April 1, 1969 R. M. WALKER 3,436,694

CONTROLLING GHOST-MODE RESONANT FREQUENCIES IN SEALED WAVEGUIDE WINDOWS

Filed July 28, 1966 Sheet 1 of 3

PRIOR ART

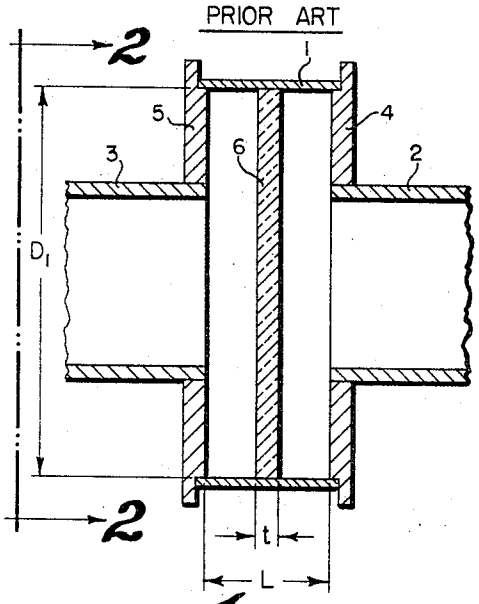


Fig. 1

PRIOR ART

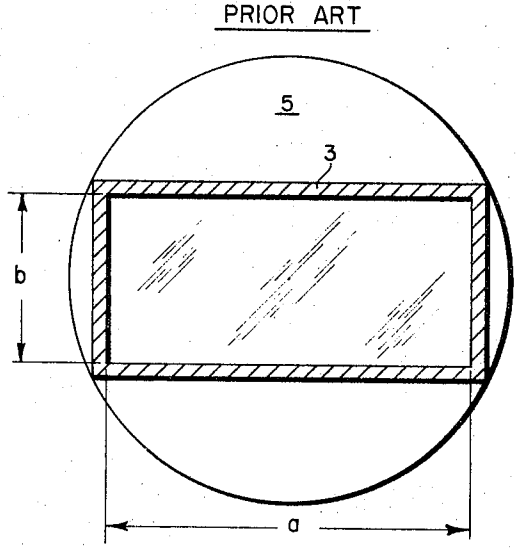


Fig. 2

