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WAVEGUIDE WINDOW STRUCTURE HAVING THREE RESONANT SECTIONS GIVING BROADBAND TRANSMISSION WITH MEANS TO FLUID COOL CENTER SECTION

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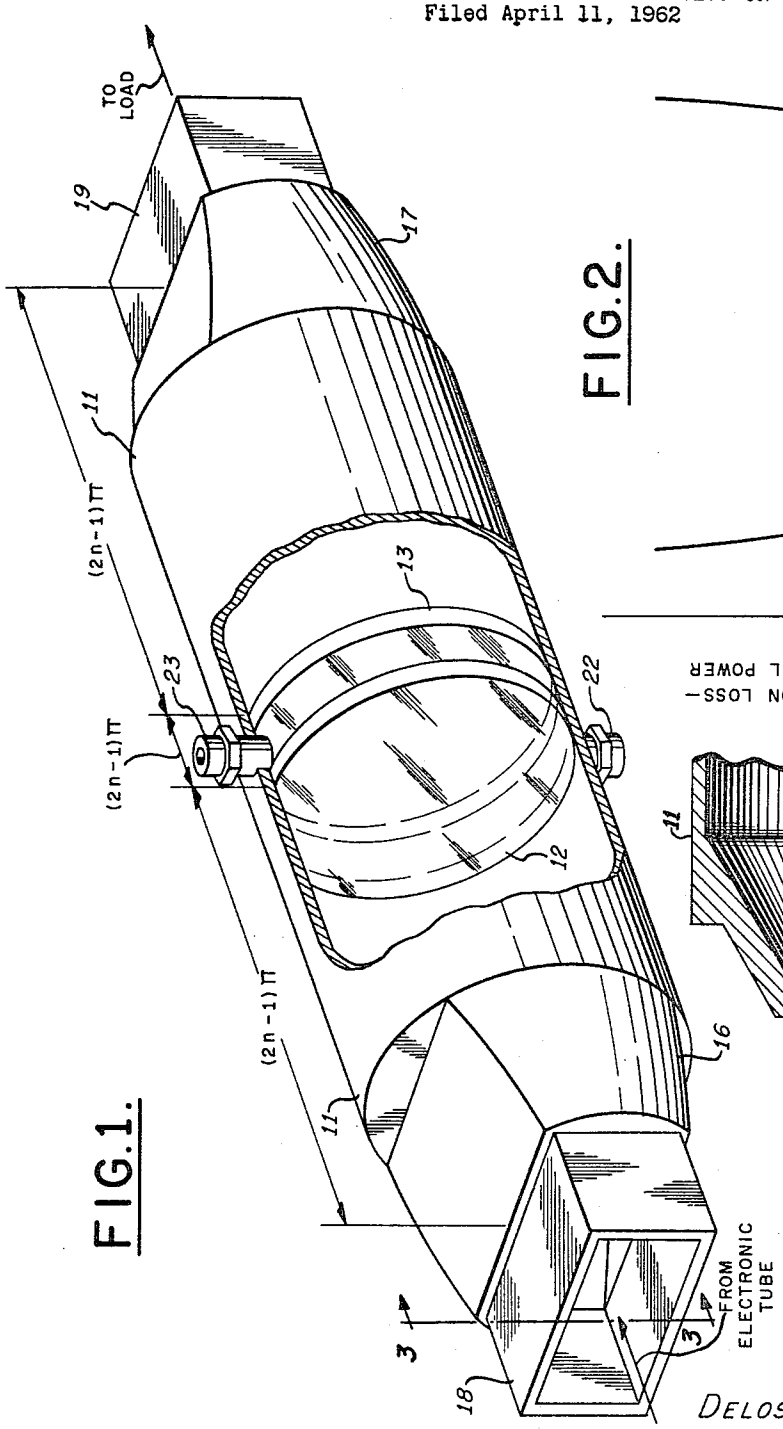


FIG. 1.

