United States Patent [19]

Forman et al.

[11] **3,728,650**

[45] **Apr. 17, 1973**

[54] **GHOST-MODE SHIFTED DIELECTRIC WINDOW**

[75] Inventors: **Robert J. Forman,** Southboro; **Robert R. Dame,** Needham, both of Mass.

[73] Assignee: **Raytheon Company,** Lexington, Mass.

[22] Filed: **July 23, 1971**

[21] Appl. No.: **165,548**

[52] **U.S. Cl.**.....**333/98 P,** 333/98 M, 315/39.53

[51] **Int. Cl.**.....**H01p 1/00**

[58] **Field of Search**.....333/98 P, 98 M; 315/39.53

[56] **References Cited**

UNITED STATES PATENTS

3,082,351	3/1963	Okress	333/98 P
2,854,603	9/1958	Collier et al.	315/39.53
3,163,835	12/1964	Scott	333/98 P
3,593,224	7/1971	Eggers	333/98 P
3,339,102	8/1967	Johnson	333/98 P
3,594,667	7/1971	Mann	333/98 M

FOREIGN PATENTS OR APPLICATIONS

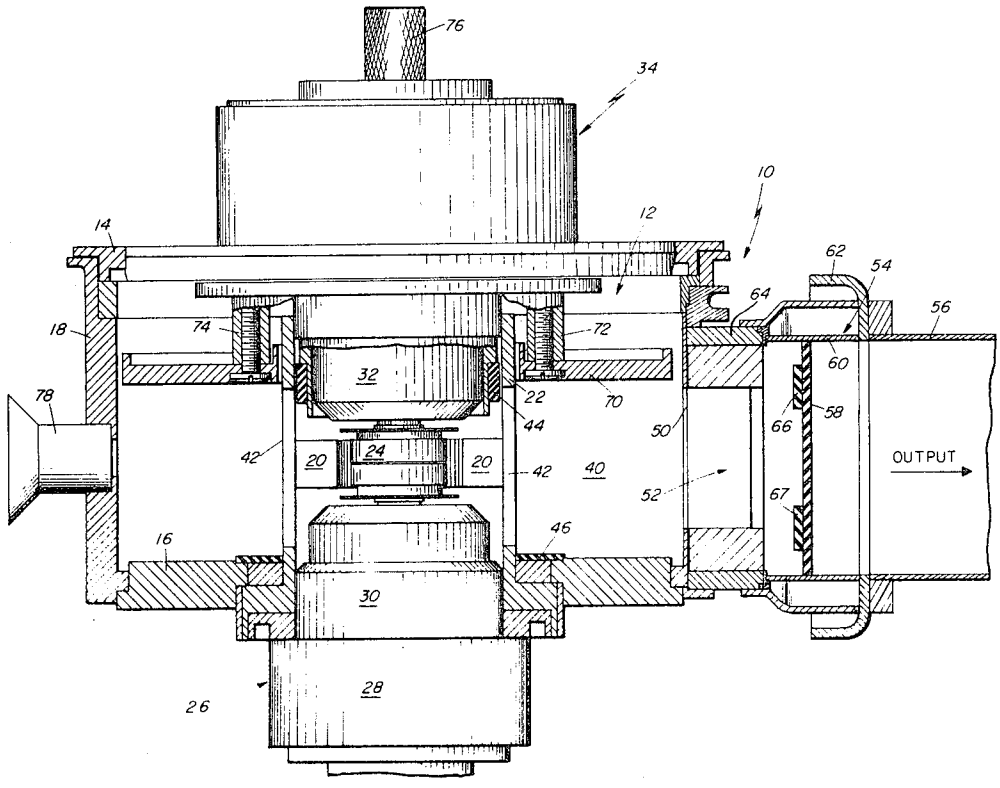
733,655	7/1955	Great Britain	333/98 P
635,000	3/1950	Great Britain	333/98 P

Primary Examiner—Rudolph V. Rolinec
Assistant Examiner—Saxfield Chatamon, Jr.
Attorney—Harold A. Murphy et al.

[57] **ABSTRACT**

The invention discloses a dielectric window serving as an interface between different atmospheric media and/or propagating structures incorporating means for detuning ghost-modes to frequencies outside of a desired tuning range. The window is provided with a thicker cross-sectional interface of a compatible dielectric material principally disposed in the diametrically spaced regions of zero electric field intensity of the normal resonant frequency resonant mode. Crossed field devices having tunable coaxial cavity resonators employ the applicable structures in the output energy coupling section. Dielectric materials such as alumina ceramic or beryllium oxide provide high peak power handling capability for devices employing the disclosed window.