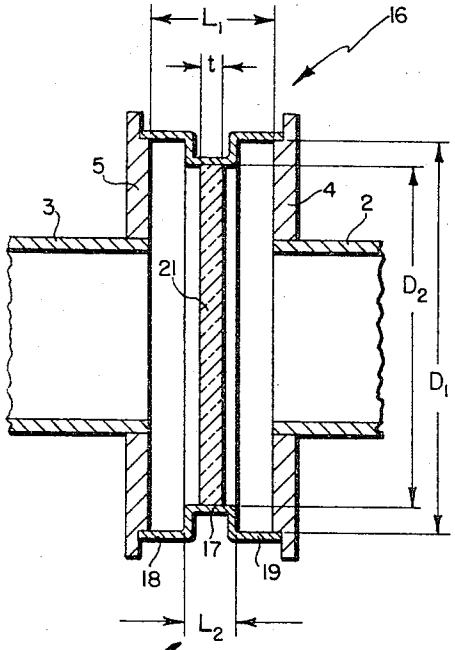


Fig. 3

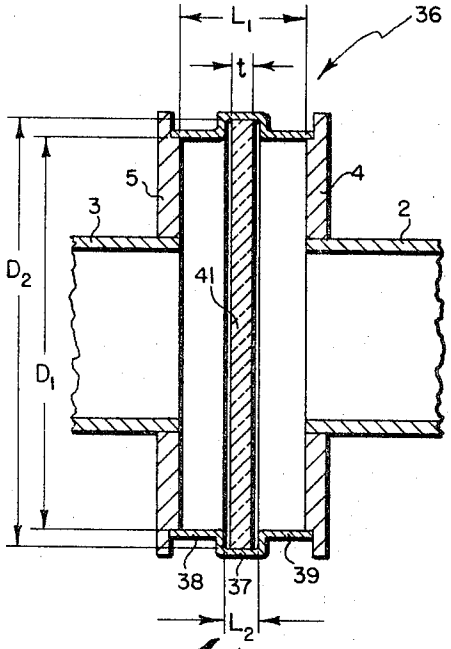
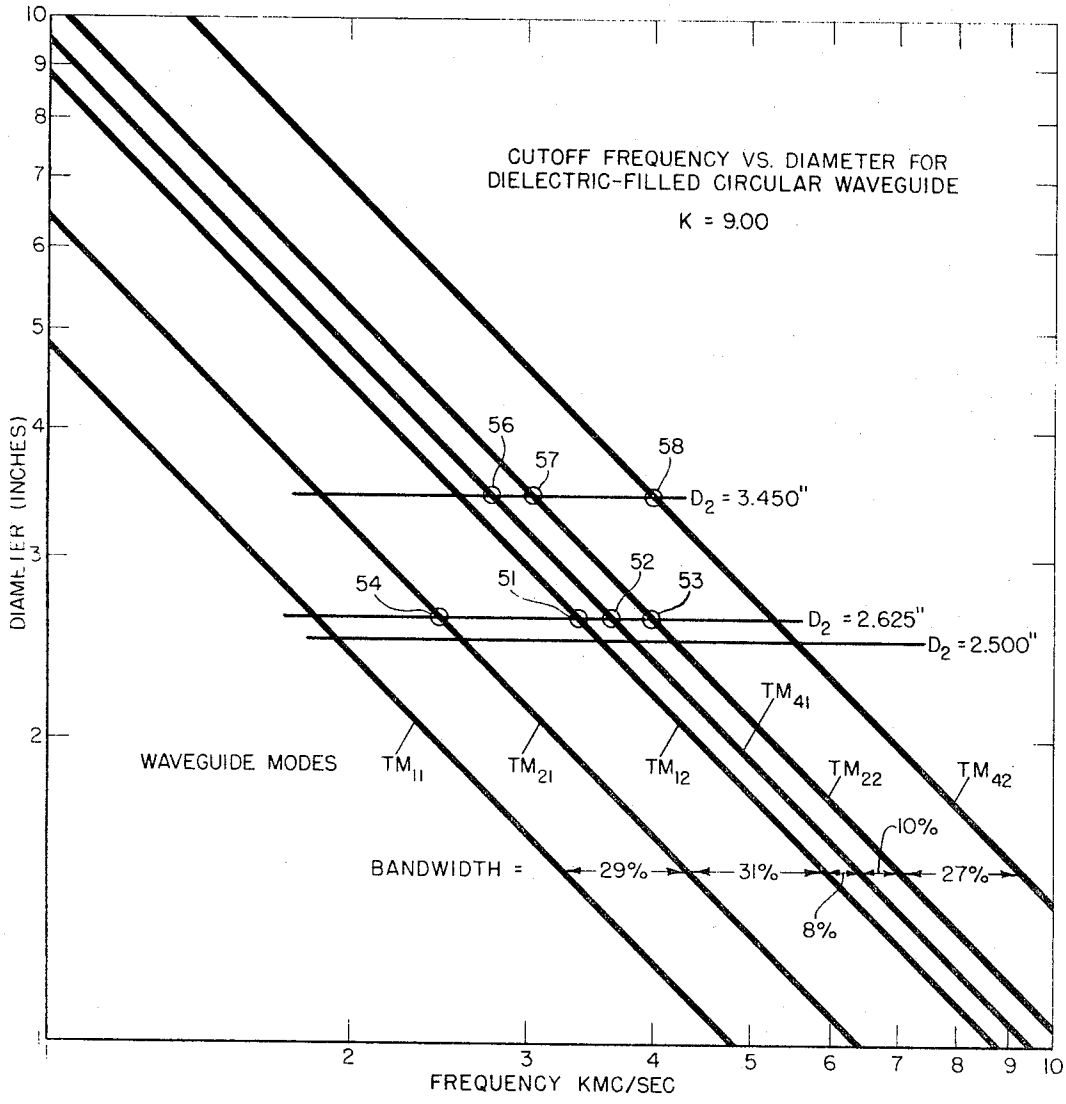


Fig. 4

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Fig. 5



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April 1, 1969 R. M. WALKER 3,436,694