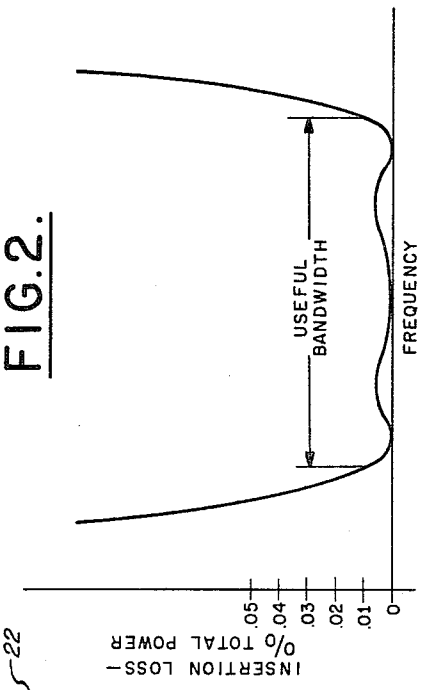


FIG. 2.

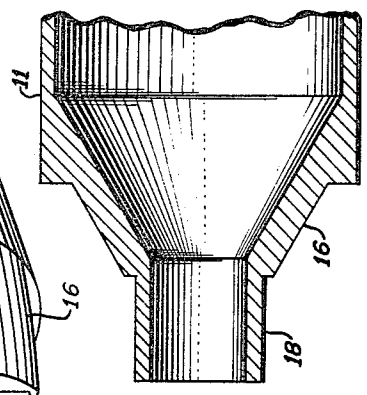


FIG. 3.

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WAVEGUIDE WINDOW STRUCTURE HAVING THREE RESONANT SECTIONS GIVING BROADBAND TRANSMISSION WITH MEANS TO FLUID COOL CENTER SECTION

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5 Claims. (Cl. 333—73)

This invention relates to a high power, broadband waveguide window, and more particularly to a sealed window structure constructed as a three-resonator filter.

Sealed windows that are pervious to electromagnetic energy but impervious to air and gases are used at the output of microwave electron tubes such as klystrons to hermetically isolate the evacuated portions of the tubes from the connecting transmission lines which very often are pressurized. The development of suitable windows long has been a problem in the electron tube art, and particularly so in the more recent years since the development of the very high power klystron tubes. The electrical characteristics of the output window often limit the use of the full bandwidth and power capabilities of a tube. The windows must be mechanically strong and must be able to freely pass high power microwave energy over a relatively wide frequency range with a minimum of insertion loss. Window failures most often take one or more of the following form:

(1) Arcing within the window or in the waveguide region adjacent thereto because of excessively high local electric fields.
(2) Erosion and puncture of the dielectric material forming the window by high-energy electron bombardment.
(3) Mechanical failure caused by thermal expansion, pressures and stresses which occur when the dielectric material over-heats because of absorption of microwave energy.

The first two of these types of failures are more likely to occur when there are irregularities such as protrusions, restrictions or sharp corners in the waveguides in the regions adjacent the window. These irregularities significantly contribute to the creation of spurious modes in the dielectric material of the window and in the waveguide regions adjacent thereto. The spurious modes may be propagating or non-propagating modes. Spurious modes may initiate a condition of resonance which is characterized by a standing electromagnetic wave pattern having an electric field intensity much higher than that of the desired dominant propagating mode, thus giving rise to breakdown at relatively low power levels of the propagating waves.

The above-mentioned irregularities also significantly contribute to electron bombardment on the high-vacuum side of the dielectric material of the window. The very high electric field intensities associated with the output of high power tubes extract electrons directly from the metallic waveguide walls, particularly at sharp corners and discontinuities of small radii. Combined with this is the fact that the spurious modes, created by the irregularities, very often have axially extending electric field components in the region of the dielectric window, and because the free electrons receive their kinetic energy from, and have major velocity components parallel to the electric field components, the electrons travel to and strike the dielectric surface with sufficient energy to cause erosion and puncture of the window. It thus may be seen that it is desirable to avoid the use of sharp corners and abrupt discontinuities in a waveguide window structure intended to pass high power electromagnetic waves.

It therefore is an object of the present invention to

provide a sealed waveguide window that is capable of operating at high power levels over a relatively wide frequency range.

It is another object of the present invention to provide a simple waveguide window structure that is devoid of sharp corners and abrupt discontinuities.

A further object of the invention is to provide a high power waveguide window structure that substantially emilinates the erosion and puncture caused by electron bombardment.

Another object of this invention is to provide a high power waveguide window structure that is readily cooled.