16 Claims, 15 Drawing Figures



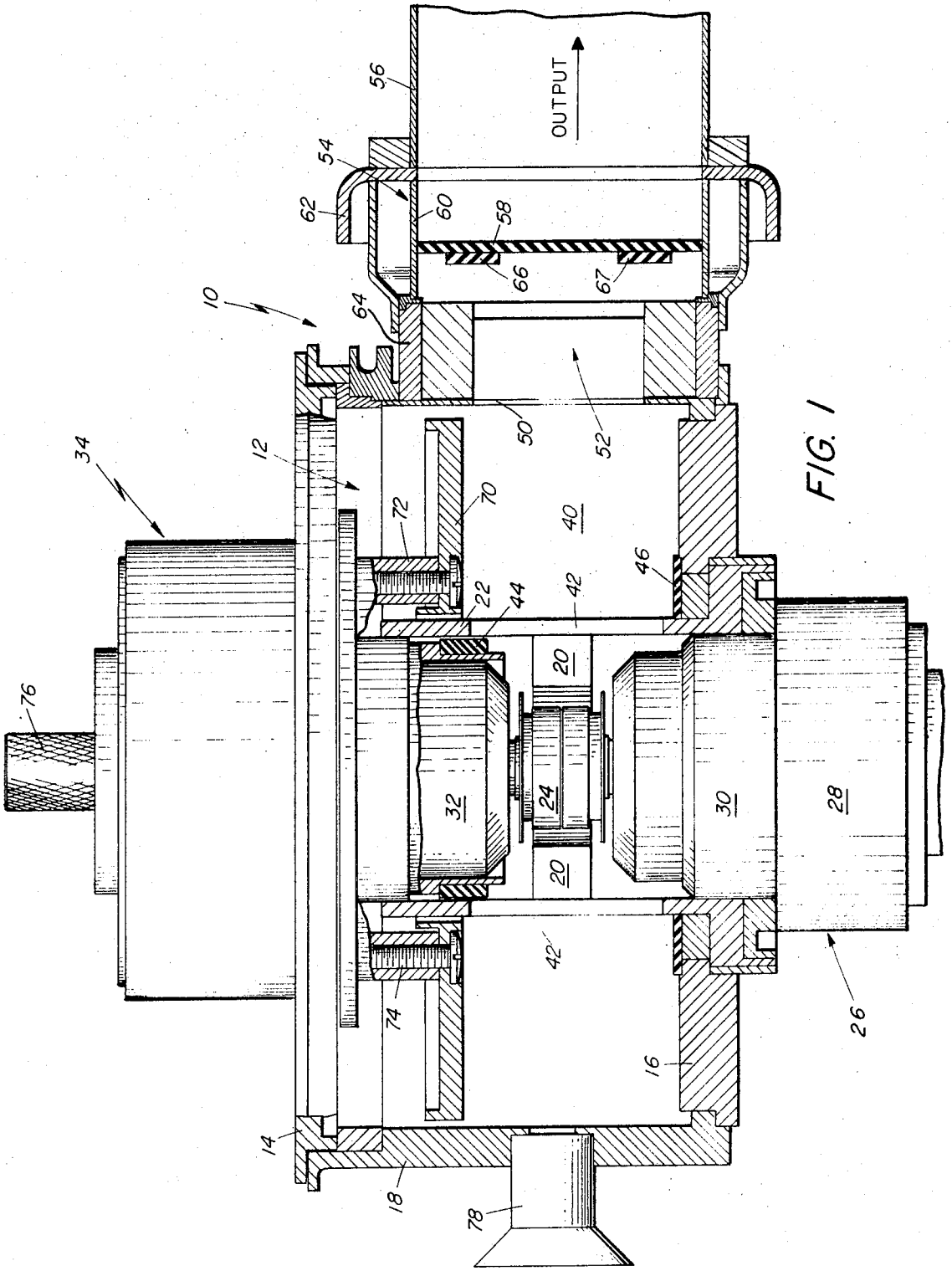

OUTPUT
56
54
62
60
58
66
67
64
10
50
52
34
12
72
70
40
46
22
44
42
20
76
32
24
30
28
74
16
26
14
18
78

FIG. 1

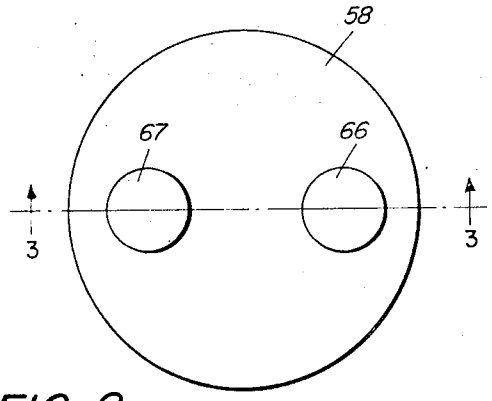


FIG. 2

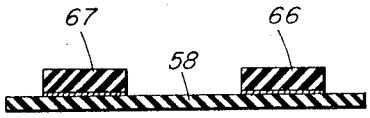


FIG. 3

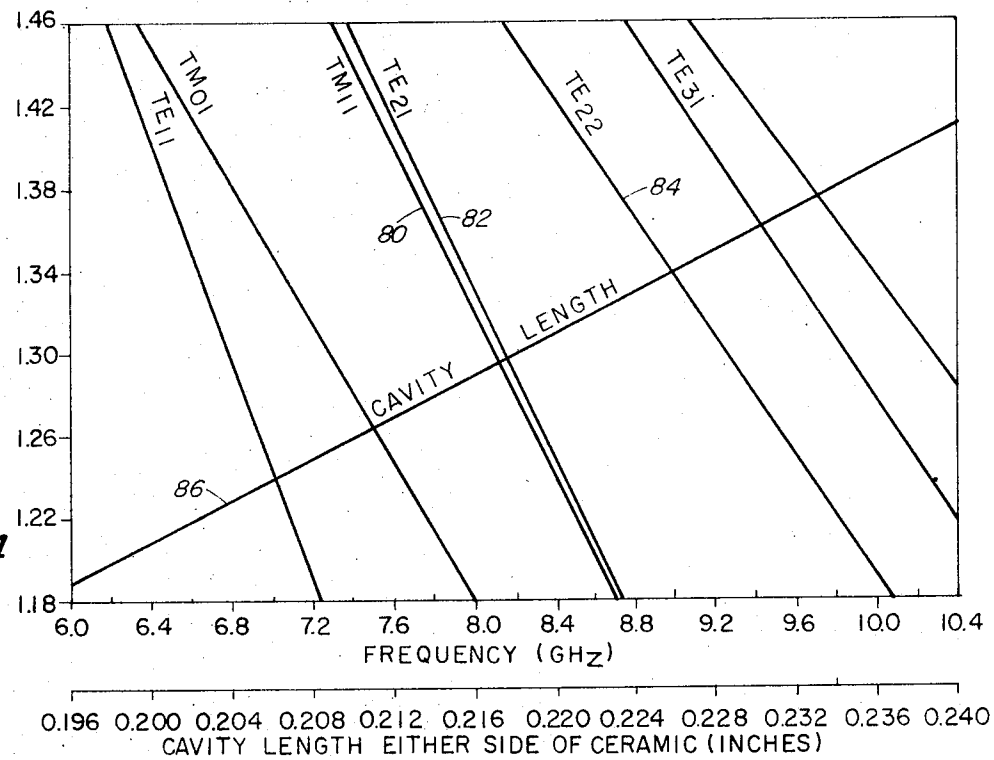


FIG. 4

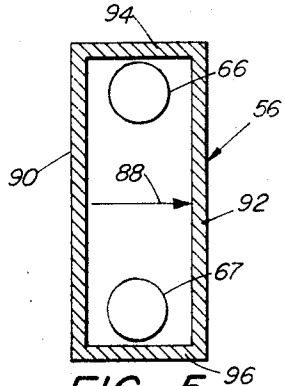


FIG. 5

