United States Patent

[11] 3,594,667

[72] Inventor **Joseph K. Mann**
Palo Alto, Calif.

[21] Appl. No. **776,088**
[22] Filed **Nov. 15, 1968**
[45] Patented **July 20, 1971**

[73] Assignee **Varian Associates**
Palo Alto, Calif.

[54] MICROWAVE WINDOW HAVING DIELECTRIC VARIATIONS FOR TUNING OF RESONANCES

4 Claims, 11 Drawing Figs.

[52] **U.S. Cl.** ..... **333/98 P,** 333/34, 333/98 M
[51] **Int. Cl.** **H01p 1/08**
[50] **Field of Search** ..... 333/98 M, 98 P, 98, 83, 35, 34; 315/5 DW; 343/783

[56] **References Cited**

UNITED STATES PATENTS

2,508,479	5/1950	Wheeler	343/783 X
2,577,158	12/1951	Rosencrans	333/34 X
2,644,930	7/1953	Luhrs et al.	333/34 X
2,706,275	4/1955	Clark, Jr.	333/34
2,958,834	11/1960	Symons et al.	333/98 P
3,001,160	9/1961	Trousdale	333/98 P
3,066,269	11/1962	Barlow	333/98
3,434,774	3/1969	Miller	343/785 X
3,436,694	4/1969	Walker	333/98

OTHER REFERENCES

Olin; I. D., " Dielectric Transformers," ELECTRONICS, 12— 55, pp. 146— 147.

Lebacqt et al., " High-Power Windows At Microwave Frequencies," PRO. IEE 1958, 105B, Sup. #11, pp. 617— 621.

Jaynes; E. T., " Ghost Modes In Imperfect Waveguides," PRO. IRE. 2-1958, pp. 416— 418.

Forrer et al., " Resonant Modes In Waveguide Windows," IRE. TRANS. ON MICROWAVE THEORY & TECH. 3-1960, pp. 147— 150.

Primary Examiner—Herman Karl Saalbach
Assistant Examiner—Wm. H. Punter
Attorneys—Leon F. Herbert and William J. Nolan

ABSTRACT: A high-power microwave window structure is disclosed. The window structure includes a hollow waveguide having a dielectric wave permeable gastight partition sealed thereacross to form the window assembly. The window structure is capable of being impedance matched to the waveguide structure to provide a relatively wide passband. In certain windows the passband can be as wide as the recommended bandwidth for the waveguide itself. Such window structures are plagued by "trapped" and "ghost" resonant modes which are excited into resonance by slight asymmetries in the window structure. At their resonant frequencies, these modes couple energy from the main propogating mode to produce an impedance mismatch and at high-power levels, overheating and failure of the window structure. Thus, operation at high-power levels is typically restricted to frequency ranges between a pair of such resonant modes. The frequency separation between the resonant modes is increased to provide broader band operation by selectively tuning the resonant frequencies of these modes by selectively varying the electrical path length through the window structure for one or more of these modes. For example, the window is made thicker near the periphery where one of the resonant modes has its most intense electric fields and made thinner near the center where another of the modes has its intense electric fields to tune one of the modes higher in frequency, while the other mode is being tuned lower in frequency. The mean thickness of the window is maintained approximately constant such as not to change appreciably the passband for the main propagating mode. Alternatively, the dielectric constant for various portions of the window can be changed for changing the electrical path length through the window as aforedescribed.