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Filed July 28, 1966 Sheet 3 of 3

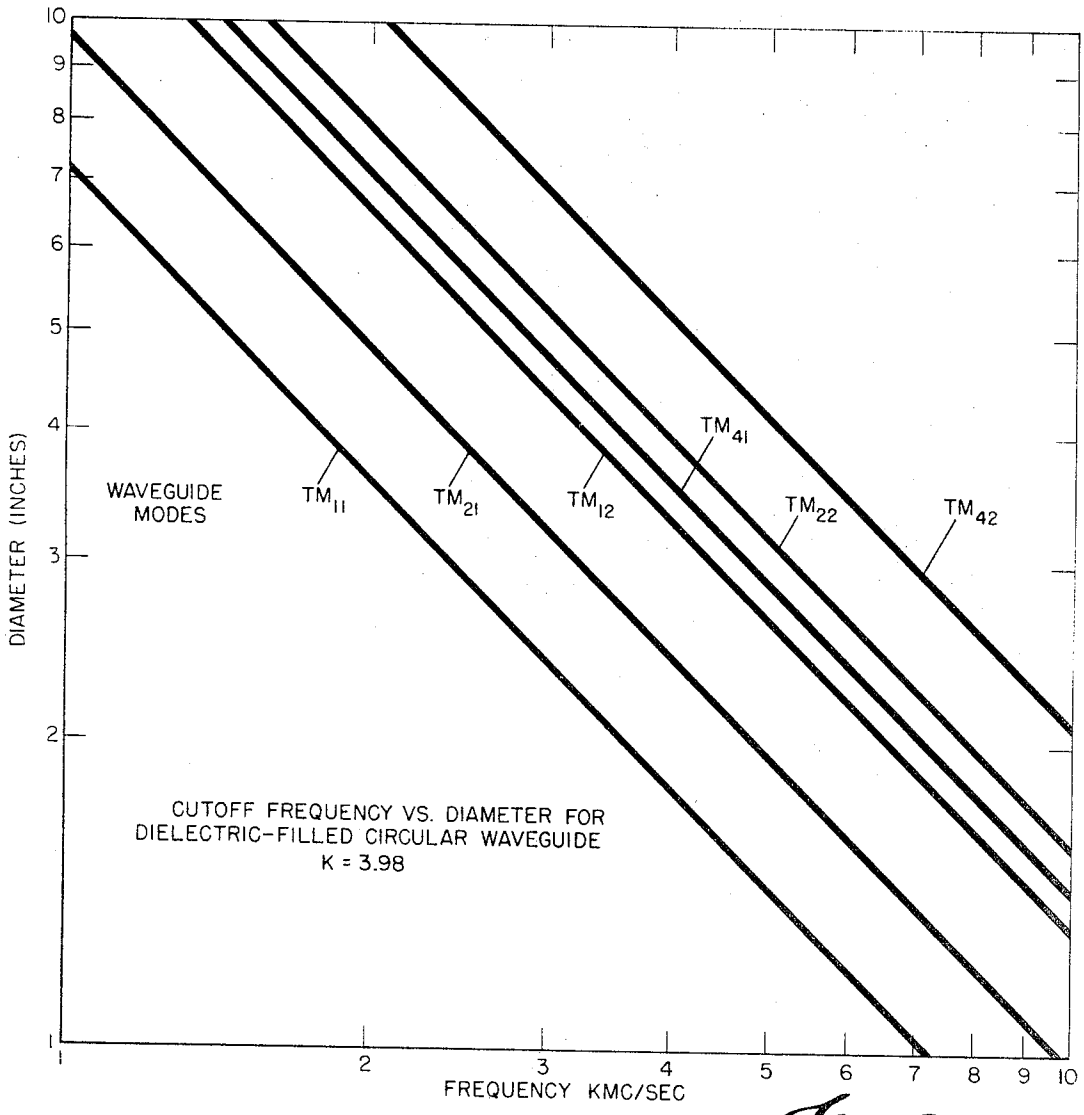


Fig. 6

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CONTROLLING GHOST-MODE RESONANT FREQUENCIES IN SEALED WAVEGUIDE WINDOWS

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U.S. Cl. 333—98 4 Claims

ABSTRACT OF THE DISCLOSURE

This invention relates to sealed waveguide windows of high-power handling capacity, and in particular to techniques and means for controlling ghost-mode resonant frequencies and shifting them out of the desired frequency range.