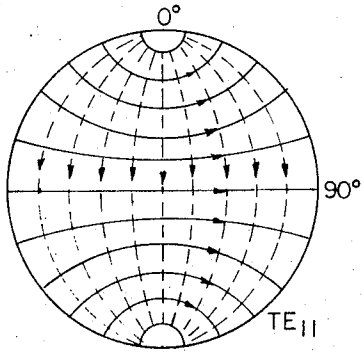


FIG. 6

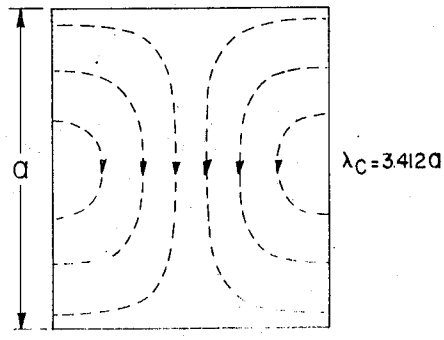


FIG. 7

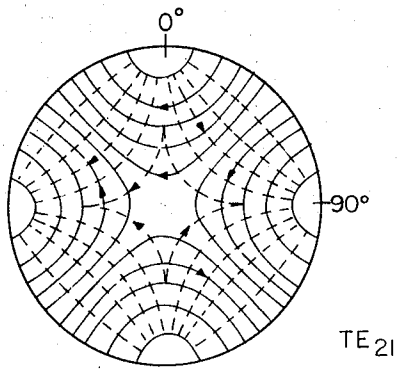


FIG. 8

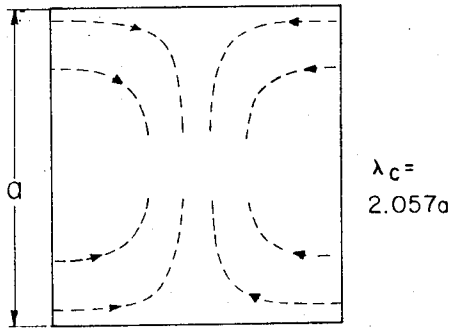


FIG. 9

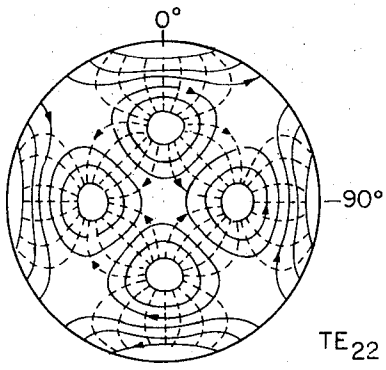


FIG. 10

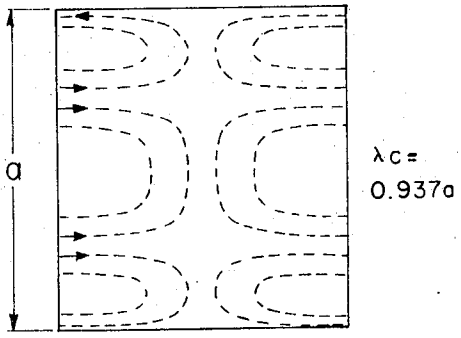


FIG. 11

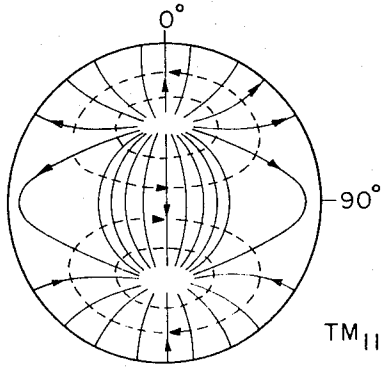


FIG. 12

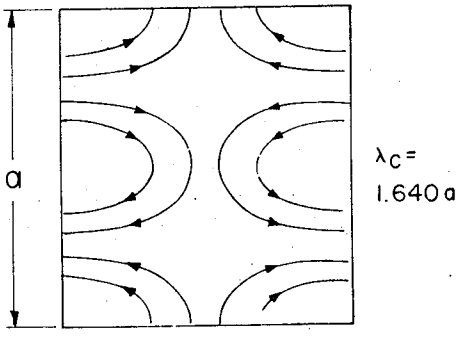