These and other objects and advantages of the present invention are achieved by a waveguide window structure comprised of two thin, axially-spaced, parallel-disposed dielectric discs sealed about their peripheries to the inner surface of a section of circular waveguide. Each end of the circular waveguide is coupled to a rectangular-to-circular waveguide transition section whose electrical length is relatively short, i.e. one wavelength or less, in order to provide reflective mismatches in the regions of the propagating paths occupied by the transition sections. The separation between the two dielectric discs, the axial dimensions and dielectric constants of the discs are so proportioned that the electrical length between the outer faces of the two discs is substantially equal to $(2n—1)\pi$ radians, where n is any integer but preferably one, whereby the discs and the waveguide region therebetween electrically function as a resonator tuned to pass substantially without reflection electromagnetic waves at the center of the desired frequency band of interest. The axial separation between a transition section and an adjacent dielectric disc is chosen so that the effective electrical distance between the disc and a reference plane of the reflective mismatch presented by the transition section is substantially equal to $(2n—1)\pi$ radians, whereby the two circular waveguide sections between the dielectric discs and transition sections function as resonators to pass substantially without reflection electromagnetic waves within the frequency band of interest. The entire waveguide window structure therefore electrically functions as a direct-coupled, triple-resonator filter whose frequency response is that of a relatively wide band-pass filter. The physical structures that comprise the elements of the direct-coupled resonators are completely devoid of any sharp corners, protrusions or restrictions.

The invention will be described by referring to the accompanying drawings wherein:

FIG. 1 is a perspective view, partially broken away, illustrating the window structure of this invention;

FIG. 2 is a graph illustrating the frequency response characteristics of the window structure of this invention, and;

FIG. 3 is a vertical sectional view showing a rectangular-to-circular waveguide transition section of the device illustrated in FIG. 1.

Referring now in more detail to the drawings, the window structure of the present invention is comprised of a section of circular waveguide **11** adapted to freely propagate electromagnetic waves within the frequency range of interest in the TE_{11} circular waveguide mode. Positioned transversely across the central region of waveguide **11** are two thin, spaced-apart, planar and parallel-disposed dielectric discs **12** and **13**. Dielectric discs **12** and **13** are of a low-loss material and are substantially impervious to air and gases. Dielectric discs **12** and **13** may be of glass, alumina, or any of the other materials suitable for this use. A single-crystal synthetic sapphire material obtainable from Linde Company, Division of Union Carbide and Carbon Corporation, Needham Heights, Massachusetts, has been used with success. Also, a sintered alumina

material identified as AD995, and obtainable from the Coors Porcelain Company, Golden, Colorado, has been used with success.

Rectangular-to-circular waveguide transition sections **16** and **17** couple the respective rectangular waveguide sections **18** and **19** to the opposite ends of circular waveguide section **11**. The electrical length of each of the transition sections **16** and **17** is less than one wavelength, and in a device constructed in accordance with this invention was slightly less than one-half wavelength and thus is shorter than the usual rectangular-to-circular transition section which customarily has a length of several wavelengths. The short lengths for transition sections **16** and **17** are chosen in order that they will provide reflective mismatches in the wave-propagation path and thereby serve as elements of resonators, as will be more fully explained herein below.

Fluid connectors **22** and **23** are coupled to circular waveguide section **11** at diametrically opposite points in the region between discs **12** and **13** and provide means for passing a fluid coolant through the region of waveguide **11** bounded by dielectric discs **12** and **13**. Sulfur hexafluoride gas has been used successfully as the coolant to prevent dielectric discs **12** and **13** from overheating as a result of absorbing microwave energy propagating through waveguide section **11**.

In assembling the structure illustrated in FIG. 1, the wave propagating section **11** may be comprised of a thin-walled tube of copper-plated Kovar, at least in the region bounded by dielectric discs **12** and **13**. Discs **12** and **13** may be secured about their peripheries to the thin-walled tube of copper-plated Kovar by any suitable sealing method, the usual precautions and requirements for making a seal of this type being observed in order to provide a vacuum-tight seal between the discs and the inner wall of circular waveguide section **11**.