In windows of the type employing a section of circular waveguide with a disc of dielectric material transversely mounted in it, the invention discloses that ghost-mode resonant frequencies can be shifted, and broader useful frequency ranges can be made available, by providing a circular waveguide section in which the diameter of the intermediate portion housing the dielectric disc is different from the diameter of the two outer portions. Embodiments are disclosed in which the diameter of the intermediate portion is in one case larger, and in another case smaller than the diameter of the outer portions. In either case control is maintained over the VSWR through the diameter of the outer portions with respect to the transmission line in which the window is installed, and high-power window structures having frequency ranges without ghost-mode resonances between approximately 25% and 30% bands at S-band, with VSWR <1.30 are made possible.

Background of the invention

Many types of high power microwave waveguide windows have been studied for use in microwave tubes and for pressurized wave-guide systems. A type in current use consists of a single thin disc of dielectric material, such as low loss alumina ceramic, sapphire or glass, mounted in a short section of circular waveguide. This type, sometimes known as the "poker chip" or "pill box" window, is suitable for insertion in a rectangular waveguide transmission line, in that it will handle peak power levels approaching breakdown in the rectangular waveguide. It is described in U.S. Patent No. 2,958,834, and illustrated in FIG. 1 of the accompanying drawings.

The portion of a circular waveguide filled with a disc of material of high dielectric constant will propagate many higher order modes. Since the air-filled sections of circular waveguide will not propagate these higher modes, they are, in effect, "trapped" in the vicinity of the disc. These modes have been described in the literature as "ghost modes." See, for example, "Microwave Engineering," by A. F. Harvey, published 1963 by Academic Press, Inc., 111 Fifth Avenue, New York, New York, Section 2.5 at page 74, where it is stated "Many designs are intended for high power operation; care must be taken to prevent the excitation of higher-order of ghost modes which tend to exist in the neighbourhood of the window." The problem of ghost modes is thus seen to be an important one in this art.

Ghost-mode resonances occur at a frequency slightly lower than the corresponding cutoff frequency of the dielectric filled portion of the circular waveguide. The field in the dielectric disc when ghost-mode resonances occur can achieve a magnitude many times that of the

propagating TE_{11} mode, thereby causing excessive heating and breakdown to occur. While the "poker-chip" or "pill-box" window as described in prior art (FIG. 1) is practical and has relatively few ghost-mode problems, its design is a compromise between obtaining acceptable VSWR and the elimination of ghost-modes. When the diameter of the circular waveguide section is determined for best VSWR characteristics, ghost-modes resonant frequencies may be within the desired operating range. A change in diameter of the circular waveguide section to avoid ghost-modes results in a compromise on VSWR.

For example, a window designed for best VSWR characteristics for S-band (2600 to 4000 mc./sec.) in accordance with FIG. 1 employs a circular waveguide diameter "D_1" of 3.328 inches when coupled to type WR–284 rectangular waveguide having internal dimensions of $b=1.340$ by $a=2.840$ inches. This choice of circular waveguide diameter "D_1" so that $D_1=1.172a$ makes both circular and rectangular waveguides have the same guide wavelength at any frequency. The ratio of circular waveguide impedance to rectangular waveguide impedance

$$(Z_{oc}/Z_{or}=.943a/b)$$

is also the same at any frequency.