FIG. 13

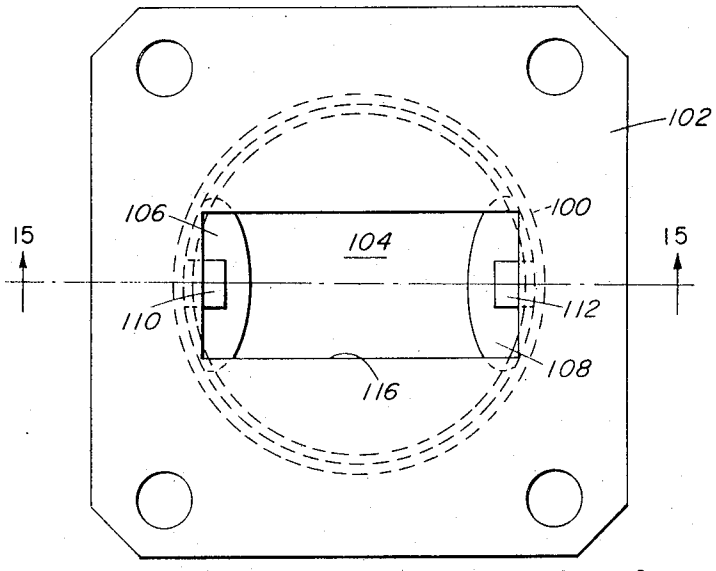

102
106
100
15
104
15
110
112
108
116

FIG. 14

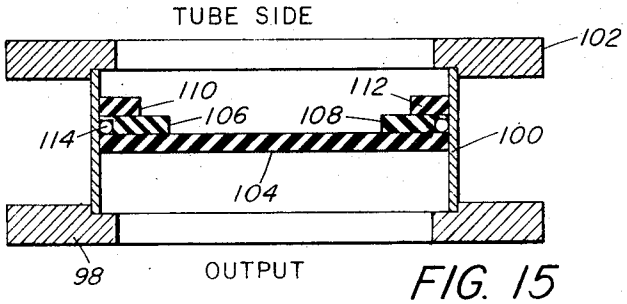

TUBE SIDE
102
110
112
106
108
114
100
104
98
OUTPUT

FIG. 15

GHOST-MODE SHIFTED DIELECTRIC WINDOW

BACKGROUND OF THE INVENTION

The invention relates to dielectric windows permeable to electromagnetic energy for transmission systems or microwave devices.