The diameter of circular waveguide section **11** is chosen to be greater than the width of rectangular waveguide sections **18** and **19** because its larger cross-sectional dimension increases the power handling capability of the window structure. This larger size waveguide, however, will support certain higher-order propagating modes if they are launched by the short transition sections **16** and **17**. The higher-order modes can become trapped between the two transition sections and can set up a self-resonance condition within the structure, thereby creating high insertion loss to waves propagating in the desired dominant waveguide mode. The window structure of this invention successfully avoids this condition because the transition sections **16** and **17** launch the circular waveguide TE_{11} dominant mode into waveguide section **11** with a high degree of purity, i.e., the energy in cross-polarized and higher-order modes is negligibly small. In window structures built in accordance wtih this invention, the interiors of transition sections **16** and **17** were machined to the shape of truncated right circular cones, as illustrated in FIG. 3. This simple machining operation not only provides a short smooth transition section that greatly avoids the undesired cross-polarized and higher-order modes, but also provides a simple means for changing the angle of taper of the transition section to obtain the correct impedance discontinuity, this being largely an empirical procedure. It is to be understood, however, that short, smoothly-tapering transition sections having other cross-sectional shapes may be employed without departing from the present invention.

Considering now the electrical characteristics of the window structure of FIG. 1, the thickness of dielectric discs **12** and **13**, their dielectric constants, and the propagation constant of the medium therebetween are proportioned with respect to each other so that the electrical distance between the two outer faces of the discs is substantially equal to $(2n-1)\pi$ radians, where n is any integer but preferably one. With this condition fulfilled, the arrangement of the two discs electrically functions as a resonator that substantially completely transmits electromagnetic waves within a given range of frequencies. The arrangement of dielectric discs to serve as transmission line elements is disclosed in U.S. Patent 2,407,911, issued September 17, 1946. Similarly, the sections of circular waveguide **11** between dielectric discs **12** and **13** and the respective transition sections **16** and **17** serve as resonators, and are comprised of a section of transmission line bounded on one end by a reflective discontinuity formed by a transition section, and on the other end by a reflective discontinuity formed by a dielectric disc. The electrical length between a dielectric disc and a reference plane taken through the adjacent reflective discontinuity is substantially equal to $(2n-1)\pi$ radians. The position of a reference plane of a discontinuity is a function of the angle of taper of a transition section and of the frequency of the electromagnetic waves propagating therethrough. The exact location of such a reference plane will be between the ends of a transition section and is best determined empirically, as is customary practice in the art. The circular waveguide resonators are tuned to have frequency responses slightly different from the frequency response of the resonator formed by the spaced dielectric discs **12** and **13**. Thus, the device of FIG. 1 electrically functions as a direct-coupled, triple-resonator filter which has a transmission characteristic of the type illustrated in FIG. 2, this being the relatively broadband characteristic of direct-coupled resonators tuned in the manner described.

It may be seen that the use of direct-coupled resonators results in a relatively small and compact structure having the required transmission function. Additionally, the use of the transition sections **16** and **17** as elements of the resonators provides a relatively unobstructed propagating path for the electromagnetic waves and avoids the protruding or restricting structures, and sharp corners that characterize other known waveguide window structures. Thus the propagating path existing throughout the window structure of this invention has high power handling capabilities. An additional important electrical feature of the window structure of this invention is that the propagating path introduces relatively little distortion of the dominant TE_{11} mode of the electromagnetic waves. The slight fringing or distortion of the dominant mode (i.e., excitation of higher order modes) that is introduced by the transition section **16**, is attenuated to negligible proportions in the half wavelength section between transition section **16** and dielectric disc **12**, so that at the point where the waves are incident upon dielectric disc **12**, the electric field pattern is substantially that of the circular waveguide TE_{11} mode and thus parallel to the face of disc **12**.

The use of the two thin dielectric discs to form the sealed window reduces the likelihood of power breakdown within or adjacent to the window. It has been found that thick slabs of dielectric material which serve as windows can support the spurious mode resonances that have high electric field intensities which lead to power breakdown. Generally speaking, the prevention of spurious mode resonance in the dielectric discs can be reasonably assured by choosing the thickness of each of the dielectric discs **12** and **13** to be no greater than approximately one-eight wavelength of the waves propagating therethrough. The arrangement of the two spaced-apart sealed discs **12** and **13** also affords a convenient means for cooling the window. All of these advantageous features of the window are in addition to its electrical characteristic of providing an excellent transmission line resonator of low insertion loss.