Two further requirements for broadband matching are (1) the capacitive susceptance of the dielectric disc is adjusted by varying its thickness to balance the junction susceptances at the ends of the circular waveguide, and (2) the circular waveguide section is the proper length so that the capacitive susceptances cancel each other. The former may be accomplished by a binomial design (1–2–1) or a Tchebysheff design for desired bandwidth and ripple as used in filters. A window as described above using a ceramic disc of high purity alumina ceramic having a dielectric constant $K=9.00$ has a VSWR <1.30 over the 2600 to 4000 mc./sec. frequency range and a VSWR <1.10 over 65% of this range, or 2900 to 3700 mc./sec. Ghost-mode resonances occur at 2625, 2860 and 3160 mc./sec. as indicated in FIG. 5 of the accompanying drawings. This window design can be used in practice from 2675 to 2800 mc.; 2920 to 3100 mc.; and 3220 to 4075 mc., allowing for approximately $\pm 2\%$ shift in ghost-mode or cutoff frequencies from theoretical values due to variations in dielectric constant K and mechanical tolerances on parts. The theoretical ghost-mode-free bands are, of course, larger; for the purposes of the present application all references to bandwidths will be understood to mean practical bandwidths within these tolerance limits, unless specifically stated to be theoretical bandwidths. The practical bandwith ranges are thus 4%, 6% and 23%, respectively. Therefore, the choice of diameter D_1 for best VSWR provides an acceptable ghost-mode-free operating band (23%) only at the upper half of the waveguide operating range. In order to cover the lower half of the waveguide operating range (2600 to 3220 mc.) we must shift to a diameter D_1 of 4.200″ or 2.625″, with a a sacrifice in VSWR characteristics.

According to the present invention, new structural forms of sealed waveguide windows are disclosed which enable a designer to alter the ghost-mode resonance frequencies without changing the impedance condition governing the choice of the diameter of the circular waveguide section where it is coupled to the transmission line in which the window structure is installed. The new structure embodies an intermediate portion of the circular waveguide section which is electrically of different diameter from the remainder. This change in diameter can be achieved by physically altering the diameter of a portion of the circular waveguide section, or by changing its dielectric constant.

It is thus the principal object of the present invention to provide new sealed waveguide windows which can be designed for (1) optimum VSWR characteristics over the entire frequency range recommended for each rectangular waveguide and (2) ghost-mode-resonance-free operation over any portion of the recommended frequency range up to approximately 30% (theoretical) in bandwidth.

Another object is to provide such improved windows having power handling properties as good as or better than the power handling properties of prior sealed waveguide windows of corresponding types.

A still further object is to facilitate the design of sealed waveguide windows to the end that ghost-mode resonances can be predicted, and can be shifted out of the operating frequency band.

The foregoing and other objects and features of the invention will be apparent from the following description of exemplary embodiments of it. This description refers to the accompanying drawings, wherein:

FIG. 1 shows a prior art sealed waveguide window according to Patent No. 2,958,834;

FIG. 2 is a view of FIG. 1 in the direction indicated by line 2—2 in FIG. 1;

FIG. 3 shows in cross-section an improved high-power window according to the invention;

FIG. 4 shows in cross-section a second embodiment of the invention;

FIG. 5 shows ghost-mode or cutoff frequencies for dielectric-filled circular waveguide with $K=9.00$ vs. diameter for each troublesome mode; and

FIG. 6 shows ghost-mode or cutoff frequencies for dielectric-filled circular waveguide with $K=3.98$ vs. diameter for each troublesome mode.

Referring to FIG. 1, the prior art window comprises a cylindrical section **1** coupled to rectangular waveguide sections **2** and **3** by end plates **4** and **5** respectively, and having a ceramic disc **6** transversely mounted in the median portion of the cylindrical section **1**. The circular waveguide section is of uniform diameter D_1 throughout its length L. The thickness of the window section is designated by the small letter *t*.

When the dielectric disc **6** is glass or fused quartz, for which K is equal to 3.98, the cutoff frequencies for higher order modes occur at higher frequencies than when alumina ceramic, for which $K=9.00$, is used, and the bandwidth between modes is the same in either case, as shown in FIG. 6. A window designed for S-band (2600 to 4000 mc./sec.) employing the optimum circular waveguide diameter of 3.328 inches and coupled to type WR–284 rectangular waveguide has the following characteristics; VSWR <1.30 over the 2600 to 4000 mc./sec. frequency range, a TM_{11} resonance at 2170 mc., a TM_{21} resonance at 2920 mc., a TM_{12} resonance at 3980 mc., a bandwidth of 25% between 2170 and 2920 mc. and a bandwidth of 27% between 2920 and 3980 mc. In this case the useful frequency ranges can be shifted up or down by using the structures of FIGS. 3 and 4 respectively. An analysis of FIGS. 5 and 6 shows that the new designs of FIGS. 3 and 4 are not always necessary to obtain ghost-mode-free operation over a given frequency range. The cases cited above for S-band are typical since the recommended frequency ranges for all rectangular waveguides were determined on the same basis.