A dielectric material window currently in use for high power applications is commonly disposed within a circular waveguide section which is coupled to a rectangular waveguide transmission system. The output energy section of crossed field devices such as the coaxial cavity resonator magnetron is commonly provided with a thin disc of a low loss material such as alumina, beryllium oxide or glass with the choice of material dependent upon the peak power levels desired. Such material have a high dielectric constant value in the excess of 3.0 and excite many higher order modes as well as the normal working resonant frequency mode. In the coaxial cavity resonators the TE_{11} mode is the conventional operating mode. The circular waveguide output section within which the window member is disposed provides a boundary interface between a vacuum atmosphere within the tube enclosure and the adjacent rectangular coupling section filled with dielectric medium. There are seven additional modes which are excited in the cavity resonator structure and these higher order modes normally will not propagate in dielectric-filled structures and, accordingly, exist only inside the dielectric window with very rapid decay outside.

Certain modes of interest are the modes adjacent to the TE_{11} operating mode which are often referred to in the art as ghost-modes. The TE_{21}, TE_{22} and TM_{11} are the modes under consideration which are effectively trapped within the dielectric material. The ghost-modes resonate at certain frequencies within many desired tuning ranges which seriously limits bandwidth for, particularly, tunable crossed field devices. Additionally, the existence of the ghost-mode resonances within the window results in extremely high field intensities above the normal operating mode to cause excessive heating and electrical breakdown. To circumvent these disadvantages and shift the ghost-mode resonances prior art structures provide for a physically different diameter of the dielectric window disposed within the circular waveguide section which results in a compromise of the VSWR characteristics. Additionally, pressurization of the adjacent waveguide transmission section may be necessary to eliminate electrical breakdown which requires a second window within the output structure. Such procedures are both costly as well as cumbersome without measurably enhancing overall bandwidth and high power handling capabilities. The significance of the ghost-mode problem is described in the text "Microwave Engineering," by A. F. Harvey, 1963, Academic Press, Inc., New York, N. Y., page 74. Another prior art description is found in U.S. Pat. No. 3,436,694 issued to R. M. Walker on Apr. 1, 1969. The commonly referred to "-pill box" or "poker chip" dielectric window structure for waveguide transmission lines having ghost-mode resonance problems in also described in U.S. Pat. No. 2,834,834 issued Nov. 1960 to Symons et al.

SUMMARY OF THE INVENTION

In accordance with the teachings of the present invention a microwave energy permeable dielectric window is provided which is relatively free of ghost-mode resonances within the desired normal resonant frequency operating mode. Means are incorporated in the window structure to alter the boundary conditions of the ghost-mode resonances excited within the window material to lie outside of the predetermined frequency band without varying the diameter in a circular waveguide section. Enlargement of the window cross section in the diametrically spaced regions of zero electric field intensity of the operating mode provides a thicker interface to detune ghost-mode resonances. Enlargement of the interface layer is accomplished by various means including a step configuration or a button-shaped member disposed in the desired region. The various structures may be fabricated as a single unitary dielectric window body member or separate structures may be united by suitable metallizing techniques. The additional interface region is provided of a compatible material or the same material as the dielectric window member and extends only from one side thereof. The invention is equally applicable to structures for operating in any frequency range of the microwave portion of the electromagnetic energy spectrum where the ghost-mode problem exists.

In an exemplary embodiment to be described herein for a frequency of 8,500 MHz to 9,600 MHz the VSWR characteristics were maintained at a value of 1.12 maximum over the tuning range. The structure provided a 30 percent improvement in the usable bandwidth and no electrical breakdown was noted at high peak power levels. Consequently, no pressurization structures are required to prevent electrical breakdown in the output window coupling assembly. The enlargement technique by maintaining a constant diameter dielectric window assembly in the circular waveguide section also results in less costly structures.

BRIEF DESCRIPTION OF THE DRAWINGS

Details of illustrative embodiments of the invention will be readily understood after consideration of the following description and reference to the accompanying drawings, wherein:

FIG. 1 is a detailed cross-sectional view of the illustrative embodiment;

FIG. 2 is a plan view of a dielectric window member incorporating the invention;

FIG. 3 is a cross-sectional view taken in the direction indicated by line 3—3 in FIG. 2;

FIG. 4 is a chart illustrating the extraneous and ghost-modes excited within dielectric window members;

FIG. 5 is a cross-sectional view of a rectangular waveguide section;

FIGS. 6 and 7 illustrate the electric and magnetic field distributions associated with the normal resonant frequency operating TE_{11} mode;

FIGS. 8 and 9 show the electric and magnetic field distributions of the adjacent TE_{21} ghost-mode;

FIGS. 10 and 11 illustrate the electric and magnetic field distributions associated with the TE_{22} adjacent ghost-mode;

FIGS. 12 and 13 illustrate field distributions associated with the adjacent TM_{11} ghost-mode;