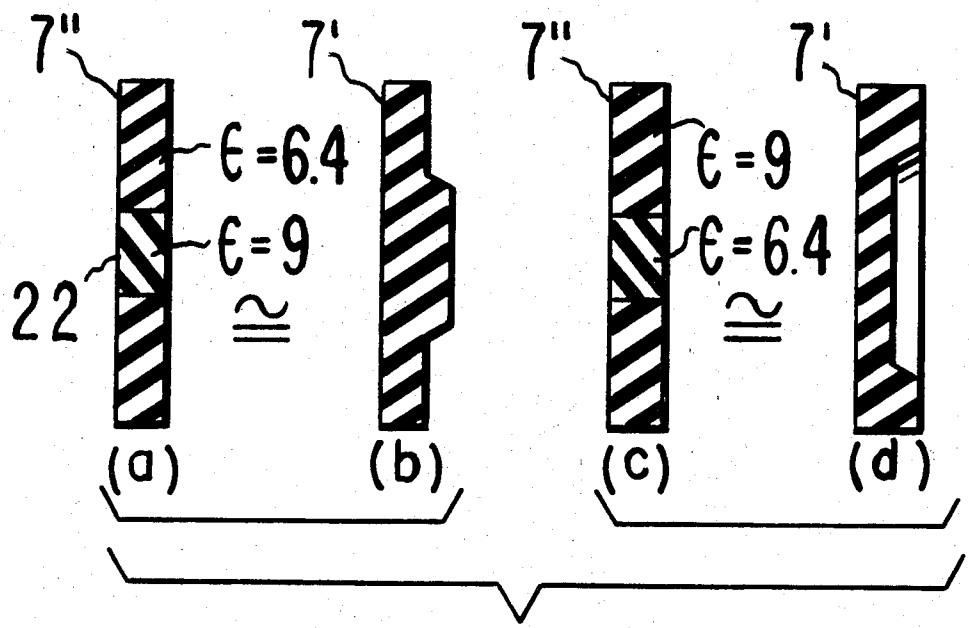


FIG.1
PRIOR ART

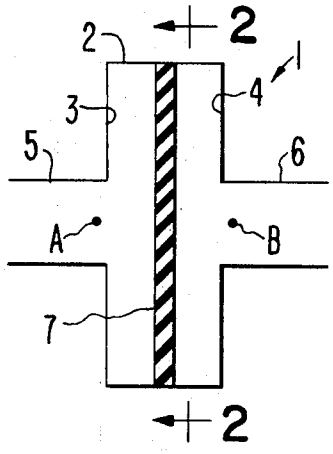


FIG.2
PRIOR ART
TE_{11} (MAIN)

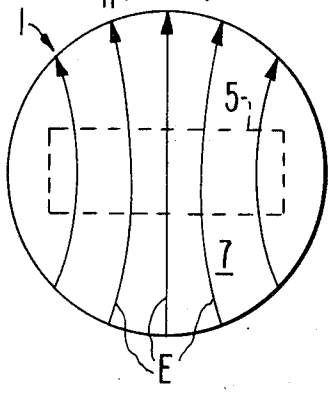


FIG.3
PRIOR ART
TE_{111} (ORTHOGONAL TRAPPED MODE)

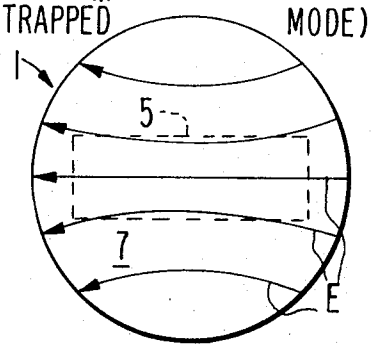


FIG.4
PRIOR ART
TM_{010}
(TRAPPED MODE)

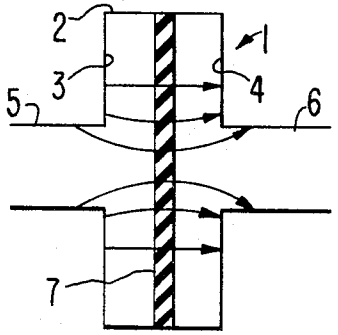


FIG.5
TE_{21}
(GHOST MODE)

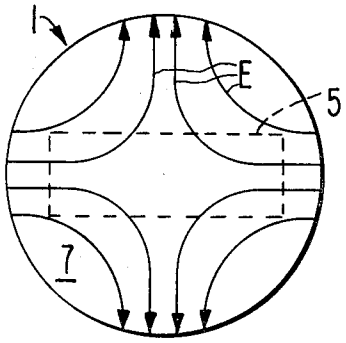


FIG.6
TE_{21}
(GHOST MODE)

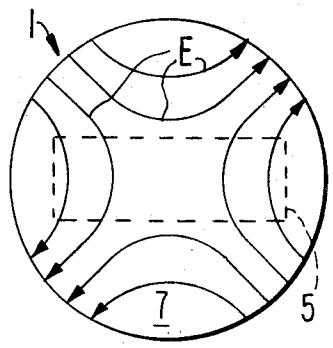
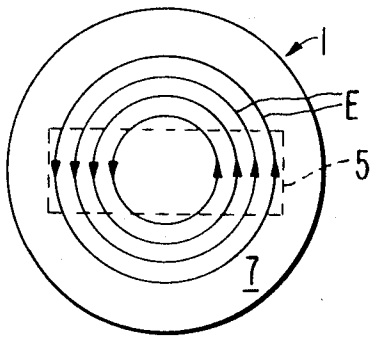


