of said cavity having radial currents in said end wall to thereby load said undesired modes for suppression thereof.

2. In an electronic circuit, means defining a first circular electric mode cavity resonator, means defining a second system of resonators, a common wall member separating said first cavity resonator from said second system of resonators, means communicating through said common wall member for coupling said first and second resonators, coupling means for coupling wave energy from said first circular electric mode cavity resonator to a load, said coupling means being formed and arranged to more heavily couple the load to non-circular electric modes of oscillation of said first cavity resonator than the circular electric mode of said first resonator for mode suppression of the non-circular electric modes in said first cavity resonator.

3. In a crossed field tube apparatus, a cathode, an anode wall with a plurality of anode resonators formed therein adjacent said cathode, means for defining with said anode wall a second cavity resonator, means for coupling certain ones of said anode resonators to said second cavity resonator and including a plurality of slots communicating through said anode wall between said anode resonators and said second cavity resonator, said second cavity resonator having an end wall, an elongated coupling hole provided in said end wall of said second cavity resonator, said elongated coupling hole being directed peripherally of said end wall for coupling wave energy from said second cavity resonator to a load, and said peripherally directed coupling hole serving to more heavily couple modes of the said second cavity resonator having currents tending to flow radially across said elongated coupling hole than other modes having currents flowing in the peripheral direction of said coupling hole, whereby said certain modes having radially directed currents are more heavily coupled to the load for suppression thereof.

4. In a magnetron apparatus, a circular electric mode cavity having a pair of axially spaced apart energy reflective end wall members defining with a side wall said circular electric mode cavity, an array of resonant cavities, coupling means communicating through said side wall of said circular electric mode cavity for coupling said circular electric mode cavity to said array of resonant cavities, one of said end reflective wall members being provided with a peripherally directed elongated coupling slot therethrough, circular electric mode waveguide disposed in registry with said elongated coupling slot for providing wave energy communication between said circular electric mode cavity and a load, and said elongated coupling slot being disposed in said end reflective wall member nearer to said circular electric cavity side wall than to the center of said end wall whereby the non-circular electric modes are more heavily coupled to the load than the circular electric mode and whereby the non-circular electric modes are selectively suppressed.

5. The apparatus according to claim 4 wherein said cavity end wall reflective member having the coupling hole therein is provided with a plurality of peripherally directed coupling holes interrupted by radially directed conductive members, said radially directed conductive members serving to join said cavity side wall to said reflective end wall.

6. The apparatus according to claim 5 wherein there are an odd number of radially directed conductive members to heavily couple to the undesired $TE_{3,1,1}$ mode for suppression thereof.

7. The apparatus according to claim 4 wherein said circular electric mode cavity includes, a centrally disposed axially directed member affixed to said slotted end wall reflective member.

8. The apparatus according to claim 7 wherein said axially directed member affixed to said slotted end wall is axially translatable for moving said slotted reflective end wall for tuning of said circular electric mode cavity.

9. The apparatus according to claim 8 wherein said axially directed centrally disposed member is made of an electrically conductive material.

10. A reverse magnetron tube apparatus including, an evacuable body portion, a cylindrical cavity resonator centrally disposed of said body portion for sustaining a $TE_{0,1}$ mode of oscillation and having an outer cylindrical side wall, a circumferential array of anode resonators surrounding said cylindrical outer cavity wall, means for electrically locking the π mode of oscillation of said array of anode resonators to said $TE_{0,1}$ mode of said central cavity resonator, said locking means including a circumferential array of axial slots extending through said outer cavity wall member at alternate ones of said anode resonators, a ring of glossy material disposed adjacent the ends of said slots on the outside of said outer cylindrical wall for loading certain unwanted modes of oscillation of said slots, said central cavity resonator having a fixed end closing wall with an axially directed bore therethrough, a centrally disposed axially directed rod extending axially through said central cavity resonator and movable through said bore, and said central cavity resonator having a movable end wall defined by a conductive disc carried upon said axially directed rod, said disc being spaced at its periphery from the outer side wall of said central cavity resonator for defining an annular coupling slot through said end wall, said annular coupling slot serving to selectively more heavily couple non-circular electric modes of said inner cavity to a load than the desired $TE_{0,1}$ mode

of oscillation of said central cavity, whereby said noncircular electric modes are suppressed.

11. A selective coupling apparatus for coupling to circular electric mode structures including, a circular electric mode cavity resonator having an end wall, said end wall having an elongated coupling hole therethrough, a hollow circular electric mode wave supporting structure axially aligned with said coupling hole for wave communication between said cavity and said wave supporting structure, said elongated coupling hole being elongated in the circumferential direction of said cavity end wall to provide coupling to the desired circular electric mode while more heavily and selectively coupling to the undesired noncircular electric modes of said cavity resonator characterized by radially directed currents in said end wall to thereby more heavily couple said undesired modes for suppression thereof.

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