FIG. 14 is an end view of an alternative embodiment of the invention; and

FIG. 15 is a cross-sectional view taken in the direction indicated by line 15—15 in FIG. 14.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawings the illustrative embodiment in FIG. 1 comprises a crossed field device 10 of the coaxial cavity resonator magnetron type including an envelope 12 defined by cover members 14 and 16 hermetically sealed to cylindrical wall member 18 to provide a vacuum type enclosure. Anode vane elements 20 supported by common boundary wall 22 define cavity resonators therebetween of the inner resonant system circumferentially disposed about a central cathode emitter 24. Cathode 24 is supported by a supporting assembly 26 including outer tubular member 28 which is secured to magnetic pole piece member 30. The electric leads for energizing the cathode structure as well as providing the electric field potentials to operate the device extend within the cathode assembly 26. Conventional tubes of this type are designed to operate in the pi-mode of oscillation over a tunable frequency range which is controlled by the outer coaxial cavity resonator having a normal resonant frequency operating mode, for example, the TE_{11} mode.

The magnetic field producing means includes the aforementioned pole piece member 30 as well as oppositely disposed inner pole piece member 32 which extends within the tuner assembly 34. External C-shaped permanent magnets contact pole piece adapters and two such magnets are commonly provided, disposed in a plane extending perpendicular to the surface of the drawing. The magnetic field extends parallel to the axis of the cathode 24 in the interaction region between the anode elements 20 and cathode 24. The electric field lines extend perpendicular to the magnetic fields between the cathode and anode to thereby provide for the crossed field interaction in this class of devices.

The coaxial cavity resonator 40 is defined by cylindrical wall member 18 and common boundary wall 22 together with covers 14 and 16. The dimensions of the circular cavity resonator are selected to be resonant in the TE_{11} operating mode. Energy generated in the inner resonant system is coupled to the coaxial cavity resonator by means of slots 42 in boundary wall 22. Any extraneous modes are suppressed by annular lossy members 44 and 46. Such materials as carbonized alumina ceramic, barium titanate and ferrites are employed for lossy members 44 and 46.

The energy generated within the crossed field magnetron is coupled from coaxial cavity resonator 40 through iris 50 and a suitable transformer section 52 which may, for example, be H-shaped. Dielectric window assembly 54 hermetically seals iris 50 and is permeable to the microwave energy to be coupled to a utilization load by means of output waveguide sections 56, possibly of a rectangular configuration filled with air at normal atmospheric pressure. The generated energy is tuned over the desired frequency band by an axially translated tuning ring member 70 secured by posts 72 and screws 74 to an appropriate tuner assembly 34. Deformable bellows arrangements having gear actuated shaft means are conventionally employed in such tunable devices. The assembly is actuated by control knob 76 which may be manually or automatically driven.

Exhaust tubulation 78 is provided in wall member 18 to evacuate the envelope. The remaining structure utilized in coaxial cavity resonator magnetrons including cooling fins, magnet mounting plates and anchor plates have been purposely omitted since they are well known in the art.

Referring now to FIGS. 2 and 3 the dielectric window assembly 54 includes dielectric window member 58 supported within circular waveguide 60 which is in turn appended to flange member 62. The window assembly is supported by a tubular member 64 extending from wall member 18. Window member 58 is fabricated of a dielectric material having a high dielectric constant value in excess of 3.0 for optimum peak power capability. Such material as alumina ceramic will provide a dielectric constant value of 9.0. Other materials include beryllium oxide having a dielectric constant of 6.00 as well as any of the high temperature glasses or fused quartz having slightly lower dielectric constant values. With the elimination of the ghost-mode problem leading to excessive heating it is possible to operate the applicable devices at high peak power levels with less costly dielectric materials. The outer perimeter of the thin circular window member 58 is suitably metallized to join this member to the cylindrical waveguide section 60 of a highly conductive metal such as copper.

Means for shifting of definitive ghost-mode resonant frequencies are provided by enlargement of the boundary conditions of such modes within the dielectric window member 58. Such means extend on the side facing the vacuum enclosure or structure supporting the operating mode. A button-type member 66 and 67 of a compatible or similar dielectric material define an interface of thicker cross section to substantially detune the ghost-mode resonances. The positioning of the ghost-mode shifting means may be provided by an integral structure or separately appended by metallizing means such as a sputter coating of titanium on the abutting surfaces. In an exemplary embodiment for operation in a frequency band of 8,500 MHz to 9,600 MHz the additional interface material region has a thickness of approximately twice the thickness of the remainder of window member 58. The principal disposition of the additional interface material is determined by the orientation of the zero electric field intensity of the electric and magnetic fields of the normal resonant frequency operating mode within cavity resonator 40 and circular waveguide section 60. The zero electric field intensity orientation is readily determined by exciting probes and is typically at spaced diametrically opposite positions. Further details regarding this critical positioning will be evident from the ensuing discussion.