FIG.7
TE_{01}
(GHOST MODE)



INVENTOR.
JOSEPH K. MANN
BY
Leon F. Herbert
ATTORNEY

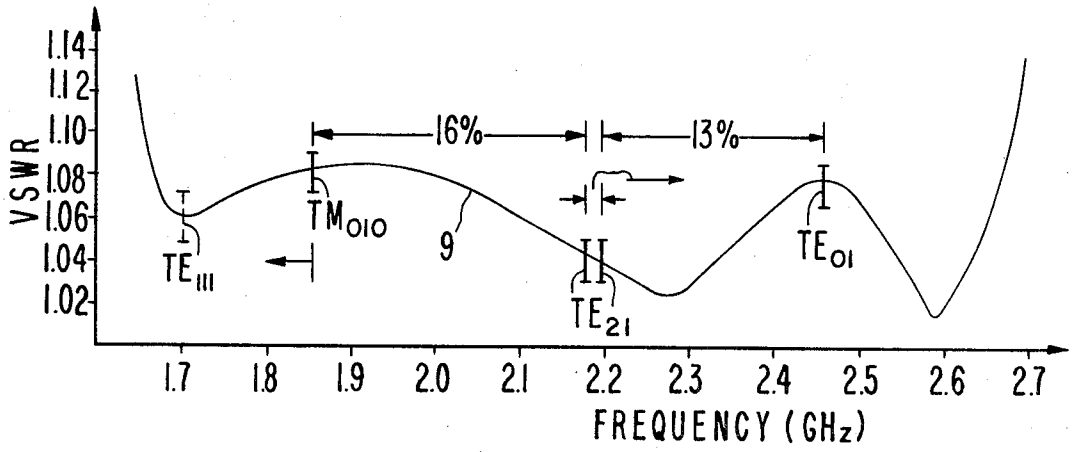


FIG. 8

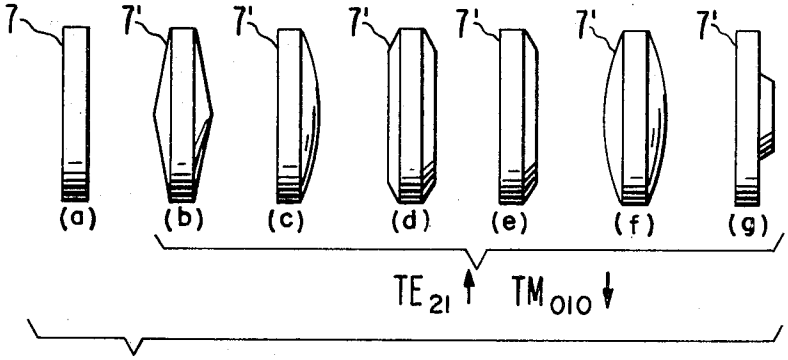


FIG. 9

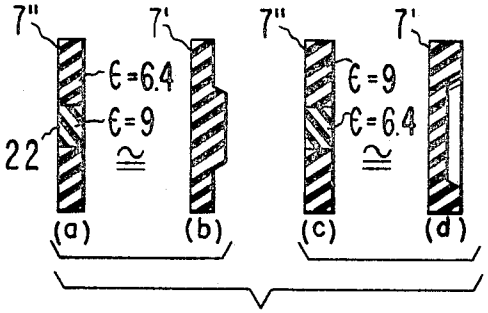


FIG. 11

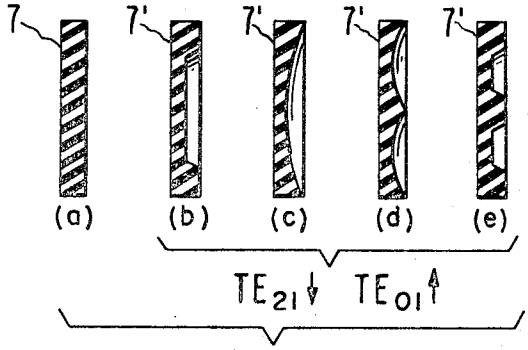


FIG. 10

INVENTOR.
JOSEPH K. MANN
BY
Leon F. Herbert
ATTORNEY

MICROWAVE WINDOW HAVING DIELECTRIC VARIATIONS FOR TUNING OF RESONANCES

DESCRIPTION OF THE PRIOR ART

Heretofore, conductive structures have been provided in the dielectric window structure for selectively shorting out or tuning the frequency of certain unwanted resonant modes of the window structure out of the passband or for moving the frequency of the modes to provide a wider high-power operating bandwidth within the passband of the main propagating mode. Such prior conductive structures have included arrays of painted conductive stripes on one of the faces of the window member, or have included a conductive bar embedded in the window member itself. Alternatively, conductive structures have been disposed in the immediate vicinity of the window for selectively operating upon certain of the unwanted resonant modes for tuning their frequencies without changing substantially the passband of the window structure for the main propagating mode. An example of such a prior art window is found in copending U.S. Pat. application Ser. No. 627,127 filed Mar. 30, 1967 as a continuation of U.S. Pat. No. 3,325,671 issued June 13, 1967.

The problem with the use of conductive probes, rods, painted conductive stripes and the like disposed in the immediate vicinity of the window is that they introduce a substantial amount of complexity into the design of the window structure, whereby substantially increasing the manufacturing costs. In addition, many of these conductive structures can also introduce additional unwanted trapped resonant modes in the vicinity of the window, thereby further complicating the design. Moreover, at high-power levels such probes can produce arcing and sputtering of the metal onto the window structure, thereby deteriorating the performance of the window.

Therefore, the need exists for a simple means for tuning the resonant modes of the window to provide an improved high-power operating bandwidth for such structures.

SUMMARY OF THE PRESENT INVENTION

The principal object of the present invention is the provision of an improved high-power microwave window structure.

One feature of the present invention is the provision, in a high-power microwave window structure, of variations in the dielectric of the window member for tuning of certain unwanted modes of resonance associated therewith to provide an increased high-power operating bandwidth.

Another feature of the present invention is the same as the preceding feature wherein the dielectric variations comprise variations in the thickness of the window member such that one region of the window has a thickness greater than a mean overall thickness for the window to tune a resonant mode having its intense electric fields in the thick regions of the window to a lower frequency, whereas the portions of the window having less than the mean thickness can serve to tune modes having their highest electric fields in this region to higher frequencies and the thinner region of the window can also serve to provide a constant mean value for the thickness of the window such as not to change the passband of the window structure for the main propagating mode.