Glass and fused quartz are seldom used in practice due to sealing problems and breakage in handling. Power handling capacity of glass or fused quartz is about one-half that for single crystal alumina ceramic (known as sapphire) or beryllium oxide. Beryllium oxide has a dielectric constant of 6.00 and an attenuation factor double that of sapphire; however its high thermal conductivity (equal to brass) provides high power capability equal to sapphire.

Experience of the present inventor has shown that higher order TE modes do not present any significant difficulty, and that many of the TM modes are not troublesome if the windows are manufactured to reasonable tolerances and are symmetrical. The particular ghost-modes shown in FIGS. 5 and 6 are those which are critical.

It is customarily believed that ghost-mode resonances occur at frequencies slightly lower than the cutoff frequency of the guide section containing the dielectric window. In practice this deviation is small for the type of window considered, and resonance frequencies have been noted on both sides of the calculated cutoff frequency due to variations in dielectric constant between lots of the same type of dielectric material, e.g.: lots of the same ceramic type. However, within this small region of variability one can resonably accurately predict the ghost-mode resonance frequencies if the diameter and nominal dielectric constant of the dielectric disc are known. FIGS. 5 and 6 show that the frequency ranges for theoretical bandwidths are respectively 31% between the TM_{21} and TM_{12} mode resonances and 27% between the TM_{22} and TM_{42} mode resonances. The relative positions of these ranges within the recommended frequency ranges for rectangular waveguide have up to now been determined only by the dielectric constant of the disc, given that optimum VSWR is to be achieved.

Referring now to FIG. 3, in which parts which are similar to FIG. 1 bear like reference characters, the circular waveguide section **16** has an intermediate portion **17** of reduced diameter D_2 while the outer portions **18** and **19** retain the original diameter D_1 as compared with FIG. 1. The dielectric disc **21** is in the intermediate portion **17** of reduced diameter D_2. With all other conditions being identical to the conditions in FIG. 1, in a first unit built according to FIG. 3 having D_2 reduced to 2.625 inches while D_1 remains at 3.328 inches (the disc being an alumina ceramic disc of $K=9.00$), VSWR was found to be less than 1.30 over the entire S-band, and ghost-mode resonances in the S-band were measured at 3360 and 3620 mc./sec.; these occurred for the TM_{12}, TM_{41} modes, respectively, as shown at points **51** and **52** respectively in FIG. 5. The ghost-mode resonance for the TM_{22} mode was shifted to 4000 mc./sec. as shown at point **53** in FIG. 5 to fall out of the operating frequency band (2600 to 4000 mc./sec.). Similarly, the ghost-mode resonance for the TM_{21} mode was shifted to 2450 mc./sec., as shown at point **54** in FIG. 5. The useful frequency ranges for this improved model according to FIG. 3 are thus approximately 2510 to 3300, 3420 to 3560 and 3700 to 3920 mc./sec. respectively. The first range covers a 27% frequency range of the lower half of the waveguide range; this is shown as a theoretical bandwidth of 31% (2440 to 3310 mc./sec.) in FIG. 5. As is evident in FIG. 5, a smaller diameter D_2 of 2.500" would provide a ghost-mode-free band of 27% from 2630 to 3450 mc./sec. centered at 3040 mc./sec. The most used range at S-band is 2800 to 3200 mc./sec., which is easily covered by a single design using the new structure of FIG. 3.

Referring now to FIG. 4, in which portions which are similar to FIGS. 1 and 2 bear like reference characters, the circular waveguide section **36** has an intermediate portion **37** of which the diameter D_2 is larger than the diameter D_1 of the end portions **38** and **39**. The dielectric disc **41** is contained in the intermediate portion **37**. The effect of this change was to shift the ghost-mode resonances to lower frequency ranges, and it was found that the TM_{41} ghost-mode resonance dropped to about 2750 mc./sec. with the larger diameter D_2 set at 3.450 inches, as shown at point **56** in FIG. 5. At the same time the TM_{22} resonance dropped to 3040 mc./sec. (point **57** in FIG. 5) while the TM_{42} resonance occurred at 4000 mc./sec. (point **58** in FIG. 5) with the result that this design, using an alumina ceramic window material **41**, covers the range from 3120 to 3920 mc./sec., for a 23% band, 27% theoretical, without interruption by any ghost-mode resonances. Again VSWR was preserved at less than 1.30 for the 2600 to 4000 mc./sec. frequency range.