In FIG. 4 a chart of dielectric window diameter and resonant frequencies of the ghost-modes is shown. In view of the desired tuning range of the exemplary embodiment which operates in the 8,500 to 9,600 MHz

range the adjacent ghost-modes of paramount importance are the TM_{11}, TE_{21} and TE_{22} shown by lines **80**, **82** and **84**, respectively. In a window having a diameter of approximately 1.260 inches the upper ghost-mode TE_{22} exists at a resonance of approximately 9,270 MHz which is well within the desired tuning range while the remaining ghost-modes adversely affect the lower end of the tuning range around 8,500 MHz. Line **86** indicates the circular cavity dimensions either side of the dielectric window member. To operate in the TE_{11} mode this dimension is determined to be between 0.201 and 0.203 inch.

FIGS. **6** and **7** indicate the electric and magnetic field distributions for a circular cavity having a radius denoted by the letter "*a*." The wavelength of electromagnetic energy in this mode of operation is 3.412*a*. The electric lines are solid and the magnetic dotted. The normalized distributions commonly employed in the art indicate electric field intensity regions of 0° at the polar coordinates somewhat similar to the diametrically spaced North and South Poles while the maximum or 90° electric field distribution would be oriented equatorially in the globular comparison. To assist in an understanding of the invention, the orientation of the 0° and 90° fields may be explained by referring to a section of rectangular waveguide similar to section **56** adjacent to the output end of the window assembly **54**. The vector **88** extending between the broad walls **90** and **92** indicates the maximum electric field distribution while the zero electric field intensity would be adjacent the narrow walls **94** and **96**. In order for the energy in the desired TE_{11} resonant operating mode to be launched to the utilization load through rectangular waveguide section **56** the thicker interface material to shift the ghost-mode resonances is principally disposed in a region which is adjacent to the narrow walls of the companion rectangular waveguide section defined by walls **94** and **96**. The button members **66** and **67** have been shown in FIG. **5** to denote the resultant orientation.

In the exemplary embodiment for operation at X-band a VSWR electrical characteristic of 1.12 maximum was maintained over the desired tuning range by the enlargement of the interface material in the specified region. Measurements indicated that the resonance frequencies of the ghost-modes were 8,342 MHz for the TM_{11} mode, 8,390 MHz for the TE_{21} and 9,652 MHz for the TE_{22} modes. The net effect, therefore, is that the lower ghost-modes have been detuned to well below the lower range value of 8,500 MHz and the higher ghost-modes have been shifted outside of the operating tuning range having the upper value of 9,600 MHz. The overall bandwidth has now been expanded to 14 percent whereas with the conventional dielectric window assembly the bandwidth was only 11 percent. In other window embodiments with the thicker interface region bandwidths as high as 17 percent have been achieved. High peak power levels of from 220 to 270 KW can be realized with crossed field devices incorporating the improved dielectric window assembly of the present invention. In this embodiment no electrical breakdown was observed over the entire tuning range which eliminated the need for any pressurization within the waveguide section **56**.

FIGS. **8** and **9** indicate the magnetic and electric field distributions for the TE_{21} lower ghost-mode. The electric lines are again shown as solid while the dotted lines indicate the magnetic fields. The wavelength of the energy in this mode is 2.057 times the radius "*a*." The positioning of the additional interface material represented by the buttons **66** and **67** apparently tunes this ghost-mode to a new point of excitation within the dielectric material to much lower values than those attainable with the thin dielectric disc members of the prior art devices.

FIGS. **10** and **11** indicate the electric and magnetic field distributions for the TE_{22} or the upper ghost-modes. In this manner of propagation the wavelength is 0.937*a*. Again the orientation of the interface buttons **66** and **67** seriously attenuates or perturbs the electric fields in the zero region to result in the shifting of the upper bandwidth limits to a higher value. It is observed in the exemplary embodiments that the upper ghost-mode resonances are not tuned as rapidly as the lower ghost-modes TM_{11} and TE_{21}.

FIGS. **12** and **13** show the electric and magnetic fields for the TM_{11} or other lower ghost-mode which has now been detuned.

In FIGS. **14** and **15** an alternative embodiment of the invention is illustrated. A rectangular flange member **98** is provided adjacent the outer end of circular waveguide section **100**. A similar flange member **102** may also be provided to be hermetically sealed to the output coupling section of a crossed field device. The dielectric window member **104** comprises a thin disc of a material having a high dielectric constant such alumina ceramic. Appended in a step manner to enlarge the interface region are first, substantially semicircular members **106** and **108** joined to the surface of window member **104**. Next smaller body members **110** and **112** are symmetrically disposed in the zero electric field intensity region to provide the necessary enlargement. Copper ring member **114** is sandwiched between the respective additional interface members and the surface of the window **104** which will provide the necessary brazing interface to secure the assembled components. In FIG. **14** the view through rectangular opening **116** is shown to reveal the amount of dielectric material exposed to the microwave energy propagating within the coaxial cavity resonator adjacent the output section.