Another feature of the present invention is the same as the first feature wherein the electrical path length through the window is effectively changed by providing one portion of the window with a first dielectric constant and a second portion of the window with a different dielectric constant for effectively changing the electrical path length through the window structure for tuning of the resonant modes associated therewith to provide a wider operating bandwidth.

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

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic longitudinal sectional line diagram of a prior art microwave window structure,

FIG. 2 is a sectional view of the structure of FIG. 1 taken along line 2–2 in the direction of the arrows and depicting the electric field lines for the main propagating mode,

FIG. 3 is a view similar to that of FIG. 2 depicting the electric field lines for an interfering orthogonally trapped mode,

FIG. 4 is a view similar to that of FIG. 1 depicting a certain interfering trapped mode,

FIGS. 5—7 are similar to those of FIGS. 2 and 3, depicting the electric field line patterns for certain interfering ghost modes,

FIG. 8 is a plot of voltage standing wave ratio (VSWR) versus frequency for the prior art window of FIGS. 1 and 2,

FIGS. 9(*a*)—9(*g*) are side elevational views of the dielectric window member including variations in the dielectric thickness for tuning certain modes higher in frequency and other modes lower in frequency,

FIGS. 10(*a*)—10(*e*) depicts a series of longitudinal sectional views of dielectric window members having thickness variations for tuning certain unwanted modes lower in frequency and certain other unwanted modes higher in frequency, and

FIGS. 11(*a*)—11(*d*) are longitudinal sectional views for the window structure of the present invention depicting the equivalence of varying the dielectric constant in certain regions of a uniformly thick window to varying the thickness of the window for selectively tuning the frequency of certain unwanted resonant modes associated therewith.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIGS. 1 and 2, there is shown a prior art microwave window assembly 1. This type of window forms the subject matter of and is claimed in U.S. Pat. No. 2,958,834 issued Nov. 1, 1960. Briefly, the window assembly 1 includes a section 2 of cylindrical waveguide closed at both ends by means of transverse conductive partitions 3 and 4. A pair of rectangular waveguide sections 5 and 6 are joined to the cylindrical waveguide section 2 at the ends thereof and in axial alignment therewith. A disc 7 of dielectric material is sealed across the section of cylindrical waveguide 2 in a gastight manner and with the plane of the disc 7 being substantially coextensive with the midplane of the cylindrical waveguide section 2. A suitable dielectric material for the window 7 is alumina or beryllia and the electrical length of the window structure for the main propagating mode, which is the TE_{11} mode indicated in FIG. 2, is approximately one-half a wavelength from point A to point B. Such a window structure has a passband characteristic as indicated by line 9 of FIG. 8. From FIG. 8 it is seen that a VSWR of less than 1.10 to 1 can be obtained over the complete recommended frequency range of the rectangular waveguide section.