One waveguide window structure constructed in accordance with the present invention, and designed for operation in a band of frequencies between 5,000 and

6,000 megacycles per second, had the following approximate dimensions;

Length of waveguide section 11	inches	4.76
Diameter of waveguide section 11	do	2.065
Axial length of transition sections 16 and 17	do	.98
Half-angle of taper of transition sections 16 and 17	degrees	30
Diameter of dielectric discs 12 and 13	inches	2.065
Thickness of dielectric discs 12 and 13	do	.085
Axial separation between adjacent faces of dielectric discs 12 and 13	do	.198

While the invention has been described in its preferred embodiments, it is understood that the words which have been used are words of description rather than of limitation and that changes within the purview of the appended claims may be made without departing from the true scope and spirit of the invention in its broader aspects.

What is claimed is:

1. A waveguide window structure comprising

a section of circular waveguide,

a pair of thin, spaced-apart, planar dielectric discs sealed about their peripheries in a vacuum-tight manner to the interior surface of said circular waveguide at its central region intermediate its two ends,

said dielectric discs being pervious to electromagnetic wave energy but being impervious to air and gases,

first and second conical rectangular-to-circular waveguide transition sections respectively coupled to the opposite ends of said circular waveguide,

said transition sections having lengths no greater than one wavelength of the electromagnetic waves propagating therethrough to provide at a respective transverse reference plane between the ends of each transition section a respective reflective discontinuity,

the electrical separation between the outer faces of said two discs being substantially equal to $(2n-1)\pi$ radians for electromagnetic waves at a frequency in a band of frequencies,

the electrical separation between each of said discs and the transverse reference plane through the adjacent transition section being approximately equal to $(2n-1)\pi$ radians for electromagnetic waves within said band of frequencies,

whereby the combination of said two spaced-apart dielectric discs, the circular waveguide sections and transition sections on each side thereof comprise a triple-resonator filter.

2. The combination claimed in claim 1 wherein said transition sections are in the shape of truncated right circular cones.

3. The combination claimed in claim 1 further including

first and second fluid passages extending through the walls of said circular waveguide in the region intermediate said two dielectric discs to provide means for passing a fluid coolant between said two discs.

4. The combination claimed in claim 1 wherein,

each of said resonators of the triple-resonator filter is tuned to a different center frequency that is within said band of frequencies,

whereby said filter passes electromagnetic waves in a frequency band that is wider than the band of frequencies passed by any one of said resonators by itself.

5. A waveguide window structure comprising,

a section of circular waveguide,

a pair of thin, spaced-apart, planar dielectric discs extending transversely across said circular waveguide section normal to the longitudinal axis thereof,

said dielectric discs being pervious to electromagnetic wave energy but impervious to fluids and being sealed about their peripheries in a vacuum-tight manner to the interior surface of said circular waveguide,

the electrical separation between the outer faces of said two discs being substantially equal to $(2n-1)\pi$ radians for electromagnetic waves at a first frequency in a band of frequencies,

whereby said spaced-apart dielectric discs function as a resonator to substantially completely transmit electromagnetic waves at said first frequency in said band of frequencies,

first and second conical rectangular-to-circular waveguide transition sections coupled to the opposite ends of said circular waveguide,

said transition sections having axial lengths no greater than one wavelength of the electromagnetic waves propagating therethrough thereby to present a respective reflective discontinuity at a respective plane through each of said transition sections,

the electrical separations between the respective discs and the reference plane through the adjacent transition section being approximately equal to $(2n-1)\pi$ radians for electromagnetic waves at respective second and third frequencies within said band of frequencies,

whereby the two sections of circular waveguide each bounded on one end by a transition section and on the other end by a dielectric disc function as second and third resonators thereby forming with said dielectric discs a direct-coupled triple-resonator filter that passes electromagnetic waves in a frequency band that is wider than the band of frequencies passed by any one of said resonators by itself.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,110,000 November 5, 1963

Delos B. Churchill

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

In the grant, lines 1 to 3, for "Delos B. Churchill, of Oyster Bay, New York," read -- Delos B. Churchill, of Oyster Bay, New York, assignor to Sperry Rand Corporation, a corporation of Delaware, --; line 12, for "Delos B. Churchill, his heirs" read -- Sperry Rand Corporation, its successors --; in the heading to the printed specification, line 6, for "Delos B. Churchill, Ripley Lane, Oyster Bay, N. Y." read -- Delos B. Churchill, Oyster Bay, N. Y., assignor to Sperry Rand Corporation, a corporation of Delaware --.

Signed and sealed this 14th day of April 1964.

(SEAL)
Attest:

ERNEST W. SWIDER

Attesting Officer

EDWARD J. BRENNER

Commissioner of Patents