Many variations in the provision of the thicker cross section region will be evident to those skilled in the art including fabricating of the dielectric members with the additional material molded to it. The quantity of the material and the thickness of the additional interface is empirically determinable for various normal resonant frequency operating modes. The enhancement of the bandwidth characteristics without sacrificing or compromising the VSWR characteristics follows the utilization of the disclosed means for shifting of the ghost-mode frequencies outside of the operating bandwidth desired. The difference in the tuning rates between the upper and lower ghost-modes can be varied by changing the amount and shape of the dielectric material. The diameter of the circular waveguide section as well as the dielectric window member which has been optimized for transmission of the resonant frequencies will be maintained constant throughout the length of

the output sections by means of a structure disclosed herein. Still further variations, alterations or modifications will become apparent to those skilled in the art. It is intended, therefore, that the foregoing description of the illustrative embodiments be considered in the broadest aspects and not in a limiting sense.

We claim:

1. A microwave dielectric window comprising:
a member of a material permeable to electromagnetic energy having electric and magnetic field distributions in a predetermined normal resonant frequency operating mode;
said member having a thicker cross section principally disposed only in the diametrically spaced regions of zero electric field intensity of said operating mode.

2. A window as set forth in claim 1 wherein said thicker regions are in the order of at least twice the thickness of the remaining regions.

3. A window as set forth in claim 1 wherein said member is circular.

4. A window as set forth in claim 1 wherein said thicker regions have a button-shaped configuration.

5. A window as set forth in claim 1 wherein said thicker regions have a step configuration.

6. A microwave dielectric window comprising:
a member of a dielectric material having a high dielectric constant value for propagating electromagnetic energy having electric and magnetic field distributions in a predetermined normal resonant frequency operating mode disposed between media having different atmospheric pressures;
said member having additional dielectric material disposed only in the diametrically spaced regions of zero electric field intensity of said operating mode and facing the lower pressure media side.

7. A window as set forth in claim 6 wherein said material comprises beryllium oxide.

8. A window as set forth in claim 6 wherein said material comprises alumina ceramic.

9. A window as set forth in claim 6 wherein said material has a dielectric constant value in excess of 3.0.

10. A microwave dielectric window comprising:
a member of a dielectric material for propagating electromagnetic energy having electric and magnetic field distributions in a predetermined normal resonant frequency operating mode between a section of hollow circular waveguide and a section of hollow rectangular waveguide;
said member having additional dielectric material principally disposed only in the diametrically spaced regions of zero electric field intensity of said operating mode and facing the circular waveguide section.

11. A window as set forth in claim 10 wherein said member has the same diameter as the inner diameter of said circular waveguide.

12. A microwave dielectric window for tunable electromagnetic energy devices comprising:
a dielectric member permeable to such energy and capable of exciting plural modes having determinable electric and magnetic field distributions over a selected tuning range; and
means for shifting the boundary conditions of specific definitive modes outside the tuning range of a predetermined normal resonant frequency operating mode;
said means comprising enlargement of the cross section of the dielectric member principally only in the diametrically spaced regions of zero electric field intensity of said operating mode with compatible dielectric material.

13. A broad frequency band microwave dielectric window having controlled ghost-mode resonances comprising:
a member of a dielectric material serving as a boundary interface between means for propagating electromagnetic energy with electric and magnetic field distributions in normal resonant frequency operating and ghost-modes; and
means for detuning certain ghost-mode resonances comprising an enlargement of the cross-sectional interfaced dimensions with a compatible dielectric material principally disposed only in the diametrically spaced regions of zero electric field intensity of said operating mode.

14. A crossed field device comprising:
a cathode member;
a resonant system having a plurality of cavity resonators defined by anode members supported by a boundary wall surrounding said cathode member to generate electromagnetic energy;
means including said boundary wall defining a coaxial cavity resonator adapted to be resonant in a predetermined normal electric and magnetic field operating mode orientation and communicate with said anode-cathode cavity resonators;
means for coupling said energy from said coaxial cavity resonator;
said coupling means including an energy permeable dielectric window member having a thicker cross section principally disposed only in the diametrically spaced regions of zero electric field intensity of said operating mode.

15. A device as set forth in claim 14 wherein said dielectric window member is disposed within a section of hollow circular waveguide.

16. A device as set forth in claim 14 wherein said thicker cross section regions are defined by spaced button-shaped bodies.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,728,650 Dated April 17, 1973

Inventor(s) Robert J. Foreman & Robert R. Dame

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

On cover sheet, Inventor: Change "Robert J. Forman" to "Robert J. Foreman"

Column 1, line 67, change "in" to "is"

Signed and sealed this 1st day of January 1974.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

RENE D. TEGTMEYER
Acting Commissioner of Patents

FORM PO-1050 (10-69)

USCOMM-DC 60376-P69
* U.S. GOVERNMENT PRINTING OFFICE : 1969 O—366-334