However, within the wide passband of the window structure there lie a number of discrete points where resonances occur. These points are indicated in FIG. 8 by the vertical dark lines identified as TM_{010}, TE_{21} and TE_{01}, respectively. It is believed that the TE_{111} mode has a resonance at the low frequency end of the passband, as indicated by the dotted vertical line labeled TE_{111}. Although these resonant modes are mathematically orthogonal and, therefore, theoretically independent of the main propagating mode, they are, in fact, coupled to the main propagating mode, because of small asymmetries in the window structure, which are impossible to avoid. Therefore, when the operating frequency of the main propagating mode crosses one of the resonant frequencies for the undesired interfering modes, that mode is excited into resonance. Energy is then stored in that mode, and at high power levels within the window, the energy dissipated in the window 7 at the frequency of one of these interfering modes can cause the window 7 to fail. Thus, the usable bandwidth of the window, at high-power

levels, may be restricted to an amount between two adjacent interfering modes, which can be much less than the matched passband of the window structure for the main propagating mode. In fact, for the prior art structure of FIGS. 1 and 2, the high-power usable bandwidth is limited to 16 percent between the TM_{010} and the TE_{21} modes and 13 percent between the TE_{21} modes and the TE_{01} mode.

These unwanted resonant modes are of two types. A first type of resonant mode is the "trapped" mode and is caused by reflections of wave energy between conductive discontinuities in the waveguide on opposite sides of the window member 7; for example, the abrupt junctions between the rectangular waveguide sections 5 and 6 and the cylindrical waveguide section 2. Examples of the trapped modes include the TE_{111} mode and the TM_{010} mode, the mode patterns of which are shown in FIGS. 3 and 4, respectively. The second type of interfering mode is associated with resonant modes in the dielectric window member 7 itself. Examples of such modes include the TE_{21} modes and the TE_{01} mode. These modes have been referred to in the art as "ghost" modes. The electric field patterns for the aforementioned ghost modes are shown in FIGS. 5—7. The reason for two TE_{21} ghost modes is that any substantial perturbation of the mode causes it to split into two modes oriented at 45° to each other as indicated in FIGS. 5 and 6. The two TE_{21} ghost modes have slightly different resonant frequencies as indicated in FIG. 8.

From the mode patterns as shown in FIGS. 3—7, it is seen that certain of the mode patterns have their most intense electric fields in certain regions of the window member 7, whereas certain of the other modes have their most intense electric fields in other regions of the window 7. For example, the most intense regions of electric field for the TE_{21} ghost modes occur near the outer periphery of the window member 7, the most intense electric fields for the TE_{01} mode occur at an intermediate radius from the center of the window 7, the most intense electric fields for the TM_{010} mode occur in the center of the window, and the most intense electric field for the TE_{111} mode occurs in a band extending diametrically across the window member parallel to the broad walls of the waveguides 5 and 6. This variation in the most intense region of the electric field for various ones of the undesired modes permits variations to be made in the dielectric properties (parameters) of the window for these regions to selectively tune the frequencies of these modes in various ways to obtain a broader usable high-power bandwidth.