For comparison purposes an embodiment according to FIG. 1 was built in which the diameter of the circular section D_1 was set at 3.937 inches, using waveguide of type WR–340. The frequency range for WR–340 rectangular waveguide (3.400" x 1.700" I.D.) is 2200 to 3300 mc. A TM_{22} resonance appeared at about 2675 mc./sec. and another at about 3500 mc./sec. The latter could be the TM_{42} in the alumina-ceramic-filled circular waveguide or the second mode in the rectangular waveguide since both occur at about the same frequency. VSWR was less than 1.30 over the 2250 to 3300 mc. range. The other two resonances, TM_{12} at 2250 and the TM_{41} at 2420 were present but not measured.

Thus it is seen that by the new structure which incorporates a change in diameter of the intermediate portion of the circular waveguide section, the ghost-mode resonances may be adjusted out of a desired frequency operating range, while VSWR characteristics of the device remain essentially unaltered. In addition, the change in diameter of the intermediate portion of the circular waveguide section provides an iris diaphragm in the circular waveguide section which mechanically isolates the ceramic disc and maintains its concentricity during brazing operations.

While the invention has been described in relation to specific embodiments, various modifications thereof will be apparent to those skilled in the art and it is intended to cover the invention broadly within the spirit and scope of the appended claims. For example, if glass is the dielectric of the window in an S-band assembly in which diameter D_1 is 3.28", the bands between the TM_{11} and TM_{21} modes and between the TM_{21} and TM_{12} modes will be useful, as is obvious from FIG. 6. Likewise if curves similar to FIGS. 5 and 6 are derived for a beryllium window for which $K=6.00$, useful bands will be observed, and can be employed in accordance with the invention. Moreover the invention is applicable throughout the microwave and millimeter wave frequency ranges, being scalable in proportions to other sizes of waveguides.

I claim:

1. In a high frequency wave permeable window assembly for use between two rectangular waveguides having a wide dimension a, said assembly being dimensioned for passing wave energy in the TE_{11} mode therethrough over a certain passband of frequencies and with a VSWR <1.30 when inserted between such rectangular waveguides, said assembly including a circular waveguide section of diameter D_1 equal approximately to $1.172a$ for maintaining substantially the same guide wavelength in both the rectangular and circular waveguides, and a wave permeable dielectric window member disposed transversely of and within said circular waveguide section, wherein said assembly is characterized by objectionable ghost-mode resonances in one or more of the TM_{11}, TM_{21}, TM_{12}, TM_{41}, TM_{22}, and TM_{42} modes occurring in said passband at or near the respective cutoff frequencies for said modes in the dielectric-filled portion of said circular waveguide section, the improvement for shifting said ghost-mode resonances without altering the dimension D_1 with relation to the dimension a, comprising an intermediate portion of said circular waveguide section in which the diameter D_2 is physically different from said diameter D_1 of the outer portions of said circular waveguide section, said window member being disposed in said intermediate portion, said diameter D_2 of said intermediate portion being between about 20% smaller than and about 4% larger than said diameter D_1 of said outer portions of said circular waveguide section, said diameter D_2 being selected such that substantially no ghost-mode resonances occur within a desired operating frequency range in said passband.

2. An assembly according to claim 1 in which said diameter D_2 of said intermediate portion is effectively smaller than said diameter D_1 of said outer portions, to shift said resonances toward higher frequency ranges.

3. An assembly according to claim 2 in which said intermediate portion has a diameter which is physically in the order of 20% smaller than the diameter of the outer portions of said waveguide member.

4. An assembly according to claim 1 in which said intermediate portion has physically diameter in the order of 4% larger than the outer portions of said waveguide member, whereby to shift said resonances toward lower-frequency ranges.

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