Referring now to FIG. 9, there is shown a window structure according to the teachings of the present invention for increasing the usable high-power bandwidth of the window between the TM_{010} mode and TE_{21} mode. More particularly, the TE_{21} mode has its most intense electric fields near the outer periphery of the window, whereas the TM_{010} mode has its most intense electric field in the center region of the window. Thus, the prior art window 7 as shown in FIG. 9(*a*), is modified to have its thickness increased in the central region and its thickness decreased in the outer peripheral region. Thus, the TM_{010} mode will be tuned lower in frequency and the TE_{21} mode will be tuned higher in frequency to provide a wider high-power usable bandwidth for the window. Window members 7′ depicted in FIGS. 9(*b*)—9(*g*) are examples of windows which are thicker in the center and thinner in the outer periphery to provide the wider usable high-power bandwidth. And in fact, such windows result in an improvement in the usable bandwidth from 16 percent to 25 percent. In one specific example of a window member 7′ of the type shown in FIG. 9(*g*), for a window assembly 1 with a passband of FIG. 8, the resultant window 7′ had an outer periphery with a thickness of 0.145 inch, whereas the central region had a thickness of approximately 0.290 inch. The outer diameter of the window 7′ was 3.980 inches, the outer diameter of the thicker central portion of the window was 1.289 inches and the window material was beryllia. The thickness variations can be achieved by machining or otherwise forming the window member 7′. Alternatively, one or more dielectric members such as a disc, ring or slab may be affixed to or placed adjacent the surfaces of the flat window member 7 to produce the desired variation in thickness for the composite window structure.

Referring now to FIG. 10, there is shown window designs for increasing the usable high-power operating bandwidth between the TE_{21} mode and TE_{01} mode. In this case, the TE_{21} mode has its most intense electric field region at the outer periphery of the window, whereas the TE_{01} mode has its most intense electric fields at an intermediate radius from the center of the window. Accordingly, the prior art window member 7, as shown in FIG. 10(*a*), is modified as shown in FIGS. 10(*b*)—10(*e*) to increase the thickness of the window near the outer periphery and to decrease its thickness at an intermediate radius to lower the frequency of the TE_{21} mode and to raise the frequency of the TE_{201} mode.

Referring now to FIG. 11, there is shown an alternative embodiment of the present invention wherein, the dielectric constant of the window member is varied instead of the thickness of the window member 2 to achieve the same result as varying the thickness of the window. More specifically, FIG. 11(*a*) shows a window 7″ wherein the central region of the window member indicated by 22 is made of a dielectric material, such as alumina having a dielectric constant ϵ of approximately 9 and which is higher than the dielectric constant ϵ of the outer peripheral region of the window which is made of beryllia having a dielectric constant of approximately 6.4. This is equivalent to the window of FIG. 11(*b*), which is the same as the window of FIG. 9(*g*), and results in an increased high-power bandwidth between the TE_{21} mode and the TM_{010} mode by increasing the frequency of the TE_{21} mode and decreasing the frequency of the TM_{010} mode. Alternatively, the outer periphery of the window 7″ may be made of a material having a higher dielectric constant than the central region of the window, as indicated in FIG. 11(*c*) to produce a window equivalent to that shown in FIG. 11(*d*), which is the same as window 7′ of FIG. 10(*b*), and results in increasing the usable high-power bandwidth between the TE_{21} mode and the TE_{01} mode, as previously described with regard to FIG. 10.

In all of the window designs of FIGS. 9, 10, and 11 it is preferred that the mean overall electrical length through the window member remain substantially unchanged by the dielectric variations thereof, such that the passband for the main operating mode is not appreciably altered by the dielectric variations for tuning of the interfering modes.

Although the window member 7 has been described as employed in a particular window design as shown in FIGS. 1 and 2, this is not a requirement, as it may be employed to advantage in other types of window designs such as, for example, in conventional half-wave windows, wherein a block of ceramic material, half a wavelength thick, is sealed across the hollow waveguide structure.

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 I claim is:

1. A microwave window assembly comprising a hollow transmission line and a dielectric window member vacuum tightly mounted within said transmission line transversely of the direction of microwave energy flow therein, said window assembly having at least two interfering resonant microwave energy modes each having a resonant frequency falling within the passband of the microwave window, the improvement comprising, one or more of the dielectric parameters of said window member being varied as a function of the distance from the center of the window in a manner such that the lower frequency interfering resonant mode is shifted downward in frequency and the higher frequency interfering resonant mode is shifted upward in frequency, while the mean electrical path length through the window for the main propagating mode

remains substantially unchanged, whereby the usable resonant-modeafree passband for the propagating mode is increased without substantial variance of the center frequency of said passband.

2. The microwave window assembly of claim 1 wherein said dielectric parameter being varied is the thickness of the dielectric material of the window member.

3. The window assembly of claim 1 wherein said dielectric parameter being varied is the dielectric constant of the window member.

4. The microwave window assembly of claim 1 further including a length of cylindrical waveguide containing said window member and a pair of rectangular waveguides joined to opposite ends of said cylindrical waveguide, said window member being sealed across said cylindrical waveguide substantially at the midplane thereof.